MANAGING GROUND WATER CONTAMINATION
FROM
AGRICULTURAL NITRATES

by

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(ABSTRACT)

Ground water contamination from agricultural nitrates poses potential adverse health effects to a large segment of the rural population of the United States. Contamination is especially prevalent in livestock intensive areas, which produce arge quantities of animal waste with substantial nitrogen content.

In this study, potential management strategies for reducing nitrate contamination of ground water from agricultural sources were examined using an economic-physical model of a representative dairy farm in Rockingham County, Virginia. A mixed integer programming model with stochastic constraints on nitrate loading to ground water and silage production was used to simulate the impacts of various nitrate loading reduction strategies on estimated farm level net returns over variable costs. A survey of all dairy operations in the county was conducted to assist in specifying the mathematical programming model, identify current nutrient management and quality issues, and gauge farmers' attitudes toward ground water quality and agricultural chemical use.

Results of the model indicate that substantial reductions in current nitrate loadings are possible with relatively minor impacts on farmers'

net returns through the use of currently practiced approaches of cost sharing for manure storage facility construction and nutrient management planning. Greater loading reductions are achievable through presently untried policies of land use restrictions, bans on purchase of commercial fertilizer, and imposition of standards on loadings to ground water. These reductions are achieved, however, at higher costs in terms of reduced net returns.

Study results indicate that a wide range of policy options exist for reducing nitrate loading to ground water; these reductions, while varying in cost, do not appear to come at the expense of eliminating the economic viability of the county dairy sector. Model results indicate that reductions in nitrate loading of 40 to 70 percent (on average) could be achieved with reductions in farmers' net returns of one to 19 percent, respectively, when cost sharing for manure storage construction was provided. Explicit consideration was given to the annual variability in nitrate loading due to weather and other factors. The result was higher policy costs than when average loadings alone were considered.

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MANAGING NONPOINT SOURCE CONTAMINATION OF GROUND WATER: PHYSICAL, HEALTH, AND ECONOMIC ISSUES

INTRODUCTION

The Ground Water Problem

Ground water, which is the water which occurs in the saturated zone (the level to which well water will rise) beneath the earth's surface, accounts for 95 percent of the United States (U.S.) freshwater reserves (Anderson et al., 1985). Aquifers--underground reservoirs--are the major source of drinking water for 85 percent of the rural population. Total U.S. ground water withdrawals were estimated at 88 billion gallons per day in 1980, accounting for about 50 percent of the drinking water consumed and 40 percent of irrigation needs (Saliba, 1985; Fisher, 1983). Withdrawals are increasing at double the rate of the increase of surface water use (Henderson et al. 1987).

The quality of the ground water resource is a matter of primary importance. Potential contaminants of ground water include industrial wastes, municipal landfills, mining activities, septic systems, buried storage tanks, road salts, and agricultural applications (Dycus, 1984). Centralized-source pollutants from landfills, materials stockpiles, and mine tailings can be transported to ground water either through the liquid portion of the waste or as a result of contact with water moving through such potential contaminants (Bouwer,1978; Todd, 1980).

Most of these contamination sources can be characterized as site-specific or localized. The Virginia Ground Water Protection

Strategy assigns top priority to addressing the five following sources of potential ground water contamination: underground storage tanks, septic systems, waste lagoons, landfills, and pesticides and fertilizers (Virginia Groundwater Protection Steering Committee, 1987). With the exception of pesticides and fertilizers--the principal ground water contaminants resulting from agricultural land use--these are all point sources of contamination; that is, the source of contamination can be traced to individual sites. Batie (1987) notes that states may need to treat agricultural contamination differently than other contamination sources for several reasons:

-agricultural contaminants come from diffuse sources. In addition, few states maintain detailed records of amounts or locations of pesticides and fertilizers used for agricultural purposes.

-agricultural contaminants are influenced to a greater degree by probabilistic factors (such as weather) which determine the speed and amount of chemical leaching.

-environmental problems caused by agriculture have been traditionally addressed with voluntary programs, so that other forms of regulation (which may be well suited for landfills or underground storage tanks) may meet with considerable political resistance from the agricultural community.

-the health and safety issues of chronic exposure to the extremely low doses of contaminants which are typical of the situation in agricultural communities have not been resolved.

These factors suggest the need for considering different approaches for managing agricultural contamination than for managing other sources of contamination within a comprehensive ground water protection strategy. The purpose of this dissertation is to address some of these unique agricultural issues inherent in ground water contamination, and examine potential strategies for reducing the potential for ground water contamination from agricultural sources. These issues will be examined through a case study of Rockingham County, Virginia.

Agricultural Contamination of Ground Water

Agricultural wastes which contribute to ground water degradation stem from three primary sources: pesticide application, feed lots, and fertilizer use (Aller et al. 1985). Agricultural use of pesticides for the control of insects, fungi, or weeds can result in ground water contamination from spills, leaking storage tanks, or routine use (OTA, 1984). Contamination of ground water from agricultural pesticides has been documented in 36 states (O'Hare et al. 1985; OTA, 1984; Cohen et al. 1984).

Infiltration of leachate from animal wastes can contaminate ground water with nitrates (NO_3) (the principal by-product of nitrogen), as well as by introducing bacteria, viruses, and phosphates (Bouwer, 1978; OTA, 1984). Padgitt (1984) estimates that .4 pounds of nitrogen (N) per day is produced for every thousand pounds of live animal (dairy cow) weight.[1] Animal waste thus contains a significant amount of nitrogen which can either be used as crop nutrient or dispersed into the ecosystem.

Applications of fertilizer by farmers consist primarily of nitrogen, phosphorus, and potassium. It is estimated that between 40 and 80 per cent of nitrogen fertilizer applied is taken up by plants (Bouwer, 1978; Virginia Polytechnic Institute, 1974); the remainder is either returned to the atmosphere through denitrification, runs off into surface water, or percolates downward (as nitrate) to contaminate ground water. Studies have verified that farmers frequently apply substantial quantities of fertilizer--often enough for the entire growing season--prior to planting, increasing the potential for nitrate contamination (Aller et al. 1985; Kaap, 1984). Unlike pesticides, which may be subject to transformation or biodegradation in the vadose[2] zone, nitrates are conservative.[3]

PROBLEM IDENTIFICATION: AGRICULTURAL NITRATES

Contamination of ground water from agricultural sources is a difficult problem for policy makers to manage for several reasons. First, it is principally nonpoint[4] in nature, making monitoring with reasonable cost and accuracy extremely difficult. Second, agricultural contamination is inherently stochastic, influenced largely by weather and other probabilistic factors (Shortle, 1987; Shortle and Dunn, 1986). Third, movement and transformation of pesticides through the vadose zone and in ground water has not been clearly documented for many chemicals. Finally, health impacts and standards have not been clearly identified for all pesticides currently in use (OTA, 1984).

This dissertation will concentrate solely on nonpoint nitrate pollution of ground water from agricultural sources. Given the problems of managing agricultural pollution of ground water, agricultural nitrates provide a useful starting point for design of management strategies for several reasons. First, a United States health standard of 10 mg/liter (10 parts per million) has been established for nitrates. This standard eliminates the problem inherent in managing many pesticides which have no established health standard, and allows design of management strategies based on the most cost-effective means of achieving this standard without having to estimate contamination damage (Abrams and Barr, 1974). Second, nitrates are conservative in nature; they can therefore be identified by monitoring. Direct substitutes for nitrates in the biological production process are also limited, so farmers' ability to substitute for nitrogen use in crop production would be more limited than for pesticide use; therefore, responses to nitrogen use-impacting policies would be more predictable. Third, more information on characteristics such as movement and persistence is available on nitrates than for many pesticides (O'Hare et al. 1985). Finally, since nitrates have many of the same nonpoint characteristics as pesticides, a management plan designed for nitrates could possibly be adapted later for other nonpoint agricultural contaminants.

The following sections discuss the key features of the nitrate problem: potential adverse health effects of nitrate ingestion; the fate of nitrogen applied as fertilizer; and the geologic factors which influence a region's vulnerability to ground water contamination.

Health Effects of Nitrate Ingestion

Principal human and animal exposure to nitrates and nitrites (the main by-products of nitrogen fertilizer) occurs through ingestion. The most widely recognized adverse health effect of nitrate ingestion is methemoglobinemia, or "blue baby" syndrome. This condition, which inhibits oxygen transport in infants' bloodstreams, is usually reversible and can be avoided through use of alternative water supplies during infancy. In extreme cases, the disease can be fatal.

The linkage between methemoglobinemia and high drinking water nitrates is widely accepted, although still a matter of some controversy. For example, several studies of the relationship between fetal and infant mortality and nitrate content of water could not demonstrate a correlation (Gelperin et al. 1975; Shuval and Gruener, 1972); other evidence seems to confirm the relationship between drinking water nitrate and methemoglobinemia (Sattelmacher, 1962; Walton, 1951; Simon et al. 1964). At least five acute cases of methemoglobinemia have been documented in the corn belt in recent years, and one infant's death in the summer of 1986 was attributed to drinking formula prepared with water containing extremely high nitrate concentrations (Fruhling, 1986; Busch and Meyer, 1982; Hallberg, 1986b). Ascertaining the exact extent of methemoglobinemia occurrence is difficult because it is not a reportable illness in many states (Hallberg, 1986b).

Chronic effects of nitrate ingestion have not been as firmly established. Some animals' intestines have the capacity to transform nitrate into nitrite (Tillman et al. 1965); the human stomach provides favorable conditions for the conversion of nitrites to nitrosamines (NAS, 1978). Although nitrosamines are suspected carcinogens, epidemiological evidence linking nitrates to human cancer is as yet inconclusive (Hill et al. 1973; Bouwer, 1978; Forman, Al-Dabbagh, and Doll, 1985). Nitrite exposure has been found to cause lower motor activity, increased aggression, and thinning and ballooning of the cardiac vessels of rodents subjected to certain laboratory experiments (Fraser and Chilvers, 1981).

Effects of nitrate/nitrite ingestion on animals are qualitatively very similar to those found in humans, although the doses which produce toxicity are much higher for animals than for humans (Turner and Kienholz, 1972). Some reports suggest that nitrate/nitrite may increase the number of abortions in cattle or may cause weight losses or lower milk production in dairy cows, though the scientific evidence is mixed (NAS, 1978).

The Nitrogen Cycle

Nitrate occurs naturally in nearly all soils and waters (Keeney, 1986). "Background" natural nitrate levels vary, but concentrations above 2-3 mg/L are generally assumed to reflect human contributions (Hallberg, 1986c), usually from fertilizer application or septic tanks. Nitrogen takes various forms throughout its transformation process--urea, anhydrous, nitrate, and ammonium--as either gas, solid, or liquid. The form that nitrogen takes is important both for its usefulness to the plant and its potential for percolating downward to ground water.

The nitrogen cycle consists of four principal steps. First is **fixation**, which supplies nitrogen to the soil. Fixation can be either biological or industrial. Biological fixation can occur through legumes which transform nitrogen in the air (N_2) into a form usable by plants, aerial deposition from rainfall, or through animal and green manures. Industrial fixation, where N_2 is contained in either ammonia, urea, or nitrate, occurs through application as commercial fertilizer (OECD, 1986).

The second step in the cycle is **ammonification**. In this step, also called mineralization, soil organisms break down the organic residues, releasing ammonia. This ammonia can be used directly by many plants; however, after ammonification this ammonia is transformed into ammonium (NH_4), which is usable directly by most young plants (Valiulus, 1986). Ammonium also has an important characteristic from a water quality standpoint: it does not leach. It is at this stage in the nitrogen cycle that nitrification inhibitors are useful, since they retard the further conversion of ammonium into nitrates.

In the third step of the cycle, **nitrification**, ammonium is transformed into nitrate. Although nitrate is the most useful form of nitrogen for plants, it is also subject to rapid leaching to ground water. The nitrate ion is not attracted to soil particles the way ammonium is and, being water soluble, is extremely mobile (Valiulus, 1986). Losses to leaching will depend largely on factors such as available nitrate in the soil, vegetative cover, soil type, and weather patterns (OECD, 1986).

The fourth and final step of the cycle is **denitrification**, where nitrate is converted back into N_2 and nitrogen oxides and escapes back into the air. Although not always portrayed as part of the nitrogen cycle, **volatilization** may also release nitrogen to the atmosphere, primarily through the loss of liquid nitrogen as gas. The nitrogen cycle is summarized in figure 1.1.

Geologic Factors Affecting Ground Water Contamination

While similarities in farming practices and climate may exist across regions, it is not necessarily true that these practices will result in similar ground water nitrate concentrations in these regions. In addition to soil type, key factors which will influence an area's sensitivity to contamination include depth to water table, aquifer media, and topography (Aller et al. 1985). Hallberg (1986d) notes that concentrations of NO_3 found in ground water will reflect different land use and N sources in recharge areas, nature and thickness of material covering the aquifer, and the hydraulic properties of the surface material and the aquifer itself.

Aquifer media deemed to be most vulnerable to contamination are karst limestone, basalt, and sand and gravel (Aller et al. 1985). Karst limestone consists of consolidated limestone bedrock which has dissolved to the point where large, open cavities have formed, allowing contaminants to move through the aquifer relatively quickly and undiluted. This media is often characterized by the presence of sinkholes, which allow rapid introduction of contaminants into the ground water system. Basalt is an igneous bedrock subject to fracturing; pollution potential is influenced by the amount of

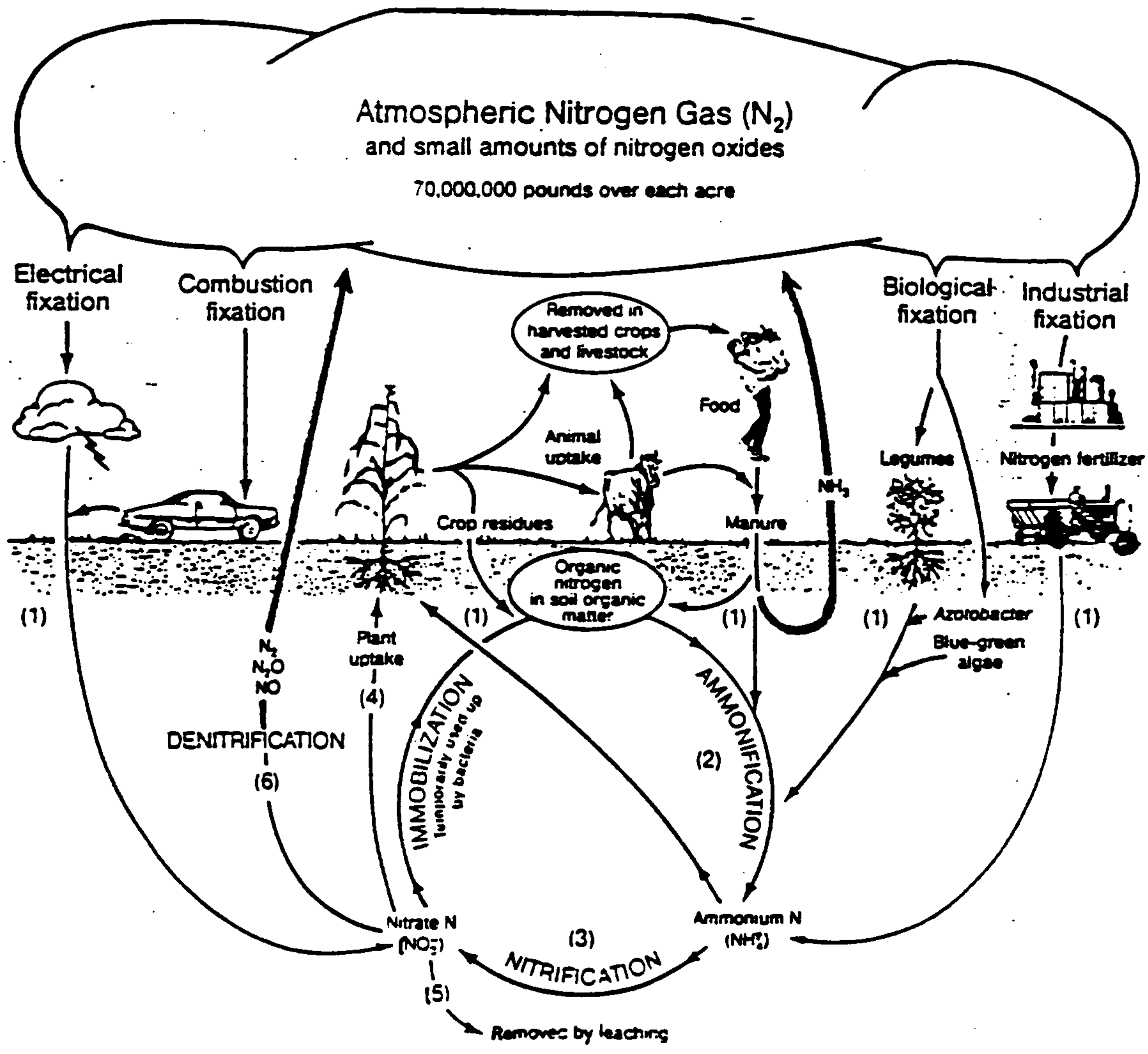

FIGURE 1.1. THE FATE OF APPLIED NITROGEN: THE NITROGEN CYCLE.

Source: Valiulus, 1986

interconnected openings present in the lava flow materials. Sand and gravel aquifers are unconsolidated mixtures of sand and gravel particles.

Contamination potential in these aquifers is largely influenced by the amount of fine-grained materials present; those composed of relatively coarse-grained material are generally higher in contamination potential. Karst limestone is found in many regions of the United States (Hallberg, 1987); for example, the Big Spring Basin area of Iowa, which has been experiencing ground water contamination problems from pesticides and nitrates, and the Shenandoah Valley in Virginia, which has been experiencing high nitrate levels in ground water, both overlie karst limestone aquifers (Hallberg, 1986d).

Scope of the Nitrate Problem

A recent survey has documented local or regional nitrate contamination of ground water from agricultural sources in thirty-two of the contiguous forty-eight states, with contamination suspected in five others. Of these states, seven have already implemented management measures (such as monitoring), while twenty-seven are currently evaluating the issue or planning monitoring systems (O'Hare et al. 1985). (A discussion of state and federal legislative responses to ground water contamination is contained in appendix A). Numerous case studies have also verified that agricultural land use and high nitrate concentrations in ground water are highly correlated (Pionke and Urban, 1985; Ritter and Chirnside, 1984; Silver and Fielden, 1980).

Keeney (1986) notes that nitrates are the most widespread of ground water contaminants. The most extensive nitrate contamination problems have been found in sites in Iowa, Wisconsin, Illinois, Colorado, Minnesota, Nebraska, New York, and California (Olson, 1986). Nielsen and Lee (1987) have used the Environmental Protection Agency (EPA) DRASTIC[5] index to estimate that approximately 6.8 million people relying on private wells in rural areas may be exposed to nitrate contamination.

Nitrates introduced into ground water from agricultural sources result either from chemical fertilizer application or animal waste. Bouwer (1978) notes that between 20 and 60 per cent of nitrogen applied to crops is lost to the atmosphere, surface runoff, or percolation to ground water, with the remainder taken up in plant tissue.[6] When one considers that about twenty-two billion pounds of nitrogen are applied to cropland each year (EPA, 1986), it becomes apparent that the volume of this "lost" nitrogen is a formidable source of potential contamination of drinking water.

The Problem of "High" Fertilization

At least part of these nitrogen losses can be attributed to nutrient application in excess of what the crop can absorb at the time of application. These losses may occur due to the timing of fertilizer application; research has shown that a crop can more efficiently use nitrogen which is applied in several small applications throughout the growing season than it can a large dose of nitrogen applied at planting. Frequently, however, farmers apply nitrogen in excess of agronomic recommendations for their given situation (Schepers and Martin, 1986). For example, Kaap (1984) estimates that farmers in the Big Spring Basin of Iowa may be supplying up to 240 lbs./acre of nitrogen to corn crops which require no more than 160 lbs. of N/acre (on average).

There are many suggested reasons for large application rates. Some possible motivations:

1. Overestimation of yield goals, which results in farmers applying nutrients in excess of what their realized crop yields can be expected to absorb (Schepers and Martin, 1986; Olson, 1986). This problem is compounded by the fact that the efficiency of nitrogen uptake by crops decreases as higher levels of nitrogen are applied (Keeney, 1986).

2. Using large amounts of commercial fertilizer may be perceived as cheap insurance against nitrogen losses in the root zone, especially when the price of commercial fertilizer is low. Farmers may in fact treat fertilizer as a risk-reducing input (SriRamaratnam et al. 1987; Olson, 1986). Norris (1989) argues that farmers apply more total nitrogen than needed by crops in **anticipation** of losses to leaching, runoff, and volatilization; in that case, farmers are compensating for low rates of crop uptake of nitrogen.

3. Farmers may not be aware of the nutrient value of the manure they spread on their fields as a disposal activity, resulting in excessive amounts of commercial fertilizer being applied.

It is important to note that what may seem like irrational behavior from an agronomic viewpoint--that is, applying nutrients in excess of what a crop can use, resulting in increased waste through runoff and percolation--may not be irrational behavior from the economic standpoint of the farmer. If farmers are either unrealistic in their yield goals or unaware of the nutrient content of readily available manure, they still may be acting rationally given the lack of information. If farmers perceive fertilizer as a risk reducing input, it may be economically sensible to apply nutrients in excess of agronomic recommendations to lessen the probability of income loss. Recent evidence indicates that farmers may indeed view fertilizer as a risk reducing input (SriRamaratnam, 1987), in spite of some experimental evidence which suggests that nitrogen fertilizer is a risk increasing input (Just and Pope, 1979; SriRamaratnam, 1985). However, Hawkins (1988) notes that nitrogen application rates would have to be extremely high (possibly in excess of 300 pounds per acre of corn) before yield reductions would be experienced, so that nitrogen applications higher than agronomic recommendations might not necessarily reduce yields.

Best management practices[7] (BMPs) recommended to reduce nitrate loading to ground water include use of cover crops or deep rooted crops, chemical additives that inhibit the rate of nitrification, split applications, slow release inorganic or organic fertilizers, or management of irrigation to improve crop yields and nitrogen uptake. Consideration of available nitrogen (both from nitrate in the rooting zone and nitrogen from manure and crop residue) in nutrient management plans can also reduce nitrate loading (Keeney, 1986). However, many farmers, particularly those in regions with concentrated dairy farming and corn production, do not take credit (that is, consider the manure's nutrient value in crop production decisions) for manure nitrogen (Kaap, 1987; Swartz, 1987; Givens, 1987).

MANAGING AGRICULTURAL NITRATE CONTAMINATION OF GROUND WATER

Policy makers considering action to reduce nitrate loadings to ground water will be interested in three principal issues: the effects on water quality of any proposed management plan; the economic impacts of these actions on affected groups such as farmers, fertilizer producers, and food consumers; and the costs of designing, implementing, and enforcing the management plan. However, it is impossible to predict with certainty any of these outcomes due to the probabilistic nature of both physical processes in the ground water system and the responses of economic agents. This section discusses the uncertainties involved in ground water management and briefly addresses available options to address this type of nonpoint source contaminant.

Uncertainty in Agricultural Nonpoint Source Pollution

Any plan designed to reduce nitrate or pesticide loadings must consider the uncertainties involved with the ground water problem. These uncertainties affect both the producer and the policy maker. On the production side, a plan to reduce or alter fertilizer use will have an uncertain impact on farmers' yields and production decisions. It has been demonstrated theoretically that a marginal increase in price or yield uncertainty can cause a reduction in output for a risk-averse producer (Sandmo, 1971). On the physical side, migration of contaminants, ground water loading, and weather variability cannot be forecast with certainty. Any policy action would have to consider that proposed targets for nitrate loadings could not be satisfied with certainty due to these factors; policy makers would therefore need to consider outcomes within a probabilistic setting, rather than a fixed standard of loading like those considered by the National Pollution

Discharge Elimination System (NPDES).

Potential Management Strategies

Pollution of ground water from nitrates constitutes what economists call an externality, or spillover effect.[8] There are several potentially applicable policies available for dealing with externalities of this type. These include:

1. "Corrective" taxes and/or subsidies which would attempt to make the farmer bear the full costs of his production process.

2. Regulation of fertilizer application practices. Regulation could effectively mandate some form of fertilizer management, or other land use controls. This plan could require compensation of parties impacted due to reduced yields, increased management costs, and other resulting cost increases, or could be implemented with no compensation mechanism. This may include imposition of standards, although standards may be better suited for point-source pollutants.

3. Reassignment of property rights. This could lead to formation of a market for pollution rights or permits, which might lead to a Pareto optimal solution (Coase, 1960; Oates, 1984). This strategy could also lead to transfer of existing pollution rights to non-polluters, possibly by use of an insurance-type scheme which could take the form of liability laws or a superfund approach, where users and/or manufacturers of fertilizer or pesticides are required to pay into a cleanup fund for ground water.

4. Other methods of causing the economic agents involved to internalize the spillover. In the case of nitrate contamination, this could entail educational efforts to induce farmers to adopt different nutrient management practices.

Of the alternative control strategies described, four will be examined in detail in this dissertation. These are the corrective tax approach, regulation of fertilizer application with compensation, reassignment of property rights (through regulation of farm management practices), and voluntary and educational approaches.

OBJECTIVES OF THIS STUDY

With the strategies detailed in the preceding section in mind, the proposed study has five objectives:

Objective 1

a) To estimate the level of "corrective" tax necessary to achieve stated ground water nitrate reduction levels.

Objective 2

a) To examine the impacts of legislation mandating fertilizer management practices, especially nutrient management practices requiring construction of manure storage facilities. Impacts on ground water loading as well as impacts on producers and local economies will also be examined.

b) To develop possible compensation techniques for farmers impacted by this legislated management. This will primarily involve subsidization of alternative nutrient management techniques through cost sharing.

Objective 3

a) To examine a range of policy initiatives designed to reduce nitrate loading to ground water which are more innovative than those currently practiced in a chosen case study area. These include a redefinition of current property rights for ground water quality in the agricultural sector, so that farmers are forced to bear more of the cost of ground water protection through restrictions on their management options. Options considered are restrictions on the purchase and use of commercial nitrogen fertilizers, and land use controls designed to reduce nitrate loading from manure spreading

Objective 4

a) To conduct analysis of survey results to determine study area farmers' attitudes toward agriculture and ground water quality, and to examine the possible effects of these attitudes on policy initiatives.

b) To examine the factors which influence farmers' likelihood of participating in manure testing programs.

Objective 5

a) To examine some of the distributional consequences of the policies proposed on specific groups in the study area

Strengths and weaknesses of each strategy will be evaluated in terms of:

-ability to successfully reduce pollutant loading to imposed levels

-possible secondary economic impacts, such as loss of employment in the area's agricultural industry

-costs of policy development, administration, and regulation

-ability to be used in conjunction with other strategies

This information should be useful to local communities and state governments facing ground water management decisions in choosing which strategy or combination of strategies might work best in a particular situation. This approach acknowledges the diversity of control situations which exist due to land use, hydrogeologic, and other factors, as well as the need for local initiative and state management imposed by current EPA policy.

THE STUDY AREA

Since much of the problem of nitrate contamination is caused by farmers' nutrient management practices, it is useful to address the contamination problem using a micro or farm-level approach within a regional case study framework. In this way, an understanding of farmers behavior can be gained; that is, knowledge of the economic stimuli to which farmers are responsive can imply the type of actions which would change nutrient management practices. Several useful results can be obtained from a study of possible altered nutrient management practices:

-estimation of impacts on output levels and production costs to area farmers,

-estimation of impacts on projected ground water loadings, and

-information on farmer behavior and response which can be extrapolated to other regions of the country with similar agricultural sectors and ground water problems.

When evaluating alternative areas to use as the case study area, several screening criteria were used. Specifically, the case study area needed to have: a major portion of its economic base in agriculture; an agricultural sector typical of many other regions of the country (that is, no areas relying heavily on specialty crops); underlying geology with a high potential for ground water contamination; and a demonstrated problem with nitrate contamination of ground water stemming from agricultural sources.

The area selected for this study was Rockingham County, Virginia. The county was chosen as a case study for several reasons. First, the county has a history of ground and surface water quality problems which have been linked to nitrates from poultry and cow manure and high applications of commercial fertilizers. Second, the county ranks first in the state in agricultural income (VAS, 1986); therefore, any ground water management program having a major effect on agriculture will have a substantial effect on the county. Finally, an extensive nutrient management program conducted by Virginia Polytechnic Institute and State

University and the Chesapeake Bay Foundation (administered through the Virginia Division of Soil and Water Conservation) is currently underway in the area, facilitating data collection and interaction with key county personnel.

General Characteristics of Rockingham County

Rockingham County is located in the northwest portion of Virginia, bordered by Page and Shenandoah Counties to the north, Albemarle and Greene Counties to the east, Augusta County to the south, and West Virginia to the west (figure 1.2). The county is bounded by the Blue Ridge Mountains on the southeast and the Allegheny Mountains on the northwest. Named for the Marquis of Rockingham, a British statesman, the county is the third largest in the state, covering 865 square miles (Hinkle and Sterrett, 1976; VAS, 1986).

Population of the county was 52,900 in 1984, an increase of less than two percent over 1980. Principal population center of the area (and only independent city) is the city of Harrisonburg (population 26,100). Per capita income for the county was $11,366 in 1984 (VAS, 1986).

Rockingham County ranks first in farm income in the state of Virginia (table 1.1). Principal crops are corn grain, corn silage, and hay, with about half of county farmland used as pasture. Livestock production in the county is mainly poultry and dairy cattle.

The county consists of three major hydrogeologic areas: the Blue Ridge, the central valley, and the area west of Little North Mountain.

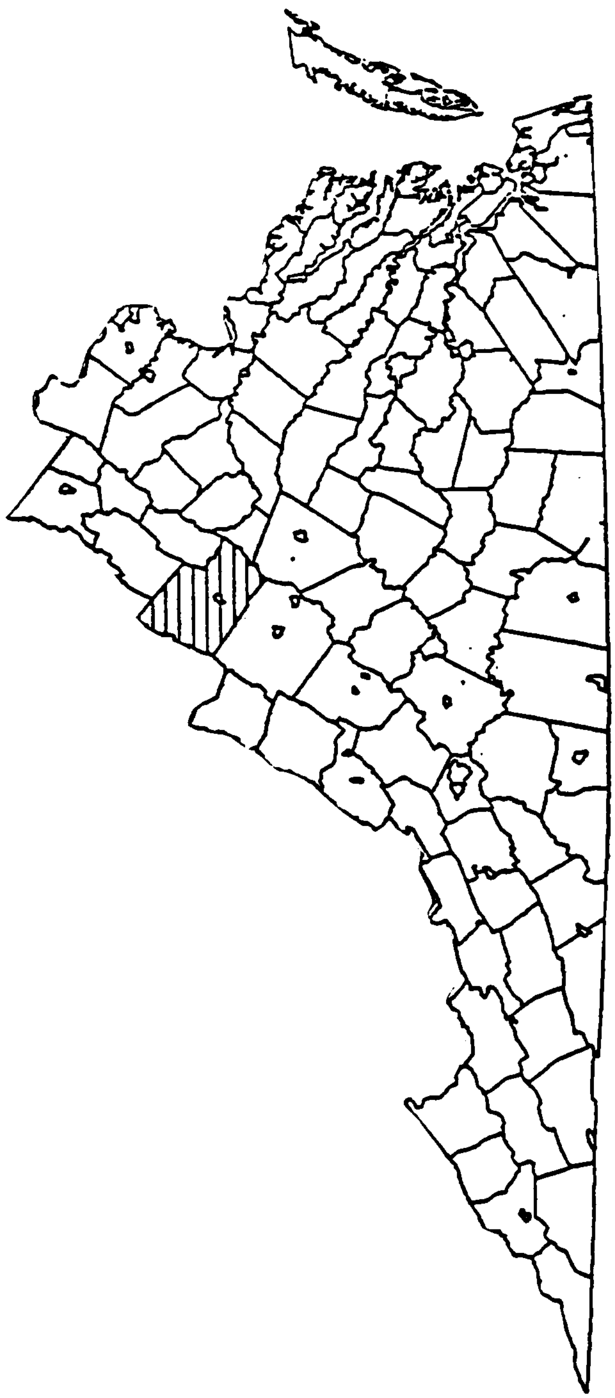

FIGURE 1.2

MAP OF VIRGINIA HIGHLIGHTING ROCKINGHAM COUNTY

TABLE 1.1. SELECTED AGRICULTURAL FEATURES OF ROCKINGHAM COUNTY, VIRGINIA.

Farm Income[a]	$212,143		
County Size	557,355 acres		
Land in Farms	199,107 acres		
Average Farm Size	128 acres		
Cropland			
	Acreage Harvested	Yield/acre	Total Production
Corn Grain	14,000	110.0 bu.	1,540,000 bu.
Corn Silage	19,700	17.5 tons	345,000 tons
Winter Wheat	1,200	39.5 bu	39,500 bu.
Pastureland (all types)	126,585		
Selected Livestock			
All Cattle and Calves			118,000 head
Dairy Cows and heifers that have calved			23,000 head
Poultry			
Broilers			896,749 birds
Layers[b]			45,387,535 lbs.
Mean Annual Precipitation[c]	41.24"		
Mean Annual Temperature			
January	35° F		
July	77° F		

[a]total sales, farms with $10,000 or more in annual sales
[b]lbs. of meat sold
[c]based on Luray gauging station estimates

Note: Soybeans, Barley, Oats, Peanuts, and Tobacco accounted for less than 1,000 acres each of total cropland Source: Virginia Agricultural Statistics, 1986.

Both the Blue Ridge and Little North Mountain areas are sparsely developed, and have little potential for ground water production. The central valley area contains three major units: carbonates overlain by alluvial deposits of the South Fork of the Shenandoah River; the carbonate formations west of the river; and the Martinsburg shale (Hinkle and Sterrett, 1976). This area, which offers the highest groundwater production potential, is also the most vulnerable to contamination due to its karst-carbonate nature. The sedimentary geology of the central valley area is typical of the Valley and Ridge aquifer which underlies western and southwestern Virginia (Virginia Groundwater Protection Steering Committee, 1987; Meng, Harsh, and Kull, 1985). Depth to water table commonly ranges between 50 and 300 feet (Meng, Harsh, and Kull, 1985).

Nitrate Contamination in Rockingham County

Livestock (excluding poultry) in Rockingham County produces nearly 500 tons of nitrogen per year. Assuming annual crop needs of about 3,300 tons of nitrogen per year, this livestock-produced nitrogen could theoretically supply more than 15 percent of crop needs.[9] In spite of this potential source of nutrients, the county ranks third in the state in the purchase of commercial fertilizer and first in sales of nitrogen for direct application (see table 1.2);[10] extension personnel working in the county feel that these commercial purchases would be reduced substantially if full consideration were given to nutrients from manure produced and applied (Givens, 1987; Hawkins, 1987).

TABLE 1.2. FERTILIZER SALES IN ROCKINGHAM COUNTY, 1986.

Total Mixed Fertilizer	10,917 tons
Nitrogen	2,048 tons[a]
Direct Application Nitrogen	8,233 tons
Phosphate	940 tons
Potash	331 tons
Annual Fertilizer Expenditures	$3,959,000

[a]this figure includes 157 tons purchased in the Harrisonburg (independent city) area

At least part of this apparent overabundance of nutrients may stem from a lack of manure storage facilities in the county. Storage facilities allow better use of the nitrogen available from manure than do the manure spreading routines necessary when no storage is available. The primary advantages gained are from improved timing of applications. However, storage facilities can cost between $6,000 and $90,000 to construct (Virginia Division of Soil and Water Conservation, 1987), and may take valuable land out of production. A recent survey of dairy farmers in Augusta, Shenandoah, and Rockingham Counties revealed that less than 40 percent of area Grade A dairies had registered manure storage facilities, with storage capacity for only about one-third of the manure generated (Gentile and Thomas, 1987).

Dairy farms with no manure storage facilities typically must spread manure on a daily or weekly basis (Givens, 1987). Since most of these dairy farmers grow corn, and manure cannot be applied to corn while it is growing, much of the manure is spread on pastureland where most of the nitrogen is lost. Nitrogen needs of the corn crop must then be supplied with commercial fertilizer.

This combination of manure and commercial fertilizer thus results in nitrogen supplies in excess of what currently grown crops can use (although not all of this manure nitrogen is recoverable without on-farm manure storage). As figure 1.1 indicates, the remaining nitrogen must be accounted for by either volatilization and denitrification, surface runoff, or percolation to ground water. Since most Rockingham County farmers use tillage practices designed to minimize erosion (Roller, 1987; Halstead, Batie, and Kramer, 1988), most of this nitrogen will either end up in the atmosphere through denitrification and volatilization or will percolate toward the ground water as nitrate. While no coordinated ground water monitoring effort has taken place in the county, available data suggest that the county is experiencing elevated nitrate levels due to agricultural land use. About 17% of wells sampled by the Virginia State Water Control Board had nitrates in excess of 5 mg/L; however, these samples were drawn in a non-random manner and may not be indicative of overall county water quality (table 1.3).

High ground water nitrate concentrations coupled with large purchases of nitrogen suggest that reduced use of nitrogen fertilizers and better nutrient management practices in the county might result in both reduced nitrate loadings to ground water and reduced input costs to area farmers. There are various options which could be used by policy makers to reduce nitrate loadings by inducing changes in application practices. In order to compare these alternative policies, it is necessary to estimate the costs incurred by the affected parties (e.g. the effect on farmers' net returns) so that both the political efficacy of various ground water management programs and an estimate of some of the distributional aspects of these programs can be determined. The following section discusses some of these options which policy makers may consider in addressing the nitrate contamination problem.

TABLE 1.3. NITRATES IN WELL WATER IN ROCKINGHAM COUNTY, VIRGINIA.[a]

Rockingham County (through 1984)

	Number of Wells	Percent of Total
Total Number of Wells Sampled	357	
Nitrates Detected	213	60
Nitrates in Excess of 5 mg/L	62	17
Nitrates in Excess of 10 mg/L	29	8
Highest Value Observed	31 mg/L	

North River Watershed[b] (through 1985)

	Number of Wells	Percent of Total
Total Number of Wells Sampled	62	
Nitrates Detected	62	100
Nitrates in Excess of 5 mg/L	29	47
Nitrates in Excess of 10 mg/L	12	19
Highest Value Observed	21.6 mg/L	

[a]Data used in this table are the results of testing done either due to complaints by landowners or instigated by the landowners themselves. They do not necessarily constitute a representative sample, and therefore cannot be used to assess the overall state of Rockingham County water quality.

[b]The North River Watershed is a predominantly agricultural area. All of the data noted in this part of the table comes from wells on agricultural properties.
Source: Virginia State Water Control Board (1987)

METHODS

The primary tools used to achieve the study objectives will be a mathematical programming model of a representative dairy farm in Rockingham County, Virginia, and a mail survey of class A dairy farms in the county. The mathematical programming model is designed to estimate both the economic and environmental effects of alternate management practices designed to achieve specified nitrate loading reductions. Information on the farmer's production processes and crop mix options will be used to develop the technical coefficients in the model's objective function, while the environmental side of the model will be developed using information on area ground water systems. Data to specify these relationships will be obtained from the dairy farm survey, expert opinion, and ground water loading estimates based on simulation model results.

A chance-constrained programming model will be used (Sengupta, 1972). Rather than using a deterministic constraint on nitrate loadings to ground water which would prohibit contamination from exceeding certain specified levels, the constraints in this model are stochastic, following the method of Charnes and Cooper (1956). Since one of the primary goals of this study is to determine the economic viability of alternative nutrient management and manure storage practices, the model allows the farmer to choose between options of owning no manure storage facilities, having manure storage capacity for 60 days, 120 days, and 180 days. In this way, it can be determined what financial compensation (or penalty) would be necessary to make adoption of storage an attractive option.

The mail survey will yield four primary sets of information: actual farm characteristics and farming practices in the county; nutrient management practices and manure storage availability on county dairy farms; the number and nature of any water quality problems encountered by area farmers, and the extent of drinking water testing and treatment currently practiced; and attitudes and knowledge of ground water and environmental issues among county dairy farmers (see appendix B for a copy of the survey). In addition to validating parameters of the mathematical programming model initially specified using expert opinion and county-level agricultural statistics, other information from the survey will be used to evaluate alternative policies in terms of acceptability and potential for affecting current practices. Finally, the survey will yield information on actual water quality in the county. Survey information will be analyzed using descriptive statistics, statistical techniques to examine differing responses by sub-samples within the survey group, and qualitative choice (logit) modeling.

Procedures

The Conventional Practice Model. The mathematical programming model designed for this study will actually represent two different sets of assumptions. The first set of model runs will assume that cropping, nutrient management, and dairy herd ration practices used by the farmer will follow those traditionally used in the county. Results generated under these assumptions will therefore represent changes in farm management practices (and nitrate loading reductions) which can be effected by policy initiatives without causing a major shift in traditional operating practices. For simplicity, this set of models will be referred to as "conventional practice" (CP).

The Need for Policy Alternatives: The Non-traditional Alternative Model. The presence of chemicals--at any concentration--in drinking water is becoming increasingly unacceptable to the general public. A recent national telephone survey found that 63 percent of respondents disagreed with the statement "If the government allows small amounts of chemicals in water, then it's safe to drink" (Center for Community Dynamics, 1985). Another survey of academicians and grocery industry professionals found that 59 percent of agricultural economists and 71 percent of grocery business leaders expect the use of agricultural chemicals to be decreased by half by the turn of the century due to increased concern over their environmental and health effects (Bogart, 1988). Agricultural chemical companies are under increasing pressure to develop non-toxic alternatives to existing pesticides due to stricter regulations mandated by public concern (U.S. Water News, 1988). In Virginia, Governor Baliles recently signed the Chesapeake Bay Agreement, which calls for a 40 percent reduction in nitrogen and phosphorus entering the Bay by the year 2000 (Virginia Natural Resources, 1988). If achieved, this reduction target, which will affect nutrient applications in the Shenandoah Valley, is likely to have profound implications for ground water quality as well.

In order to provide a means of addressing these concerns over ground water quality, a second set of model assumptions was used to generate an alternative set of activities so that nitrate loading reductions beyond those in the conventional practice model could be gained. The model is expanded to illustrate the impacts of larger nitrate loading reductions on agricultural practices and net returns. The expanded model includes: additional manure storage alternatives; alternative feed rations to those currently used; and revenue producing alternatives for the representative farm. This set of models will be referred to as the "non-traditional alternative" (NA), since they represent a divergence from those practices historically followed in Rockingham County (though some of these practices are used in other parts of the country). The nontraditional alternative model thus represents a set of alternative activities which the farmer may adopt if policy initiatives designed to reduce nitrate loadings to ground water cause him to restructure his traditional practices; the conventional practice models are essentially a subset of the nontraditional alternative models.

The nontraditional alternative model will be used to illustrate the impacts of larger nitrate loading reductions on agricultural practices and net returns. Policy options examined in the nontraditional alternative model include a combination tax-cost sharing approach, restrictions on purchase of commercial nitrogen fertilizer, minimum acreage limitations for manure spreading, and more restrictive levels of chance constraints on nitrate loading to ground water.

Specific output of the model will be used to obtain information on five principal areas:

1. Cost-effective[11] tax rate to voluntarily achieve a given standard of nitrate loading reduction.

2. An estimate of the amount of subsidy necessary to achieve the specified nitrate loading levels.

3. Amount of fertilizer application reduction needed to achieve each specified standard of nitrate loading. This will provide information as to how much of the reduction goal could be met through improved nutrient management.

4. Impacts on farmers' yields/profits due to increased price of fertilizer.

5. Changes in cropping practices and dairy herd management due to imposition of nitrate management policies, such as restrictions on nitrogen purchase or application.

Variants of the proposed technique using other root zone or soil loss models have been used for soil erosion, nutrient loss, and pesticide leaching (Segarra _et al_. 1985; Palmini, 1982; Milon, 1985). Crowder _et al_. (1985) used the CREAMS model in conjunction with a linear programming model to estimate farm-level impacts of alternative management systems.

OUTLINE OF THIS DISSERTATION

This dissertation is divided into seven chapters. The second chapter examines the foundations of the mathematical programming and chance constrained techniques, and the theoretical justification of the policy options considered. The third chapter contains the results and analysis of the survey of Rockingham County dairy farmers, and presents the results of a logit analysis of factors influencing the farmers' decision of whether to use a manure testing service. The fourth chapter constructs a model of a representative farm in the Rockingham County area. Specifically, this chapter examines the interface of an economic mathematical programming model with a physical transport model. The fifth chapter presents the output of the mathematical programming models. Both the "conventional practice" model output and the expanded or "nontraditional alternative" model results are discussed in this chapter. The sixth chapter discusses some of the policy implications and potential usefulness of the results of the Rockingham County study, both in the short and long run, and examines the regional impacts of ground water management policies on the county through a fiscal impact model. This concluding chapter also provides an overview of how study experiences relate to the Virginia ground water quality management problem in general, and discusses the implications of the study and future research needs.

In this dissertation, "results" chapter five presents very different scenarios regarding ground water quality, environmental concern, and attitudes about agriculture. The conventional practice model essentially works within the existing agricultural policy framework in Rockingham County through cost sharing and education mechanisms, with little change assumed in agricultural management systems as a result. The results of this model therefore represent a near-term prospectus for policy and ground water quality. The nontraditional alternative model evaluates more restrictive changes in both ground water quality and the county dairy sector. The two model formulations thus represent a short-run analysis of the existing situation and a long-run analysis of what could occur if public pressure to improve ground water quality increased enough to cause structural changes in county agriculture.

CHAPTER II

THEORETICAL AND EMPIRICAL APPROACHES TO THE GROUND WATER NITRATE PROBLEM

Introduction

In order to address the aspects of market failure which lead to the degradation of ground water described in the previous chapter, it is necessary to examine the theoretical issues underlying the problem. In this way, potential solutions to ground water contamination may be identified, and evaluated as to their feasibility in application. This chapter examines the problem of why markets fail to provide socially optimal prices for common property goods such as ground water. Three strategies are identified which could potentially correct these market failures: a marketable property rights approach, the use of corrective taxation, and regulation of farm management practices.

AGRICULTURAL NONPOINT SOURCE POLLUTION: THEORETICAL FOUNDATIONS OF POTENTIAL MANAGEMENT STRATEGIES

"That which is common to the greatest number has the least care bestowed upon it."

-Aristotle

This archaic quote from the Greek philosopher aptly sums up the nature of open access resources. The absence of well-defined property rights for certain resources (such as ground water) may result in their overexploitation[1] since the marginal revenue gained from employing one more unit accrues entirely to the individual producer, while the marginal cost is borne by all users of the resource. For ground water, this phenomenon can lead to overuse of the commons (in this case, the aquifer) as a disposal area (Hardin, 1973).

In an ideal market economy this divergence between the farmer's cost and the social cost of using ground water as a disposal area would not occur because prices of goods and factors in production would accurately represent their effect on social welfare. In general, market prices reflect the true social value of a good if:

1. Market prices measure the willingness to pay for the last (marginal) unit consumed.
2. Price = marginal cost.
3. Marginal costs reflect true social marginal costs (Sinden and Worrell, 1979).

In the present case, the marginal cost to the farmer of nitrogen loss to ground water is measured principally in terms of the value of the input lost (as reflected in decreased net returns); the cost of the pollution may be borne by the farmer in the form of adverse health effects caused by tainted wells or contaminated irrigation water, but it is also likely that other ground water users (for example, rural communities using ground water for drinking purposes) will bear part of the cost of the contamination. Thus, an externality occurs--that is, the utilities of certain individuals in the community are dependent upon the activities under their control <u>and</u> the pollution-generating activities of the farmer, where an activity is any human action that can be measured. In standard notation, let

$$U^a = u(X_i, Y) \qquad (1)$$

be the utility function of the farmer's neighbor a, where the X_i's are the variables under a's control, and Y represents the activities of the farmer (overapplication of fertilizer). A marginal external diseconomy exists when

$$u_Y^a < 0 \qquad (2)$$

assuming that a is a utility maximizer. This externality is potentially relevant if it generates any desire on the part of the affected party to modify the behavior of the farmer through compromise, regulation, or persuasion. However, if the costs of the institutional arrangements needed to institute this "missing market" for ground water quality exceed the potential benefits gained (for example, through a corrective tax) then the externality is considered Pareto irrelevant (Buchanan and Stubblebine, 1962; Runge, 1987).

Dahlman (1979) has argued that those phenomena commonly considered externalities are primarily a result of transactions costs and lack of information; that is, if externalities (or "side effects," as Dahlman terms them) exist, they must be of the Pareto-irrelevant variety. Dahlman does note that "setup" costs--essentially a fixed cost involved in a trade (regardless of the size of the transaction) to organize resources--may prevent internalization of an externality. Government intervention in the market may then be warranted "if the government can find a better way than markets" (Dahlman, 1979, p. 155). In the case of nitrate contamination of ground water, the large number of contributors to the problem and the large number affected by ground water contamination--each only a small part of the whole--would require a significant setup cost to cause county dairy farmers to internalize their polluting activities; in this case, government involvement provides the means for overcoming this setup cost problem.

From society's standpoint, the presence of a nonpoint externality results from the overproduction of the good in question. For Rockingham County, this good would be nitrogen fertilized corn (resulting in nitrate loadings to ground water above acceptable--as defined by health standards--limits). The farmer's marginal cost curve includes the cost of his production inputs (including the externality-generating inputs) but neglects the costs incurred in the form of the economic, health, and environmental and social impacts of nitrate contamination described in chapter one. This results in the farmer's marginal private cost curve (which represents his supply curve) lying below the appropriate marginal social cost curve (figure 2.1).

Society's problem can also be viewed within a production-possibility framework, where the axes are defined as ground water quality and agricultural production (figure 2.2). With this "pseudotechnology," society is faced with various technically efficient tradeoffs between ground water quality and agricultural production, broadly defined (it is assumed that agricultural production and fertilizer use are directly related).

To demonstrate the problem, assume that the socially optimum level of output is at point a, but the actual output level is at b, corresponding to ground water quality of c and production level of d, with a relative price line of ef. In the case of a market failure, the

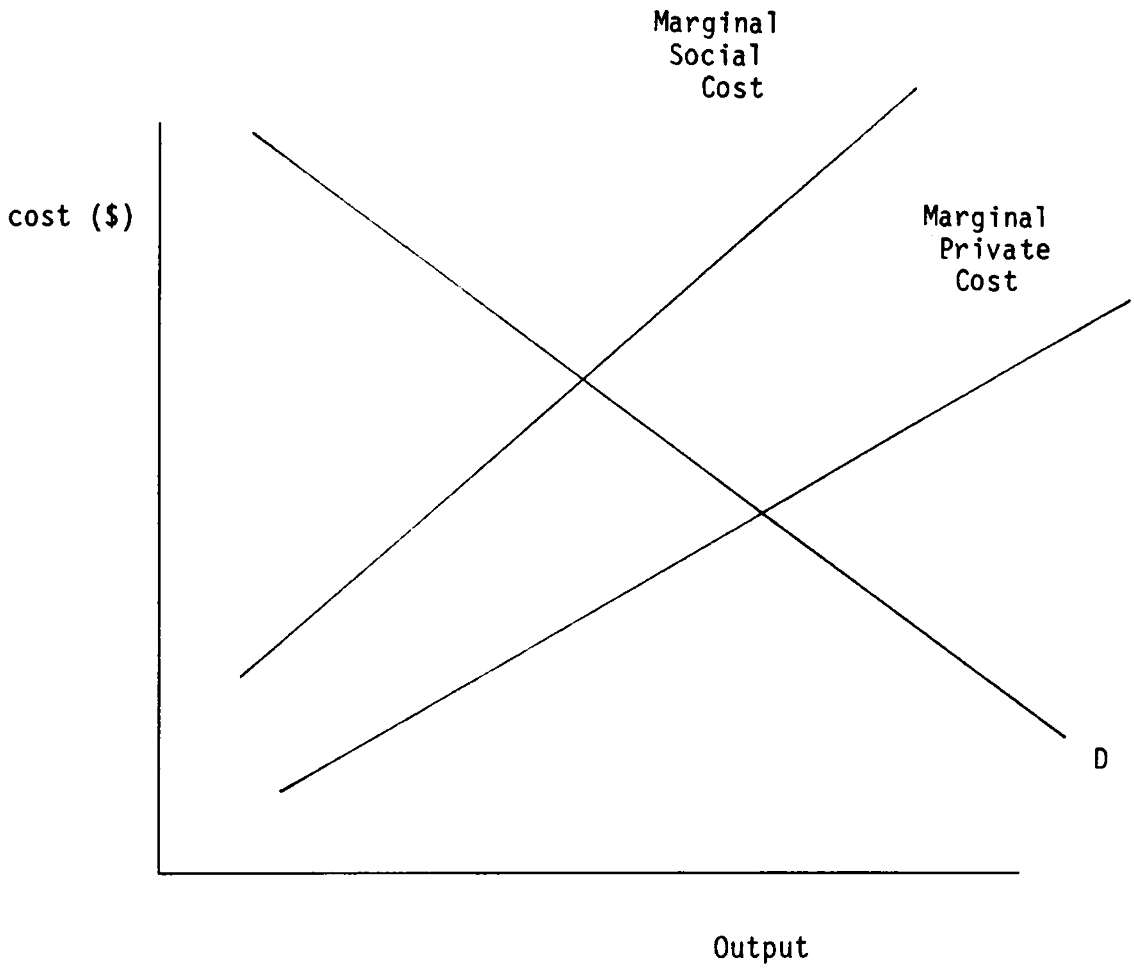

FIGURE 2.1. SOCIAL AND PRIVATE COST CURVES AND RESULTING PRODUCTION LEVELS IN THE ABSENCE OF CORRECTIVE ACTION.

Source: Adapted from Howe (1979)

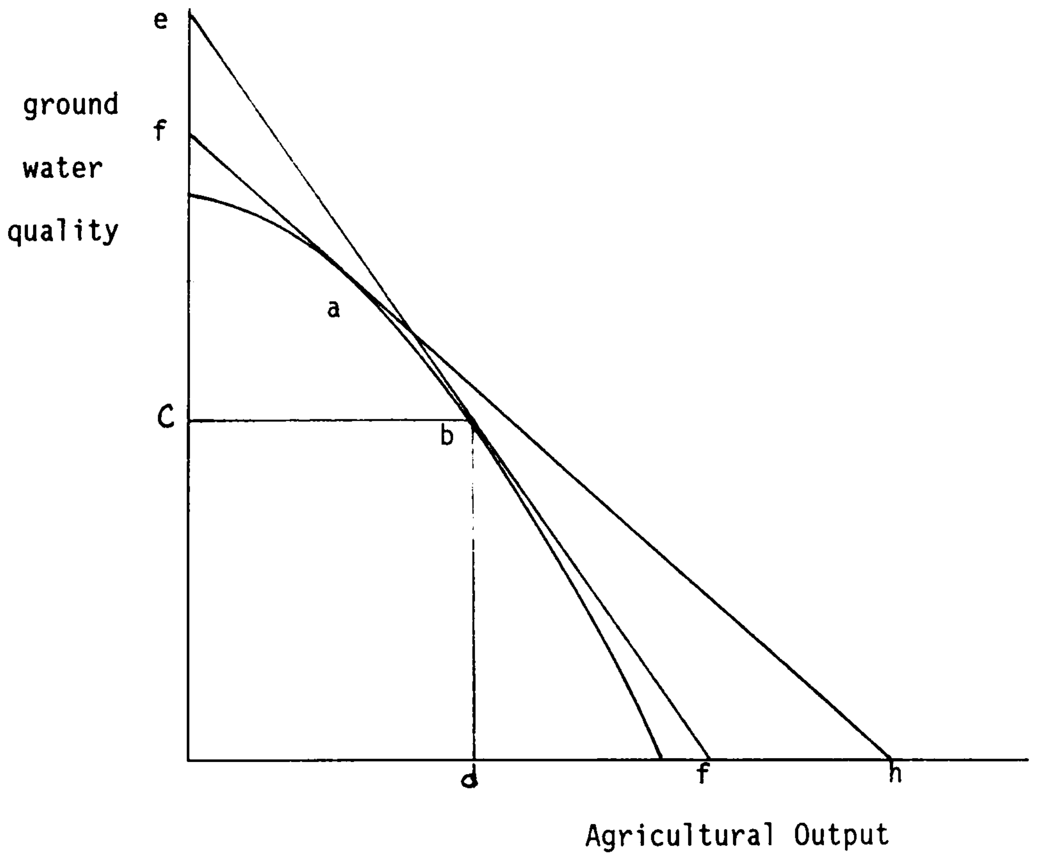

FIGURE 2.2. PSEUDOTECHNOLOGY REPRESENTING SOCIETY'S PRODUCTION POSSIBILITY FRONTIER FOR GROUND WATER QUALITY AND AGRICULTURAL PRODUCTION.

"price" of ground water quality relative to production is too high, resulting in a socially sub-optimum output mix. In order to achieve point a, society would have to face the price line of gh but, due to market distortions, gh is not effective. It may be desirable in this case to alter the slope of ef--the relative prices of the two goods--to reflect the true social costs of producing each "good."

In the presence of market failure, certain corrective measures may be necessary to move the economy to a Pareto-preferable position or to maximize social welfare. Government action in the form of taxation, subsidy, or regulation may be used to achieve equilibrium between society's willingness to pay for water quality and the marginal value of water quality to society. However, as Runge (1987) notes, development of the institutions to obtain this equilibrium are not costless, and the decisions regarding their development may not even be based primarily on economic criteria (Weaver, 1978). Some of the options for corrective action, as well as their potential cost and effectiveness, are discussed in the next section.

Alleviating Market Failure

Previous research has identified three methods of control which may result in elimination of an externality created by agricultural nonpoint contamination. These are: establishment of property rights for pollution, which in effect creates a "market" for pollution generation; imposition of a tax on the effluent itself, or subsidization of control measures; and imposition of a pollution standard.

Property Rights

Howe (1979) states that, if ownership of "in situ" resources is not clearly defined, owners who recognize the benefits of holding these resources will not be able to guarantee that they will be able to use these resources at some future date. In this case, the use of ground water as a "disposal area" will be overexploited by other farmers even if one or a few farmers try to curtail their polluting activities. This problem of ill-defined property rights was addressed in a seminal article by Coase (1960) in which he concluded that if property rights were well-defined, freedom of bargaining existed between parties, and there were zero income effects and transactions costs, all Pareto-relevant externalities would be eliminated regardless of initial assignment of property rights. This theory has been expanded on by others (for example, see Oates [1984]; Stroup and Baden [1983]; Mishan [1972]; and Randall [1981]) who examine whether the externality problem can be alleviated through a system of marketable pollution rights, which in effect give the bearer the right to a certain amount of ground water pollution.

Unfortunately, trade usually involves positive transactions costs, which violates one of Coase's assumptions. Randall (1981) has demonstrated that positive transactions costs will affect the quantity of abatement obtained by a "pollution market" solution. In general, an efficient solution will be achieved; however, this solution will not be invariant to the initial specification of property rights, a conclusion verified empirically by Crocker (1971). Russell and Wilkinson (1979) have demonstrated that even when all of Coase's assumptions are met, there are still cases where it may be impossible to reach a Pareto optimum.

Implementing the Property Rights Approach. Possibly the most widely used form of the property rights approach in United States agriculture today is in U.S. Department of Agriculture's (USDA) Conservation Reserve Program. In this program, farmers with highly erodible row crop land (as classified by the Soil Conservation Service [SCS]) remove their land from production for ten years in return for an annual payment which they negotiate from SCS through a bidding system. In effect, this program assumes that the farmer holds the rights to his topsoil on these sensitive lands, and is being compensated for the costs of conserving it at levels higher than would otherwise prevail.

A variant of the Conservation Reserve Program could also be used to reduce agricultural chemicals loading to ground water. Through a screening process for vulnerability to ground water contamination, highly sensitive areas could be removed from production or have allowable land uses restricted (for example, activities which were chemical intensive would be prohibited on land overlying sensitive aquifers). If the initial assignment of property rights was such that the farmer held the rights to ground water quality, a form of conservation easement could be purchased which compensated the farmer for loss of productive activity on the land surface. If the community held the initial property rights, the farmer could be prohibited from potentially degrading activities on land overlying sensitive areas, or would have to pay compensation to those affected by his activities.

Pigouvian Taxation

Pigou (1932) recognized that divergences between private and social net product could be resolved by the state through "extraordinary encouragements " (subsidies, or bounties in Pigou's terms) and "extraordinary restraints" (taxes); hence the name "Pigouvian taxation." The idea behind a corrective or Pigouvian tax is that the farmer faces the "wrong" price. Rather than responding to the market price p, the farmer should be paying $p + \partial U/\partial Y$, or the social price, which is the private price plus the adverse effect of the externality (Varian, 1984). To obtain an optimal solution, a tax would be placed upon the effluent (nitrate) or the effluent-generating activities (fertilization practices) in the amount of the externality.

Various authors have argued against the use of Pigouvian taxes and subsidies, on the grounds that it may increase resource misallocation in the presence of other market imperfections (Buchanan, 1969; Davis and Whinston, 1962) or that it may not even choose the right individuals to tax or subsidize (Coase, 1960). Baumol (1971) effectively refutes these criticisms by noting that the pure Pigouvian solution applies to cases of pure competition, while taxation and subsidy need not always cause misallocation, as Coase has claimed.

It has been acknowledged, however, that serious problems exist in implementation of the tax structure (Baumol, 1971; Rose-Ackerman, 1973). Abstracting from political difficulties, the primary difficulty is the estimation of the social costs of pollution, especially the psychic costs. To complicate matters, since the socially optimal composition of outputs is not known, there is no way of judging whether a given change in trial tax values will even produce a preferable situation. Finally, it has been noted that in the presence of externalities a "multiplicity of local maxima" are likely to be generated (Baumol, 1971, 1964), so that even if it were possible to use an iterative system of tax solution application, the solution achieved may only be a local maximum.

The solution to this problem lies in the use of the pricing and standards or "cost effective" approach developed by Baumol and Oates (1975). By treating the pollution generated as one of the outputs of the economic system, some maximum allowable level of that pollutant can be chosen (for example, the nitrate health standard of 10 mg/L) and a tax placed on pollution-creating inputs (such as fertilizer) to reach that level. This strategy effectively avoids the problems and costs of direct control, and is also easier to use than alternative controls due to lesser information requirements. Baumol (1971, p. 320) notes that this approach may still yield only a local optimum, but concludes that "if we allow ourselves to be paralyzed by councils of perfection we may have still greater cause for regret."

Implementing Corrective Taxes. Probably the biggest problem with designing policies to manage nonpoint source pollution is the prohibitive cost of identifying the number and contribution of polluters. Nonpoint agricultural pollution comes from a large, diffuse population, and pesticides and nitrates not absorbed by plants or insects are often subject to considerable transformation and transport before finally reaching the aquifer. The problem is thus not only how much tax to levy, but what inputs or outputs on which to levy the tax.

Griffin and Bromley (1982) demonstrate how, by the use of incentive payments or charges, an optimal management policy can be achieved. Unfortunately, before these policies can be implemented and a second best solution achieved, pollutant loadings must be estimated (Abrams and Barr, 1974). Since it is either infeasible or economically impractical to monitor nonpoint source emissions,[2] a different approach is needed.

Sharp and Bromley (1979) have proposed a "nonpoint source production function" which essentially allows policy makers to regulate the pollution-causing inputs in the farmer's production process, rather than the actual effluent loadings. The process starts with the farm's typical production set which converts inputs into marketable outputs. Now, however, it is assumed that the farm is "producing" pollution with the same inputs it used for crop and livestock output, so that it is producing externalities through the relationship

$$z^j = g(y^j) \qquad (3)$$

where

y^j = production bundle, firm j

z^j = pollutant (nitrate) emissions, farm j

This technique allows economic policies to be based upon those factors which determine pollution rather than the pollutant itself; in effect, it avoids the effluent measurement problem. Information needed to specify the relationships in equation (3) is provided by the CREAMS model, which generates nitrate loading estimates from standard nutrient management practices. The nonpoint production function approach, in conjunction with the pricing and standards method, was chosen for this dissertation; this approach, while not eliminating the need for physical monitoring, substantially reduces it.

Graphically, the tax situation is shown within a farm's profit maximization framework in figure 2.3. ABD represents the farmer's budget constraint (for simplicity, considering only expenditures on fertilizer) with price ratio P_N/P_M, with IP_1, IP_2, and IP_3, being isoproduct (isoquant) lines ($IP_1 > IP_2 > IP_3$); P_N is the per-pound price of commercial nitrogen, and P_M is the per-pound price of manure nitrogen. The shape of the isoproduct curve indicates that manure and commercial nitrogen are considered good substitutes, although in reality once a manure storage facility is constructed the farmer will use all of the manure nitrogen producible, signified by constraint level Q. The no storage situation means the farmer will use all commercial nitrogen at point A on isoproduct curve IP_1. Initial cost of constructing the storage facility is represented by AB; that is, a financial outlay equal to AB is necessary before the farmer has the option of using manure nitrogen. If he[3] makes that outlay under the initial situation

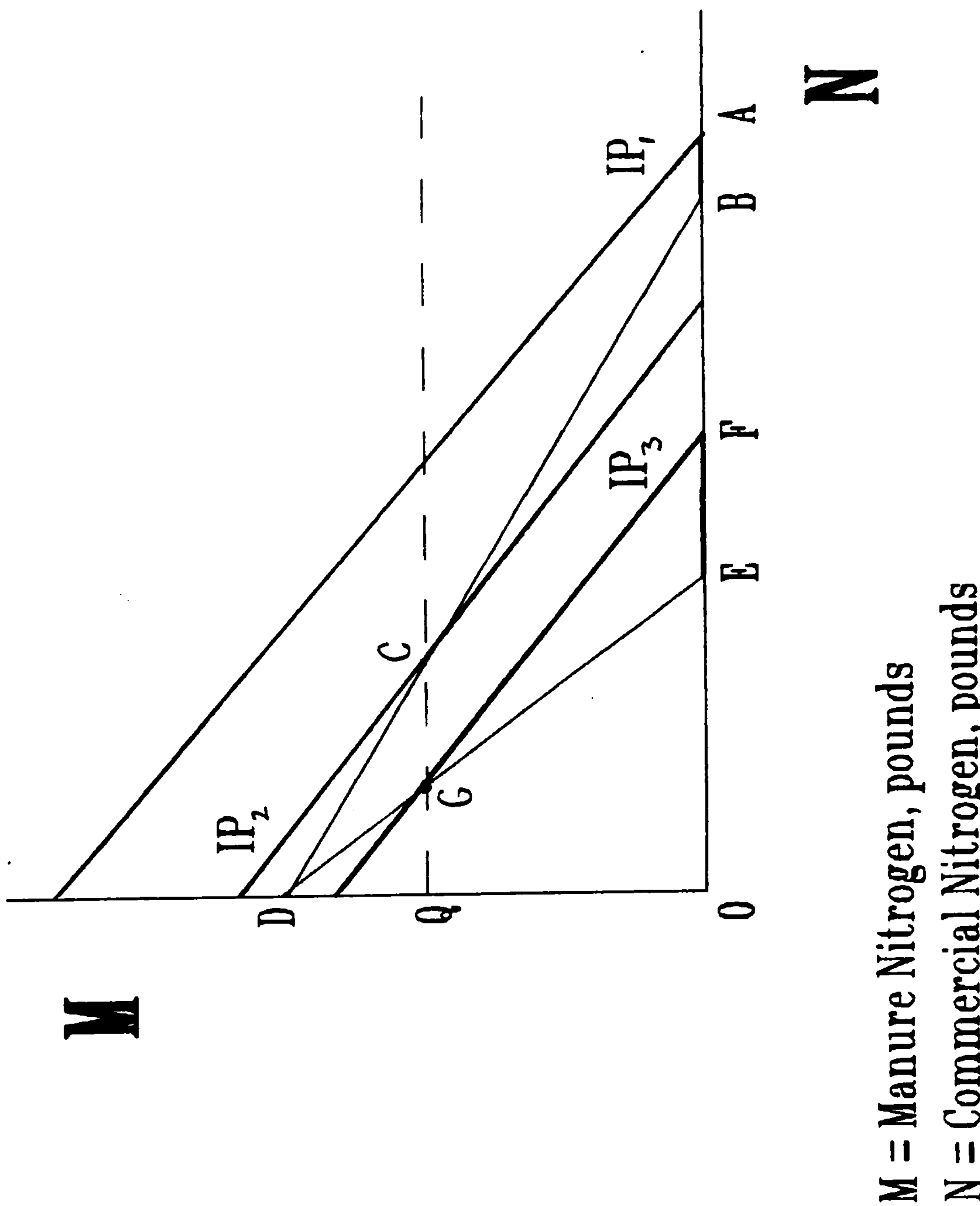

FIGURE 2.3. GRAPHICAL REPRESENTATION OF THE RESULT OF A CORRECTIVE TAX ON COMMERCIAL NITROGEN USE.

(with no incentives), he can produce at point C corresponding to IP_2 (which is less than IP_1).

Now, assume that the regulatory authority imposes a tax on commercial nitrogen which has the effect of steepening the no storage farmer's budget line to DEF with price ratio of P'_N/P_M, where $P'_N/P_M > P_N/P_M$. He can now continue to use all commercial nitrogen in his operations at point F on IP_3, or he can make the financial outlay of EF (=AB) to purchase a manure storage facility and produce at point G, also on IP_3. He is now at the threshold tax level where he is indifferent between using all commercial N or building a storage facility and using a combination of manure and commercial nitrogen. If the tax is then raised by a very small increment, so that the budget line reflects a price ratio of P''_N/P_M, the producer has the choice of producing using all commercial nitrogen, or constructing manure storage and using a combination of commercial nitrogen and manure nitrogen to produce on a higher isoproduct curve. The optimal tax to effect a changed in nutrient storage is $T > P'_N - P_N$.

There are two problems in applying this graph to the Rockingham County situation. The first is that the representative farm model will maintain the farmer's herd size even in the face of substantial fertilizer cost increases since feeding the herd with silage is still cheaper than shifting to an alternative ration such as alfalfa-corn grain. He will therefore continue his crop production activities (and nitrogen consumption) at current levels, absorbing the increased nitrogen costs through decreases in net returns. If the farmer were acting following strict economic logic, he would decrease his use of commercial nitrogen as its price increased in order to equate factor cost and marginal value product. In essence, the farmer still maximizes net returns over variable costs by maintaining his maximum herd on the silage based ration, which is still cheaper than going to a more expensive alfalfa ration base. The second problem is that the model does not consider fixed costs or capital constraints; the budget line shown in figures 2.3, 2.4, and 2.5 is therefore used only to show conceptually how the farmer reacts to the policy, and is not imposed on the model. In spite of these problems, the framework is still useful in that the isoproduct curves can be thought of as approximations of net return levels.

The graphical framework is applied to the cost sharing or "bounty" approach in figure 2.4. The farmer is initially at point A. A cost sharing policy will not affect the slope of BD, since relative prices of manure nitrogen and commercial nitrogen are unchanged (fixed costs of constructing the facility are reflected in line segment AB; if these fixed costs were not considered separately, the relative prices of manure and commercial nitrogen would change as cost sharing was provided). Cost sharing has the effect of causing a parallel shift of ABD to EFH, as the farmer's income increases. If the cost sharing funds were not earmarked for storage construction, the farmer would choose to produce at point H on IP_1. However, the nature of the program requires that he construct the facility, moving to point I on IP_2, with unchanged production, manure nitrogen use of Q and commercial nitrogen

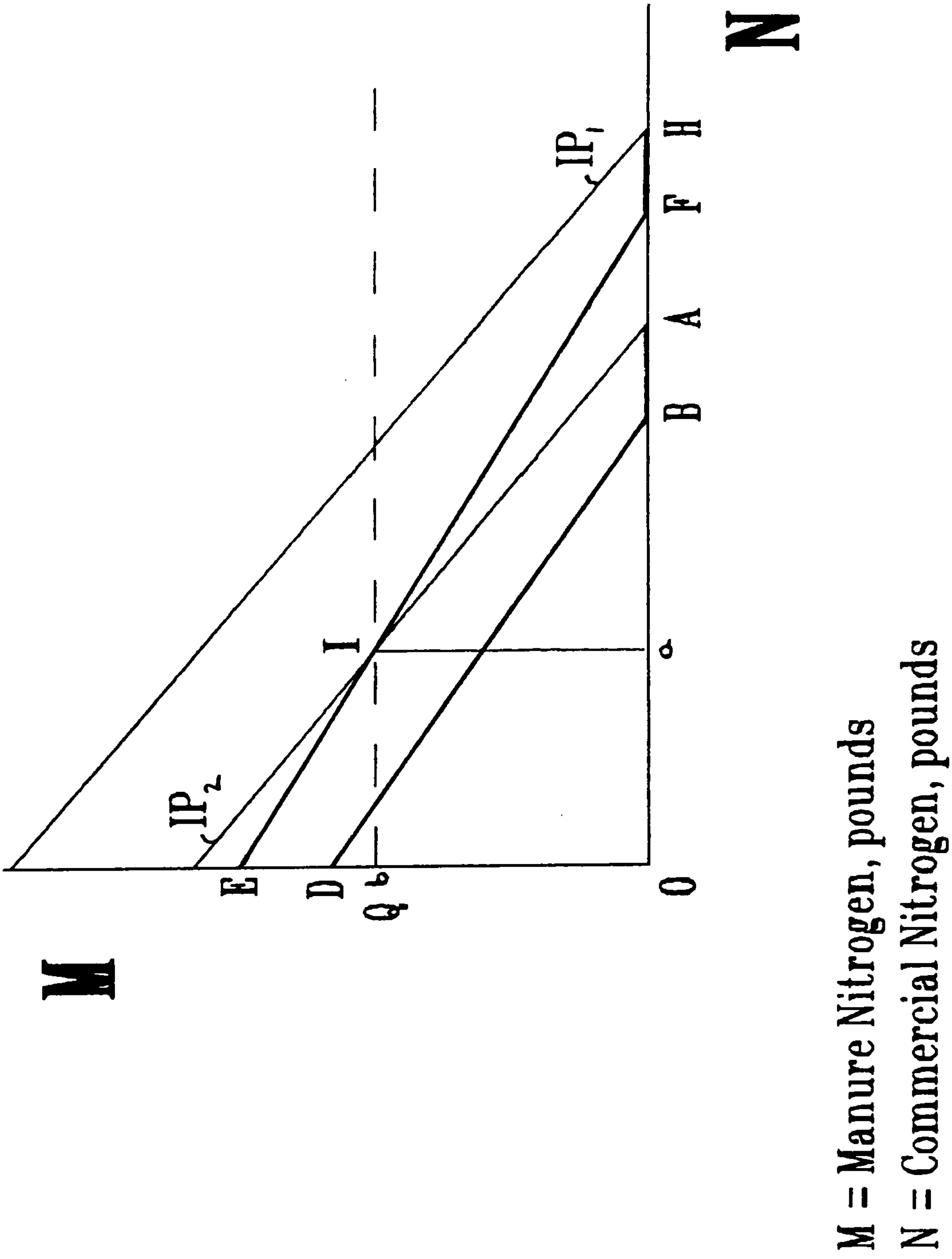

FIGURE 2.4. GRAPHICAL REPRESENTATION OF THE EFFECT OF A COST SHARING POLICY ON MANURE AND COMMERCIAL NITROGEN USE.

use of a (note that a + b is equivalent to OA, since manure nitrogen and commercial nitrogen can be substituted on a one-to-one basis).

Pollution Standards

The third method of accounting for the externality is to force the farmer to internalize social costs by placing a limit, or standard, on the maximum allowable effluent discharge. This approach has several limitations: first, it may entail substantial enforcement costs. Second, unlike taxes, the standard provides the polluter with no incentive for abatement beyond that required by the standard (Randall, 1981). This may effectively reduce the incentive to develop more efficient pollution-control technology.[4] Third, to the extent that this type of regulation mandates uniform reduction of loadings, the end result may be both inefficient and inequitable.

The final outcome will depend on the producers' pollutant reduction cost function. For example, a farmer whose land overlies a highly sensitive karst-carbonate aquifer in Rockingham County will have to reduce surface applications by substantially more to achieve a given standard than a farmer whose land is situated over a less susceptible sand and gravel aquifer in eastern Virginia. In other words, unless all farms are identical in their pollution reduction capability, there will be a disparity in pollution control costs (Stroup and Baden, 1983; Anderson et al. 1977).

Implementing Pollution Standards. Through regulation of farmers' fertilization practices, the managing agency is essentially mandating that farmers meet standards for pollutant loading. These standards could be probabilistic due to the stochastic nature of agricultural nonpoint pollution, and might need to be established on a local or regional level rather than for the individual farm in order to reduce implementation costs. There are essentially two methods of enforcement of this standard: legislation mandating that the standard be met (within a given confidence interval), with a substantial penalty for offenders; and application of fines or effluent charges if the farmer surpasses his "allowable" pollution limit. In the first case, enforcement costs may be quite high. In the second case, there would be no incentive for the farmer to reduce loadings below the standard (assuming that the farmer could discern the relationship between applications and nitrate loadings).

Using the graphical framework of the preceding section, the strict regulatory option is depicted in figure 2.5. In this case, the farmer has no choice in his manure storage adoption decision. In the status quo situation, he again chooses to produce at point A on IP_1. The regulatory authority now requires that he incur expense AB, which results in movement to point C with lower output (income) on IP_3.

Choice of Policy Approach

Uncertainty in the Policy Process. Griffin and Bromley (1982) identified four potential approaches to managing problems of a similar nature to agricultural nonpoint ground water contamination. These are:

- -economic incentives applied to estimated pollutant flow (e.g. taxes on loadings of pesticides or nitrates to ground water)
- -estimated pollutant runoff standards

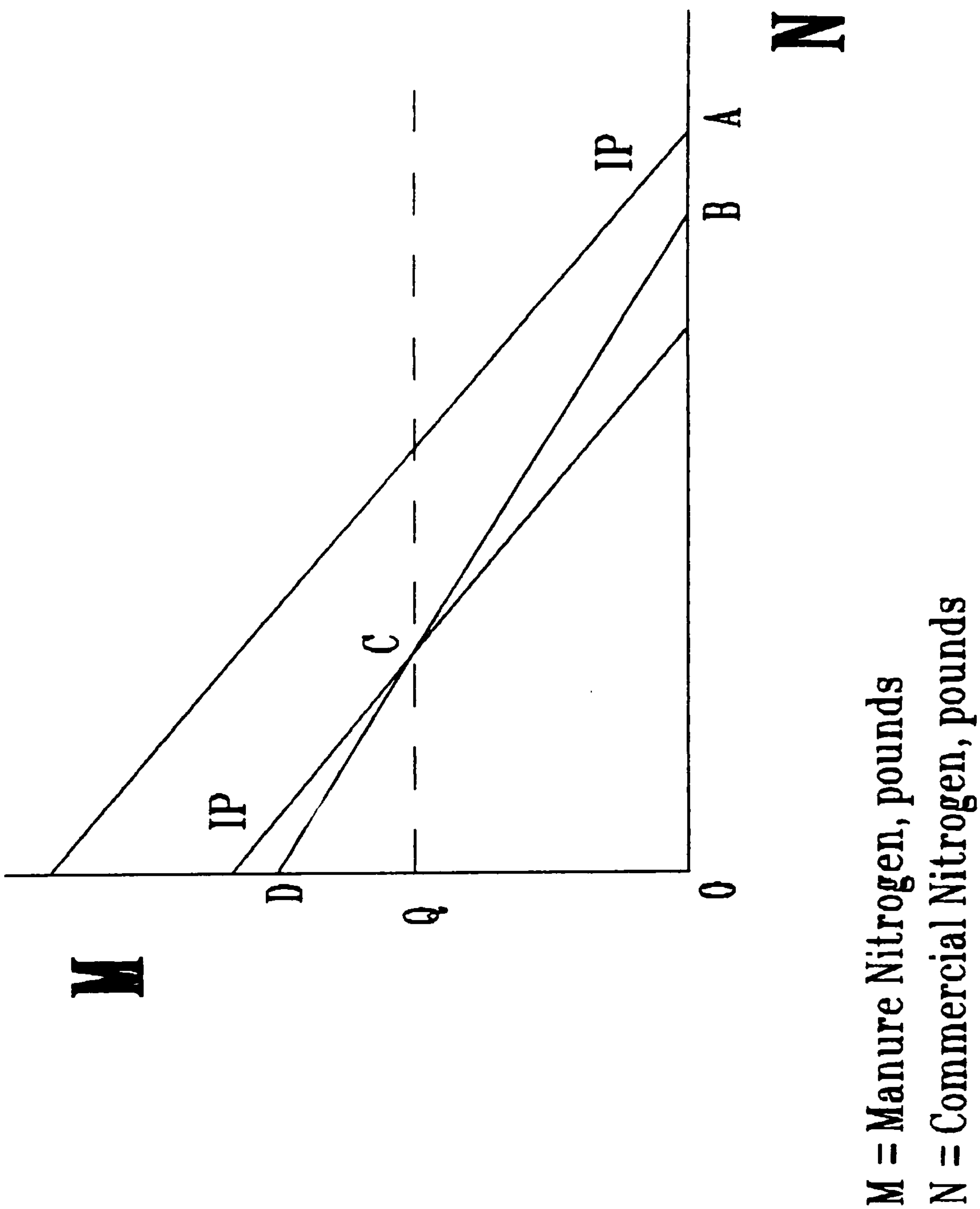

FIGURE 2.5. GRAPHICAL REPRESENTATION OF THE REGULATORY OPTION OF REQUIRED MANURE STORAGE.

- economic incentives applied to farm management practices (e.g. taxes on production inputs such as pesticides or fertilizers)

- farm management practice standards (e.g. required use of no till or integrated pest management)

The authors conclude that any one of these strategies would be equally effective in controlling nonpoint pollution when used in conjunction with their nonpoint production function. However, Shortle and Dunn (1986) have argued that the farmer has access to more information on farm-level decisions than the policy maker, which may lead to inefficiency in policy implementation.

Specifically, the policy agency is uncertain how a farmer will respond to a policy prior to its implementation. The farmer's response to a given policy will depend upon the features of the policy and the farmer's specialized knowledge of his operations. In order to achieve an efficient solution, the policy action would have to result in farm management practices which maximize society's net benefits. Since the agency does not have information on this specialized knowledge, choice among alternative policies is impossible. Shortle and Dunn have therefore argued that in most cases, due to the difference in information availability, the management practice incentive will outperform the other three strategies in reducing agricultural nonpoint pollution, primarily due to the strategy's greater capacity to induce the farmer to choose management practices that maximize expected social net benefits of his decisions. However, none of these strategies can achieve a first-best optimum where multiple pollutant sources exist and/or farmers are risk averse. Although Shortle and Dunn did not address the property rights approach, it seems plausible that the information discrepancy would also render property rights less preferred than taxation (using their previous logic) since the policy making agency has less access to information (at least, at reasonable cost) on potential uses and returns of the easement acreage.

While Shortle and Dunn's arguments are sound from a theoretical viewpoint, a combination of policies may be superior to a simple taxation scheme for several reasons. First, Shortle and Dunn argue that estimation of specialized knowledge is extremely costly and, even if a survey of farming practices/potential reactions were conducted, farmers are "notoriously reluctant to reveal their profitability to public agencies. This reluctance may become especially strong if they anticipate the information will be used to regulate their behavior (Shortle and Dunn, 1986, p. 3)." This argument may be questioned on two points: one, it is not clear that it is impossible to obtain a reasonable estimate of specialized knowledge from survey or other methods. Two, given the inherent uncertainty underlying the entire nonpoint problem, using an estimated value of specialized knowledge rather than the actual value may not cause a major difference in net benefits.

The second point of issue which could be questioned is the political tractability of a pure taxation scheme. One of the points which Shortle and Dunn emphasize is minimization of a strategy's transactions costs. Following similar practical reasoning, implementation of a taxation scheme could well prove impossible given the present political climate,[5] in which case alternative approaches would be necessary.

Transactions and enforcement costs may be lowest for the taxation scheme, since regulation and easements would require more monitoring to verify compliance. However, taxation could prove ineffective at reducing nitrate loadings if the principal source of contamination were from manure rather than commercially purchased fertilizer. Land use management practices (such as zoning and easements) are attractive in that they can be targeted to critical areas (Milon, 1986); however, these programs require substantial transactions and administrative costs to operate, and do little to promote new information on chemical transport and fate (Roberts and Butler, 1984; Kiker and Lynne, 1981). Fiscal incentives such as corrective taxes and cost sharing may best be used to target specific chemicals and may also promote Best Management Practice adoption, and have the added attractive feature of flexibility, but also may inflict high transactions costs on the parties involved due to information requirements of monitoring and enforcement (Milon, 1986). All of these policies would require at least some form of periodic physical monitoring to ensure that the desired loading reductions were being achieved. As noted above, the taxation scheme is further complicated by political unattractiveness.

Alternative Approaches

The approach to managing ground water contamination from agricultural nitrates followed in this dissertation primarily draws upon traditional neoclassical theory. The neoclassical approach is only one of several competing approaches to managing the problem, however. If the contamination problem is viewed as one of transactions costs and imperfectly defined property rights, then using public sector intervention--for example, through the corrective taxes or subsidies and regulation of management practices discussed--may not result in desired resource allocation due to public sector decision makers not being held fully accountable for their actions. Stroup and Baden (1983) maintain that the public sector provides insufficient incentives for these decision makers to manage natural resource efficiently. It has been argued that, in some cases, better assignment of property rights--leading to markets of tradable pollution rights--will yield a more efficient solution than government intervention, and avoid the possibility of the "special interest" effect (Gwartney and Stroup, 1987; Stroup and Baden, 1983; Maloney and Yandle, 1983). Although these alternative approaches will not be applied in this study, the development of better technology for measuring contaminant flows and nitrate loadings may enhance their attractiveness.

SUMMARY

It was illustrated that the three strategies discussed--a corrective tax, regulation, and a system of transferable property rights--all can be traced to underlying origins in Pigouvian taxation theory, effluent standards theory, and Coasian property rights theory. The tax strategy can be shown to dominate the others from a theoretical point of view (assuming zero transactions costs) as a means of achieving desired loading reduction levels. However, due to the fact that transactions costs are not zero and other practical considerations, other strategies should be considered. The issue of how to model nonpoint pollution problems within a standard profit maximization framework is addressed in this study through the use of a nonpoint production function.

CHAPTER III

SURVEY RESULTS

As previously detailed, the two principal methods employed in this dissertation are a mathematical programming model of a representative dairy farm in Rockingham County and a mail survey of county dairy farms. The first part of this chapter presents the results of the survey and describes some of the linkages between the survey and model. The second part of the chapter presents the results of a qualitative choice model designed to examine some of the factors involved in farmers' decisions whether to take advantage of manure testing services.

FARMING PRACTICES AND ENVIRONMENTAL ATTITUDES IN ROCKINGHAM COUNTY, VIRGINIA

Survey Structure

The survey of all 291 Grade A dairy farms in Rockingham County was conducted in the summer of 1987. The survey was designed to provide information on four principal areas:

- information on farming operations including size of farm, size of dairy herd, crops grown, and pesticide application rates,

- nutrient management practices, including manure and fertilizer application rates, and type and size of manure storage facilities (if any),

- water quality problems experienced by people or animals on the farm, water quality testing results (if any), and water treatment methods used, and

- attitudes toward ground water quality and other environmental issues (particularly as they relate to economic growth and agriculture), and levels of knowledge relating to ground water contamination potential.

Each of these areas will be discussed. Information on survey procedures and response rates is provided in appendix B.

Rockingham County Farming Operations

Cropland and Livestock

The average farm size of survey respondents was 200 acres. Virtually all of the farms grew corn as either silage or grain; this was an expected result since silage is the principal forage component of dairy cattle feed in the county. About 88 percent of the respondents primarily followed a corn/rye haylage crop rotation. Results are summarized in table 3.1. The average herd size was about 149 head, 78 of which were milking cows, 71 of which were heifers. A number of farms (19) had sizable poultry operations, averaging about 39,000 birds. Complete description and analysis of survey results can be found in Halstead, Batie, and Kramer (1988).

Conservation Practices

Most respondents use minimum tillage practices to grow corn. Strip cropping was used by 49 percent of respondents, an additional 31 percent used grass waterways, and 19 percent used some other type of conservation practice.

Since a considerable number of survey respondents rented part of their land (about 66 percent), it was hypothesized that management practices might differ substantially between rented and owned land. Of the 88 renters, over 93 percent indicated that they followed the same management practices on rented land as on owned land. About three

TABLE 3.1. CROPPING AND LIVESTOCK OPERATIONS ON ROCKINGHAM COUNTY, VIRGINIA DAIRY FARMS

CROPS

	Total Acreage	**Average[a] Acreage (per farm)**
Conventional tillage corn (52)	2,912	56.0
Minimum tillage corn (115)	7,883	62.1
Alfalfa (104)	3,559	34.2
Killed rye cover (40)	2,202	55.0
Ryelage (116)	6,908	59.6
Pasture (122)	9,331	76.5
Acres farmed (142)	28,468	200.5

LIVESTOCK

	Total (per farm)	**Average[a]**
Dairy Cattle (134)	19,953	148.9
Beef Cattle (3)	94	31.3
Swine (17)	2,222	130.7
Poultry		
Layers (16)	194,618	12,163.6
Broilers (8)	313,510	39,189.0
Turkeys (19)	488,002	25,684.0

Numbers in parentheses indicate number of respondents answering in each category.

[a]average numbers do not sum to total head because this column represents only those farms raising these animals Source: Halstead, Batie, and Kramer (1988)

percent used more intensive chemical application, about two percent usedless soil conservation, and only about one percent used less intensive chemical application. A possible explanation for this similarity in management practices between rented and owned land is that strong demand for land in the county results in renters managing rented land more carefully, since landlords can easily rent the land out to other farmers if they perceive it as being mismanaged (Roller, 1987).

Nutrient Management Practices in Rockingham County

High nitrate concentrations in Rockingham County water are due in part to leaching of nitrate from dairy manure and poultry litter. One of the main objectives of a nutrient management plan is to foster improved handling and storage of animal wastes and to insure that the nitrogen content of these wastes is used by plants. A recent survey found that nearly two-thirds of Rockingham and Augusta County dairy farmers had no long-term (120 to 180 day) storage facilities for their manure (Gentile and Thomas, 1986), a situation which results both in loss of the nutrient value of the manure for crop production and increased nitrate leaching due to land spreading of the waste as a disposal activity. Therefore, information was gathered in the survey on type and size of storage facilities, timing and application rates of both manure and fertilizer, and attitudes and knowledge regarding manure handling, nutrient content, and other factors.

Most farmers (44.9 percent) listed "commercial" laboratory recommendations as their primary influence in determining how much fertilizer to apply. The second most important source of information listed was fertilizer salesmen.

Nearly two-thirds responded that they would use a manure testing service if provided at a reasonable cost. About 29 percent said they were more likely to use this service if it were provided by VPI & SU rather than by a private firm. Most respondents were indifferent as to who supplied the service.

One of the more important findings of the survey was that some (11 percent) farmers did not consider nutrient contributions from manure when making fertilizer application decisions. About 41 percent of this 11 percent of farmers who did not consider manure nutrients followed fertilizer use recommendations from soil test results exactly whether manure had been applied, while 30 percent (equivalent to about 3.3 percent of the total survey respondent group) did not know the nutrient value of their manure. These responses may indicate why the county is the third largest purchaser of commercial nitrogen in Virginia, in spite of the large quantity of manure nitrogen available.

Manure Storage Facilities

Types of storage facilities owned by survey respondents are summarized in table 3.2. These results indicate that the percentage of responding farmers with no storage facilities is closer to 40 percent than 67 percent, in contrast to what the Gentile and Thomas study indicated. Part of the difference between the two survey estimates can be explained by Gentile and Thomas' assumption of year round confinement

TABLE 3.2. MANURE STORAGE FACILITIES IN ROCKINGHAM COUNTY, VIRGINIA, 1987.

Length of Storage Available	Number of Farms (pct.)	Total Capacity of Facilities (No. of Milking Cows)
180 days	58 (44.6)	5,059 (52.1)
120 days	19 (14.6)	1,459 (15.0)
No Storage[a]	53 (40.7)	3,189 (32.9)

[a] NS = No Storage. Many farms in the county have some type of short-term storage, ranging from concrete slabs to bedded earthen pits; however, for the purposes of this study, any farm with less than 30 days storage for its dairy herd is considered to have no storage.

for area dairy herds, when in reality dairy cows may spend only about 70 percent of the year in confinement (manure produced during the remainder of the year is therefore not economically recoverable). Their estimates of "unstored" manure were thus substantially higher than were occurring in actual practice. Gentile and Thomas also made the somewhat arbitrary assumption that about 10 percent of Shenandoah Valley dairy operations had unregistered manure storage facilities. Other discrepancies between the two surveys may be due to the fact that the earlier survey was conducted two years ago, or possibly that the sample obtained in the Rockingham County Dairy survey was not representative of the three-county area (Shenandoah, Rockingham, and Augusta) surveyed by Gentile and Thomas.

Water Quality on Respondents' Farms

Since the primary motivation behind the survey was to obtain information relating to water quality issues, a series of questions was asked regarding well testing and water treatment. About 23 percent of respondents treated their well water for household purposes; most (66 percent) who treated their water did so because of the results of well testing on their property. Over 73 percent of the survey have had their wells tested, indicating concern over water quality.

The survey questions related to three specific contaminant groups: bacteria, nitrates, and pesticides. Just over 8 percent noted that well testing revealed unsafe levels of bacteria, about 12 percent found unsafe levels of nitrates, and no respondents noted finding any unsafe levels of pesticide residue.

In a related question, just under 4 percent responded that people or animals had suffered illnesses on their farm due to nitrate ingestion. No respondents suffered illness from pesticide ingestion. Specific comments written on the surveys noted that high nitrate levels had caused reproductive problems and reduced milk production in dairy animals.

Attitudinal Responses

Respondents were asked four questions (with a total of 28 parts) which dealt with the importance of various economic and environmental issues. These questions can be generally divided into four categories: economic issues, environmental issues, knowledge issues, and economic-environmental tradeoffs.

Regarding six "issues of concern" to Virginians, about 75 percent placed protecting water quality, preventing soil erosion, and profitability in agriculture within the category of highest concern. In contrast, only 37 percent placed highest priority on maintaining economic viability of rural communities, 20 percent placed highest priority on diversifying agriculture in Virginia,[1] and less than 5 percent felt that attracting industry to Virginia should be of highest priority (see table 3.3). These answers highlight the conflict between desire for economic prosperity and maintaining environmental quality, in that reducing soil erosion and water quality degradation may result in decreased profitability. Additional questions found that county farmers are more concerned about water quality in Rockingham County and on

TABLE 3.3. PRIORITY RATINGS OF SIX ISSUES OF CONCERN FOR VIRGINIA AGRICULTURE BY ROCKINGHAM COUNTY DAIRY FARMERS

	RANKING				
	1	2	3	4	AVG
Profitability in Agriculture	0 (0.0)	6 (4.17)	20 (13.89)	107 (74.31)	3.76
Protecting Water Quality	2 (1.48)	3 (2.22)	27 (20.00)	103 (76.30)	3.71
Preventing Soil Erosion	1 (0.74)	2 (1.48)	31 (22.96)	101 (74.81)	3.70
Attracting Industry to Virginia	81 (62.31)	34 (26.15)	9 (6.92)	6 (4.62)	1.54
Maintaining Economic Viability of Rural Communities	5 (4.07)	20 (16.26)	52 (42.28)	46 (37.40)	3.13
Diversifying Agriculture in Virginia	17 (13.82)	33 (26.83)	48 (39.02)	25 (20.33)	2.66

1 = low priority, 4 = high priority. Numbers in parentheses indicate percentages of respondents.
Source: Halstead, Batie, and Kramer (1988)

their own farm than for the nation as a whole (Table 3.4).

To analyze the results of the questions which posed tradeoffs between economic and environmental quality issues, a system was developed to classify question responses. Questions fell into two main categories: (1) those reflecting satisfaction with the status quo situation of available technological ability and agricultural input use and (2) those reflecting concern that a need exists for change from the status quo. These two categories were labeled "satisfied with current situation" ("satisfied") and "concerned about current situation" ("concerned") respectively.[2] Results of these responses are summarized in Halstead, Batie, and Kramer (1988). Only one of the "satisfied" statements--"I am confident that agricultural pesticides, if used as directed, are not a threat to the environment"--received an agreement rate exceeding 50 percent (as measured by summing "tend to agree" and "somewhat agree" responses). None of the remaining "satisfied" statements received agreement ratings of greater than 40 percent. In contrast, agreement rates for the "concerned" category ranged from 55 percent to 95 percent. Respondents were extremely consistent regarding these answers--that is, there was agreement about the questions that elicited a majority of "concerned" responses, and disagreement with questions that elicited "satisfied" responses (with the exception already noted). This consistency was very similar to results obtained by Padgitt (1987) in a survey of Iowa farmers, where farmers' priority ranking of the same six issues of concern was identical to the Virginia survey results.

TABLE 3.4. LEVELS OF CONCERN REGARDING AGRICULTURAL CHEMICAL RISKS TO HUMAN HEALTH AMONG ROCKINGHAM COUNTY DAIRY FARMERS.

	LEVEL OF CONCERN			
	not at all	somewhat	very	not sure
In the nation as a whole	1 (0.74)	63 (46.67)	62 (45.93)	9 (6.67)
In Virginia	1 (0.77)	56 (43.08)	68 (52.31)	5 (3.85)
In Rockingham County	1 (0.77)	51 (39.23)	74 (56.92)	4 (3.08)
On my farm	4 (3.08)	47 (36.15)	73 (56.15)	6 (4.62)

Numbers in parentheses indicate percentages of respondents.

Source: Halstead, Batie, and Kramer (1988)

These results appear to indicate a high level of concern regarding agricultural chemicals and water quality. It may be concluded that current public concerns and expenditures on water quality are not misplaced. Although many farmers are undergoing at least some amount of economic stress, the respondents were found to consistently disagree with the position that degradation of ground water and the environment was an acceptable tradeoff for improved profitability.

Implications of the Survey for Nutrient Management in Rockingham County

Due to a large number of uninterpretable answers to survey questions on manure application, it was not possible to obtain a usable estimate of total nitrogen (commercial and manure) applied to corn on a county per-acre average. However, usable responses were provided to questions regarding application of commercial nitrogen to corn acreage. Therefore, an approximate division of respondents could be made on the basis of high nitrogen appliers and low nitrogen appliers.

The initial assumption was made (based on nutrient management plans devised for the county [Givens, 1987]) that application of available nitrogen should total 100 pounds per acre per year. Farmers applying more than 100 pounds of available nitrogen were then identified (see appendix C). This "high-applier" group was defined in two ways. The first sub-group was composed of those farmers who had 120 or 180 days manure storage on farm <u>and</u> applied at least 100 pounds of commercial nitrogen to their corn. (Although these farmers may not have spread all of their available manure on their corn land, nutrient values of their manure would still have been ignored by pasture spreading, so that from a water quality standpoint these farmers would still be practicing application of nitrogen in excess of what crops [either corn or pasture] could use.) Thirty four farmers were in this group, applying commercial nitrogen to 2,882 acres at an average rate of 114.8 lbs/acre. The second sub-group was composed of those farmers with no storage who applied at least 110 pounds of commercial nitrogen per acre. This group had 15 farmers applying to 854 acres at an average rate of 140.2 pounds of commercial nitrogen per acre. These "high appliers" comprised about one-third of both the large farm and small farm groups, so that the phenomenon appears to be due to other factors than size of operation.

The "low applier" group was composed of 51 farmers. Low appliers with four- or six-month manure storage applied commercial nitrogen at a rate of 62.5 pounds per acre to a total of 1,984 acres. Low appliers with no manure storage applied an average of 58.9 pounds of nitrogen per acre to 1,347 acres. The two groupings (high- and low-appliers) accounted for about 7,161 acres, or about 66.3 percent of total county corn acreage.[3]

These results may indicate several things. First, it is possible that farmers are applying nutrients in excess of agronomic recommendations as a means of reducing the risk of lowered yields--in effect, a form of insurance. In this case, if the cost of the additional nitrogen fertilizer were less than the risk premium which corresponded with lower yields, the farmer would choose to apply nitrogen in excess of agronomic recommendations. Second, as some respondents indicated, soil test recommendations may have superseded any other factors in their fertilization decisions. Finally, it may be that even though farmers knew that manure contained valuable nutrients, lack of knowledge as to its nitrogen content caused them to underestimate its value. In any case, these results indicate that provision of manure storage facilities alone is not sufficient to induce different nutrient management strategies, since many of the farms which appeared to be applying nitrogen in excess of agronomic recommendations already had these facilities available. These results may also be considered as further evidence in support of nutrient management programs such as those currently underway in Virginia, Pennsylvania, and other states.

Once these two groups of farmers (high- and low- appliers) were defined, a profile of various characteristics provided by the survey was compiled to determine whether substantial differences existed between management practices and attitudes of the two groups--in effect, to identify "who" these high-appliers were. Means and standard deviations were obtained for 15 farm/farmer characteristics and four attitudinal/knowledge questions for the two farm sizes. T-tests were then run between means of the high-appliers (in an agronomic sense only) and the other farmers. These statistics were run first for the large (>100 acres) and small (<100 acres) groups which have been used throughout the study, then for the combined total data set. Discussion of the results for the individual large and small farm data sets is contained in appendix C; discussion of the survey results for the combined data set of large and small farm high- and low-appliers follows.

Combined Data Set

Few differences were found between structural and operating characteristics of county farms when using the large farm-small farm classification to evaluate high- and low-appliers; therefore, it was decided to combine the two data sets to determine whether significant differences existed when the management and attitudinal variables from the farm survey were examined for the entire sample. Results of statistical analysis indicated no differences between high-appliers and low-appliers regarding crop acreage, ownership vs. rental of farmed land, types of crops grown, herd size, or other operating and management characteristics. High appliers were somewhat less concerned than other farmers about ground water contamination on their own farm; otherwise, no differences between concern over area water quality and over the effects of agricultural chemicals on ground water in general were observed.

Statistically significant differences were observed between the high- and low-applier groups in age, education, days worked off farm by the farm operator, and worker days hired. High-appliers were found to be both younger and better educated than other farmers. This result is surprising since it would usually be assumed that better educated farmers would use their inputs more carefully. High-appliers also spent more days working off farm than other farmers, possibly implying a lack of time available to devote to management decisions such as nutrient management; however, since a total of only 15 responses (which may not be a representative sample) are available for this category, it is again difficult to draw inferences for the entire county. High appliers also tended to hire more off-farm labor than other farmers, which could lead to a reduction in quality of management decisions, since hired workers might have less incentive than operators to carefully manage nutrients.

Several potentially important differences were found in the attitudinal questions. High-appliers were more in agreement with "satisfied" statements and tended to disagree more with "concerned" statements than other farmers. While this result may not entirely explain high-appliers behavior- -that is, the reasons these farmers apply larger quantities of nitrogen than low-appliers--they may suggest that since these farmers see fewer adverse consequences of nitrogen contamination, they have less incentive to moderate their application rates than those farmers who believe that nitrogen poses a threat to area water supplies.

Implications of the Survey for the Large Farm-Small Farm Groupings

The mathematical programming models constructed for this study were based on the initial assumption that about two-thirds of county farms were in the "large farm" group of greater than 100 acres. The survey confirmed this assumption. In order to determine whether cropping mixes and environmental attitudes differed between these groups, the survey data was divided into large and small farm groupings, and the results compared.

A higher percentage of small farm total acreage was devoted to corn production (58.8 versus 34.5 percent). Fewer small farms (on a percentage basis) grew alfalfa. Small farms also had fewer replacement heifers on farm relative to total herd size than large farms.

A surprising similarity was discovered between responses of the two groups to attitudinal questions. No statistically significant differences were found in responses to questions regarding the health risks of agricultural chemicals or the adverse effects of fertilizer on water quality.

Regarding the attitudinal ("satisfied" and "concerned") responses, only two differences in question responses were found. Small farm operators were slightly more confident that scientists will develop ways to "clean up" ground water if contaminated. Small farm operators were also slightly more in agreement with the statement "we must accept a slower economic growth in order to protect the environment" (both large and small farm operators' responses were in the "tend to agree" category). Based on this analysis, it can be concluded that Rockingham County farmers' attitudes do not differ based on size of farming operation. Therefore, responses to policy initiatives and economic stimuli which are influenced by these attitudes should not differ between size groups.

Significantly different responses were found regarding the desired use of manure testing services. Small farm operators were significantly less likely to use such a service if one were provided.

A more detailed examination of the manure testing issue is provided by the qualitative choice analysis later in this chapter.

FACTORS INFLUENCING THE MANURE TESTING DECISION

One of the presumed causes of the ground water nitrate problem in Rockingham County is the lack of consideration of the nitrogen content of manure applied to cropland by area farmers. In addition, a lack of manure storage facilities can preclude the possibility of using much of the manure nitrogen generated by dairy cattle. As demonstrated by the model results in chapter five, lack of storage facilities and failure to consider nutrient contributions of manure to crop needs do contribute substantially to nitrate losses.

In order to promote better use of this nitrogen, some university extension services are available to facilitate manure testing for nutrient content, either through university facilities or private laboratories. For example, the Pennsylvania State University uses a private laboratory for manure sample testing, while VPI & SU provides its own (currently free) manure testing service through a recently initiated program. The intention of these manure testing programs is to provide services which will encourage better nutrient management practices.

It is therefore useful to draw a profile of factors which influence the farmers' decision to adopt manure testing practices. In this way, information can be gained on several areas. First, the probability can be estimated of whether or not a given farmer with certain characteristics (for example, a farmer of a given age or educational level, and size of farm) will favor adoption of a manure testing service. With this information, characteristics which can be affected by educational and other programs can be targeted. Second, an idea of which factors are weighted most heavily in the farmers' test-adoption decision can be gained. Finally, program managers and policy makers can obtain an overall picture of how much participation in a newly initiated manure testing program could be expected.

The Rockingham County dairy farm survey results indicate that most (66.4 percent) respondents would use a manure testing service if it were available at a reasonable cost.[4] However, a substantial number would not use the service. In order to gain more information on this test-adoption decision, statistical analysis was performed on the survey data. This section describes the model constructed, the results of the analysis conducted, and the potential usefulness of this information to policy makers.

The Qualitative Choice Model

Ten independent variables were selected as having potential impact on the test-adoption decision: size of dairy herd (HEAD); total corn acreage (CORN); presence of other conservation practices (CONS); use of soil testing (SOILT); whether or not the farmer adjusted his commercial fertilizer application rates to reflect the contribution of his manure N (NADJ); Age (AGE); Education (EDUC); whether or not the farmer maintained (in the survey) that he did not take credit for his manure nitrogen due to lack of knowledge of its nutrient value (DKNOW); and whether or not the farmer had 120 or 180 day manure storage facilities (STOR1 and STOR2). The logit technique was used to estimate the relationship between the test-adoption decision and the independent variables. Complete descriptions of the model and the qualitative choice technique selected are contained in appendix D.

Results of the logit analysis are presented in table 3.5. The signs of the CORN (corn acreage), CONS (conservation practices), and STOR1 (120 day storage) parameter estimates were contrary to expectations in both models. The corn acreage variable had extremely small coefficient values and t-ratios in each case, and so might be dismissed as having no effect on the probability of test-adoption. The sign of the conservation practice variable is more problematic; why farmers might consider conservation practices and manure testing as substitutes is difficult to explain. Perhaps some farmers may use no till practices for non-conservation reasons (such as cost savings), in which case the initial hypothesis was misspecified. It was also expected that the presence of either storage facility should increase probability of test adoption, yet the sign of the STOR1 coefficient indicated otherwise. However, both the t-ratios and the relative magnitude of these coefficients in both models were extremely small, indicating limited importance of these variables in the manure testing decision. All other signs were as hypothesized.

The results indicate that the most important variables affecting the test-adoption decision are the Age (AGE), Soil Testing (SOILT),

TABLE 3.5. RESULTS OF LOGIT MODEL ANALYSIS TO DETERMINE FACTORS INFLUENCING ADOPTION OF MANURE TESTING.

	Maximum Likelihood Estimates		
	Parameter Estimate	Standard Error	Asymptotic t-ratios
HEAD	0.2393E-01	0.13851E-01	1.7275*
CORN	-0.7054E-02	0.80253E-02	-0.8790
CONS	-0.2835	0.6782	-0.4180
SOILT	1.5498	0.6349	2.4409*
NADJ	2.7188	1.2289	2.2123*
AGE	-0.5918	0.3756	-1.5757
EDUC	0.8191	0.5797	1.4130
DKNOW	2.1875	1.4024	1.5599
STOR1	-0.5579	0.8005	- 0.6969
STOR2	1.1604	0.6571	1.7657*
CONSTANT	-2.6674	1.6107	-1.6561

*significant at 95% level

log of likelihood function = -44.0480
likelihood ratio test 40.0227 (10 d.f.)
n = 106
d.f. = 95
McFadden's R^2 = .3124

Source: Halstead, Kramer, and Batie (1988).

adjustment of nitrogen applications to account for manure contributions (NADJ), and presence of 180 day on-farm manure storage (STOR2). The soil test and nitrogen adjustment variables indicate that farmers who already are taking steps to minimize nutrient application are more likely to use the testing service. The 180 day storage variable is further manifestation of this tendency toward efficiency in resource use. Significance of the age variable indicates a negative impact of age on the test-adoption decision. Thus, older, less educated farmers may be less likely to adopt manure testing than younger, more educated farmers. The sign of the DKNOW variable was positive as anticipated, but not significant. Finally, although farm size as measured by the corn acreage variable had no significant impact on the test-adoption decision, herd size as measured by number of head had a positive and significant impact. The sign of the dairy head variable thus indicates that as farmers' manure-generating capacity (that is, his number of cows) increases, they are more likely to adopt manure testing to take advantage of the additional nitrogen produced.

Calculation of Probability Estimates

One useful result yielded by qualitative choice analysis is a means of assessing the probability that a farmer of given characteristics will participate in a manure testing program. If it is assumed that the representative farmer in Rockingham County is described by the means of the ten variables in the model, the probability that the average farmer will participate in the program can be obtained. Using the method described in appendix D, the probability that the average farmer in Rockingham County will adopt manure testing is approximately 77.7 percent.

Extension of Analysis to the Representative Farm Models

The logit model can also reveal whether farm size and the characteristics of operators on these farms affect the test- adoption decision. As previously described, it was felt that county farms could be roughly divided into two groups, greater than and less than 100 acres.

For the large farm case, where HERD = 100 and CORN = 90 (and all other variable values representing the mean for the large farm group), the probability of adoption is .84062 or about 84 percent, so that the larger farm is more likely to adopt manure testing than the average size county farm. For the smaller farm with 60 milking cows and 55 acres of corn, the probability of adoption is about 55 percent. This result indicates that, other variables held constant, small farmers are less likely to adopt manure testing than the average Rockingham County farmer. This logit result is validated by analysis of survey data, which indicates that farmers with 100 acres or less of cropland are significantly less likely to use a manure testing service than farmers with more than 100 acres of cropland.

SUMMARY

The survey results revealed potentially important information on three aspects of the county dairy farm situation: current agricultural and nutrient management operations; water quality on respondents' farms; and environmental attitudes of county farmers. Regarding the first category, many farmers are applying nitrogen to their cropland in excess of agronomic recommendations, resulting in increased loadings to ground water. Most would use a manure testing service if provided, possibly reducing these nitrogen/nitrate losses. Those applying high quantities of nitrogen per acre differ significantly from other farmers in that they are less concerned with the effects of agricultural chemicals on the environment. Many county farms do not have manure storage facilities. Second, most respondents have had their drinking water wells tested, indicating concern over water quality. Problems were noted with nitrate contamination of some wells. Respondents noted no problems with pesticide contamination. Third, farmers view protecting water quality of equal importance with maintaining profitability in agriculture and preventing soil erosion. Attitudinal questions revealed concern over the effect of agricultural chemicals on ground water quality, and acknowledged that economic tradeoffs may be necessary to protect ground water quality.

Examination of the desired use of manure testing services (as a proxy for improved nutrient management practices) revealed that farmers' age, use of soil testing services, adjustments of commercial nitrogen applications to reflect manure contributions, farm size, and whether or not the farm had storage facilities in place were the most important factors in determining whether a farmer would use a manure testing service if one were provided. Owners of small farms, while more likely than not to use a manure testing service, were less likely to adopt manure testing than large farm owners (large and small were defined by herd size and corn acreage).

CHAPTER IV

CONSTRUCTION OF THE MATHEMATICAL PROGRAMMING MODEL

Whether or not corrective taxation, regulation, or other policy options have the desired effect on nitrate loadings to ground water will depend on how the affected clientele--farmers--react to these actions. By examining farmers' reactions to these external economic stimuli, an estimate of the effectiveness of each strategy can be gained, as well as grounds for comparing the relative merits of the different strategies. This chapter discusses the theoretical foundations and construction of a model designed to demonstrate how these strategies might affect a typical or "representative" farmer. The first section discusses the risk and uncertainty inherent in both the farmer's standard decision processes and in the ground water problem in particular, and how this information can be incorporated into the modeling process. The second section discusses the general characteristics of the representative farm model. The third section discusses the incorporation of risk into the modeling framework through the use of chance constraints and the CREAMS physical modeling system. The fourth section discusses specific activities and policy formulations of the conventional practice and nontraditional alternative (Nontraditional Alternative) models.

INCORPORATING RISK INTO THE MODELING FRAMEWORK

The model designed for this study must be able to accommodate both production risk and uncertainty borne by the farmer and environmental risk and uncertainty in achieving maximum allowable ground water contaminant standards.[1] Spofford et al. (1986) have recently modified the idea of risk versus uncertainty by expanding the classification of possible outcomes into three categories:

1. Risk1--events and probabilities of events are known _a priori_.

2. Risk2--either events are not available _a priori_ or events are known but probabilities of those events are not. However, either the events or the probabilities could be made available through further research or data gathering; risk2 could thus in principle be converted into risk1.

3. Uncertainty--events are not available _a priori_ or events are known _a priori_ but the probabilities of those events are not.

Spofford _et al._'s classification scheme lends itself to the ground water problem. For example, weather is a key stochastic element for which probability distributions can be generated using historical data, so would fall into the category of risk1. Health effects of long-term exposure to low doses of agricultural chemicals may never be determined, and so may be classifiable as uncertainty. Many issues in contaminant movement through the ground water system are presently not well defined, but ongoing research shows promise of resolving these issues, so that risk2 may be the appropriate classification. In practice, of course, it is often extremely difficult to distinguish between types of risk.

However one chooses to define the risk and uncertainty inherent in the ground water problem, they must be incorporated into the process for policy design and evaluation. For risk2 measures, models can be designed which consider that these types of risk will later be quantifiable as risk1; for example, admittedly imperfect ground water transport models can be incorporated into the management system and later replaced with more accurate models.

Economic Issues

Standard Agricultural Risk

Farmers face risk from three main sources: price variability, yield variability, and changing government programs.[2] How the farmer reacts to this risk may also affect ground water quality. For example, expected market prices and their variability and government support prices will determine what crops and how much acreage a farmer cultivates, which in turn influence the types and volumes of herbicides, insecticides, and nutrients used. Finally, yield variability will influence the amounts of nutrients and pesticides used by the crop, which in turn determines the availability of contaminants for leaching. Yield variability may also affect application of agricultural chemicals if they are viewed as risk-reducing inputs.

Modeling Problems

Economic tools to predict or evaluate the effects of alternative strategies on net returns, income distribution, or other key issues often take the form of farm-level models designed to simulate typical or representative farms in a given area. Use of these models has become fairly commonplace; in particular, the mathematical programming approach has been used frequently (see, for example, Palmini, 1982; McSweeney and Kramer, 1986; Taylor and Frohberg, 1977; Kramer et al., 1984). The quadratic programming model (Freund, 1956) is especially attractive in that it allows for consideration of the price and yield variability described above, as well as allowing incorporation of differing attitudes toward risk in the farmer's objective function (McSweeney and Kramer, 1986; Paris and Easter, 1985); however, the level of risk aversion chosen will affect the solution to the problem, and empirical evidence on the structure of risk preferences is limited (Pope, 1982; Hazell, 1982). The standard linear programming framework assumes risk neutrality, and represents a simple profit (or net return) maximizing objective function. These mathematical programming approaches can be applied in single or multi-period frameworks.

The farm-level mathematical programming approach isolates producer response to different policy initiatives. This approach is especially useful for simulating the effects of policies for which no historic data exists--such as the corrective tax, regulation, and input restricting policies considered in this study. If the initial farm model is correctly specified, model responses to proposed policy alternatives (which may take the form of constraints or subsidies on production practices) can be viewed as a general indicator of how the area's farm sector would respond to implementation of these policies, which in turn gives an estimate of the policy's potential cost and effectiveness.

The linear programming approach was chosen as suitable for this research for three primary reasons. First, consultation with dairy experts revealed that dairy farmers' primary source of risk is in forage production, rather than output price and yield variability (Groover, 1987; Moore, 1987). Price risk is reduced because of government programs which stabilize the price of milk, and the fact that milk production is typically not subject to the weather-induced yield fluctuations experienced in crop production. Second, there is some empirical evidence to suggest that most dairy farmers are risk neutral (Tauer, 1986), which would imply that the risk aversion coefficient in a quadratic programming framework would be zero. The influence of price and yield variability on production decisions would therefore be negated. Finally, nonlinear (quadratic) programming routines could not used in conjunction with the mixed integer algorithm used for the dairy farm model due to software limitations.

This assumption--that the model objective function was linear--essentially means that the farmer is maximizing net returns (as a proxy for actual profit) rather than his expected utility, as is assumed with a quadratic objective function. The model does incorporate the effects of variability in the prime source of risk--feed production--through chance constraints on yield production. Stochastic environmental elements were also incorporated into the structure to reflect the probabilistic nature of contaminant loading.

Criticisms of the Representative Farm Approach

Beyond the questions of whether activities and constraints of the representative farm model were accurately specified and whether the farm truly is typical of regional operations, questions have been raised as to whether the representative farm approach has any policy relevance. Although the representative farm framework has been used frequently to model policy-induced changes in agricultural practices, Miranowski and Reichelderfer (1987) have directed several criticisms at this approach:

- most of these analyses are static rather than dynamic

- most micro-level approaches assume that the farmer is risk-averse; there is not sufficient empirical evidence to assert this

- studies of risk tend to focus on the implications of a small set of activities without considering substitute or alternative activities

- economists do not know how existing risk preferences influence current or future resource use patterns and, although risk-averse farmers may be slow in adopting new practices, they may also be slow in abandoning them

Using static rather than dynamic mathematical programming models in policy analysis fails to incorporate the nature of farmers' long run decisions. This criticism is valid for issues such as soil erosion, where the farmer's management decisions this year will affect soil productivity or other variables in years ahead. However, for this study, it is assumed that the farmer is not considering the stock effect of his nutrient management on long-run water quality. In addition, exogenously imposed regulatory constraints to improve water quality are simply viewed as external constraints which the farmer must meet; for example, chance constraints placed on production processes by policy makers would be viewed simply as additional constraints in his technical matrix rather than causing the farmer to consider actual nitrate loadings over time.

For the Rockingham County study, no attempt was made to elicit risk preferences. Risk aversion is an important issue since the high application of nutrients common in the area may be essentially risk-reducing behavior. However, the type of risk aversion incorporated into the model (silage feed production) seems to be a valid assumption since there are few alternatives available to the county farmer who fails to meet his herd's silage ration needs. In addition, experts on area dairy farmers felt that area operators were indeed risk averse when considering silage production.

The third criticism, that a broader perspective is needed, is a valid criticism of the current study. Rather than concentrating on nutrient management practices in the Shenandoah Valley, it may be more relevant from a policy perspective to determine whether cost sharing and other funds for ground water management would provide greater social welfare increases if they were spent in other counties or on other contaminants, or whether any cost sharing funds should be invested in a sector of the industry which is already heavily supported for producing a surplus commodity. The Rockingham County study starts from the assumption that the area's nitrate problem is one that demands attention. The micro approach inherent in a representative farm model is useful in that it focuses on individual farmer response to policy initiatives. These responses may not be captured when using a broader approach to policy analysis.

The final potential criticism of the representative farm approach, that economists do not know enough about existing risk preferences, is well taken and should be the subject of additional research. Such research is beyond the scope of the present study. In sum, while these criticisms and caveats on using the representative farm approach are valid, it would seem that they point to the need for careful specification and application of the tool rather than its abandonment.

THE MODEL

The representative farm model used in this study was based on an average dairy farm in Rockingham County. The model's objective function maximizes returns over variable costs from milk sales and sales of cull cows, calves, alfalfa, and strawberries. The model does not include fixed costs such as insurance, utilities, and interest on debt. Therefore, the objective function value should be interpreted as net returns over variable costs rather than true profit; the objective function will overstate actual profit by the amount of fixed costs (although technically the cost of siting and debt servicing for the manure storage facility is a fixed cost, it will not be treated as such in the model so that all aspects of the manure storage decision can be viewed in detail). In any case, short term profit maximization decisions disregard fixed costs, so that activities chosen by the model would not be affected if a fixed cost component were included.[3]

The model consists of 99 activities and 71 constraints. Many of these constraints and activities were designed simply to reflect the fact that there were four different manure storage scenarios which could not be combined. The model was refined and validated using the results of the Rockingham County Dairy Farm Survey, conducted as part of the study. The model was solved using the mixed integer programming routine of the LINDO (Linear Interactive aNd Discrete Optimizer) microcomputer algorithm. A detailed description of the model and tableau is provided in appendix E.

The model was designed for two representative farms, one with a maximum herd size of 60 cows, the other with a maximum herd size of 100 cows. This herd size distinction was made to capture operating differences between large and small operations in the county. In particular, it was assumed that many of the smaller farms were owned by farmers of the Mennonite religion. This distinction is important since, in accordance with their religion, Mennonites generally do not participate in government programs such as cost sharing or price supports. This religious distinction in turn limits policy options for management of the nitrate loading problem (such as cross-compliance[4]) on these farms.

The survey revealed that about one-third (34.6 percent) of responding farmers were in the small farm category. Model construction and formulation were similar to the large model. Principal differences (other than crop acreages) were in feed and labor requirements (due to the assumption that the small farm did not raise its own replacement heifers) and the relaxation of the requirement that alfalfa be grown on the farm (Roller, 1988; Halstead, Batie, and Kramer, 1988). The percentage of total small farm acreage devoted to pasture was reduced from 42.5 percent in the large farm to 31.2 percent. This is potentially a very important adjustment, since the ratio of herd size to total acreage is larger for the small farm than for the large farm (.75 versus .5). Small farms with no manure storage facilities are therefore required to spread manure on pasture land at a higher rate than large farms with no storage, with commensurate increases in nitrate loadings to ground water.

Introducing Risk into the Model: The Chance Constraints

As noted, management of ground water nitrates is especially problematic due to the great degree of risk and uncertainty involved. It was therefore essential for the model to incorporate risk into both the economic decision and the environmental components of the model. In this way, the model could reflect both risk affecting farmers' management decisions and the uncertainty inherent in the way these decisions affected ground water quality.

The chance constraint incorporates the effect of the standard deviation of the loading or yield coefficient into the model coefficient (a_{ij}); this explicitly recognizes the variability of either crop production or nitrate loadings. The chance constraint then mandates that the chosen standard (b_i) be met within a specified confidence interval rather than deterministically. For a "greater than/equal to" constraint (such as corn yield requirements), the mean value of the a_{ij} is discounted or reduced; for a "less than/equal to" constraint (such as for nitrate loading), the a_{ij} is supplemented by a risk "premium" which combines the effects of the loading coefficient's standard deviation and a specified value from the standard normal distribution. Thus, for higher confidence intervals of the less than/equal to constraint or for larger standard deviations of the variable, the a_{ij} becomes larger to reflect parameter variability. Specific derivations of the chance constraints are in appendix F.

Economic Risk

Consultation with dairy experts revealed that the principal production risk faced by these dairy farmers is in feed production (Groover, 1987; Moore, 1987). In the model, it is assumed that all corn crop activities are transferred to dairy herd feed. Since no provision is made for purchase of silage,[5] the model requires each farm to produce enough silage to supply the forage ration needs of its entire herd. A farmer who assumes that his annual silage production per acre will simply be equal to the historical average may underestimate the number of acres (due to the annual silage yield variability) he will need to plant to silage to insure an adequate feed supply; he may therefore experience a shortage of feed for his dairy herd.

Survey results indicated that county farmers were growing more corn silage than necessary for cattle feed (on average). Farmers typically plant a large amount of corn acreage; all or most of this corn is then harvested for silage rather than for grain in low-yield years to fulfill ration needs. In high-yield years, part of this corn is used as silage with the remainder harvested for grain for feed or sale (Groover, 1987). This "extra" silage acreage is thus a buffer against silage shortfall, and so may reflect a form of risk-reducing behavior on the farmer's part.

In order to accommodate this production risk in the model, a chance constraint was constructed for silage production (see appendix F). This constraint effectively discounts the parameters for silage production per acre to reflect the annual yield variability; in this way, the yield parameter will represent the number of tons per acre that will be realized within the given confidence interval. Two levels of constraint are specified: the 50 percent level, which assumes that yield variability does not affect the farmer's cropping decisions (that is, he is making planting decisions based on mean yield values); and the 90 percent confidence interval. These alternative confidence intervals allow consideration of a range of risk aversion levels for the representative farm operator.

One of the problems with the chance constraint technique is that it is theoretically difficult to choose the appropriate level of risk aversion (as represented by the confidence interval) without explicit information on county farmers' risk preferences. In addition, critics of chance-constrained programming maintain that it gives no information to the decision maker as to what should be the appropriate level of confidence nor does it incorporate information about costs of failure to meet the constraint (Hogan, Morris, and Thompson, 1981). In the present case, it may be reasonably argued that extreme risk aversion (as represented by the 99 percent confidence interval) is a luxury that the farmer cannot afford, and that risk preferences represented by the 90 percent constraint level is more typical.

Environmental Risk

Agricultural nonpoint pollution is inherently stochastic. Nitrate movement and leaching to ground water will be heavily influenced by rate and timing of application and by rainfall and other weather events. The average nitrate losses per acre presented in the representative farm model runs were subject to a high degree of variation over the 20 year CREAMS simulation. Standard deviations for these loading coefficients ranged from 71.4 to 94.7 percent of corresponding mean values (see table 4.1). Given the high degree of variability in these values, any ground water management program which attempted to achieve a given water quality level considering only the mean loading values for nitrate might be in violation of the intended standard a high percentage of the time.

Construction of the Chance Constraints on Nitrate Loading. Loadings of nitrate to ground water from alternative fertilizing practices are a function of four principal factors: timing of application, rate of application, plant uptake capacity, and weather. It was therefore felt that constraints on nitrate loadings should reflect at least some of these random elements.

These constraints were generated using the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model. CREAMS was developed through a national research project of the USDA Agricultural Research Service to provide a relatively simple, computerized mathematical model for evaluating nonpoint source pollution which required little calibration. The model was designed for the field scale, since this level is where conservation management systems are applied, a field being defined as an area with homogeneous soil type, under a single management practice, and small enough so that rainfall variability was minimal (Knisel, Foster, and Leonard, 1983). Loadings

TABLE 4.1. MEANS, STANDARD DEVIATIONS, AND ADJUSTED COEFFICIENTS FOR NITRATE LOADING BY CROP FOR ROCKINGHAM COUNTY.

Activity	Mean	Standard Deviation	Confidence Interval 80%	Confidence Interval 90%
		No Storage		
CORN SILAGE/NT[a]	18.715	13.369	30.012	35.854
CORN SILAGE1/NT	14.299	10.162	22.886	27.327
CORN SILAGE2/NT	13.070	9.245	20.882	24.922
CORN SILAGE/CT	10.116	9.579	18.210	22.396
CORN SILAGE1/CT	8.667	8.216	15.610	19.200
CORN SILAGE2/CT	8.449	7.889	15.116	18.563
PASTURE (small)	27.282	23.981	47.546	57.998
PASTURE (large)	14.353	12.661	25.052	30.584
		60 Day Storage		
CORN SILAGE/CT	10.985	10.212	19.614	24.077
CORN SILAGE1/CT	9.504	8.691	16.847	20.645
CORN SILAGE2/CT	9.316	8.404	16.420	20.095
CORN SILAGE/NT	19.212	13.572	30.681	36.612
CORN SILAGE1/NT	14.683	10.393	23.465	28.007
CORN SILAGE2/NT	13.566	9.639	21.711	25.923
PASTURE (small)	20.318	17.849	35.401	43.201
PASTURE (large)	10.472	9.252	18.290	22.333
		120 Day Storage		
CORN SILAGE/CT	12.219	11.417	21.866	26.856
CORN SILAGE1/CT	10.702	9.701	18.900	23.139
CORN SILAGE2/CT	10.960	10.054	19.455	23.849
CORN SILAGE/NT	20.409	14.222	32.427	38.642
CORN SILAGE1/NT	16.446	11.630	26.274	31.356
CORN SILAGE2/NT	15.342	10.986	24.625	29.426
		180 Day Storage		
CORN SILAGE/CT	11.541	10.719	20.599	25.283
CORN SILAGE1/CT	10.260	9.497	18.285	22.435
CORN SILAGE2/CT	10.008	9.135	17.727	21.719
CORN SILAGE/NT	20.196	14.038	32.058	38.193
CORN SILAGE1/NT	15.833	11.202	25.2992	30.194
CORN SILAGE2/NT	14.576	10.554	23.494	28.107

CT = conventional tillage
NT = no till
[a]Nitrate loadings are identical for corn silage and grain
Source: Heatwole, 1988

to ground water are generated on a per-hectare basis by crop planted rather than for the entire farm.

CREAMS consists of three model components: hydrology, erosion/sedimentation, and chemistry. The hydrology component estimates runoff volume, infiltration, evapotranspiration, soil water content, and percolation on a daily basis. The erosion component estimates erosion and sediment yield on a daily basis. The chemistry component estimates dissolved pesticides and nutrients in runoff, sediment, and percolation water.

Inputs to CREAMS are divided into two principal groups: management inputs, which include land use, cultural practices, pesticide application, and plant nutrients; and natural inputs, which include precipitation, radiation, and temperature. Outputs are surface runoff, evapotranspiration, erosion/sedimentation, and percolation, which translate into dissolved and adsorbed chemicals (Knisel and Foster, 1981; Crowder et al. 1984).

The nutrient component of the model simulates nitrate lost from the root zone by plant uptake, denitrification, and leaching. The amount of nitrate leached is a function of the amount of water percolated out of the root zone as estimated by the hydrology component and concentration of nitrate in soil water (Knisel, Foster, and Leonard, 1983).

CREAMS was designed to provide maximum generalizability with minimum data input. Principal drawbacks of CREAMS in the Rockingham County study are that it does not consider the special problems associated with no till or minimum tillage systems (Hallberg, 1987) and that it is designed as a field-scale root zone model, so that estimates of nitrate leached are only crude approximations of the effect of agricultural management practices on ground water quality.

CREAMS Inputs for the Rockingham County Nutrient Simulations. The soil type specified in CREAMS is the Frederick Silt Loam. This soil type accounts for 10 percent of the soil in the county and underlies most of the agricultural land. Representative slope was in the C range, and was estimated at 8 percent.

Daily precipitation records from 1966-85 were used to specify the rainfall component. Average monthly temperatures and solar radiation were obtained by averaging the records from 1949-85. Since CREAMS simulations are generated on a per hectare (2.4 acres) basis, absolute farm size was not an input.

The CREAMS model was run for a hypothetical 20 year period by Dr. Conrad Heatwole of the Department of Agricultural Engineering at VPI & SU. From this simulation, parameters for nitrate loading to ground water by type of crop grown and nitrogen application rate were generated. Based on this data series, the standard deviations for these parameters were derived and incorporated into a second chance constraint following the approach developed by previous studies (Milon, 1985; Segarra, Kramer, and Taylor, 1985) (detailed in appendix F). In contrast to the silage constraint, which mandates a minimum level of feed production by reducing the mean yield of silage tons per acre, the environmental constraint tends to add a premium to the mean value of the loading parameter to provide a margin of safety for water quality.

This constraint effectively allows the decision maker to consider the impacts of requiring that loading reduction standard be met 90 percent of the time in order to adequately safeguard human health. The linkage between the farmer's standard production activity--nutrient application--and nitrate loading to ground water resulting from nitrogen application (as estimated by CREAMS) is an explicit representation of the nonpoint production function of equation (3) in chapter two.

Chance Constraint Levels. Nonpoint agricultural contamination is subject to stochastic "pulses" throughout the year due to rainfall events, manure spreading timetables, and other factors which introduce uncertainty into the management process. However, while nitrates are suspected of contributing to a number of health problems, NO_3 is still fairly innocuous when compared to persistent organochlorine insecticides like Lindane or heptachlor. Thus short-term violations of nitrate target standards may not be as detrimental to human and animal populations as violations of standards for more noxious contaminants. By incorporating loading uncertainties into the policy making process, the relative consequences of short-term violations of target loading levels can be reflected by tightening or loosening the confidence interval of any regulated constraint.

Average loading coefficients, standard deviations, and adjusted coefficients for crop activities are shown in table 4.1.[6] All coefficients are based on the 20 year CREAMS simulations. As table 4.1 indicates, the chance constrained coefficients are substantially larger than the mean values; in some cases the adjusted values are double the average. This means that, in order to satisfy loading constraints within these confidence intervals (80 and 90 percent), average loading reductions will be much higher than the reductions "guaranteed" by the chance constraint.

Two confidence interval levels were chosen to apply the chance constraint, 80 and 90 percent. Higher levels than 90 percent were considered inappropriate for a contaminant such as nitrates, since adverse health effects are likely to occur only at very high levels of ingestion, so that violation of the constraint only 10 percent of the time would probably not prove an unacceptable health risk. Two levels of reduction from current nitrate loadings (assumed to be equal to the baseline values) were chosen, 20 percent and 40 percent. Estimation of agriculture's contribution to county ambient water quality is not possible without a more sophisticated physical modeling approach, so that loading reductions required to insure that the 10 ppm nitrate health standard be achieved cannot be accurately specified. However, Virginia Governor Baliles has stated that the flow of nutrients into the Chesapeake Bay must be reduced by 40 percent by the end of the century, so that use of this target reduction level as an upper limit seemed reasonable.

Additional Risk Considerations

Consultation with dairy experts and subsequent results of the dairy farm survey led to the discovery of one further risk-reducing activity that could not be incorporated into the model's decision-making structure. Specifically, a large number of farmers were found to grow alfalfa in excess of their needs for livestock feed.

Apparently, the alfalfa not only serves as a source of roughage for the dairy herd but is a greater stimulant to milk production than ryelage (the DAIRYLP model allows a fixed two-to-one ryelage-alfalfa hay substitution which does not account for these nutritional differences) (Thatcher, 1987). A certain amount of risk is also involved in using ryelage as an alfalfa substitute since its harvest timing, quantity, or quality may not be suitable to a particular year's ration needs (rye is a winter cover crop, harvested in early spring, while alfalfa is grown during spring, summer, and fall) (Roller, 1987). Therefore, based on these findings and the survey figure for average acreage, the large farm model was constrained to grow 25 acres of alfalfa (smaller farms in the region were not generally believed to grow alfalfa [Roller, 1987], a result confirmed by the survey). The alfalfa constraint is thus a qualitative means of incorporating production risk into the model.

A Note on Input Price Variability in the Rockingham County Area

It is possible that the risk-averse farmer will consider uncertainty in input prices (such as corn grain) in his decision making process. If this uncertainty plays a substantial role in input purchase and production decisions (for example, through devotion of large percentages of the farm acreage to production of corn grain), mathematical programming efforts should reflect this price uncertainty through techniques such as symmetric quadratic programming. However, an examination of historical trends in prices of corn grain in the Harrisonburg-Shenandoah Valley region indicates that deflated average per-bushel prices for corn grain have trended downward over the 1975-1986 period,[7] from an average of $2.81 in 1975 to $2.06 in 1986 (prices are adjusted to 1977 dollars). The mean for the entire period was $2.44 with a standard deviation of $.31. Since variability of these prices tended to be small over the period (and because the downward trend in prices may serve to further reduce farmers' concern over input supply, variability of corn grain prices was assumed not to have a significant impact on farmers' decisions, and no attempt was made to build grain price variability into the model.

MODEL CONSTRUCTION

Activities. The mathematical programming model contained nine basic activities: milk production, sale of calves and cull cows, corn grain/ryelage production, corn silage/ryelage production, alfalfa production, barley production, strawberry production, and pasture production. Income was provided by milk, cull cow, and calf sales, and by sales of alfalfa and strawberries; the remainder of the activities were undertaken to provide feed for the dairy herd.

Land. Total acreage was assumed to be 200 acres per farm for the large farm and 80 acres for the small farm.[8] These numbers were generated from expert opinion and through results of the Rockingham County Dairy Farm Survey. Farm acreage was divided into 115 and 55 acres of cropland and 85 and 25 acres of pastureland, respectively. Pastureland was restricted both to reflect the representative situation and because modeling limitations necessitated a fixed amount of acreage for spreading manure for farms with no manure storage facilities.[9]

Crops. Survey results indicated that 86 percent of respondents' cropland was planted to corn, rye, and alfalfa. While only two types of corn are grown, grain and silage, corn growing activities were divided into eight separate categories. These categories reflect conventional tillage and no-till, and nutrient management options with manure storage and without manure storage. No-till corn crops are also assumed to be grown in conjunction with a ryelage crop.[10]

Survey results revealed that corn was grown either following agronomic nitrogen application rate recommendations or higher than recommended agronomic applications. To provide the model with more flexibility to respond to nitrogen-limiting policies, two groups of crop production alternatives not currently practiced were added to the model: alternative nutrient application rates for currently grown crops, and alternative revenue producing crops.

The first option considered was continued production of corn grain and corn silage using reduced nitrogen application. To compensate for the reduction in applied nitrogen from currently recommended rates, new values for model yield coefficients were developed. Based on previous research and consultation with VPI & SU personnel familiar with nitrogen-response functions, it was determined that within the given range of nitrogen application the response of yield was approximately linear (Virginia Cooperative Extension Service, 1984; Hawkins, 1988;

Norris, 1988). Therefore, application rates of 80 and 90 pounds of nitrogen per acre (compared to the agronomically recommended application rate of 100-110 pounds, with yields of 100/110 bushels or 15-17 tons) for corn and corn silage were estimated to result in yields of 85.4 and 92.7 bushels per acre for conventional till corn grain, 88.5 and 95.8 bushels per acre of no till corn grain, 12 and 13.5 tons per acre of conventional till corn silage, and 12.4 and 14.8 tons per acre of no till corn silage. These new corn activities essentially reduce inputs by 10 to 30 pounds of nitrogen while reducing yields by 7.3 to 21.5 bushels; it is thus not cost-effective for the farmer to choose these activities voluntarily, and it was hypothesized that he would do so only when faced with restrictions on nitrogen use or nitrate loadings per acre.

In order to include economic alternatives in the model in the event of restrictions placed on dairy operations, two revenue producing activities (currently not widely practiced in the area) were added: alfalfa production for sale, and specialty crop production as a supplement to dairy income. Alfalfa was chosen because it is currently produced in Rockingham County; area farmers and extension personnel thus are acquainted with the problems and procedures with growing, feeding, and marketing the hay. Strawberries were chosen as an example of a specialty crop which could be produced by a farmer with excess capacity or labor resources resulting from a policy-induced down sizing of his dairy herd, rather than as an opportunity for widespread adoption.

Incorporating an alfalfa selling activity into the model posed some difficult conceptual problems. The price of alfalfa in the area was approximately $120 per ton during summer of 1988, which is substantially more than the $60 per ton production cost built into the model. However, this $120 price also reflects costs of transporting the alfalfa to the region, which may add as much as $10 per ton per 100 miles travelled. Therefore, a price of $80 per ton was chosen as a reasonable selling price in the model. This estimate is based on prices commonly paid in the Lancaster County region of Pennsylvania, an area which, like Rockingham County, is livestock intensive but also has a well established alfalfa production and distribution network (Fales, 1988).

Demand for alfalfa in the region is strong, particularly in the northern Shenandoah Valley (Harrison, 1988). Much of the alfalfa and timothy hay used to feed livestock in the area is imported from Kentucky and Pennsylvania. There are no apparent differences in quality between Virginia-produced alfalfa and these imports; therefore, other reasons for the lack of local production must be sought. A combination of these supply-limiting factors, transportation costs, and the strong regional demand for alfalfa may account for the difference between the regional price of $120 per ton and the national average of $60 per ton.

If alfalfa production and sales were adopted on a widespread basis, these marketing problems would have to be addressed. It is possible that existing organizations such as the Southern States Marketing Cooperative could take an active role in developing the regional market; if these production and distribution avenues were used, they would have the advantage of an existing marketing network, distribution and pricing system, and communications network. Large-scale alfalfa production could also lead to establishment of specialized support operations such as customized harvesting and drying facilities, as well as possible economies of scale in harvesting and distribution. Finally, the existence of a large, dependable supply of alfalfa could lead to establishment of exports outside the region (Coale, 1988).

Alfalfa is assumed to be grown in four year stands. Due to problems with insects, nematodes, and disease, alfalfa is usually not planted continuously; that is, after four years, another crop is planted on the alfalfa acreage. Therefore, total acreage which can be planted to alfalfa is constrained to 80 percent of the farm's cropland. Lack of existing market infrastructure could also hamper the establishment of specialty crops such as market strawberries. For example, no processing or grading facilities for vegetables are located in the Shenandoah Valley; expertise in growing and marketing these crops is also lacking, since area extension personnel are principally trained in livestock and crop production (Odell, 1988). This expertise problem could prove especially important since the transition from row crops to horticultural crops could be difficult for many dairy farmers. Finally, the scale of horticultural crop production needed to establish this infrastructure may not be justified if the final crops produced could not compete in the marketplace (in terms of both quantity and quality) with the same crops produced in other states and regions.

Because of these potential problems faced by Rockingham County dairy farmers diversifying into specialty crops, pick-your-own (PYO) strawberries were chosen as a viable alternative. PYO strawberries also have the advantage of requiring substantially less labor than market strawberries or other horticultural crops, and can be profitable grown on relatively small acreages. Several Rockingham County farmers (including dairy farmers) currently grow PYO strawberries (Roller, 1988). Limitations on maximum acreage grown are principally based on size of local population; one extension specialist estimates that 5,000 families are needed to support one acre of PYO strawberries (Odell, 1988).[11]

Strawberries require small plots of land, yield a relatively high per-acre return, and require relatively small (50 pounds) per acre nitrogen applications. Unlike most crops, nutrients are applied to strawberries after the harvest, so that root systems can be regenerated. Nitrogen is therefore applied in July rather than the prime leaching periods of late winter and early spring. Total land that could be devoted to the crop was limited to two acres. Since specialty and small fruit crops such as strawberries are not currently grown on most county dairy farms, strawberry production is assumed to occur only under nitrate loading reduction scenarios. For this case, the no commercial nitrogen scenario is chosen, although other policy simulations could have been used without loss of generality.

Assuming a price of $.40 per pound and an 8,000 pound average yield per acre (Odell, 1986), it may be possible to clear up to $1,200 per acre over variable costs. However, fixed costs are extremely high for strawberry production, with about $6,000 of irrigation equipment required per acre (at 12 percent interest, this would require $720 per acre per year in debt servicing).

The option of growing a barley crop as a feed ration supplement was also built into the model. Finally, two types of pasture are grown, to reflect differences in manure spreading activities on pasture for storage and no storage scenarios.

Nutrient Sources. It is assumed that all farmers have access to commercial fertilizer, which provides an inexpensive means of providing crop nutrients. However, if restrictions were imposed on the purchase of commercial nitrogen, or if the price of nitrogen were to increase substantially, alternative (currently more expensive) nutrient sources would be sought.

One nutrient management option considered was the carryover effect of nitrogen from increased legume production. Very little alfalfa production is built into the baseline representative farm model, but if alfalfa production were increased both to supply herd feed and to sell on the open market, substantial quantities of nitrogen would be made available. Fifty pounds of nitrogen per acre can be conservatively assumed to be available for corn uptake following alfalfa production (Tisdale and Nelson, 1966). Since alfalfa is grown in the model in four year stands (with rotation following), one-fourth of the alfalfa acreage is assumed to be planted to corn the following year, so that a credit of 12.5 pounds of nitrogen to the model's nitrogen budget is allowed for each acre of alfalfa planted.

Poultry litter is also an excellent source of nitrogen, containing an average of about 36 pounds of available nitrogen per ton of broiler litter (Collins, 1987). The poultry industry in Rockingham County also produces large quantities of litter which are often treated merely as a refuse product. Thus, the potential exists if the price is right to use this litter as a source of nutrients for area crops. However, the poultry litter market in the area is poorly defined, so that the price of a pound of nitrogen from poultry litter (together with its application cost) is difficult to estimate. Estimates of delivered price of litter per ton range from eight to sixteen dollars. In addition, although most farmers currently have the equipment to apply dry dairy manure, it is not always possible to calibrate these implements to apply poultry litter at a slow enough rate (Roller, 1988).[12] Poultry litter can be mixed with liquid dairy manure and applied as a slurry along with the dairy products, but this would increase handling and application costs for the liquid manure (Groover, 1988). Harris (1987) notes that less than half of the respondents to a recent survey in Delaware calibrate their manure spreaders for litter application; this lack of calibration may lead to application of higher nitrogen levels than plants can use, which in turn will increase nitrate loadings to ground water (Ritter, Chirnside, and Scarborough, 1986).

Given these uncertainties, application time and cost for litter are assumed identical (on a per cubic foot basis) to dairy manure; depending on delivery charges, the average applied cost per pound of litter nitrogen ranges from .25 to .49. It was initially hypothesized that, if area farmers' ability to purchase commercial nitrogen were limited, they would attempt to obtain alternative nitrogen sources. Although poultry litter nitrogen is currently priced higher than commercial nitrogen, the elimination of commercial nitrogen as an input option or a major increase in commercial nitrogen price would make litter purchase more attractive. By including these activities, the representative farm model was thus given a wider range of response options to restrictions on the purchase of commercial nitrogen.

Dairy. The dairy portion of the model is principally drawn from the DAIRYLP model developed by the Agricultural Economics Department at VPI & SU (Groover and Allen, 1986). Cows were assumed to weigh 1,300 lbs. each and produce 16,000 lbs. of milk per year (based on regional averages). The herd is renewed at the rate of one third per year. Calf sales, which are part of farm income, are generated assuming a birth rate of .39 per head per year (.78 for the small farm, since the small farm model did not raise its own heifers as the large farm did).

Three dairy herd rations are permitted: silage based, with ryelage and alfalfa supplement; alfalfa based, with corn grain; and alfalfa based, with barley (details of these rations are provided in appendix G). Although most farmers in the county use corn silage as a ration base, a wide range of substitution possibilities exist for supplying the nutrients necessary for milk production. Thus, there are a continuum of feed mixes for a variety of annual milk production levels rather than a fixed number of set rations for a fixed level of milk output. Dairy farmers in Virginia and elsewhere are using a variety of alternative feeds and feed supplements, including wheat, brewers grain, whole cottonseed, dry distillers' grain, peanut meal, soybean hulls, and citrus pulp (Thatcher, 1988; Stallings, 1988). For the purposes of this study, a fixed number of alternative ration mixes will be considered, principally as examples of available alternatives.

With the assistance of dairy nutrition specialists at the Virginia-Maryland Regional College of Veterinary Medicine, two alternative feed rations--alfalfa-corn grain and alfalfa-barley (Thatcher, 1988; Remillard, 1988)--were constructed. These rations were all alfalfa-based, since alfalfa production is already within area farmers' and extension personnel's expertise and has the added environmental benefit of not requiring applied nitrogen. In cases requiring extreme reductions of nitrate loading from agricultural land, dairy manure could also be applied to the alfalfa crop with little or no increase in nitrate loadings; however, this alternative was not considered in the model.

Alfalfa is also an excellent source of fiber and protein for dairy herds. Both rations were more expensive than the silage-ryelage ration. All other model specifications for dairy cows (labor, variable costs, and manure production) were assumed the same for all feed rations.

Initial herd size in the large and small representative farm models was assumed to be 100 and 60 cows, based on survey data. Farmers in the area would likely expand their dairy herds to take maximum advantage of existing physical facilities since their marketing arrangements with local cooperative services allow them to sell as much milk as they produce at a set price. This "blend" price essentially results from a pooling of members milk bases at the cooperative level, so that area farmers are not restricted in the amount of Grade A milk they can sell. These herd sizes may therefore be considered an upper bound.

Enough flexibility was built into the model to consider the effect of policies which might actually decrease the farmers' herd size, so that a lower as well as an upper bound to herd size would need to be specified. To accomplish this, the farmer's profit from his dairy farm operation was adopted as a measure of his opportunity cost; therefore, he would continue as a dairy operator as long as his opportunity cost was higher than what he could otherwise earn in the area, either producing alternative crops or as a wage laborer. The herd size corresponding to this threshold profit level was thus chosen as a lower bound.

The threshold profit level where the shift away from dairy farming would occur is assumed to be the median family income for the county. Since the model's objective function only measures returns to variable costs, the omitted costs of farm interest, taxes, and utilities (as a per-cow average) were subtracted from this figure to obtain an estimate of actual profit. These average fixed costs were obtained from the <u>Aggregate Analysis of Grade A Dairy Farms</u> (Edgar <u>et al.</u> 1986), which includes dairy income and operating expenses from surveys of Virginia and West Virginia. By using the model's objective function (less

$28,000 for the large farm and about $17,000 for the small farm in fixed costs) as a constraint set to equal the county median income of $15,000, lower limits on herd size of 67 and 43 milking cows, respectively, were obtained. It was then assumed that a policy which reduced the model herd below this figure would drive the farmer from the dairy business.

Manure Storage. The storage assumption built into the model was that the farmer was starting from the position of having no manure storage facilities available. He then had the option of continuing operations with no storage, in which case he saved the capital required to construct and operate storage facilities but incurred higher fertilizer costs; or of constructing storage, in which case he incurred the annual expense necessary to construct the facility.

A representative storage structure was included in the model, using information from the Shenandoah Valley Soil and Water Conservation District and county extension staff. the least cost facility (earthen pit) was not considered because of potential ground water hazard and State Water Control Board regulations which specify minimum permeability requirements. These requirements are not met by earthen pits (Knicely, 1988). The most expensive type of facility (glass-lined tanks) was eliminated from the model under the assumption that most farmers would choose not to expend the additional $50,000 or more for the more elaborate structure. Eliminating these storage options left either poured concrete or precast panel structures, which were assumed to be approximately equal in price. Although wide variability in storage price occurs in the county (due primarily to site preparation costs), a conservative figure was arrived at for cost per gallon of manure stored. In addition to the 120 and 180 day storage structures currently in use in the county, a 60 day storage activity was also allowed in the model to determine the effects on net returns and nitrate loadings of the smaller structure. Detailed description of the derivation of manure storage requirements, structure costs, and site preparation estimates is provided in appendix H.

Currently, the Virginia Division of Soil and Water Conservation permits state cost sharing on manure storage facilities if they meet State Water Control Board standards for minimum allowable leaching and if they are large enough to provide at least 60 days storage for the farmer's dairy herd. However, the Shenandoah Valley District Office of the Division of Soil and Water Conservation has determined that this 60 day confinement period is insufficient to safeguard water quality, and will only provide cost sharing funds for manure storage facilities in the Rockingham County area which provide at least 120 days containment (Patterson, 1988). This 120 day limitation does not seem to have caused any controversy in the county; even in areas of the state which only require the 60 day minimum, virtually all requests for cost sharing on new manure storage facilities are for structures with 120 days or more storage, principally due to the added convenience provided by the larger facilities (Patterson, 1988; Givens, 1988).

However, since many of the problems caused by manure result from pasture spreading by farmers with no storage facilities, the 60 day storage option represents a potential improvement in nutrient availability and nitrate loading reduction over the no storage regime--in effect, an intermediate point in nitrate loading reduction between no storage and 120 day storage which is less costly to the farmer. Therefore, a nutrient management plan was developed to examine the impacts on farmers' net returns and ground water quality of a 60 day storage scenario, to determine if it would be a viable policy option to encourage the establishment of these structures.

Several differences in manure management practices between the 60 and 120 or 180 day storage schemes are involved in the adoption of 60 day storage. First, the length of storage period mandates that at least one tank pumping be done during the winter, so that about 60 percent of the winter pumping's nutrient value may be lost through application to frozen ground (Givens, 1988). Second, a tank pumping will have to occur during corn season, requiring one pasture application. Still, about 73 percent of the available nitrogen in the manure which could be recovered with 120 or 180 days storage will be recovered with 60 day storage, as opposed to only about 29 percent recovered under the no storage scenario.

Fixed costs (site preparation) are assumed to be identical to the 120 and 180 day storage facilities. In the absence of any data on construction costs, variable costs (per cubic foot) were assumed to be the same for the 60 day structure as for the 120 day structure. Using this information on capacity and cost, a nutrient management plan was developed for the 60 day storage facility.

Storage Facility Site Preparation Costs. A substantial proportion of the total cash expenditure (estimated to range from 7 to 30 percent of total facility cost) for a new manure storage facility in Rockingham County is devoted to preparing the area where the facility will be sited. Because no explicit cost figures for this preparation were available, Soil Conservation Service guidelines were used. These guidelines assume costs of $2,500 for low site preparation, $8,000 for medium site preparation, and $18,000 for high site preparation (Blodgett, 1987). These site preparation costs are unrelated to facility size, and include land clearing, excavation, and blasting expenses.

The medium site preparation cost was assumed typical for Rockingham County, based on consultation with Soil and Water Conservation District personnel. Model results were generated with both low and medium preparation costs included to demonstrate the difference in net returns over variable costs which could result.

Tax Advantages of Siting Manure Storage Facilities. Farmers' in the United States are entitled to certain tax advantages for siting pollution control facilities such as manure storage structures (IRS, 1987a; IRS, 1987b). These advantages accrue to the farmer either through amortization or writeoff of the cost of the facility over some portion of its life, and take the form of reductions in annual taxes for which the farmer is liable. All model analyses assume that the farmer is aware of and takes full advantage of these tax-saving opportunities.

There are essentially three types of tax advantages for which a farmer siting a manure storage facility can qualify. The first type of program allows the farmer to amortize the cost of a certified pollution control facility over a five year period if the dairy or poultry business was in operation prior to 1976. Amortization begins the month after the facility was acquired. The other two plans allow the farmer to depreciate the cost of the facility over periods of seven and 15 years, respectively. Since a large majority of respondents to the Rockingham County Dairy farm survey had been farming longer than 12 years (over 80 percent, farming for 21.8 years on average), it is assumed that all qualify for the first writeoff scheme; details of all three writeoff options and a mathematical example are presented in appendix I.

Using the methods detailed in appendix I to calculate net present value using an interest rate of 12 percent results in present value savings of about 35.72 percent of the facility's cost over its 15 year life (assuming that the farmer remains in the 28 percent tax bracket for the term of the writeoff). The net present value of the tax advantages gained is deducted from the purchase price of the storage facility, so that the annual value (over the facility's 15 year life) of these tax advantages are actually calculated into the model's objective function.

MODEL FORMULATIONS

As noted in chapter one, the policy scenarios generated by the model represent two different situations: the first corresponds closely to the existing management practice situation in the county (termed the "conventional practice" model); the second incorporates a number of activities not currently practiced in order to speculate on how county operations might change in the face of stricter environmental constraints (this is the "non-traditional alternative" model). The baseline or "status quo" solutions are thus a subset of the Conventional Practice model solutions; these solutions represent the levels of net returns and nitrate loadings to which the policy models' net returns and loadings are compared.

The "Conventional Practice" Model

The first variation of the mathematical programming model approximated the current situation in the county. Crop production and dairy feed ration practices were assumed to be unchanged from the corn-rye-alfalfa practices currently used. All other model activities were constrained to be zero for the conventional practice model.

The model was run in three basic formulations for each of the two typical or "representative" dairy farms of 200 acres and 80 acres for Rockingham County (hereafter designated as "large" farm and "small" farm). The first scenario simply let the model choose among no manure storage, 120 day storage, and 180 day storage, with no constraints on nitrate loadings, and will be referred to as the baseline solution. The second scenario constrained the farmer to choose 120 day storage, with no specific nitrate loading constraints and no public cost sharing. The third scenario was identical to the second (120 day storage) scenario, except that the model was constrained to choose 180 day storage (again, with no cost sharing). In this way, differences in net returns over variable costs for each manure storage/application scenario--in effect, the financial impact on the farmer of each scheme--could be compared. An accounting row, which recorded how many pounds of nitrates were leaching to ground water for each storage scenario (generated with data from CREAMS) was used to determine nitrate loading under each of these scenarios.

Chance constraints, which explicitly consider the effect of the variability of the constraints' coefficients, were calculated for the silage yield coefficients. The chance constraints were used to generate alternative results for the daily and 120 day storage models,[13] in order to recognize explicitly the production risk faced by the dairy farmer.

Policy options considered in the conventional practice situation were cost sharing, regulation, and corrective taxation. Cost sharing for manure storage construction is currently supplied through the State Division of Soil and Water Conservation and the Agricultural Stabilization and Conservation Service (ASCS) of USDA. While strict regulation is not currently practiced, the State Water Control Board does have certain regulations designed to protect ground water quality. Taxation of commercial fertilizer, while not currently practiced in Virginia, is an option which has been used by other states, albeit only for revenue generation.

<u>The Need for Policy Options: The Non-traditional Alternative Models</u>

One important consideration when evaluating the environmental and distributional impacts of these scenarios is that the Conventional

Practice representative farm model implicitly assumes that dairy herds continue to be supported on a silage-based feed ration, that farmers produce all of their own forage, that no options are available for revenue generation other than milk, calf, and cull sales, and that available on-farm-produced feed products are corn grain, corn silage, alfalfa, and rye. The types of nitrate loading reductions examined in the Conventional Practice model are within the scope of current efforts in the area; many farmers are adopting new nutrient management strategies and constructing manure storage facilities. However, the potential for reduction of nitrate loading in the current situation is limited to a narrow range of options and total amount of nitrate loading reduction. From a policy standpoint, the question is, are these reductions "enough," or are further reductions in nitrate loading from agricultural sources necessary to protect the quality of drinking water?

Given current concerns over drinking water purity and agricultural chemicals, policy makers must be ready to consider the distributional and environmental impacts of a range of policy alternatives beyond those already discussed so that greater contaminant loading reductions can be achieved. Toward that end, the Nontraditional Alternative model formulates a variety of alternatives to expand both the policy maker's strategy options and the range of responses to these options available to the farmer. Options incorporated into the model are:

-a 60 day manure storage option,

-alternative dairy herd feed rations,

-alternative nutrient sources,

-alternative manure storage activities,

-modified corn production activities, and

-alternative revenue sources.

All Conventional Practice model activities are also available in the Nontraditional Alternative model. However, the chance constraint on silage production was not included in the nontraditional alternative model for two reasons: first, initial results of the model indicated that incorporation of silage production risk, while it affected model net returns and cropping mixes, had no effect on ground water quality (an so was of little interest in the expanded model which focused more closely on ground water issues); and second, it was uncertain whether farmers' risk attitudes would change under the scenarios of the nontraditional alternative model.

Policy options in the Nontraditional Alternative model include: limitations or bans on commercial fertilizer sales in the area; a combination of the tax and cost sharing policies applied in the conventional practice model; imposition of a chance constraint on total nitrate loadings; and imposition of requirements limiting the ratio of herd size to pasture acreage for farmers with no storage facilities.

One of the alternative revenue sources permitted in the nontraditional alternative model is production of alfalfa for sale at $80/ton. All policy alternatives applied in the Nontraditional Alternative model include results both with and without allowing the alfalfa selling activity. Comparisons of policy scenarios between models with different assumptions regarding the alfalfa selling activity (that is, with or without alfalfa selling included) should be made with caution, since the no-alfalfa-selling model approximates the current situation and the alfalfa selling model assumes the existence of a local alfalfa marketing structure.

Policy scenarios generated by both the conventional practice and the nontraditional alternative models are in the following chapter. A summary of model activities and formulations run is presented in table 4.2.

SUMMARY

This chapter has described the foundations of the representative farm model used in this study. The theoretical concepts presented in chapter two were used to construct an economic/physical model to estimate the effects of cropping practices and alternative policies on ground water quality. The model combines the standard linear programming framework with uncertainty built into both farm level production constraints and environmental constraints. Actual model parameters were generated using a combination of survey data, expert opinion, and secondary data sources.

Two distinct sets of assumptions were used in constructing the models. The first group of models--the "conventional practice" models--assume that little variation from traditional county cropping and management practices occurs. The second group of models--the

TABLE 4.2. ACTIVITIES AND POLICY SCENARIOS INCLUDED IN CONVENTIONAL PRACTICE AND NONTRADITIONAL ALTERNATIVE REPRESENTATIVE FARM MODELS.

MODEL ACTIVITIES

Activities Common to Both Conventional Practice and Nontraditional Alternative Models

Conventional tillage corn grain/silage production
No till corn grain/silage production (with winter rye crop)
Alfalfa production
Native pasture maintenance
Silage based dairy rations
Milk production
120 day manure storage option
180 day manure storage option
Tax writeoff advantages

Additional Activities Included in Nontraditional Alternative Models

Alfalfa nitrogen carryover credit
Alternative dairy rations (alfalfa forage based)
Reduced nitrogen corn production (silage and grain)
Alfalfa selling
Strawberry Production and Sales

MODEL SCENARIOS

Conventional Practice Model Scenarios

1. No Constraints on Nutrient Management or Manure Storage (baseline)
2. 120 Day Manure Storage Required
3. 180 Day Manure Storage Required
4. Chance Constraint on Silage Production
5. Fertilization Rates in Excess of Agronomic Recommendations
6. Corrective Taxation
7. Regulation of Farm Management Practices
8. Cost Sharing for Manure Storage Facility Construction

Nontraditional Alternative Model Scenarios

9. 60 Day Manure Storage Required
10. Ban on Purchases of Commercial Nitrogen Fertilizer
11. Use of Poultry Litter as an Alternative Nitrogen Source
12. Minimum Herd-to-pasture Spreading Requirements
13. Corrective Taxation/cost Sharing Combination
14. Standards (via chance constraints)
15. Reductions in on-farm Herd Size
16. Strawberry Production/selling

"nontraditional alternative" models--assume that a wide variety of options are available both for the farmer and the policy maker.

CHAPTER V

RESULTS OF THE MATHEMATICAL PROGRAMMING MODELS

The second major tool used in this study was a mathematical programming model. This model was run using two principal situations with different assumptions regarding the amount of reduction in nitrate loading to ground water which policy makers might want to achieve in Rockingham County. This chapter presents the results of these model simulations.

The first section presents the results of the conventional practice model, describing net returns and nitrate loadings under the scenarios of no manure storage, 120 day manure storage, and 180 day manure storage. The second section applies several policy tools to the conventional practice model. The third section presents the specifications of the nontraditional alternative model, and reports the model's results. The fourth and final section examines the effects of a range of policy initiatives on nontraditional alternative model projections.

A list of variable names is provided in table 5.1. Although no differentiation is made between crops grown with no manure storage available and those grown with either 120 or 180 day storage facilities in the results tables, production costs between these activities actually vary in the model.

TABLE 5.1. ABBREVIATIONS OF VARIABLE NAMES USED IN THE REPRESENTATIVE FARM MATHEMATICAL PROGRAMMING MODEL.

TOTAL ACRES	Total farm acreage (acres)
CORN SILAGE/NT	Corn silage, no till (acres)
CORN GRAIN/CONV	Corn grain, conventional tillage (acres)
BUY CORN GRAIN	Buy corn grain (bushels)
BUY N	Buy nitrogen fertilizer pounds/N)
SELL CALF	Sell dairy calves (head)
SELL CULL	Sell cull cows (head)
SELL MILK	Sell milk (cwt)
SURPLUS HAY	Surplus hay (tons)
STORE HAY	Store alfalfa hay (tons)
STORE RYE	Store rye (tons)
LABOR1	Labor requirements, December-March (hours)
LABOR2	Labor requirements, April-May (hours)
LABOR3	Labor requirements, June-August (hours)
LABOR4	Labor requirements, September-November (hours)
DAIRY	One dairy cow/year (head)
BORR15	Borrow capital, 15 year payback (dollars)
BUY4	Buy 120 days manure storage (dollars)
BUY6	Buy 180 days manure storage (dollars)
MTND	Conversion of manure (tons) to available nitrogen (pounds)
MTN2	Conversion of manure (gallons) to available nitrogen (pounds)
MTN4	Conversion of manure (gallons) to available nitrogen (pounds)
MTN6	Conversion of manure (gallons) to available nitrogen (pounds)
SPREAD MANURE	Spread manure from 120 or 180 day storage (gallons)
TAX WRITEOFF	Net present value (at 12 percent interest) of tax advantages of siting a manure storage facility. This figure is deducted from the post-cost sharing (if any) purchase price of the storage structure.
COSTSHARE	Amount of cost sharing assumed in the specific version of the representative farm model, which is then deducted from purchase price of storage facility

RESULTS OF THE CONVENTIONAL PRACTICE MODELS

The Large Farm Model

Results of the Unconstrained Large Farm Model

The first model scenario used mean values for crop yield coefficients and placed no constraints on nitrate loading. Results of this model (considered the baseline results) are summarized in table 5.2a. As the results indicate, the farmer who is faced with no regulatory constraints or financial incentives to alter his nutrient management practices (that is, the "status quo" farmer) finds a daily spreading routine more profitable than any storage scenarios. The net returns of $55,406 over variable costs generated by the model under this scenario compare with an actual average income of $50,706 available for family living, debt payment, and other uses for a Virginia dairy farm with an average herd size of 117 cows (Virginia Cooperative Extension Service, 1987c). However, this figure should not be interpreted as profit in the accounting sense of the term, since the model objective function considers only returns above variable costs, while a measure of overall profit would need to include fixed costs and taxes as well.[1]

Principal crop production for the representative farm is corn silage and corn grain. About 64 of these 90 acres of corn (71.1 percent) are grown using no-till cultivation practices, while the remaining 26 acres of corn are planted, using conventional tillage, to corn grain. Actual county survey results indicate that minimum tillage practices are used for about 73 percent of corn grown on respondents'

TABLE 5.2a. RESULTS OF THE UNCONSTRAINED LARGE (CP) REPRESENTATIVE FARM MODEL.

Net Returns (over variable costs)	$55,406.81
Activity	**Level**
TOTAL ACRES	200.00
DAIRY COWS (head)	100.00
SELL CALVES (head)	39.00
SELL CULLS (head)	33.00
SELL MILK (cwt)	16,000.00
CORN SILAGE/NO TILL (acres)	37.76
CORN GRAIN/CONV TILL (acres)	26.08
CORN GRAIN/NO TILL (acres)	26.15
ALFALFA (acres)	25.00
PASTURE (acres)	85.00
BUY CORN GRAIN (bu)	5,192.92
BUY N FERTILIZER (lbs)	11,504.40
STORE CORN SILAGE	642.00
STORE CORN GRAIN (tons)	5,485.08
STORE HAY (tons)	125.00
STORE RYE (tons)	319.60
LABOR1 (hrs)	2,176.65
LABOR2 (hrs)	1,302.13
LABOR3 (hrs)	1,881.50
LABOR4 (hrs)	2,272.35
MTND (lbs)	3,940.00

TABLE 5.2b. SIMULATED NITRATE LOADINGS FOR THE UNCONSTRAINED LARGE FARM MODEL (Average over 1966-85 period).

	Acres	**Average Loading Per Acre (lbs)**	**Total NO_3 Losses (lbs)**
CORN SILAGE/NT	37.765	18.713	706.696
CORN GRAIN/NT	26.155	18.713	489.436
CORN GRAIN/CONV	26.080	10.116	263.825
ALFALFA	25.000	0.000	0.000
PASTURE	85.000	14.373	1,221.705
TOTAL NO_3 LEACHED (lbs)			2,681.662

NO_3 = nitrates
Source: Rockingham County Nutrient Simulations (Heatwole, 1988)

farms (Halstead, Batie, and Kramer, 1988), which tends to corroborate the model results. No-till corn requires a winter ryelage crop to be planted and harvested; based on survey results and DAIRYLP, the model allows substitution of ryelage for alfalfa in the small farm dairy cow feed ration, as well as including ryelage as part of the ration. Activities on the other 110 acres consist of 85 acres of pasture land and 25 acres of alfalfa (as mandated by constraints).

Since much of the manure nitrogen generated by the dairy farm is lost under the no-storage scenario, the farm is required to purchase 11,504.4 pounds of commercial nitrogen fertilizer for corn and rye production. This figure reflects the recommended application rates for the area. As the Rockingham County Dairy Farm Survey revealed, many farms in the area practice higher application rates than the 110 lbs nitrogen/acre assumed for corn and 60 lbs nitrogen/acre assumed for rye. Therefore, the 11,500+ pounds estimate may be an understatement of many farms' actual expenditures for nitrogen fertilizer.

Nitrate Loadings in the Unconstrained Large Farm Model

Table 5.2b indicates that, on average, about 2,700 lbs. of nitrate are lost annually to ground water from corn and pasture land from the large representative farm under the no storage scenario. Nearly half of this amount is leached from the 85 acres of pasture, where the manure is spread during periods when conditions in the corn or rye acreage prohibit spreading it on cropland. These loadings of pounds per acre convert to an average of 27.6 parts per million (ppm) of nitrate for corn/no till, 20.4 parts per million for corn/conventional till, and 31.3 parts per million for pasture acreage in percolation water leaving the field.[2] Concentrations are higher for the no till crops due to the rye cover crop, which requires 60 pounds of nitrogen in addition to the 110 pound per acre requirement for corn.

Results of the Constrained Large Farm Model: 120 Days Storage

Since the representative farm model operating with no constraints on production decisions chose the daily manure spreading option (no manure storage), it was necessary to force the model to choose each of the other two (storage) scenarios in order to discover the impact on net returns of construction of manure storage facilities (assuming no cost sharing is provided). This constraining method can identify the dollar amount needed to offset the difference between the farmer's different net return levels--in effect, to leave him as "well off" financially after manure storage adoption as he was before construction.[3]

It was hypothesized, a priori, that adopting a manure storage system would increase the farmer's costs because of the necessity of borrowing capital for site construction (at 12 percent interest).[4] At the same time, some of the farmer's variable costs would decrease, since more efficient use of manure would allow reduction in the amount of commercial nitrogen purchased. Since the unconstrained model did not purchase the storage facility, these fertilizer cost reductions were not sufficient to induce voluntary adoption of a storage regime. Forcing the model to choose 120 day manure storage proved that this was indeed the case, as net returns decreased by $2,620 to $52,886 (see table 5.3a). Values for the BORR15 (which represents total borrowed capital for facility construction) and BUY 120 DAY STORAGE (which represents the variable cost of the storage facility) variables are adjusted by the model's objective function to reflect annual carrying costs of these expenses; for example, although the total amount financed to construct a 120 day manure storage facility for 100 cows is $41,043, the annual cost to the farm (assuming 12 percent interest and a 15 year loan) is about $6,025.

Cropping activities are unchanged in the constrained model, as the representative farm continues to grow no-till corn silage, no-till corn grain, conventional till corn grain, and alfalfa. This result was expected since the relative cost of each of these activities and the demand for the crops in the dairy rations do not change among the three models. Due to the use of more manure nitrogen, only 6,656 pounds of commercial fertilizer are purchased, in contrast to 11,504 pounds of commercial nitrogen purchased under the no-storage scheme. Thus, 120 day storage allows the use of 4,848 pounds of manure nitrogen on corn and rye crops which would otherwise have been spread on pasture land.

<u>Nitrate Loadings in the Large Farm Model with 120 Day Storage</u>

The reduction in volume of manure spread on pasture (due to the option of using more of the manure on cropland) leads to substantial reductions in nitrate loadings to ground water for the 120 day storage scenario from a total of 2,681.7 pounds under the no storage option to 1,623.2 pounds (a decrease of about 39.5 percent [table 5.3b]). Average

TABLE 5.3a. RESULTS OF THE LARGE (CP) REPRESENTATIVE FARM MODEL, 120 DAY STORAGE CONSTRAINT.

Low Site Preparation Costs	
Net Returns[a]	$53,405.64
BORR15	$35,542.46
Medium Site Preparation Costs	
Net Returns[a]	$52,886.24
BORR15	$41,042.46
Activity	**Level**
TOTAL ACRES (acres)	200.00
DAIRY COWS (head)	100.00
CORN SILAGE/NO TILL (acres)	37.76
CORN GRAIN/CONV TILL (acres)	26.08
CORN GRAIN/NO TILL (acres)	26.15
ALFALFA (acres)	25.00
PASTURE (acres)	85.00
BUY CORN GRAIN (bu)	5,192.92
BUY N FERTILIZER (lbs)	6,655.67
SELL CALVES (head)	39.00
SELL CULLS (head)	33.00
SELL MILK (cwt)	16,000.00
SURPLUS HAY (tons)	205.20
STORE CORN SILAGE (tons)	642.00
STORE CORN GRAIN (bu)	5,485.08
STORE HAY (tons)	125.00
STORE RYE (tons)	319.60
LABOR1 (hrs)	2,138.65
LABOR2 (hrs)	1,281.13
LABOR3 (hrs)	1,849.50
LABOR4 (hrs)	2,240.35
MTN4 (lbs)	6,818.73
SPREAD MANURE (gallons)	568,000.00
TAX WRITEOFF ($)	1,575.34
BUY 120 DAY STORAGE ($)	4,850.57

[a]over variable costs

TABLE 5.3b. SIMULATED NITRATE LOADINGS IN THE LARGE REPRESENTATIVE FARM MODEL, 120 DAY STORAGE CONSTRAINT (Average over 1966-85 period).

	Acres	**Average Loading Per Acre (lbs)**	**Total NO_3 Losses (lbs)**
CORN SILAGE/NT	37.765	20.409	770.761
CORN GRAIN/NT	26.155	20.409	533.808
CORN GRAIN/CONV	26.080	12.219	318.668
ALFALFA	25.000	0.000	0.000
PASTURE	85.000	0.000	0.000
TOTAL NO_3 LEACHED (lbs)			1,623.237

nitrate concentrations of percolation water (water leaving the field through the root zone) are 30.1 ppm for corn silage/no till and corn grain/no till, and 24.7 ppm for conventional till corn. Since it is assumed that no manure is applied to pasture, there are no nitrate losses from pasture land.

Results of the Constrained Large Farm Model: 180 Days Storage

Forcing the model to choose 180 day storage led to net returns of $51,690, a decrease of $1,196 from the 120 day scenario and of $3,716 from the no storage scenario (table 5.4a). Although the total cost of the 180 day storage facility is greater than that of the 120 day facility, storage costs per gallon are cheaper due to the assumption that site preparation costs are identical for each facility. Due to this large fixed cost factor, the average total cost per gallon declines as the size of the storage facility is increased, even though the variable cost per gallon (represented by the BUY activity divided by total storage capacity) is approximately equal. By building the larger facilities, the farmer captures some economies of size.

Cropping activities are again unchanged from the no-storage and 120 day storage options, since the constraint that the farmer maintain and feed his dairy herd requires that the farmer devote his acreage to corn silage and grain production. Commercial fertilizer purchases total 7,012 pounds, an increase of 356 pounds over the 120 day option. This increase occurs because the total liquid manure volume estimated under the 120 day option is greater than the 180 day option, due to the SCS

TABLE 5.4a. RESULTS OF THE LARGE (CP) REPRESENTATIVE FARM MODEL, 180 DAY STORAGE CONSTRAINT.

Low Site Preparation Costs	
Net Returns[a]	$52,209.78
BORR15	$47,508.36
Medium Site Preparation Costs	
Net Returns[a]	$51,690.85
BORR15	$53,008.36

Activity	**Level**
TOTAL ACRES	200.00
DAIRY COWS (head)	100.00
CORN SILAGE/NO TILL (acres)	37.76
CORN GRAIN/CONV TILL (acres)	26.08
CORN GRAIN/NO TILL (acres)	26.15
ALFALFA (acres)	25.00
PASTURE (acres)	85.00
BUY CORN GRAIN (bu)	5,192.92
BUY N FERTILIZER (lbs)	7,012.22
SELL CALVES (head)	39.00
SELL CULLS (head)	33.00
SELL MILK (cwt)	16,000.00
SURPLUS HAY (tons)	205.20
STORE CORN SILAGE (tons)	642.00
STORE CORN GRAIN (bu)	5,485.08
STORE HAY (tons)	125.00
STORE RYE (tons)	319.60
LABOR1 (hrs)	2,138.65
LABOR2 (hrs)	1,281.13
LABOR3 (hrs)	1,849.50
LABOR4 (hrs)	2,240.35
MTN4 (lbs)	6,462.18
SPREAD MANURE (gallons)	538,300.00
TAX WRITEOFF ($)	2,202.79
BUY 180 DAY STORAGE ($)	6,607.23

[a]over variable costs

TABLE 5.4b. SIMULATED NITRATE LOADINGS IN THE LARGE REPRESENTATIVE FARM MODEL, 180 DAY STORAGE CONSTRAINT (Average over 1966-85 period).

	Acres	**Average Loading Per Acre (lbs)**	**Total NO_3 Losses (lbs)**
CORN SILAGE/NT	37.765	20.196	762.702
CORN GRAIN/NT	26.155	20.196	528.220
CORN GRAIN/CONV	26.080	11.541	300.991
ALFALFA	25.000	0.000	0.000
PASTURE	85.000	0.000	0.000
TOTAL NO_3 LEACHED (lbs)			1,591.913

method of storage capacity calculation used which allows for relatively more precipitation volume on the 120 day structure (essentially, both storage structures consider the same precipitation input from 25 year storms. For a complete description of how storage facility capacity was calculated, see appendix H). The margin of error built into the 12 pounds of nitrogen per 1,000 gallons liquid manure estimate does not consider the effect of nutrient dilution which occurs from this additional precipitation. That is, even though the higher percentage precipitation volume on the 120 day storage facility tends to dilute the manure more, both 120 day and 180 day liquid manure are considered to have the same average nutrient value per gallon. In any case, these 350 pounds of nitrogen represent only about a five percent difference in total nitrogen recovered, and only a $75 difference in total annual costs, so that the 120 and 180 day facilities provide essentially the same benefits in terms of nitrogen recovery.

Nitrate Loadings in the Large Farm Model with 180 Day Storage

Nitrate loadings on a per-acre basis are slightly lower for the 180 day storage regime than under 120 day storage (table 5.4b). These reduced loadings are attributable to differences in timing of manure applications, resulting in slightly lower loadings on average per acre for each crop activity. These manure application timing changes result in total average loadings of 1,592 pounds, or about 1.9 percent lower than for the 120 day scenario. Average nitrate loadings in the percolation water leaving the field are 29.8 ppm for corn/no till and

23.3 ppm for conventional till corn.

Incorporating Production Risk: The Chance Constraint on Silage

Since silage production variability (as discussed in the previous chapter) is one of the major sources of risk faced by the farmer, it must be incorporated into the model to reflect the farmer's risk preferences. It is assumed (somewhat arbitrarily) that risk aversion levels reflected by the 96-99 percent range are too expensive. The level chosen throughout the remainder of this dissertation will be 90 percent, based on consultation with dairy specialists and to reflect the recent history of summer droughts in the area (which may tend to make area farmers revise yield predictions downward). This constraint would insure that the model meets the silage requirements 90 percent of the time; for the years when this constraint was violated, more expensive forage bases (such as alfalfa) could be substituted. However, the model can be easily adapted to reflect higher or lower confidence intervals through the methods described in appendix F. Results of the 90 percent constraint for the large model (with and without 120 day storage) are shown in table 5.5. (Results for both large farm and small farm model behavior under a more restrictive 95 percent chance constraint are demonstrated in appendix F).

The chance constraint had the effect of lowering the coefficient on the silage production activity from 17 tons/acre to 13.1 tons/acre for no till silage production and from 15 tons/acre to 11.5 tons/acre for conventional till silage. In response, the model shifted acreage from

TABLE 5.5. RESULTS OF THE LARGE REPRESENTATIVE FARM MODEL, 90 PERCENT CHANCE-CONSTRAINTS ON SILAGE PRODUCTION COEFFICIENTS.

	No Storage	120 Day Storage
Net Returns (over variable costs)	$52,751.65	$50,742.24
Activity		
TOTAL ACRES	200.00	200.00
DAIRY COWS (head)	100.00	100.00
SELL CALVES (head)	39.00	39.00
SELL CULLS (head)	33.00	33.00
SELL MILK (cwt)	16,000.00	16,000.00
CORN SILAGE/NO TILL (acres)	49.01	49.01
CORN GRAIN/CONV TILL (acres)	26.08	26.08
CORN GRAIN/NO TILL (acres)	14.91	14.91
ALFALFA (acres)	25.00	25.00
PASTURE (acres)	85.00	85.00
BUY CORN GRAIN (bu)	6,429.64	6,429.64
BUY N FERTILIZER (lbs)	11,504.40	6,655.67
STORE CORN SILAGE (tons)	642.00	642.00
STORE CORN GRAIN (bu)	4,248.36	4,248.36
STORE HAY (tons)	125.00	125.00
STORE RYE (tons)	319.60	319.60
LABOR1 (hrs)	2,176.65	2,138.65
LABOR2 (hrs)	1,302.13	1,281.13
LABOR3 (hrs)	1,881.50	1,849.50
LABOR4 (hrs)	2,272.35	2,240.35
MTND (lbs)	3,940.00	0.00
MTN4 (lbs)	0.00	6,818.73
SPREAD MANURE (gals)	0.00	568,000.00
TAX WRITEOFF ($)	0.00	1,575.31
BUY 120 DAY STORAGE ($)	0.00	4,850.57
BORR15 ($)	0.00	41,040.46

the corn grain/no till activity to corn silage/no till--11.4 more acres of corn silage/no till were grown under the 90 percent chance constraint than under risk neutrality. Corn grain (conventional tillage) production remained constant at 26 acres in both models. More silage was grown by the model to offset the loss in per-acre yield imposed by the chance constraint; however, total acres of no-till corn are unchanged because the model continues to use the rye crop grown under this tillage practice as part of the dairy feed ration.

Due to the reduced per-acre silage yields in these models, net returns were reduced from $55,406.81 to $52,751.65 for the 90 percent constraint. (Although this loss in net returns is substantial, the nature of the chance constraint is such that, on average, the farmer will still realize the same returns as in the unconstrained model; this $52,752 figure merely represents his returns in a year when there is below average silage yield per acre, and the additional corn acreage will be harvested as silage rather than grain.) More corn grain is purchased to offset the grain formerly produced on acreage lost to the silage "insurance" and less corn grain is stored; otherwise, activities are unchanged from the unconstrained model. This type of behavior is typical of farmers in the Rockingham County area; farmers generally fill their silos to insure their forage supply, then harvest the remainder (in good years) as corn grain. Since there is no difference between loadings for no till corn silage and no till corn grain in the CREAMS simulations, and the chance constraint on silage yield essentially only alters the harvested product (silage versus grain) rather than the type of crop planted, nitrate loadings to ground water remain unchanged in the silage chance constrained scenario. Therefore, the incorporation of this type of production risk has no effect on ground water, and nitrate loadings are not listed for any of the chance constraint tables.

The Small Farm Model

The Unconstrained Small Farm Model

The small farm model was initially run with no constraints on choice of storage, nitrate loading, or silage yield. In this situation, the small farm model chose the no storage option to optimize net returns, just as the large farm did. Results are summarized in table 5.6a.

Due to the smaller herd size, the net returns over variable costs of $40,554.98 are much lower than the large farm net returns of about $55,400. All of the small farm's discretionary (that is, non-pasture or cropland) crop acreage is devoted to corn: 19.76 acres of corn silage/no till, 31.355 acres of corn grain/no till, and 3.88 acres of corn grain/conventional tillage. A total of 7,896.4 pounds of commercial nitrogen are purchased for application to this corn, compared to more than 11,500 in the large farm model.

Nitrate Loadings in the Unconstrained Small Farm Model

Nitrate loadings to ground water for the unconstrained small farm model total 1,678 lbs. per year for the 80 acre farm. Although the small farm's acreage is only 40 percent of the large farms, loadings for the small farm are 62.6 percent of the loadings for the large farm, due

TABLE 5.6a. RESULTS OF THE UNCONSTRAINED (CP) SMALL REPRESENTATIVE FARM MODEL.

Net Returns (over variable costs)	$40,554.98
Activity	**Level**
TOTAL ACRES	80.00
CORN SILAGE/NO TILL (acres)	19.76
CORN GRAIN/CONV TILL (acres)	3.88
CORN GRAIN/NO TILL (acres)	31.35
PASTURE (acres)	25.00
BUY CORN GRAIN (bu)	1,262.92
BUY N FERTILIZER (lbs)	7,896.40
SELL CALVES (head)	46.80
SELL CULLS (head)	19.80
SELL MILK (cwt)	9,600.00
SURPLUS HAY (tons)	40.20
STORE CORN SILAGE (tons)	336.00
STORE CORN GRAIN (bu)	3,837.08
STORE RYE (tons)	255.60
LABOR1 (hrs)	794.33
LABOR2 (hrs)	468.39
LABOR3 (hrs)	622.90
LABOR4 (hrs)	960.12
MTND (lbs)	2,364.00
SPREAD MANURE (lbs)	1,182.00

TABLE 5.6b. SIMULATED NITRATE LOADINGS IN THE UNCONSTRAINED SMALL REPRESENTATIVE FARM MODEL (Average over 1966-85 period).

	Acres	**Average Loading Per Acre (lbs)**	**Total NO_3 Losses (lbs)**
CORN SILAGE/NT	19.765	18.713	369.864
CORN GRAIN/NT	31.355	18.713	586.746
CORN GRAIN/CONV	3.880	10.116	39.250
PASTURE	25.000	27.283	682.063
TOTAL NO_3 LEACHED (lbs)			1,677.923

Source: Rockingham County CREAMS Nutrient Simulations (Heatwole, 1980) primarily to the increased per-acre manure spreading on pasture required to dispose of dairy manure (table 5.6b). Loadings per crop/acre are approximately the same between the large and small farms, since these depend heavily on the cow/crop ratio which is virtually identical for the large farm model and the small farm model. Over 40 percent of the nitrate loadings for the unconstrained small farm come from the pasture acreage, although pasture for the small farm accounts for only about 31 percent of total acreage. This percentage compares to 45.6 percent of large farm total nitrate loadings coming from pasture land; however, pasture land on the large farm accounts for about 42.5 percent of total acreage. Nitrate concentrations in percolation water under small farm pasture acreage are 59.5 ppm, nearly double the concentration of percolation water from the large farm pasture.

The Small Farm Model: 120 Day Storage Constraint

Since the small farm model was, with several adjustments, merely a smaller version of the large farm model, it was anticipated that the small model would parallel the large model in its behavior under the various imposed constraints. This was the case as the model chose the 120 day storage with unchanged cropping activities when the no storage option was removed. Results are summarized in table 5.7a.

Net returns (assuming medium site preparation costs) are reduced by $1,396 when the storage requirement is imposed. Fertilizer sales are reduced to 4,987 pounds of commercial nitrogen, for a net saving of 2,909 pounds.

TABLE 5.7a. RESULTS OF THE SMALL (CP) REPRESENTATIVE FARM MODEL, 120 DAY STORAGE CONSTRAINT.

Low Site Preparation Costs	
Net Returns[a]	$39,555.46
BORR15	$22,325.48
Medium Site Preparation Costs	
Net Returns[a]	$39,159.16
BORR15	$27,825.48
Activity	**Level**
TOTAL ACRES	80.00
DAIRY COWS (head)	60.00
CORN SILAGE/NO TILL (acres)	19.76
CORN GRAIN/CONV TILL (acres)	3.88
CORN GRAIN/NO TILL (acres)	31.35
PASTURE (acres)	25.00
BUY CORN GRAIN (bu)	1,262.91
BUY N FERTILIZER (lbs)	4,987.16
SELL CALVES (head)	46.80
SELL CULLS (head)	19.80
SELL MILK (cwt)	9,600.00
SURPLUS HAY (tons)	40.20
STORE CORN SILAGE (tons)	336.00
STORE CORN GRAIN (bu)	3,837.06
STORE RYE (tons)	255.00
LABOR1 (hrs)	771.53
LABOR2 (hrs)	455.72
LABOR3 (hrs)	603.70
LABOR4 (hrs)	940.92
MTN4 (lbs)	4,091.24
SPRM (gallons)	340,800.00
TAX WRITEOFF ($)	882.27
BUY 120 DAY STORAGE ($)	2,910.38

TABLE 5.7b. SIMULATED NITRATE LOADINGS IN THE SMALL REPRESENTATIVE FARM MODEL, 120 DAY STORAGE CONSTRAINT (Average over 1966-85 period).

	Acres	Average Loading Per Acre (lbs)	Total NO_3 Losses (lbs)
CORN SILAGE/NT	19.765	20.409	403.392
CORN GRAIN/NT	31.355	20.409	639.924
CORN GRAIN/CONV	3.880	12.219	47.410
PASTURE	25.000	0.000	0.000
TOTAL NO_3 LEACHED (lbs)			1,090.726

[a]over variable costs

Nitrate Loadings in the Small Farm Model with 120 Day Storage

Total nitrate losses to ground water are 1,090.7 lbs. for the 120 day storage scenario (table 5.7b), a decrease of 587.2 lbs. (35 percent) from the no storage regime. Since per acre nitrate losses under corn acreage are identical to those of the large farm model, concentrations in percolation water are 30.1 ppm for corn/no till and 24.7 ppm for corn/conventional till.

The Small Farm Model: The 180 Day Storage Constraint

Since the model chose the 120 day storage option when denied the no storage regime, it was known beforehand that net returns would be less when the model was constrained to the 180 day scenario than under the 120 day scenario. This was the case, as net returns were $38,481 under the 180 day scenario, or $678 less than for the 120 day scheme. As expected, crop activities stayed the same. Purchases of commercial nitrogen increased slightly to 5,201 (an increase of 214 lbs., or 4.3 percent) due to the method of estimating waste generation used. Results are summarized in table 5.8a.

Nitrate Loadings in the Small Farm Model with 180 Days Storage

Since average nitrate leaching per crop per acre decreases under 180 day manure handling practices, it was expected that total nitrate loadings for the 180 day storage regime would be slightly lower than for the 120 day scenario. As expected, nitrate loadings for 180 day storage were 23.5 lbs. (about 2 percent) less than for 120 day. Average nitrate concentrations in percolation water were 29.8 ppm for corn/no till and

TABLE 5.8a. RESULTS OF THE SMALL (CP) REPRESENTATIVE FARM MODEL, 180 DAY STORAGE CONSTRAINT.

Low Site Preparation Costs	
Net Returns[a]	$39,000.31
BORR15	$37,819.67
Medium Site Preparation Costs	
Net Returns[a]	$38,481.31
BORR15	$35,005.02
Activity	**Level**
TOTAL ACRES	80.00
DAIRY COWS (head)	60.00
CORN SILAGE/NO TILL (acres)	19.76
CORN GRAIN/CONV TILL (acres)	3.88
CORN GRAIN/NO TILL (acres)	31.35
ALFALFA (acres)	0.00
PASTURE (acres)	25.00
BUY CORN GRAIN (bu)	1,262.92
BUY N FERTILIZER (lbs)	5,201.09
SELL CALVES (head)	46.80
SELL CULLS (head)	19.80
SELL MILK (cwt)	9,600.00
STORE CORN SILAGE (tons)	336.00
STORE CORN GRAIN (bu)	3,837.08
STORE RYE (tons)	168.00
LABOR1 (hrs)	771.53
LABOR2 (hrs)	445.80
LABOR3 (hrs)	603.70
LABOR4 (hrs)	940.92
SPRM (gallons)	322,980.00
TAX WRITEOFF ($)	1,459.05
BUY 180 DAY STORAGE ($)	3,964.34

[a]over variable costs

TABLE 5.3b. SIMULATED NITRATE LOADINGS IN THE SMALL REPRESENTATIVE FARM MODEL, 180 DAY STORAGE CONSTRAINT (Average over 1966-85 period).

	Acres	**Average Loading Per Acre (lbs)**	**Total NO_3 Losses (lbs)**
CORN SILAGE/NT	19.765	20.196	399.170
CORN GRAIN/NT	31.355	20.196	633.246
CORN GRAIN/CONV	3.880	11.541	44.779
PASTURE	25.000	0.000	0.000
TOTAL NO_3 LEACHED (lbs)			1,077.195

23.3 ppm for corn/conventional till. Total nitrate loadings for the 180 day storage scenario were 35.8 percent lower than for the unconstrained, no storage scenario.

The Small Farm Model: 90 Percent Chance Constraints on Silage Production

Results of the small farm model with 90 percent chance constraints on silage production and both no storage and 120 day storage options are shown in table 5.9. Net returns decrease to $39,131 in the no storage option. For the 120 day storage option, net returns (which were already lower due to the increased expense of purchasing the manure storage facility) are further reduced to $37,735. The chance constraint has the effect of shifting acreage from the corn grain/no till activity to the corn silage/no till activity to reflect the risk considerations incorporated in the chance constraint, just as in the larger model. Since the acreage shift due to these risk preferences has no effect on tillage practices or fertilizer application, the chance constraint has no effect on water quality under the small farm.

OVERVIEW OF THE LARGE AND SMALL FARM CONVENTIONAL PRACTICE MODELS

Net returns for the large farm were between $14,852 (about 36.6 percent) and $13,209 (about 34.3 percent) higher than for the small farm, depending on the chosen storage scenario, due to the differences in herd size and the need for the small farm to purchase more of its dairy feed rations off farm due to limited production acreage available. Principal differences in activities were alfalfa production (25 acres

TABLE 5.9. RESULTS OF THE SMALL REPRESENTATIVE FARM MODEL, 90 PERCENT CHANCE-CONSTRAINTS ON SILAGE PRODUCTION COEFFICIENTS.

	No Storage	120 Day Storage
Net Returns (over variable costs)	$39,131.02	$37,735.36
Activity		
TOTAL ACRES	80.00	80.00
DAIRY COWS (head)	60.00	60.00
SELL CALVES (head)	46.80	46.80
SELL CULL (head)	19.80	19.80
CORN SILAGE/NO TILL (acres)	25.65	25.65
SELL MILK (cwt)	9,600.00	9,600.00
CORN GRAIN/CONV TILL (acres)	3.88	3.88
CORN GRAIN/NO TILL (acres)	25.47	25.47
ALFALFA (acres)	0.00	0.00
PASTURE (acres)	25.00	25.00
BUY CORN GRAIN (bu)	1,910.17	1,910.17
BUY N FERTILIZER (lbs)	7,896.00	4,987.15
STORE CORN SILAGE (tons)	336.00	336.00
STORE CORN GRAIN (bu)	3,189.00	3,189.00
STORE RYE (tons)	255.00	255.00
LABOR1 (hrs)	794.33	771.53
LABOR2 (hrs)	468.39	455.79
LABOR3 (hrs)	622.90	603.70
LABOR4 (hrs)	960.12	940.92
MTND (lbs)	2,364.00	0.00
MTN4 (lbs)	0.00	4,091.24
TAX WRITEOFF ($)	0.00	882.27
BUY 120 DAY STORAGE ($)	0.00	2,910.38
BORR15 ($)	0.00	27,825.48

for the large farm, no acres for the small farm) and the assumption that the large farm raised its own replacement heifers while the small farm simply purchased them off the farm. Both models behaved similarly when faced with the manure storage decision and the silage constraint. Based strictly on net returns, neither model chose to construct manure storage facilities.

Nitrate loadings to ground water varied considerably between the unconstrained large and small farm models, principally due to the smaller amount of pasture acreage (relative to total farm size) owned by the small farm. This smaller pasture necessitated higher per acre applications of manure for the no storage scenario on the small farm, which led to higher nitrate loadings from the pasture acreage.

Validity of the Conventional Practice Models

The mathematical programming approach used in this study is designed to model a representative or "average" farm for Rockingham County. Once specified, this typical situation is then used to simulate the effects of various policy options (such as cost sharing or corrective taxation) on the agricultural sector in the county. However, if the farm structure modeled is not truly representative of the county, impacts of alternative policies on nitrate loading to ground water cannot be estimated with the model. Therefore, it is extremely important that the model results be comparable to the actual county situation.

Some of this validation is provided by information from the Rockingham County dairy farm survey and secondary data sources. A second source of information on the model results' validity is provided by the shadow prices of the representative farm activities. If the model is a good representation of actual economic conditions in Rockingham County, these shadow prices should approximate area market prices. Shadow prices in the baseline (no storage) model were therefore examined so as to determine whether the model was representative of the Rockingham County situation.

The shadow price for land--that is, the value added to the objective function by an additional acre of cropland--in the three farm models (no storage, 120 day storage, and 180 day storage) ranged between $53 and $69. This price, if accurate, should approximate rental rates for land in the Rockingham County area. Rental rates in the area commonly range between $45 and $65 for cropland (Roller, 1988), so the shadow price of land in the model was considered appropriate. Pasture land in the county commonly rents for $15-$20 (Roller, 1988); the shadow price of pasture in the model was $19.01, so the pasture shadow price was also considered to be representative of county conditions.

The shadow price for an additional dairy cow ranges between $463 and $504. Since the model assumes a three year rotation of the dairy herd, net present values for three years of this shadow price lead to a value per cow of from $1,245 to $1,355. Current prices for fresh heifers in the region is $1,100 (Harris, 1988); when the additional time and expense of bringing this heifer into 16,000 lb/year milk production is considered, the dairy cow shadow price is comparable to the actual dairy cow market value.

As previously stated, no well-defined market exists in the region for forage (silage and ryelage). However, shadow prices for silage and ryelage are approximately equal to their cost of production. All shadow prices of storage activities accurately reflect the cost of production or purchase of feed items less any storage cost. Therefore, the model's shadow prices lend support to the model's overall representativeness of the Rockingham County dairy farm situation. A complete listing of shadow prices for the representative farm model is provided in appendix J.

It should be noted that the practice of comparing shadow prices to market values to validate the model assumes that market prices accurately reflect the true costs of the commodity in question. As Beneke and Winterboer (1973, p. 168) state, "reasonable correspondence of the simulated outcome to what actually occurred provides an excellent foundation on which to structure planning models." This validation assumes that there are no distortions in the market place which are not reflected in the model. The results of this type of validation should therefore be viewed with caution; however, it is nonetheless encouraging that the model shadow prices are comparable to prevailing area market prices.

The Case of "High" Fertilization: Water Quality Impacts

All large and small farm nutrient management scenarios previously described were formulated assuming ideal nutrient management practices (described in appendix H). However, the survey found that many farmers--even those with storage facilities already in place--were applying nitrogen (from manure and commercial sources) well in excess of agronomic recommendations. At least 15 farmers (about 11 percent of survey respondents) with 120 or 180 days of manure storage capacity were applying from 110-200 pounds of commercial nitrogen to about 1,300 acres of corn. An additional 19 farmers (about 13 percent of survey respondents) who had 120 or 180 day manure storage available were applying 100 pounds of commercial nitrogen per acre to about 1,600 acres of corn (Halstead, Batie, and Kramer, 1988); this group as a whole applied an average of about 115 pounds per acre. This high-applier group accounted for about one-third of survey respondents; other respondents (as previously discussed) were found to apply about 60 pounds of commercial nitrogen per acre. This latter group would appear to be following agronomic recommendations. If manure contributions were approximated at 75 pounds per acre, the high-applier group would be applying from 180 to 190 pounds of available nitrogen to corn acreage, a situation akin to ignoring manure nutrient contributions.

To examine the effect of this "worst case" management practice, additional CREAMS simulations were run based on these high-application rates, assuming commercial nitrogen applications of 168.2 lbs/acre for corn/rye no till, with an additional 77.9 lbs/acre of nitrogen added through manure application (survey results indicated that applications to rye were approximately equal to recommended rates). Commercial nitrogen applications for corn/conventional till are assumed to be 128 lbs/acre. This nutrient application practice is equivalent to ignoring the nutrient value of the manure. Results are shown in table 5.10.

As the loading parameters indicate, this scenario results in per acre loadings of 66 lbs. for no till corn/ryelage, an increase of 45.6 lbs. per acre (223.4 percent) over the optimal nutrient management scenario (table 5.3b). For the conventional till scenario, average loadings total 49.1 lbs. per acre or 37 lbs. per acre (301.9 percent) more than the optimal nutrient management scenario. These loadings translate to nitrate concentrations in percolation water of 97.3 ppm for no till corn/ryelage and 99.1 ppm for conventional till corn.

Making a number of assumptions, this scenario of high nitrogen application can be extrapolated to the county level. If the survey respondents are assumed to be representative of the entire population of dairy farmers in the county, and that these high-appliers make up one-third of the 291 Grade A dairy farmers in the county, the percentage contribution of each group (high-appliers and low-appliers) can be estimated. Assuming 115 acres of no till corn and 30 acres of conventional till corn for the large and small farms combined, and using the loading coefficients in tables 5.3b and 5.7b as approximations of per acre nitrate loadings, the results indicate that the high-applier farms could account for approximately 62 percent of

TABLE 5.10. NITRATE LEACHING FOR NO TILL CORN/RYELAGE AND CONVENTIONAL TILL CORN, HIGH FERTILIZATION SCENARIO.

Crop	Acres	Average Loading Per Acre (lbs)	Total NO_3 Losses (lbs)
Corn/rye (no till)	63.920	65.993	4,218.272
Corn (conventional)	26.080	49.112	1,280.841

Assumes 183 lbs/acre commercial nitrogen applied to corn/ryelage no till, 128 lbs/acre commercial nitrogen applied to corn/conventional till. Available nitrogen from manure application is 77.9 lbs/acre for both types of corn.

Source: Rockingham County Nutrient Simulations (Heatwole, 1988) total nitrate loadings from cropland in the county.

This high fertilization (as defined in an agronomic sense) situation demonstrates the water quality problems of high nitrogen application and the major contribution to ground water contamination that may be emanating from a minority (30 percent) of county farmers. The present mode of analysis prohibits drawing any inferences for ambient water quality in the area (as such analysis would require the use of a watershed model in addition to the CREAMS field scale model). However, this high application scenario does indicate that lack of consideration of the nutrient value of manure has detrimental implications for ground water quality. In addition, per acre fertilizer costs to the farmer are increased by about $16.36 for no till and $20.21 for conventional till corn (compared to the baseline scenario), which would decrease net returns by $1,747 for the large farm and $1,055 for the small farm.

ANALYSIS OF POLICY OPTIONS FOR NITRATE MANAGEMENT IN ROCKINGHAM COUNTY

Ideally, policies directed at reducing nitrate loadings to ground water should be able to estimate and manage nitrates leaving the field through leaching or runoff. However, since the nonpoint nature of agricultural nitrates makes monitoring and enforcement of loading standards at present economically infeasible, policy options are needed which would approximate the results given by loading constraints. Those options considered for the conventional practice model are corrective taxation, strict regulation of farm management practices, and cost sharing.

Corrective Taxation

In the absence of strict regulation of nutrient management and manure storage practices or provision of cost sharing, the price of commercial nutrients could be increased to the point where the additional cost of building a manure storage facility would be offset by the savings in nutrient costs generated. Graphically, this tax situation was shown within a profit maximization framework in figure 2.3. This policy was simulated in the model by iteratively increasing the price of commercial nitrogen, without changing application rates for crops grown in the model.

Model results indicated that a savings of about 4,850 lbs. nitrogen/year was generated for the large farm by the adoption of the 120 day storage option. However, net returns for the 120 day storage scenario were $2,520 less than the no storage scenario (when no cost sharing was provided). These results indicate that the increase in commercial nitrogen prices would have to be at least $.73 in order to induce voluntary manure storage adoption. This cost per pound would require more than a tripling of current prices.

For the small farm, net returns are reduced by $1,395 when the 120 day storage requirement is imposed (assuming low site preparation costs), and commercial fertilizer purchases are reduced by 2,909 lbs. In this case, the price of commercial nitrogen would have to increase to at least $.69 to induce voluntary adoption, which would result in more than a three-fold increase in current prices.

In both the large and small farm models, crop and dairy production activities were unchanged from the unconstrained conventional practice results when the nitrogen tax was applied. This result was expected since optimal crop production mixes to feed the dairy herd are not affected by the storage-no storage decision.

These results indicate that it would take a major increase in the price of commercial nitrogen fertilizer to make construction of a manure storage facility profitable. In addition, numerous studies have indicated that the price elasticity of fertilizer is relatively low (see, for example, Roberts and Heady, 1982; Roberts, 1986; Heady and Yeh, 1959). This lack of responsiveness to price changes could negate some of a tax's desired corrective effect and remove some of its usefulness as a tool to be used in conjunction with another policy option.

In any case, an increase in the price of nitrogen fertilizer of the magnitude necessary to induce storage construction--if not combined with other programs--would substantially lower area farmers' net returns (to about $49,400 for the large farm and $36,765 for the small farm). In addition, the present political and economic climate may not allow the three-fold increase in fertilizer price that a strict corrective tax policy would necessitate.

The Regulatory Option

The second possibility for reducing nitrate loading to ground water is to impose restrictions on the amount of nitrate lost through farm operations. Regulation could either take the form of requiring manure storage and nutrient management, or imposing nitrate loading constraints on the farmer's operations.

The strict regulatory option was depicted in figure 2.4. In this case, the farmer must construct a manure storage facility. Results of the combined mathematical programming/CREAMS simulations demonstrated that manure storage combined with recommended nutrient management practices had the effect of reducing average nitrate loadings to ground water by about 40%. However, the survey results showed that many farmers who already had manure storage facilities in place were applying too much nitrogen (from an agronomic standpoint) to much of their cropland, even when they clearly stated that they were taking credit for the nutrient content of the manure spread on their cropland. Thus, even if manure storage facilities were required by law, ground water nitrate loadings might not be reduced.

Required nutrient management practices would be difficult to enforce; a possible mechanism might be permits issued for commercial nitrogen purchase based on crop acreage. This permit system might also be tied in with manure testing results, which would determine how much nitrogen the farmer had available. Unless this policy were implemented on a regional rather than local basis, however, problems with importing nitrogen across state and county lines would be encountered. Many Rockingham County farmers already purchase their fertilizer outside of the county (Hawkins, 1987a).

Chance constraints on nitrate loading can help to incorporate the effects of leaching uncertainty on the management process. However, since there are only three discrete levels of nitrate loading reduction in the conventional practice model (represented by the three manure storage scenarios), using chance constraints to constrain the farmer's nitrate loadings would result in threshold levels of contaminant loading where no storage would shift to 120 day storage, and 120 day storage would shift to 180 day storage. This type of constraint would be more effective in the case of a contaminant where loading reductions could be achieved more or less continuously, such as topsoil loss to surface water; or in the nontraditional alternative model, where specification of a more diverse set of production activities yields more policy alternatives. In any case, imposing these constraints on the initial model would be identical to requiring the construction and use of manure storage facilities. Therefore, the effects of this policy on net returns are illustrated in tables 5.3 and 5.7.

The Cost Sharing Option

One policy which has been extensively practiced in the control of agricultural pollution is cost sharing. Funds are currently available for farmers in Rockingham County to construct manure storage facilities. Recipients of these funds, which are allocated to "improve water quality by storing and spreading waste at the proper time, rate, and location," are required to submit a written operation plan (based on SCS specifications) and to maintain the system in accordance with this plan for a minimum of 10 years (DSWC, 1987).[5] The cost sharing framework was graphically illustrated in figure 2.5.

Model results indicate that a one-time payment of between about $13,702 and $19,900 for the large farm and about $14,783 for the small farm (with medium site preparation costs) would need to be provided for voluntary construction of poured concrete storage facilities.[6] (When provided with the maximum $11,000 cost sharing allowance and faced with low site preparation costs [$2,500], the small farm model moved from no storage to 120 day storage.) However, maximum cost sharing allowances from the Division of Soil and Water Conservation and ASCS totaled only $11,000 during 1988. When provided with maximum cost sharing, net returns for the large farm model increase to about $54,500, while net returns for the small farm model increase to $40,200. Therefore, based solely on the criteria of net returns over variable costs as derived in the representative farm model, it is not economically feasible for a farmer to construct even a 120 day manure storage facility given current conditions in the county, although nitrate loadings would be reduced by nearly 40 percent from the no storage situation.

Yet, the Rockingham County Dairy Farm survey found that many farmers in the county already have manure storage tanks in place, and many more area farmers have applied for permits and cost sharing to construct new facilities (Patterson, 1988; Givens, 1988). It was therefore concluded that the representative farm model was not capturing the effect of all of the variables influencing many farmers' storage-adoption decisions. The following section comments on possible factors influencing adoption.

Additional Factors in the Manure Storage Construction Decision

Consultation with agronomists and extension personnel and examination of the attitudinal responses generated by the survey revealed that at least four factors other than net returns to the dairy operation may be influencing Rockingham County dairy farmers manure storage decisions. Each of these is discussed in turn, without attempting to rank these factors in order of importance.

One advantage to the increased use of manure provided by the storage option is the agronomic qualities which manure use possesses in addition to nutrient value. These include improved soil structure, greater moisture retention, and improved tilth. Manure use leads to a well-aggregated, water stable soil which results in less water breakdown and reduces the potential for surface runoff, and eventually could increase yields (Hawkins, 1988). No attempt was made to incorporate these long term yield enhancing production considerations in the model.

The "Annoyance" Factor. A second reason often cited for construction of manure storage facilities is the convenience of not having to spread manure every day or every few days. While the representative farm model captures the strict cost differences between daily spreading and spreading two or three times per year, there is apparently an "annoyance factor" in the daily spreading regime which was beyond the scope of this study to calculate. Farmers place substantial value on being rid of this annoyance factor (Givens, 1988; Patterson, 1988).

In order to examine this factor more closely, the actual time spent spreading manure daily was broken out of the DAIRYLP model. It was estimated that 1.23 hours per cow per year is spent spreading manure when no storage is available, or a total of 123 hours for the large farm and 73.8 hours for the small farm. The annoyance factor would therefore have to be worth approximately $6.83 per manure spreading hour for the large farm and $4.83 per manure spreading hour for the small farm in order to account for the differences in net returns between the no storage and 120 day storage models. If it is assumed that the spreading hours are logged by the farm operator (rather than his hired laborers), the annoyance factor translates into a per hour opportunity cost wage of $11.16 (the hourly wage of $4.31 plus the annoyance factor cost) for the large farm operator and $9.14 for the small farm operator. These estimates are equivalent to per-hour wages in the annual earnings range of $19-23,000 (which is probably less than most dairy farmers' profit range), so that the "annoyance factor" seems a reasonable means of explaining at least a part of the differences in net returns between the no storage and 120 day storage scenarios.

A third reason farmers may adopt storage is to improve water quality in the area and on their own farm. County survey results indicate that farmers are concerned about water quality and are willing to make financial tradeoffs to protect and improve this water quality. Farmers are aware that agricultural chemicals are a threat to water quality. Part of the economic value of pure drinking water is revealed in averting behavior such as purchasing water treatment equipment (for example, chlorinators; the survey revealed that about one-fourth of respondents treated their water). Farmers may also be willing to forego some of their net returns in order to obtain better water quality, a factor which is not built into the model objective function but may very well be an argument in the farmer's utility function.

The fourth and final non-model factor which may increase storage adoption is the "bandwagon" effect. It has been demonstrated that an individual (such as a farmer) may demand more of a commodity (such as a manure storage facility) because some or all individuals in the market are demanding more of the commodity (Leibenstein, 1950). While this phenomena may be more prevalent for the case of tractors than manure pits, the "bandwagon" effect may counteract part of the net return difference between the storage and no storage scenarios.

It must be recognized that in spite of these financial and non-market benefits, it may still not be economical for certain individual farmers to construct a manure storage facility, especially if their site preparation costs fall in the high range ($18,000). In fact, many farmers who initially sign up to participate in the Division of Soil and Water Conservation (DSWC) cost sharing program withdraw from the program when they obtain an estimate of what the facility will actually cost them. Recognition of this problem has prompted some administrators of the DSWC cost sharing program to investigate the possibility of providing additional cost sharing, up to a maximum of $20,000 ($9,000 more than currently provided, and sufficient to change the optimal solution of the model from no storage to storage in all but high site preparation cost [$18,000] scenarios)(Givens, 1988). For many farmers, the combination of cost sharing, the annoyance factor, and the other factors mentioned seem sufficient to induce construction of manure storage facilities. This is borne out by the fact that 60 percent of county survey respondents currently have at least 120 day manure storage facilities in place, and 20 permits for new facilities (representing an additional 7 percent of county farms) have been issued for 1987-1988 (Halstead, Batie, and Kramer, 1988; Knicely, 1988).

RESULTS OF THE NON-TRADITIONAL ALTERNATIVE MODELS

As discussed in the previous chapter, one of the alternative revenue sources incorporated in the nontraditional alternative (NA) model is production of alfalfa for sale at $80/ton. Comparisons of policy scenarios between models with different assumptions regarding the alfalfa selling activity (that is, with or without alfalfa selling included) should be made with caution, since the no alfalfa selling model approximates the current situation and the alfalfa selling model assumes the existence of a local alfalfa marketing structure. Table 5.11 provides a summary of key differences in activities and returns between the conventional practice model with no alfalfa selling activity, and the same model with alfalfa sold at $80 per ton. Differences between with and without alfalfa selling are less dramatic in the small farm models due to the minimal amount of "discretionary" acreage left in the small farm model after fulfilling feed requirements.

The following section describes the outcome of the conventional practice model under the assumption that a 60 day manure storage system

TABLE 5.11. SELECTED VARIABLE VALUES OF LARGE AND SMALL FARM MODELS, WITH AND WITHOUT ALFALFA SELLING ACTIVITY.

STORAGE SCENARIO (farm size)	NET RETURNS	ALFALFA ACREAGE	ALFALFA SOLD (tons)
No Storage			
Large/with[a]	$57,338	51.1	255.4
Large/without	$55,407	25.0	0.0
Small/with	$41,064	3.9	19.4
Small/without	$40,555	0.0	0.0
60 Day Storage			
Large/with	$56,105	51.1	255.4
Large/without	$54,604	25.0	0.0
Small/with	$39,996	3.9	19.4
Small/without	$39,849	0.0	0.0
120 Day Storage			
Large/with	$56,001	51.1	255.4
Large/without	$54,567	25.0	0.0
Small/with	$40,345	3.9	19.4
Small/without	$40,197	0.0	0.0
180 Day Storage			
Large/with	$54,882	51.1	255.4
Large/without	$53,371	25.0	0.0
Small/with	$39,667	3.9	19.4
Small/without	$39,519	0.0	0.0

[a]"With" signifies the farm model with the alfalfa selling activity included at a price of $80 per ton. "Without" signifies baseline model runs with alfalfa production activities included, but with no alfalfa selling activities.
fulfilling feed requirements.

is constructed and used. The option to build 60 day storage is then included in all of the succeeding policy formulations.

The 60 Day Storage Option

Table 5.12a illustrates the effects that construction of a 60 day storage facility would have on net returns of the large and small representative farms. Acreage allocations mirror those of the daily, 120, and 180 day storage scenarios, as expected since cropping mixes are principally determined by dairy herd ration needs, which are unchanged. Both optimal objective function values are inferior to the no storage scenarios. However, for the large farm, the net returns of $54,604.41 for 60 day storage are slightly higher than the returns of $54,566.67 for the 120 day storage option. It is also important to note that no cost sharing is provided in the 60 day scenario (the current situation in the Shenandoah Valley). For the small farm, returns under the 60 day storage scenario are slightly less than those for 120 day storage ($39,849.09 vs. $40,197.16). This difference in net returns is due to the relative effect of cost sharing on the small farm; after the $11,000 allowance is made, the small farm model with 120 day storage actually finances less than the small farm model with 60 day storage.

Model results allowing for the 60 day manure storage structure indicate that net returns for the 60 day facility are higher than the 120 day scenario even when cost sharing is not provided; if cost sharing were provided, the 60 day storage scenario would dominate even the no storage option. The lack of requests for these shorter-term storage

TABLE 5.12a. RESULTS OF THE LARGE AND SMALL (CP) REPRESENTATIVE FARM MODELS, 60 DAY STORAGE CONSTRAINT.

	Large Farm	Small Farm
Net Returns[a]	$54,604.41	$39,849.09
Activity	**Level**	**Level**
TOTAL ACRES	200.00	80.00
CORN SILAGE/NO TILL (acres)	37.76	19.76
CORN GRAIN/NO TILL (acres)	26.15	31.35
CORN GRAIN/CONV TILL (acres)	26.08	3.88
ALFALFA (acres)	25.00	0.00
PASTURE (acres)	85.00	25.00
BUY CORN GRAIN (bu)	5,192.92	1,262.92
BUY N FERTILIZER (lbs)	8,089.85	5,847.61
SELL CALF (head)	39.80	46.80
SELL CULL (head)	33.80	19.80
SELL MILK (cwt)	16,000.00	9,600.00
STORE CORN SILAGE (bu)	642.00	336.00
STORE CORN GRAIN (bu)	5,485.08	3,837.08
STORE HAY (bu)	125.00	0.00
STORE RYE (bu)	319.60	255.60
LABOR1 (hrs)	2,138.65	771.53
LABOR2 (hrs)	1,281.13	455.79
LABOR3 (hrs)	1,849.50	603.70
LABOR4 (hrs)	2,240.35	940.92
DAIRY COWS (head)	100.00	60.00
MTN2 (lbs)	5,384.55	3,230.73
SPREAD MANURE (gallons)	611,900.00	367,140.00
TAX WRITEOFF ($)	1,284.82	938.69
BUY 60 DAY STORAGE ($)	2,422.49	1,453.51
BORR15 ($)	24,502.16	17,901.29

[a]Medium site preparation costs of $8,000 are assumed. To calculate alternative site preparation cost, simply multiply cost differences by .0944 and add or subtract from the objective function.

TABLE 5.12b. SIMULATED NITRATE LOADINGS IN THE LARGE AND SMALL REPRESENTATIVE FARM MODELS, 60 DAY STORAGE CONSTRAINT (Average over 1966-85 simulation period).

	Acres		Average Loading Per Acre (lbs)	Total NO_3 Losses (lbs)	
	Large Farm	Small Farm		Large Farm	Small Farm
CORN SILAGE/NT	37.765	19.765	19.213	725.58	369.14
CORN GRAIN/NT	26.155	31.355	19.213	502.52	602.43
CORN GRAIN/CONV	26.080	3.880	10.985	286.49	42.63
ALFALFA	25.000	0.000	0.000	0.00	0.00
PASTURE (large)	85.000	0.000	11.421	970.78	0.00
PASTURE (small)	0.000	25.000	22.157	0.00	557.93
TOTAL NO_3 LEACHED (lbs)				2,485.37	1,572.11

facilities in areas of the state where cost sharing is available seems to reinforce this finding, although it is also possible that state agency promotion of longer term storage (120 or 180 day) could bias farmers against the shorter term storage.

Nitrate Loadings in the 60 Day Storage Models

As expected, total average nitrate loadings of 2,485 and 1,572 for the large and small farm models under 60 day storage option were lower--7.3 percent for the large farm and 6.3 percent for the small farm--than for the no storage model. However, they were higher than for either the 120 or 180 day storage, due principally to the increased pasture spreading involved. Thus, while costs to the farmer (and the regulating agency, since no cost sharing is provided) are lower than the longer term storage options, adoption of the 60 day storage plan results in higher rates of nitrate loading to ground water than either of the other storage options.

ALTERNATIVE POLICY OPTIONS IN THE NONTRADITIONAL ALTERNATIVE MODEL

In this chapter, several policy options are considered which provide the farmer with incentives to adopt some of the alternative cropping and ration practices previously described, as well as still having the option to construct manure storage facilities. These include: imposition of a ban on the purchase of commercial nitrogen fertilizers in the county; imposing requirements limiting the ratio of herd size to pasture acreage for farmers with no storage facilities;

and a combination of several of these policies to determine whether combined policy strategies would work better than each policy applied separately.

Input Regulation: Imposing a Ban on Commercial Fertilizer

To evaluate the effects of limiting the amount of nitrogen which could be purchased, a ban on all nitrogen purchases was imposed through constraints on the NA model. In this scenario, the only nitrogen available to the farm model was that produced by the dairy herd (in manure form) and that available in the soil following legume rotation.

This ban was imposed both on the large farm model and on the small farm model, under the assumptions that alfalfa produced on the farm could not be sold, and under the alternative that alfalfa could be sold at $80 per ton. This distinction is important, since alfalfa production requires no fertilizer input (and actually increases nitrogen available on the farm through fixation), and alfalfa production for sale replaces much of the corn grain acreage. The marginal value per pound of nitrogen will differ substantially depending on the assumption made regarding alfalfa sales.

This ban could have several effects on model outputs. First, the lack of commercial nitrogen would reduce the amount of corn silage available for the dairy herd, leading to either a reduction in herd size or a shift to different rations requiring less nitrogen application. Second, the nitrogen "shortage" would cause the model to produce corn using low yield corn activities. Finally, the ban would tend to increase the marginal value of nitrogen; the ban would tend to make manure storage a more attractive option, so as to make maximum use of on-farm produced nitrogen.

Large Farm Results

Results of the with/without (alfalfa sales)/no commercial nitrogen scenarios for the large farm nontraditional alternative model are presented in table 5.13a. Prohibiting commercial fertilizer use has the effect of causing the model to opt for 120 day storage in both cases. This result is plausible, since the 120 day storage regime allows capture of maximum nutrient value from dairy manure. While herd size is unchanged at 100 cows, rations in the no-alfalfa-sales model change so that 22.2 cows are now fed on an alfalfa-corn grain ration.[7] This result reflects the deficit of available nitrogen, which reduces the amount of corn silage which can be grown on farm (causing alternatives to be used). Crop mixes also change, as reduced yield corn silage and corn grain are substituted for regular yield corn. Net returns under this scenario are substantially reduced from the conventional practice 120 day storage model (with cost sharing), from $54,604 to $47,293 (13.4 percent).

For the alfalfa sales model, part of the herd (15.3 cows) is also fed on an alfalfa-corn grain ration; low-yield corn activities in this solution again reflect the loss of available commercial nitrogen. However, additional corn can now be grown with the legume nitrogen provided by the alfalfa acreage produced for sale, which accounts for

TABLE 5.13a. RESULTS OF THE LARGE (NA) REPRESENTATIVE FARM MODEL, NO COMMERCIAL FERTILIZER SCENARIO. ALFALFA NITROGEN CREDIT ALLOWED.

	No Alfalfa Sales	Alfalfa Sales
Net Returns[a]	$47,293.00	$51,002.77
Activity	**Level**	**Level**
TOTAL ACRES	200.00	200.00
CORN SILAGE1/NO TILL (150)	33.77	0.00
CORN SILAGE2/NO TILL (140)	0.00	43.85
CORN GRAIN2/NO TILL (140)	15.99	10.29
ALFALFA (acres)	38.84	60.86
PASTURE (acres)	85.00	85.00
BUY CORN GRAIN (bu)	11,160.87	11,078.77
BUY N FERTILIZER (lbs)	0.00	0.00
SELL CALVES (head)	39.00	39.00
SELL CULLS (head)	33.00	33.00
SELL MILK (cwt)	16,000.00	16,000.00
SELL ALFALFA (tons)	0.00	145.53
STORE CORN SILAGE (tons)	499.79	543.76
STORE CORN GRAIN (bu)	1,415.24	910.43
STORE HAY (tons)	194.21	158.77
STORE RYE (tons)	248.80	270.70
LABOR1 (hrs)	2,123.00	2,123.00
LABOR2 (hrs)	1,270.89	1,367.72
LABOR3 (hrs)	1,960.23	2,136.39
LABOR4 (hrs)	2,140.49	2,253.74
DAIRY4 (head)	77.85	84.70
DAIRYAC4 (head)	22.15	15.30
MTN4 (lbs)	6,818.73	6,818.73
SPREAD MANURE (gals)	568,000.00	568,000.00
TAX WRITEOFF ($)	1,575.31	1,575.31
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	4,850.57	4,850.57
BORR15 ($)	30,042.46	30,042.46

[a]Medium site preparation costs of $8,000 are assumed.

TABLE 5.13b. SIMULATED NITRATE LOADINGS IN THE LARGE REPRESENTATIVE FARM MODEL, NO COMMERCIAL FERTILIZER SCENARIO. ALFALFA NITROGEN CREDIT ALLOWED. (Average over 1966-85 period)

	No Alfalfa Sales		Alfalfa Sales		
	Acres	NO_3 Losses (lbs)	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs.)
CORN SILAGE1/NT	33.77	555.38	0.00	0.00	16.45
CORN SILAGE2/NT	0.00	0.00	43.85	672.78	15.34
CORN GRAIN2/NT	15.99	245.32	10.29	157.28	15.34
ALFALFA	38.84	0.00	60.86	0.00	0.00
PASTURE	85.00	0.00	85.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		800.700		830.600	

the smaller percentage of the dairy herd fed on an alfalfa-based ration in the alfalfa sales model. Allowing the production of alfalfa for sale has the expected result of increasing net returns.

Net returns in both of the without-alfalfa-models (large and small farm) are reduced by about $8,000. The cost to the farmer of nitrate loading reductions achieved under this scenario is thus quite high.

Nitrate Loadings for the Large Farm Under the No Commercial Nitrogen Scenario

Based simply on consideration of nitrogen applied to the reduced yield corn crops and the large acreages of alfalfa grown, nitrate loadings to ground water could be expected to be reduced considerably by the no commercial nitrogen policy. These reductions were substantial--only 801 pounds of nitrate for the no-alfalfa-sell model and 831 pounds in the alfalfa-sell model were lost in percolation water. On average, this policy can reduce loadings by more than 70 percent over the no storage option (table 5.13b). However, the ban on commercial fertilizer simulated here allows no substitution of alternatives for local nitrogen purchase, such as poultry litter or imported nitrogen. This case should thus be viewed as a lower bound.

Small Farm Results

Results of the commercial nitrogen ban on the small farm are shown in table 5.14a. These results mimic the large farm, as the no-alfalfa-sold small farm model shifts part of its herd (7.9 cows) to the alfalfa-corn grain ration. Alfalfa production increases to 15

TABLE 5.14a. RESULTS OF THE SMALL (NA) REPRESENTATIVE FARM MODEL, NO COMMERCIAL FERTILIZER SCENARIO. ALFALFA NITROGEN CREDIT ALLOWED.

	No Alfalfa Sales	Alfalfa Sales
Net Returns[a]	$34,314.86	$35,838.61
Activity	**Level**	**Level**
TOTAL ACRES	80.00	80.00
CORN SILAGE/NO TILL (150)	19.77	20.27
CORN GRAIN/NO TILL (140)	9.46	7.73
PASTURE	25.00	25.00
ALFALFA (acres)	15.11	24.99
SELL ALFALFA (tons)	0.00	55.43
BUY CORN GRAIN (tons)	4,794.87	4,669.76
BUY N FERTILIZER (lbs)	0.00	0.00
SELL CALF (head)	39.00	46.80
SELL CULL (head)	33.00	19.80
SELL MILK (cwt)	16,000.00	9,600.00
STORE CORN SILAGE (tons)	291.65	300.06
STORE CORN GRAIN (bu)	837.12	861.27
STORE HAY (tons)	75.56	69.53
STORE RYE (tons)	145.82	150.03
LABOR1 (hrs)	769.20	769.20
LABOR2 (hrs)	466.78	507.99
LABOR3 (hrs)	724.59	803.65
LABOR4 (hrs)	864.14	908.51
DAIRY4 (head)	52.08	53.58
DAIRYAC4 (head)	7.92	6.42
MTN4 (lbs/N)	4,091.24	4,091.24
SPREAD MANURE (gallons)	340,800.00	340,800.00
TAX WRITEOFF ($)	882.27	882.27
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	2,910.38	2,910.38
BORR15 ($)	16,825.00	16,825.48

[a]Medium site preparation costs of $8,000 are assumed. To calculate alternative site preparation cost, simply multiply cost differences by .0944 and add or subtract from the objective function.

TABLE 5.14b. SIMULATED NITRATE LOADINGS IN THE SMALL REPRESENTATIVE FARM MODEL, NO COMMERCIAL FERTILIZER SCENARIO. ALFALFA NITROGEN CREDIT ALLOWED.

	No Alfalfa Sales		Alfalfa Sales		
	Acres	NO_3 Losses (lbs.)	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs)
CORN SILAGE1/NT	19.70	324.08	20.27	333.44	16.45
CORN GRAIN2/NT	9.46	145.12	7.73	118.62	15.34
ALFALFA	15.11	0.00	24.99	0.00	0.00
PASTURE	25.00	0.00	25.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		469.205		452.067	

acres, with the remainder of small farm cropland devoted to low yield corn production. As with the large farm model, net returns are reduced substantially from the conventional practice run, from $41,121 to $38,056 (about 7.5 percent).

When the alfalfa sales are allowed, net returns increase substantially, and a slightly smaller part of the herd (about six cows) are shifted to the alfalfa-corn grain ration. As in the large farm model, alfalfa production increases so that more legume nitrogen is available for corn production.

Nitrate Loadings for the Small Farm Under the No Commercial Nitrogen Scenario

As with the large farm model, it was anticipated that nitrate loadings for the small farm model would be substantially reduced by the ban on commercial fertilizer purchase. Loading reductions in the small farm model were in the same range as reductions in the large farm model, on average in the 70 percent range (tables 5.14b). Thus, although the price of this policy is high in terms of impacts on net returns, the policy also yields major reductions in nitrate loading.

The Poultry Litter Option

As already discussed, various issues must be resolved before the actual value of poultry litter is as a fertilizer can be estimated. For the purposes of this analysis, of more interest is determining how low the price of delivered and applied litter and other necessities such as nutrient testing (and the subsequent price per pound of litter nitrogen) would need to be before the possibility of using poultry litter affected the solution of the no-fertilizer scenario. If the actual price of poultry litter were below this threshold level, the nitrate loading reductions presented would be overstated, because the farmer would take advantage of poultry litter to produce more corn silage.

Visual inspection of the decreases in net returns after the commercial fertilizer ban is imposed indicates that poultry litter would enter the solution at a fairly high price. Actual model results indicated that if a pound of poultry litter nitrogen (delivered and applied) cost less than $2.76 for the large farm and $2.61 for the small farm, the solutions illustrated in tables 5.13 and 5.14 would not be valid. In other words, if poultry litter nitrogen were cheaper than these threshold level prices, poultry litter would be purchased and applied, and more corn would be grown (with increases in nitrate loadings). Model results indicate that If the price of litter nitrogen were slightly less than these threshold values of about $2.75 per pound, the farm would revert to a silage-based ration with just over 10 acres of cropland idled (since it would be cheaper to buy corn grain than to grow it). This result does indicate that if a ban were placed on commercial nitrogen, demand for poultry litter would increase dramatically, and the market for litter sales, distribution, and application would likely develop quickly.

<u>Environmental Quality Implications of Using Poultry Litter</u>. Widespread use of poultry litter as a substitute for commercial nitrogen could

also have different implications for water and air quality than current practices. If area farmers applied poultry manure without incorporation, substantial losses of nitrogen to volatilization could occur, due to the relatively high percentage of litter nitrogen which is in ammonium form (Collins, 1988). For example, Salter and Schollenberger (1939) found that poultry litter plowed under four days after spreading had only 60 percent of the effect on small grain yield of poultry litter plowed under immediately, while Carreker et al (1973) estimate that a 30 percent loss of NO_3 occurs due to volatilization in unincorporated manure.

Field studies in Delaware by Ritter, Chirnside, and Scarborough (1986) indicate that poultry manure tends to create greater nitrate contamination of ground water than commercial fertilizer, although preliminary results of studies in Maryland indicate that poultry litter may cause less ground water nitrate contamination. These Maryland studies also indicate that poultry manure may create less surface contamination than commercial nitrogen due to the "mulch" effect provided by the litter (Magette, 1988).

Land Use Controls: Imposition of Minimum Acreage Requirements

CREAMS results indicated that most of the ground water quality problems inherent in the no storage scenario stem from spreading manure on pasture land. Differences in loadings between small farm/no storage pasture and large farm/no storage pasture indicate that the rate of manure application significantly affects nitrate leaching. Therefore, policies which reduced this per acre manure application rate would also reduce per acre nitrate loading.

This type of policy could be implemented by mandating that farmers with no manure storage facilities maintain a certain amount of pasture acreage for the express purpose of spreading manure. These restrictions could be in the form of a fixed pasture/cow ratio based on water quality considerations. Without explicit knowledge of the maximum nitrate losses permissible under pasture land, this ratio would be impossible to determine precisely.

However, sensitivity analyses can be performed to determine when the effects of a minimum spreading acreage policy on net returns would effect a shift to manure storage adoption. For the large model, it can initially be determined that the ratio of pasture to cows is .85 (since by assumption and survey confirmation the large farm had 85 acres of pasture and 100 cows). If it is assumed that ratios stricter than .85--which would require more pasture land be acquired to meet the policy constraint--must be satisfied by taking producing cropland out of production,[8] each additional increment to the herd/pasture ratio of .01 would require that one acre be taken out of production for manure spreading, or that the herd size be reduced by 1.2 cows. Sensitivity analysis of the large farm model indicates that if this ratio is increased to .93 acres per cow (requiring that eight acres be taken out of production), net returns are reduced from about $55,400 to less than $52,886; it is therefore more profitable to adopt the 120 day manure storage program. For the small farm, the initial ratio of pasture to herd is only .42. An increase in this ratio to only .48 is sufficient to reduce net returns to below $39,159, which would make it more profitable for the farm to construct a 120 day storage facility. Imposing these minimum herd-to-pasture spreading ratios also would have the effect of reducing per-acre nitrate leaching on pasture land, as well as reducing the number of acres of corn grain grown.

Compliance with this policy might be difficult to monitor, although the use of remote sensing could effectively identify land maintained as pasture. Since small farms in the area possess so little pasture acreage, this type of policy would have more impact on small farms than large farms. Model results indicate that imposition of the pasture/herd spreading requirement would prove sufficient inducement to those farmers still practicing daily manure spreading to construct a storage facility.

This policy is similar to restrictions placed on poultry operations in the county which require that an approved waste disposal plan (usually involving land spreading) be demonstrated before a permit for the poultry house is issued (Virginia Poultry Federation, 1987). Henderson, Trauberman, and Gallagher (1984) note that land use controls are useful for restricting activities on identifiable, sensitive ground water recharge areas; land use controls are usually best at protecting shallow, unconfined aquifers (like the type found in Rockingham County)(Conservation Foundation, 1986). The State of Virginia recently passed legislation adding ground water protection to the list of purposes for local zoning ordinances (HB 920) and allowing designation of areas for implementation of reasonable ground water protection measures to be included in local comprehensive plans (HB 38).

Combining Policies: The Corrective Taxation-Cost Sharing Approach

In the conventional practice model, it was determined that a corrective taxation policy used alone would require a substantial increase in the price of commercial nitrogen to effect a change from no storage to 120 or 180 day storage. Likewise, the amount of cost sharing currently available is insufficient to induce storage adoption considering only the effects on net returns. However, as the results presented in this chapter indicated, provision of cost sharing reduces the gap between net returns in the no storage and 120 day storage scenarios substantially. It was therefore hypothesized that if a corrective tax were applied to nitrogen and the cost sharing option were provided, the magnitude of the corrective tax needed to induce storage adoption would be substantially lower.

In order to determine the minimum tax necessary to equate net returns between the no storage option and the 120 day option (after cost sharing), the price of nitrogen was raised iteratively until the model opted for 120 day storage. This analysis was performed for both the large and small farm models, again using the with- and without-alfalfa sales assumption. The minimum tax needed to induce storage adoption was expected to be higher for the with-alfalfa sales option, since this option used less nitrogen due to lower crop needs and the availability of legume nitrogen.

As table 5.15a shows, imposition of a tax of $.16 on nitrogen to raise total price to .37 per pound had the effect of causing the large farm model to adopt the 120 day storage option when no alfalfa sales were allowed. However, the threshold tax necessary to cause the model to adopt 120 day storage when alfalfa sales were allowed was .28, for a nitrogen price of .49 per pound. This higher value is due to the lower demand for nitrogen in the alfalfa selling model (that is, given the option the model will shift away from corn grain and into alfalfa production), which reduces the difference between total commercial nitrogen purchased in the storage and no storage scenarios. However, nitrate loadings in the alfalfa-selling model are substantially lower than the no alfalfa sales model, due to the smaller corn acreage grown. The greater this difference in nitrogen purchased, the greater the impact a tax will have on the storage adoption decision. Cropping decisions are unchanged from the original models. Total tax revenues of $1,178 and $955 per year are generated under this policy for the no-alfalfa and alfalfa-sell assumptions, respectively.

Small farm results are similar to large farm results under the tax-cost sharing strategy. Table 5.16a indicates that a tax of .13 per pound (for a total price of .34) under the no-alfalfa sell assumption would induce adoption of 120 day storage, and a tax of .16 per pound (for a cost of .37 per pound) would be sufficient to make the 120 day storage facility economical in the model. Total tax revenues of $648 and $728 per farm per year for sell and no-sell alfalfa are raised under this policy.

TABLE 5.15a. RESULTS OF THE LARGE (NA) REPRESENTATIVE FARM MODEL, CORRECTIVE TAX ON COMMERCIAL FERTILIZER WITH COST SHARING. ALFALFA NITROGEN CREDIT ALLOWED.

	Tax Level	
	.16/lb (no alfalfa sales)	.28/lb (alfalfa sales)
Net Returns[a]	$56,673.340	$58,240.71
Activity	**Level**	**Level**
TOTAL ACRES	200.00	200.00
CORN SILAGE/NO TILL (acres)	37.76	37.76
CORN GRAIN/NO TILL (acres)	26.15	26.15
CORN GRAIN/CONV (acres)	35.16	0.00
ALFALFA (acres)	15.92	51.08
PASTURE (acres)	85.00	85.00
BUY CORN GRAIN (bu)	4,284.92	7,800.92
BUY N FERTILIZER (lbs)	7,364.67	3,409.17
SELL CALVES (head)	39.00	39.00
SELL CULLS (head)	33.00	33.00
SELL MILK (cwt)	16,000.00	16,000.00
SELL ALFALFA (tons)	0.00	175.80
STORE CORN SILAGE (tons)	642.00	642.00
STORE CORN GRAIN (bu)	6,393.08	2,877.08
STORE HAY (tons)	79.60	79.60
STORE RYE (tons)	319.60	319.60
LABOR1 (hrs)	2,144.10	2,123.00
LABOR2 (hrs)	1,257.80	1,348.16
LABOR3 (hrs)	1,776.86	2,058.14
LABOR4 (hrs)	2,229.72	2,270.86
DAIRY COWS (head)	100.00	100.00
MTN4 (lbs)	6,818.73	6,818.73
SPREAD MANURE (gallons)	568,000.00	568,000.00
TAX WRITEOFF ($)	1,575.31	1,575.31
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	4,850.57	4,850.57
BORR15 ($)	30,042.46	30,042.46

[a]Medium site preparation costs of $8,000 are assumed. To calculate alternative site preparation cost, simply multiply cost differences by .0944 and add or subtract from the objective function.

TABLE 5.15b. SIMULATED NITRATE LOADINGS IN THE LARGE REPRESENTATIVE FARM MODEL, CORRECTIVE TAX ON COMMERCIAL FERTILIZER WITH COST SHARING. ALFALFA NITROGEN CREDIT ALLOWED. (Average over 1966-85 period)

	.16 Tax		.28 Tax		
	Acres	NO_3 Losses (lbs.)	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs)
CORN SILAGE/NT	37.76	770.75	37.76	770.75	20.41
CORN GRAIN/NT	26.15	533.80	26.15	533.80	20.41
CORN GRAIN/CONV	35.16	429.62	0.00	0.00	12.22
ALFALFA	15.92	0.00	51.08	0.00	0.00
PASTURE	85.00	0.00	85.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		1,734.16		1,304.54	

TABLE 5.16a. RESULTS OF THE SMALL (NA) REPRESENTATIVE FARM MODEL, CORRECTIVE TAX ON COMMERCIAL FERTILIZER WITH COST SHARING. ALFALFA NITROGEN CREDIT ALLOWED.

	Tax Level .13/lb (no alfalfa sales)	Tax Level .28/lb (alfalfa sales)
Net Returns[a]	$39,548.83	$39,617.32
Activity	**Level**	**Level**
TOTAL ACRES	80.00	80.00
CORN SILAGE/NO TILL (acres)	19.76	19.76
CORN GRAIN/NO TILL (acres)	31.35	31.35
CORN GRAIN/CONV (acres)	3.88	0.00
ALFALFA (acres)	0.00	3.88
PASTURE (acres)	25.00	25.00
BUY CORN GRAIN (bu)	1,262.92	1,650.92
BUY N FERTILIZER (lbs)	4,987.16	4,550.66
SELL CALF (head)	39.00	39.00
SELL CULL (head)	33.00	33.00
SELL MILK (cwt)	16,000.00	16,000.00
SELL ALFALFA (tons)	0.00	19.40
STORE CORN SILAGE (tons)	336.00	336.00
STORE CORN GRAIN (bu)	3,837.08	3,449.08
STORE HAY (tons)	0.00	75.56
STORE RYE (tons)	255.60	255.60
LABOR1 (hrs)	771.53	769.20
LABOR2 (hrs)	455.79	465.76
LABOR3 (hrs)	603.70	634.74
LABOR4 (hrs)	940.92	945.46
DAIRY COWS (head)	60.00	60.00
MTN4 (lbs/N)	4,091.24	4,091.24
SPREAD MANURE (gallons)	340,800.00	340,800.00
TAX WRITEOFF ($)	822.27	822.27
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	2,910.38	2,910.38
BORR15 ($)	16,825.00	16,825.00

[a]Medium site preparation costs of $8,000 are assumed.

TABLE 5.16b. SIMULATED NITRATE LOADINGS IN THE SMALL REPRESENTATIVE FARM MODEL, CORRECTIVE TAX ON COMMERCIAL FERTILIZER WITH COST SHARING. ALFALFA NITROGEN CREDIT ALLOWED. (Average over 1966-85 simulation period)

	.13 Tax		.28 Tax		
	Acres	NO_3 Losses (lbs.)	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs)
CORN SILAGE/NT	19.76	403.38	19.76	403.38	20.41
CORN GRAIN/NT	31.35	639.92	31.35	639.92	20.41
CORN GRAIN/CONV	3.88	47.41	0.00	0.00	12.22
ALFALFA	0.00	0.00	3.88	0.00	0.00
PASTURE	25.00	0.00	25.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		1,090.72		1,043.31	

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Restrictions on Nitrate Loading: The Chance Constraint Revisited

As noted in the previous chapters, agricultural nonpoint pollution is inherently stochastic. The average nitrate losses per acre presented in the representative farm model runs were subject to a high degree of variation over the 20 year CREAMS simulation. This loading uncertainty was incorporated in the model through use of the chance-constrained programming technique used for the silage production activity.

Two confidence interval levels were chosen to apply the chance constraint, 80 and 90 percent. Two levels of reduction from current nitrate loadings (assumed to be equal to the baseline values of 2,681 pounds for the large farm and 1,678 for the small farm) were chosen, 20 percent and 40 percent.

The 20 Percent Reduction Level

Results of the specified reductions in nitrate loadings for the large farm model are presented in table 5.17a. The large farm model achieves the mandated reductions by adopting 120 day storage (to eliminate pasture spreading) and essentially eliminating the corn grain/conventional till activity, continuing to feed the dairy herd a silage-based ration and purchasing most of the required corn grain. The nitrate loading constraint also results in the idling of 33 acres. Other crop production activities and methods are unchanged from the conventional practice runs for 120 day storage. Although the chance constraint will insure that the required 20 percent reduction is only violated about 20 percent of the time, average loadings over the period

TABLE 5.17a. RESULTS OF THE LARGE (NA) REPRESENTATIVE FARM MODEL, 20 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVELS.

	Reliability Level 80%	90%
Net Returns[a]	$54,647.59	$54,206.80
Activity	**Level**	**Level**
TOTAL ACRES	200.00	200.00
DAIRY COWS (head)	100.00	100.00
CORN SILAGE/NO TILL (acres)	37.76	0.00
CORN GRAIN/NO TILL (acres)	26.15	19.31
CORN GRAIN/CONV TILL (acres)	3.30	0.00
CORN SILAGE1/NO TILL (150)(acres)	0.00	43.38
CORN GRAIN1/NO TILL (150)(acres)	0.00	1.23
ALFALFA (acres)	15.92	15.92
PASTURE (acres)	85.00	85.00
BUY CORN GRAIN (bu)	7,470.42	8,435.85
BUY N FERTILIZER (lbs)	4,179.17	2,956.56
SELL CALVES (head)	39.00	39.00
SELL CULLS (head)	33.80	33.80
SELL MILK (cwt)	16,000.00	16,000.00
STORE CORN SILAGE (tons)	642.00	642.00
STORE CORN GRAIN (bu)	3,207.58	2,242.15
STORE HAY (tons)	79.60	79.60
STORE RYE (tons)	319.60	319.60
LABOR1 (hrs)	2,124.98	2,123.00
LABOR2 (hrs)	1,212.25	1,207.52
LABOR3 (hrs)	1,776.86	1,776.82
LABOR4 (hrs)	2,139.57	2,130.22
MTN4 (lbs)	6,818.73	6,818.73
SPREAD MANURE (gallons)	568,000.00	568,000.00
TAX WRITEOFF ($)	1,575.31	1,575.31
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	4,850.57	4,850.57
BORR15 ($)	30,042.46	30,042.46

[a]Medium site preparation costs of $8,000 are assumed.

TABLE 5.17b. SIMULATED NITRATE LOADINGS IN THE LARGE REPRESENTATIVE FARM MODEL, 20 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVEL.

	Reliability Level 80%		90%		
	Acres	NO_3 Losses (lbs)	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs.)
CORN SILAGE/NT	37.76	770.74	0.00	0.00	20.41
CORN GRAIN/NT	26.15	533.80	19.31	394.18	20.41
CORN GRAIN/CONV	3.30	40.32	0.00	20.17	12.22
CORN SILAGE1/NT	0.00	0.00	43.38	713.40	16.45
CORN GRAIN1/NT	0.00	0.00	1.23	394.18	16.45
ALFALFA	15.92	0.00	15.92	20.18	0.00
PASTURE	85.00	0.00	85.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		1,344.86			1,127.75

are reduced by substantially more than 20 percent, about 50 percent (table 5.17b).

When the chance constraint is tightened to the 90 percent level, net returns are reduced by about $1,400 from the 80 percent chance constraint. Although 120 day storage is still adopted, 45 acres of low nitrogen no-till corn are now produced to supplement the 19 acres of normal no-till corn. Nearly 1,000 more bushels of corn grain are also purchased to offset the drop in on-farm production caused by the nitrate loading constraint. Finally, 36 acres of cropland are idled since no nitrogen can be used to raise any feed ration crops, and alfalfa selling is not permitted in the model.

The 20 percent nitrate loading reduction (at the 80 percent confidence interval) has the effect of causing the small farm model to idle about 10 acres of cropland (table 5.18a). About five acres of alfalfa for feed are grown (as opposed to none in the unconstrained small farm model) to take advantage of the fact that alfalfa needs no nitrogen application. Finally, the farm model opts for 120 day storage to take full advantage of manure nitrogen.

When the constraint is tightened to the 90 percent level, corn production practices are unchanged except that five fewer acres are grown, with alfalfa production increasing to about eight acres. Commercial nitrogen purchases decrease by more than 1,100 pounds, and 700 additional bushels of corn grain for feed are purchased. Net returns over variable costs are reduced by about $700. Increasing the constraint tightness also increases the number of idled acres to 12.

TABLE 5.18a. RESULTS OF THE SMALL (NA) REPRESENTATIVE FARM MODEL, 20 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVELS.

	Reliability Level	
	80%	90%
Net Returns[a]	$37,857.10	$36,866.53
Activity	**Level**	**Level**
TOTAL ACRES (acres)	80.00	80.00
CORN SILAGE/NO TILL (acres)	19.76	19.76
CORN GRAIN/NO TILL (acres)	21.62	14.96
ALFALFA (acres)	4.87	8.19
PASTURE (acres)	25.00	25.00
BUY CORN GRAIN (bu)	2,721.74	3,453.92
BUY N FERTILIZER (lbs)	2,883.42	1,710.26
SELL CALF (head)	39.00	39.00
SELL CULL (head)	33.80	33.80
SELL MILK (cwt)	16,000.00	16,000.00
STORE CORN SILAGE (tons)	336.00	336.00
STORE CORN GRAIN (bu)	2,378.26	1,646.08
STORE HAY (tons)	24.34	40.98
STORE RYE (tons)	206.93	173.64
LABOR1 (hrs)	769.20	769.20
LABOR2 (hrs)	450.24	450.24
LABOR3 (hrs)	642.64	669.26
LABOR4 (hrs)	893.43	868.47
DAIRY COWS (head)	60.00	60.00
MTN4 (lbs/N)	4,091.24	4,091.24
SPREAD MANURE (gallons)	340,800.00	340,800.00
TAX WRITEOFF ($)	882.27	882.27
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	2,910.38	2,910.38
BORR15 ($)	16,825.48	16,825.48

[a]Medium site preparation costs of $8,000 are assumed.

TABLE 5.18b. SIMULATED NITRATE LOADINGS IN THE SMALL REPRESENTATIVE FARM MODEL, 20 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVEL.

	Reliability Level 80%		Reliability Level 90%		
	Acres	NO_3 Losses (lbs)	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs.)
CORN SILAGE/NT	19.76	403.38	19.76	403.38	20.41
CORN GRAIN/NT	21.62	441.26	14.96	305.40	20.41
ALFALFA	4.87	0.00	4.87	0.00	0.00
PASTURE	25.00	0.00	25.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		844.647		708.784	

Source: CREAMS Nutrient Simulations, Rockingham County, Virginia (Heatwole, 1988).

The 40 Percent Nitrate Reduction Level

Decreasing allowable nitrate loadings to ground water to 60 percent of assumed current loadings (that is, a 40 percent reduction) decreases net returns in the large farm model to $52,714 when the 80 percent level confidence interval is specified (table 5.19a). Both dairy rations and corn production processes are altered to meet the constraint. Although the herd size is maintained at 100 milking cows, about 2.27 percent of the ration is shifted from corn silage base to alfalfa-corn grain base. About 62 acres of corn are produced using reduced nitrogen practices, and 18 acres of alfalfa are grown, with the remainder of the cropland idled. Corn grain purchases increase to 9,096 bushels, while purchases of commercial fertilizer are reduced to 2,122 pounds (this compares to 11,504 pounds in the original, unconstrained [no storage] large farm model). The 120 day storage plan is again adopted.

Mandating that this 40 percent reduction be met within the 90 percent confidence interval substantially reduces net returns by over $7,000 to $48,397. About 18 percent of the herd feed ration must now be supplied by alfalfa-grain to offset reduced on-farm corn production. Only 51 acres of no-till corn are produced, all using low nitrogen methods, and alfalfa production is increased to nearly 35 acres to supply additional feed. Commercial nitrogen purchases total only 432 pounds, and virtually all of the dairy ration corn grain is purchased off farm (on farm grain production is represented by the store corn grain activity).

TABLE 5.19a. RESULTS OF THE LARGE (NA) REPRESENTATIVE FARM MODEL, 40 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVELS.

	Reliability Level	
	80%	90%
Net Returns[a]	$52,714.44	$48,397.36
Activity	**Level**	**Level**
TOTAL ACRES	200.00	200.00
CORN SILAGE1/NO TILL (150)(acres)	42.39	35.53
CORN GRAIN1/NO TILL (150)(acres)	20.07	0.00
CORN GRAIN2/NO TILL (140)(acres)	0.00	16.82
ALFALFA (acres)	18.27	34.65
PASTURE (acres)	85.00	85.00
BUY CORN GRAIN (bu)	9,086.08	10,740.27
BUY N FERTILIZER (lbs)	2,122.07	432.31
SELL CALF (head)	39.00	39.00
SELL CULL (head)	33.80	33.80
SELL MILK (cwt)	16,000.00	16,000.00
STORE CORN SILAGE (tons)	627.41	525.79
STORE CORN GRAIN (bu)	1,776.63	1,488.87
STORE HAY (tons)	91.36	173.26
STORE RYE (tons)	312.34	261.75
LABOR1 (hrs)	2,123.00	2,123.00
LABOR2 (hrs)	1,214.02	1,207.52
LABOR3 (hrs)	1,795.67	1,776.86
LABOR4 (hrs)	2,131.27	2,138.61
DAIRY COWS (SILAGE)(head)	97.73	81.90
DAIRY COWS (ALFALFA/CORN)(head)	2.27	18.10
MTN4 (lbs)	6,818.73	6,818.73
SPREAD MANURE (gallons)	568,000.00	568,000.00
TAX WRITEOFF ($)	1,575.31	1,575.31
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	4,850.57	4,850.57
BORR15 ($)	30,042.46	30,042.46

[a]Medium site preparation costs of $8,000 are assumed.

TABLE 5.19b. SIMULATED NITRATE LOADINGS IN THE LARGE REPRESENTATIVE FARM MODEL, 40 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVEL.

	Reliability Level				
	80%		90%		
	Acres (lbs.)	NO_3 Losses	Acres	NO_3 Losses (lbs.)	Avg Loading Per Acre (lbs.)
CORN SILAGE1/NT	43.39	713.64	35.53	521.63	14.68
CORN GRAIN2/NT	20.07	307.99	16.82	228.22	13.57
ALFALFA	18.27	0.00	34.65	0.00	0.00
PASTURE	85.00	0.00	85.00	0.00	0.00

TOTAL NO_3 LEACHED (lbs) 1,021.63 749.85

Source: CREAMS Nutrient Simulations, Rockingham County, Virginia (Heatwole, 1988)

The results of the 40 percent reduction/90 percent confidence interval for the large farm are very similar to those of the outright ban on commercial fertilizer purchase illustrated in table 5.13a. The principal difference is that the chance constraint allows the purchase of a small amount of nitrogen, which thus allows a slightly larger percentage of the herd to be fed on the less expensive silage ration. However, if it can be assumed that there are few commercial nitrogen substitutes, these results seem to indicate that a ban on commercial fertilizer would achieve a 40 percent reduction in nitrate loading within a slightly less than 90 percent confidence interval (or alternatively, a slightly less than 40 percent loading reduction within the 90 percent interval).

Impacts of the 40 percent nitrate loading reduction (80 percent confidence interval) on the small farm are financially quite drastic (table 5.20a). Net returns are now only $36,456, and 14 acres of cropland are idled.[10] About 13 acres of no till corn silage are produced using low nitrogen practices. Unlike the large farm, the small farm model is still able to maintain its entire milking herd on the silage based ration; about nine acres of alfalfa are grown for feed under this scenario.

When the constraint is tightened to the 90 percent level, net returns are reduced to $35,574. About 2.5 percent of the dairy herd ration is shifted to alfalfa-corn. All corn grown on farm (about 23 acres) is produced using low nitrogen practices, and alfalfa production is increased to about 10 acres to reflect the new feed ration demand.

TABLE 5.20a. RESULTS OF THE SMALL (NA) REPRESENTATIVE FARM MODEL, 40 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVELS.

	Reliability Level 80%	90%
Net Returns[a]	$36,455.82	$35,574.96
Activity	**Level**	**Level**
TOTAL ACRES	80.00	80.00
CORN SILAGE1/NO TILL (150)(acres)	13.41	22.14
CORN GRAIN/NO TILL (acres)	12.10	0.00
CORN GRAIN2/NO TILL (140)(acres)	0.00	10.63
CORN SILAGE/NO TILL (acres)	8.09	0.00
ALFALFA (acres)	8.76	9.95
PASTURE (acres)	25.00	25.00
BUY CORN GRAIN (bu)	3,768.97	4,259.08
BUY N FERTILIZER (lbs)	1,243.12	593.51
SELL CALVES (head)	39.00	39.00
SELL CULLS (head)	33.80	33.80
SELL MILK (cwt)	16,000.00	16,000.00
STORE CORN SILAGE (tons)	336.00	327.69
STORE CORN GRAIN (bu)	1,331.03	940.56
STORE HAY (tons)	43.80	49.75
STORE RYE (tons)	168.00	163.85
LABOR1 (hrs)	769.20	769.20
LABOR2 (hrs)	450.24	453.34
LABOR3 (hrs)	673.78	683.30
LABOR4 (hrs)	864.24	864.22
DAIRY COWS (SILAGE)(head)	60.00	58.52
DAIRY COWS (ALFALFA/CORN)(head)	0.00	1.48
MTN4 (lbs)	4,091.24	4,091.24
SPREAD MANURE (gallons)	340,800.00	340,800.00
TAX WRITEOFF ($)	882.27	882.27
COST SHARING ($)	1,822.00	1,822.00
BUY 120 DAY STORAGE ($)	2,910.38	2,910.38
BORR15 ($)	16,825.48	16,825.48

[a]Medium site preparation costs of $8,000 are assumed.

TABLE 5.20b. SIMULATED NITRATE LOADINGS IN THE SMALL REPRESENTATIVE FARM MODEL, 40 PERCENT REDUCTION IN NITRATE LOADING WITH 80 AND 90 PERCENT CHANCE CONSTRAINT LEVELS.

	Reliability Level 80%		90%		
	Acres	NO_3 Losses	Acres	NO_3 Losses	Avg Loading Per Acre
CORN SILAGE/NT	8.09	165.17	0.00	0.00	20.41
CORN GRAIN/NT	12.10	246.95	0.00	0.00	20.41
CORN SILAGE1/NT	13.41	220.49	22.14	364.13	16.45
CORN GRAIN2/NT	0.00	0.00	10.63	163.05	15.34
ALFALFA	8.76	0.00	9.95	0.00	0.00
PASTURE	25.00	0.00	25.00	0.00	0.00
TOTAL NO_3 LEACHED (lbs)		632.61		527.19	

Source: CREAMS Nutrient Simulations, Rockingham County, Virginia (Heatwole, 1988)

Fertilizer purchases drop to about 593 pounds; like the large farm model, virtually all of the dairy herd corn grain requirements are purchased off farm. Average nitrate loadings are reduced to only 527 pounds, which represents nearly a 70 percent reduction in a typical year. The difference between this figure and the 40 percent reduction that is mandated via the chance constraint highlights the effect of the variability of nitrate loading from year to year, and gives an estimate of the costs of minimizing violations of a proposed ground water nitrate standard.

The explicit cost of imposing the 80 and 90 percent confidence intervals of the chance constraint can be seen by comparing tables 5.19 and 5.20 with results of the large and small farm models constrained to 120 day storage (tables 5.3 and 5.4), since these tables approximately represent a 40 percent decrease in average nitrate loadings; average loadings are essentially equivalent to a chance constraint met within the 50 percent confidence interval. For the 90 percent confidence interval, the difference in net returns between the chance constrained and average loading reduction models is equal to $4,500 annually for the large farm and about $3,500 annually for the small farm, or a reduction of about 8-9 percent.

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Other Policies: Herd Reduction

The lower limit on herd size was initially specified as an economic "break even point" for the dairy farm; that is, below this limit, the farmer could achieve greater returns to his capital elsewhere, and would shut down his dairy operation. At this point, he could liquidate much of his physical capital and sell his cows and milk base. However, the policies considered had the effect of changing crop mixes and dairy rations rather than lowering total herd size, so that this lower limit and shut down point were never an issue.

If nitrate loadings were constrained to the point that the manure nitrate alone from the 100 cow herd violated the imposed loading standard, herd size may have to be reduced to meet the standard (essentially source reduction). The threshold nitrate reduction level at which actual herd reduction occurred was identified through sensitivity analyses to be 47 percent for both the large and small farm models (at the 90 percent confidence interval; at the 50 percent confidence interval, this would translate into an average reduction of about 75 percent). Therefore, reductions in nitrate loading of nearly one-half would have to be imposed before reductions in herd size occurred. Thus, although the model is allowed to vary herd size as part of its optimization process, the upper bound was consistently chosen except in the face of environmental constraints which are violated by spreading manure (and no commercial fertilizer) on cropland. This behavioral phenomenon is consistent with expert opinion on dairy farm operations--that is, that the farmer's herd size will be principally limited by his physical plant (Groover, 1988; Stallings, 1988; McDowell, 1988).

This threshold level may not hold if substitute disposal activities are available, however. For example, manure spread on alfalfa would not result in nitrate loading problems, although weed problems may occur. A second alternative may be hauling the manure to manure-poor areas of the state. In any case, it can reasonably be assumed that except in the case of extremely constraining nitrate management policies, dairy farmers will choose other loading reduction options (such as growing alfalfa and purchasing corn grain) than herd size reduction.

Cropping Alternatives: Taking Advantage of "Idled Acreage"

Many of the scenarios presented in the preceding sections resulted in ground water quality improvements being achieved at the expense of decreased net returns and idled acreage. The alfalfa selling activity demonstrated how this idled acreage could be turned into revenue producing land should a market develop for alfalfa hay. A second alternative would be to devote part of this surplus acreage to specialty crops. One example of such a specialty crop, strawberries, was built into the model.

When the large farm model was provided with the opportunity to grow two acres of PYO strawberries under the no commercial fertilizer policy scenario, net returns increased about 4.5 percent from $47,293 to $49,422. Cows fed on the alfalfa-corn grain ration increased from 22.2 to 23.1 (about four percent), as the model shifted some of its available manure N from corn production to strawberry production.

Although nitrogen applications for strawberries are relatively low, CREAMS results indicated that nitrate loadings to ground water were quite high--34.6 pounds per acre per year over the 20 year simulation period (the standard deviation for nitrate loading was 30.2).[11] These high loadings were probably due to the fact that very little nitrogen is tied up in the strawberry plant itself, as opposed to the more substantial amounts of nitrogen contained in corn stover. Total average loadings for the no commercial fertilizer-strawberry scenario were 859.5 lbs., an increase of about 7.4 percent over the no commercial fertilizer-no strawberry scenario. Therefore, based on this limited information, strawberries may not be a desirable revenue producing alternative from a ground water quality standpoint. This information also indicates that restricting county farmers' silage production capabilities to the point where other revenue producing activities are more actively sought may result in adoption of crops which are more damaging to ground water quality than corn (on a per acre basis, that is; total nitrate loadings of 860 lbs. are still far below the starting [baseline/no storage] point of 2,681 lbs.).

SUMMARY

This chapter described the nature of dairy operations and nitrate loading to ground water in Rockingham County, through simulation of typical current agricultural and hydrological situations with the representative farm mathematical programming model and the CREAMS field scale physical model. A comparative summary of the model simulations run in this chapter is provided in table 6.1. Results of the representative farm models indicate that, based strictly on the criterion of net returns over variable costs, it is not profitable for a dairy farmer in the county to construct 120 or 180 day manure storage facilities. At the same time, the CREAMS model indicates that nitrate loadings to ground water are substantially higher for the no storage scenario than for either 120 or 180 day scenarios. The difference in average nitrate loading to ground water between 120 and 180 day scenarios was negligible. "Worst case" CREAMS simulations--that is, applying large amounts of manure nitrogen without considering its nutrient value--of higher than agronomically recommended fertilization rates of corn acreage (using nitrogen application values consistent with many county farmers' practices) resulted in increased nitrate loadings of from two to three hundred percent over those resulting from the use of "optimal" nutrient management practices as indicated by the representative farm model. CREAMS simulations indicate that as few as one-third of responding farmers may be responsible for as much as 60 percent of total nitrate loadings (from county dairy farms) to ground water.

Three policies which were designed to induce manure storage construction and better nutrient management practices were examined: corrective taxation, regulation, and cost sharing. Model results indicated that the price of commercial nitrogen would have to be increased by from three to four hundred percent before manure storage would be constructed voluntarily. Regulation of nutrient management practices (by mandating that storage facilities be constructed) would result in substantial reductions in net returns, without the leverage for promoting nutrient management planning provided by cost sharing. Cost sharing has the effect of narrowing the gap between net returns with no storage and net returns with 120 days storage in the model. Provision of cost sharing seems to be having the desired effect of encouraging adoption of storage facilities in the county, possibly due to the non-market benefits provided by manure use in addition to its nutrient values. Cost sharing has the disadvantage of not providing any influence on Mennonite farms in the county since these farms do not participate in government sponsored programs; however, the low interest loans often provided within the church are similar in outcome to cost sharing (Groover, 1988).

This chapter also demonstrated that a wide range of potential alternatives are available for reducing nitrate contamination of ground water. In addition to the nutrient management and storage options considered, both farmers' practices and the underlying structure of county agriculture could change in response to public demands for lower nitrate concentrations in ground water.

The policy which is closest to those currently in practice is a combination of cost sharing and corrective taxation. This policy has the advantage of spreading the cost of the substantial nitrate loading reduction among several different economic entities. Consideration of the 60 day manure storage system revealed that, while reductions in nitrate loading were achieved (compared to no storage plans), the achievable loading reductions may be too small to make this a viable consideration as a ground water policy option. The 60 day storage plan represents less of a reduction in net returns to the farmer than the 120 day system; however, nitrate loading reductions of only about 6-7 percent are obtained under this system.

Other policy options considered would require important shifts in current agricultural practices, redefinition of ground water quality property rights, or both. Shifts to alternative feed production methods would require either substantial restructuring of farmers' thinking or major economic disincentives (such as the nitrogen ban) before they would be likely to occur. However, these policies would substantially reduce nitrate loadings in the absence of close substitutes for commercial nitrogen, and could also have the added benefit of helping to solve the poultry litter disposal problem. It was shown that shifting dairy feed rations from silage to alfalfa-corn grain was a viable means of achieving ground water quality objectives while maintaining profitability. The alfalfa-barley dairy feed alternative never entered the solution, as it was more expensive than either the silage or the alfalfa-corn grain ration and offered no nitrate management benefits.

If stricter water quality measures were imposed so that production and herd ration practices changed and cropland was idled, it is possible that alternative agricultural sources of revenue could be found. Available evidence seems to indicate that county farmers could diversify into alfalfa production for sale. This option would require changes in the currently underdeveloped alfalfa market structure in the area, such as establishment of marketing and distribution channels. Individual farmers could also devote part of their acreage to specialty crops; although strawberries were chosen as an example of such a practice, this option could conceivably include other specialty crops, such as other small fruits and vegetables. However, CREAMS simulations and the type of pesticides used indicate that there may not be any environmental quality improvements gained by converting acreage from row crops to horticultural crops, except that horticultural crops may provide a higher return per acre than row crops, resulting in less acreage cultivated.

Finally, the chance constraint demonstrated the nitrate loading reductions that would have to be achieved on average to minimize loading constraint violations. The analysis demonstrated that the higher the standard deviation of mean loadings, the more limiting the reductions in average nitrate loading levels to assure compliance within the given confidence interval. It is interesting to note that the strictest chance constraint, which required that 40 percent loading reductions be achieved 90 percent of the time, provoked the same basic response from the farm model as the commercial fertilizer ban.

CHAPTER VI

CONCLUSIONS AND IMPLICATIONS OF THE ROCKINGHAM COUNTY STUDY

Introduction

The results of the survey analyses, conventional practice and nontraditional alternative mathematical programming models can provide useful information to decision makers about the effect on ground water quality of alternative management strategies. This chapter analyzes the implications of the results provided in chapters three and five, and discusses the broader implications of the Rockingham County study.

The first section discusses the results of the mathematical programming model, in particular the effects on net returns of various policy options, the effects on nitrate loading of these actions, and the relative efficiencies of these policies in terms of impacts on environmental quality and net returns. The second section examines the relevance of some of the survey results and the logit analysis. The third section examines some of the distributional effects of the proposed nitrate loading reduction policies on area farmers, the non-farm public, and the fertilizer industry. These impacts are incorporated into a fiscal impact model to determine the overall effect of the policies on the region's economy. The fourth section discusses how the results of the Rockingham County can be generalized to other regions of the country. The fifth section points out some of the limitations of the approach used.

Specific implications of the Rockingham County study are then presented, including the possible failure of options which provide only the currently provided cost sharing for manure storage to improve the ground water situation and incentives to promote better nutrient management. Effectiveness of the current efforts to achieve water quality improvement and the potential for additional nitrate loading reduction are examined. The final section discusses the conclusions and limitations of the study, the usefulness of study results, and the need for further research.

IMPLICATIONS OF THE MATHEMATICAL PROGRAMMING MODEL FOR GROUND WATER MANAGEMENT POLICY

Results of the representative farm models demonstrate that, in the absence of other economic or nonmonetary incentives, the profit maximizing farmer will choose not to construct manure storage facilities. From a water quality standpoint this means that, even with optimal nutrient management for his dairy operation, he will be forced to dispose of much of his manure on pasture land, resulting in nitrate losses to surface and ground water in excess of losses which would result if manure storage facilities were constructed and used properly. Total losses of nitrate to ground water of the unconstrained (conventional practice/no storage) large representative farm averaged 2,682 pounds per year, compared to losses of 1,623 pounds under the 120 day storage regime and 1,592 pounds under the 180 day storage framework. For the small farm model, no storage nitrate losses averaged 1,678 pounds, 120 day storage losses averaged 1,091 pounds, and 180 day storage losses averaged 1,077 pounds per year. Total loadings are thus considerably higher on average over the 20 year simulation period for the no storage option than for either of the storage options. Additional policy measures were shown to have the effect of reducing nitrate loadings even further, to a minimum of 800 lbs. loaded to ground water under the scenario of no commercial nitrogen sold.

OVERVIEW: COSTS AND NITRATE LOADING REDUCTIONS OF ALTERNATIVE POLICY APPROACHES

The policy approaches discussed in this dissertation illustrate a variety of ways in which nitrate reduction could be achieved, at a variety of costs. Table 6.1 highlights these differences. Policies restricting the pasture to herd ratio for the no manure storage scenario are not illustrated in table 6.1 as they would result in loadings identical to the 120 day storage scenario when the threshold limits of .93 and .48 acres per cow are imposed for the large and small farm models, respectively and so can be considered analogous to the 120 day storage scenario. For simplicity, the alfalfa selling scenarios are omitted from this discussion; however, these scenarios represent a potentially viable long run option for Virginia farmers, and need to be considered in policy decisions which could substantially impact the status quo. These scenarios could be included here without loss of generality, with the result that farm model net returns would be slightly higher (about 3 - 5 percent) in all cases.

Policy results simulated by the mathematical programming model in table 6.1 represent the embodiment of the theoretical bases outlined in chapter two. The taxation scenarios are essentially corrective or Pigouvian taxation; the options of mandated storage construction and

TABLE 6.1. COMPARISON OF SELECTED FEATURES OF POLICY SCENARIOS TO REDUCE NITRATE LOADINGS TO GROUND WATER, ROCKINGHAM COUNTY, VIRGINIA (LARGE FARM MODEL).

Scenario	Annual Net Returns ($)	Nitrate Loadings (lbs)	Loading Reduction (pct)	Cost Sharing[a] ($)	Annual Tax Revenues ($)
NO STORAGE	$55,407	2,681	--	0	0
60 DAY	$54,604	2,485	7.3	0	0
120 DAY	$54,500	1,623	39.5	11,000	0
TAX/CS	$53,380	1,623	39.5	11,000	1,178
180 DAY	$53,305	1,591	40.7	11,000	0
TAX	$49,944	1,623	39.5	0	3,461
N BAN (with strawberries)	$49,422	859	68.0	11,000	0
N BAN (no strawberries)	$47,293	801	70.1	11,000	0
LOADING RESTRICTIONS[b]					
20 percent reduction		2,145		11,000	0
80%	$55,647				
90%	$54,206				
40 percent reduction		1,609		11,000	0
80%	$52,714				
90%	$48,397				

[a]This is the one-time outlay for cost sharing; net present annual value of this cost sharing over the 15 year facility life is approximately $1,822 (see footnote 2).

[b]These restricted loadings will be achieved within the given confidence intervals; all other loadings will only be achieved 50 percent of the time.

bans on nitrogen purchases define the property rights to water quality (and place the onus on the farmer to protect it); the chance constraint applications represent what might occur if a standard were enforceable; and the cost sharing options represent what Pigou called "extraordinary encouragement" to improve ground water quality by changing management practices.

One of the major drawbacks of this study is the lack of a target level of nitrate loading to achieve under Rockingham County farmland. In the absence of such a standard, a possible role of analysis is to provide the policy maker with a range of options to achieve different levels of nitrate loading reduction. The situation facing the policy maker can be viewed as the trading off of lower net returns and higher regulatory and cost sharing expenditures for lower nitrate concentrations in percolation water leaving cropland.

Table 6.1 illustrates this point. For the large farm,[1] average nitrate loadings can be reduced from 2,681 pounds to 801 pounds, a decrease of over 70 percent. However, this reduction in nitrate loading imposes a loss in the farmer's net returns of $8,115, or about 15 percent. In addition, cost sharing of $11,000 through federal and state agencies is expended. Table 6.1 presents a continuum of nitrate reduction levels (from about 2,700 to about 800 pounds) with their corresponding costs, and represents a "menu" of choices to the policy maker. When the assumption is made that the county's agricultural sector will adapt to encompass other revenue producing activities, the impacts of nitrate loading reduction policies on the model's net returns over variable costs are softened considerably. For the strawberry production scenario, nitrate loadings increase slightly due to the high per acre nitrate loading of strawberries (relative to corn).

Choice of Nitrate Loading Reduction Strategy

Comparisons of the policies in table 6.1 can be made on the basis of dollars expended per pound of nitrate loading reduction achieved. Total costs of these policies, total pounds of nitrate loading reduction (below the no storage scenario), and average cost per pound of nitrate loading reduced are shown in table 6.2. The specific assumption made in these calculations is that the no storage scenario represents the status quo, and that total cost to society of reduction is equal to losses in net returns (from the no storage results) plus an annual estimate of cost sharing expenditures[2] minus revenues from corrective taxes, to reflect the fact that these taxes simply represent a transfer from society's viewpoint.

As table 6.2 indicates, the 120 day storage option with cost sharing is the least expensive on a per pound basis, with the 180 day storage option nearly 50 percent more expensive on a per pound basis. The tax option is slightly less expensive in total than the tax-cost sharing option, although the effects on farmers' net returns are greater when no cost sharing is provided. The pure tax strategy thus seems to dominate the tax-cost sharing strategy from a total cost standpoint. However, the tax-cost sharing strategy spreads the program cost among several different groups, which may be politically attractive, while the pure tax strategy may be politically unacceptable.

TABLE 6.2. TOTAL NITRATE LOADING REDUCTION ACHIEVED, TOTAL COST OF REDUCTION,[a] AND COST PER POUND OF NITRATE LOADING REDUCED, ROCKINGHAM COUNTY, VIRGINIA (LARGE FARM MODEL).

Scenario	**Total Cost ($)**	**Nitrate Loading Reduction (lbs)**	**Cost ($ per lb)**
NO STORAGE	-	-	-
120 DAY/CS	$2,530	1,058	2.57
180 DAY/CS	$3,760	1,090	3.62
60 DAY STORAGE[b]	$803	196	4.10
TAX	$5,147	1,150	4.48
TAX/CS	$5,597	1,150	5.03
N BAN (with strawberries)	$10,733	1,914	5.71
N BAN (no strawberries)	$12,862	1,856	7.03
LOADING RESTRICTIONS[c]			
20 percent reduction			
80%	$4,538	628	7.53
90%	$5,979	628	9.82
40 percent reduction			
80%	$7,471	1,072	7.15
90%	$11,788	1,072	11.18

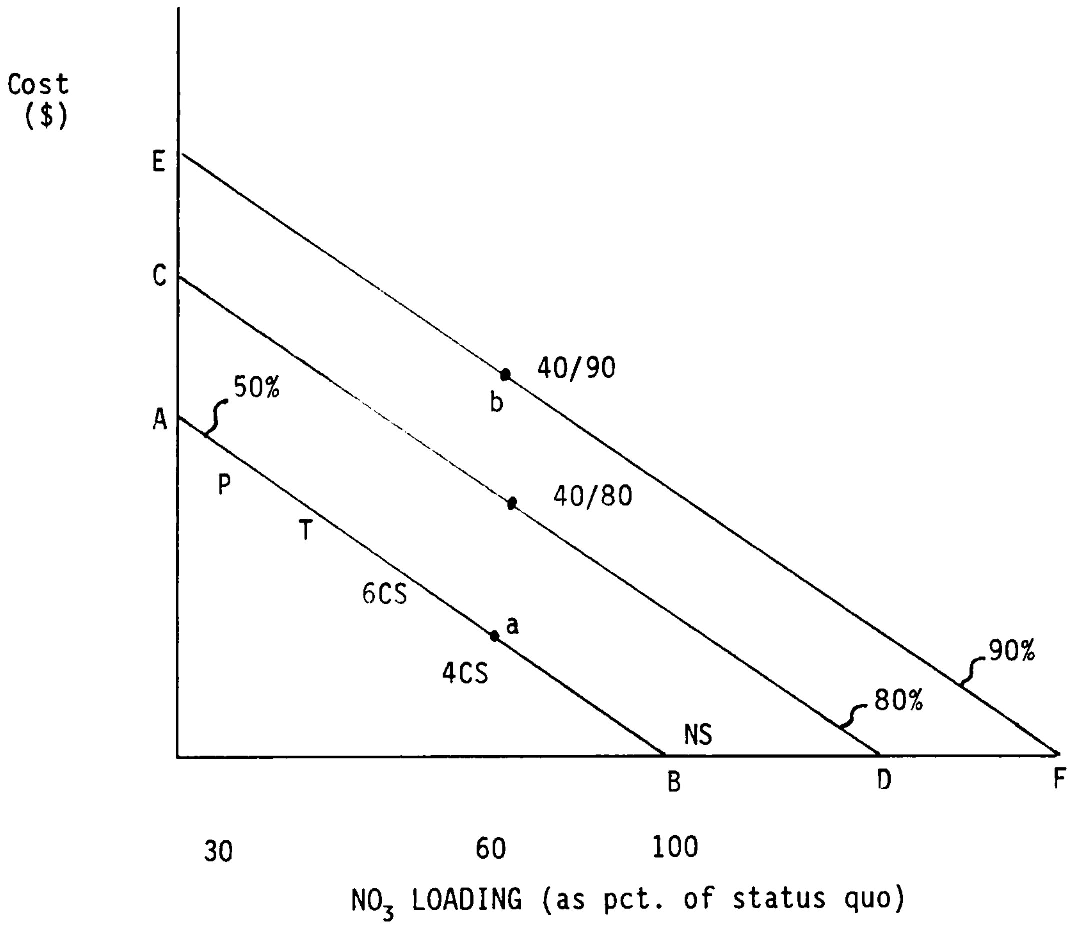
[a]As measured by losses in farm net returns plus cost sharing expenditures less tax revenue.
[b]No cost sharing is provided for the 60 day storage facility; the total cost figure represents the reduction in net returns from constructing the facility.
[c]These restricted loadings will be achieved within the given confidence intervals; all other loadings will only be achieved 50 percent of the time.

Examining the other strategy costs, one sees a tradeoff of increased costs for nitrate loading reduction. The 120 and 180 day storage options with cost sharing are similar in terms of total cost, total nitrate reduction, and cost per pound of nitrate reduced. The 60 day storage facility has the least impact on net returns of the three storage facilities considered; however, the relatively small reduction in nitrate loading gained under this option makes the per-pound reduction cost higher than either 120 or 180 day storage. The tax-cost sharing option is almost twice as expensive as the 120 day storage. The nitrate ban option is considerably more expensive than the other options in terms of both total cost and cost per pound of nitrate reduction achieved.

The chance constraint reductions are not directly comparable to the other strategies, since these reductions are met a larger percentage of the time (30 to 40 percent more often). The difference between the per pound cost under the chance constraints and the other policy costs can be viewed as a risk "premium." For example, the tax/cost sharing option represents approximately a 40 percent reduction in nitrate loadings, just as the 90 percent level chance constraint does, but the cost per pound is only $5.03 (compared to $11.18 under the chance constraint). The extra $6.15 per pound is thus sort of an "insurance" payment to guard against violation of the loading constraint, and is one way of representing the cost of managing a stochastic contaminant in the policy process.

As these cost differences indicate, incorporation of the variability in nitrate loading can add considerable cost to the chosen policy strategy. The chance constraint will consider loading variability when mandating that the desired loading constraint be met; in reality, however, the level of nitrate loading reduction will be substantially greater (on average) than the reductions gained with constraints on average loading, so that the level of water quality enjoyed under the chance constraints will actually be much higher.

Viewing the economic-environmental tradeoffs within a graphical framework illustrates the effect of this uncertainty on policy decisions (figure 6.1). Consider the curve AB to be the tradeoffs between policy costs and average nitrate loading reduction percentages. Alternative policies are arranged along this curve (cost-reduction relationships are only approximated to provide a more readable graph, although the actual cost relationships could be represented without loss of generality; similarly, the vertical distance between the two curves would be a function of the cost incurred when the loading variability is considered; this distance corresponds to the premium or insurance payment which separates the chance constraint policies from the other policies. For example, ab represents the difference in cost of about \$9,300 between the cost sharing (120 days storage) strategy and 40 percent reduction (90 percent confidence interval) scenarios. The graph thus represents the effect of loading uncertainty on policy cost; note that if the variability of nitrate loadings was zero (that is, the contaminant loadings were deterministic rather than stochastic), there would only be one curve (AB).



NS = no storage
T = pure taxation
4CS = cost sharing, 120 day storage
6CS = cost sharing, 180 day storage
P = no commercial nitrogen purchase allowed (prohibition)
20/80 = 20 percent reduction, 80 % confidence interval
20/90 = 20 percent reduction, 90 % confidence interval
40/80 = 40 percent reduction, 80 % confidence interval
40/90 = 40 percent reduction, 90 % confidence interval

FIGURE 6.1. POLICY COST-ENVIRONMENTAL QUALITY TRADEOFFS OF VARIOUS NITRATE LOADING REDUCTION POLICIES.

Feasibility of Policy Options Considered

At present, the encouragement of 120 or 180 day storage construction with approved nutrient management plans probably represents the preferred policy (judging by current policy efforts) in Rockingham County. However, the other policy options for reducing ground water contamination simulated by the model are all in practice in some form or another at either the local, state, or national regulatory level in Virginia or other states. For example, mandating construction and use of manure storage is akin to imposing facility design and operation requirements; this type of regulation is currently followed by the State of Nebraska, which requires that approved nitrification inhibitors be used with nitrogen applications in critical areas, and in California, where programs are in use to encourage substitution of less persistent, less mobile pesticides for persistent, leaching chemicals (Montague, 1988; NRC, 1986; Holden, 1986).

Similarly, the ban on the use of commercial nitrogen simulated in the nontraditional alternative model may seem extreme given current policy efforts in the county. However, bans have been imposed at the national level by the EPA for agricultural chemicals shown to have adverse health effects (such as the herbicide dinoseb) or a high potential for leaching (such as the insecticide chlordane). Several states have also banned specific agricultural chemicals (Holden, 1986). While nitrates are not as noxious as these pesticides, bans on nitrate loading might be effectively applied on a regional basis, such as over critical recharge areas; for example, Clarke County, Virginia has developed several county ordinances restricting fertilization around sinkhole areas (Clarke County, 1986, 1987). In another example of the "property rights" approach, the RIM (Reinvest in Minnesota) conservation reserve program provides funding for land retirement in a similar fashion to USDA's Conservation Reserve Program, but the program places greater emphasis on off-site water quality benefits (Bushwick, Brichford, and Brockway, 1987).

Although the chance constraint approach demonstrated problems with using a ground water standards approach, some states have used loading standards as a policy option to control nitrate contamination. For example, Nebraska bans fertilizer applications on sandy soils if ground water monitoring reveals that ground water nitrate concentrations are in a given critical range (Montague, 1988), while New Jersey has used a differential approach which sets a standard of 2 ppm under the sensitive Pine Barrens region, compared to a 10 ppm standard in other parts of the state (NAS, 1986). Thus, while cost sharing and education have been and may continue to be the principal means of protecting ground water quality in Rockingham County, the other approaches simulated in the model (demonstrated to reduce nitrate loadings to ground water substantially) have been successfully used in other states to protect ground water.

OPPORTUNITIES FOR IMPROVED NUTRIENT MANAGEMENT PRACTICES IN ROCKINGHAM COUNTY

Various options are available to policy makers to encourage or require that these adjustments to nutrient management practices be made.

However, survey results revealed two relevant issues which need to be considered in administering these programs.

Targeting Nonpoint Pollution Reduction Programs

The two-pronged program directed at manure storage and management in Rockingham County--cost sharing for storage facility construction and nutrient management education and planning--can provide the farmer with both the tools to make his manure nutrients available when he needs them and the information necessary to use these nutrients efficiently. The study results have direct implications for two aspects of this program. First, the survey found that provision of the manure storage facility (through cost sharing or other incentives) is not enough in itself to insure that nutrient management practices will be substantially improved. In this case, potentially achievable improvements in water quality may not be realized. Second, the logit analysis (and other statistical testing) of factors influencing the manure testing decision revealed that larger farms are more likely to use this testing service than small farms.

Based on comparison of responses to questions concerning application rates of commercial fertilizer, size of herd, and existing manure storage capacity, it was determined that a large amount of the corn acreage in Rockingham County is subject to high applications of nutrients. At the same time, many of these farmers who are applying high levels of nutrients maintain that they are taking credit for the nutrient value of their manure. Possible reasons for this practice have already been discussed; whatever the reasons, this information indicates that extension and other programs to improve nutrient management through increasing awareness of manure value, educating farmers on the negative consequences of application in excess of agronomic recommendations, and disseminating information on realistic yield goals are a necessary complement to cost sharing. It would seem that in order to obtain maximum results from state and federal subsidies for facility construction, additional efforts must be devoted to insuring that the facilities are used to their full potential.

Part of the current effort in Rockingham County aimed at promoting improved nutrient management practices includes the provision of manure testing services. Better information on actual nutrient value of dairy manure is assumed eventually to result in reduced use of commercial nitrogen and hence, a reduction in nitrate loadings to ground water. However, in response to the survey question on using manure testing services, small farmers were less likely than large farmers to use such a service if one were available. This finding has potentially negative implications for ground water quality since (according to CREAMS results) small farms account for between 22.2 and 22.5 percent of total average annual nitrate loadings.[3]

This substantial contribution of the small farm group to the nitrate contamination problem indicates that efforts such as the nutrient management program cannot afford to concentrate all of their resources on the larger farmers in the area. Additional efforts to encourage these small farmers to use the manure testing service could result in lower nitrate loadings to ground water. These small farm owners may not be interested in manure testing due to a perception that they have less to gain in terms of nutrient or time savings than large farms, or the perception that small farm owners may not be as efficient managers as large farm owners. Another possibility is that many of these small farms are owned and managed by Mennonite farmers who traditionally do not participate in government agricultural programs. If these farmers perceived manure testing as analogous to government programs such as cost sharing or price supports, they may be less likely to participate than other Rockingham County dairy farmers.[4]

Reducing Nitrate Contamination from High Appliers

As the survey results indicated, roughly one-third of county farmers fall in the category of high-appliers of nitrogen. While the CREAMS results demonstrate the adverse water quality effects of this form of management, the farmer also incurs higher input costs with no commensurate increases in yield. Simply encouraging these farmers to install manure storage facilities is not sufficient to rectify this problem. Therefore, consideration of methods to reduce nitrogen application rates of this group are needed to supplement the options already discussed. Actions to promote adoption of manure storage essentially provide the farmer with the basic "tools" for reaping the full nutrient benefits of his manure, while the measures discussed below either instruct or encourage (or force) the farmer to use these tools in his fertilizer input decisions.

The Potential for Voluntary Nitrogen Application Reduction

Approaches based on education have the advantages of few legal constraints and widespread political acceptability (Montague, 1988; Conservation Foundation, 1987). Educational programs aimed at improving agricultural practices which adversely affect ground water have been implemented in Wisconsin, Vermont, and Iowa, as well as Virginia (Holden, 1986; Henderson, Trauberman, and Gallagher, 1984).

Educational efforts aimed at fostering voluntary reductions of nitrogen application could take a variety of forms. For example, the Pennsylvania and Virginia approaches strongly encourage manure and litter testing as a means of better using animal waste nutrients, under the implicit assumption that better knowledge of nutrient value can reduce overall application rates. Provision of information on nutrient management benefits and technical assistance in designing these plans is valuable in promoting changes in management practices. Actual test plots displaying various rates of manure and commercial nitrogen application are useful as physical evidence of the yield and cost merits of reduced nitrogen application. In some cases (such as Rockingham County), involving key individuals in the local agricultural community in nutrient management programs is useful as a means of encouraging more widespread participation (Givens, 1987; Bushwick, Brichford, and Brockway, 1987).

The voluntary approach to nitrogen application reduction is already being practiced in the Shenandoah Valley through the education and technical assistance efforts of the nutrient management program. This program not only assists farmers in planning efficient nutrient utilization plans, but also cultivates test plots in Rockingham County which demonstrate that nitrogen applications can be substantially reduced from historic levels with no reduction in yields. Personnel involved with the program indicate that they have been making progress with most area farmers (Hawkins, 1988; Givens, 1987; Roller, 1987), although no survey work has been performed to estimate changes in manure and nitrogen application rates.

Evidence from other areas of Virginia and other states indicates that voluntary programs can have a positive effect. Limited evidence from farmers in the Charles City-James City-New Kent region of Virginia indicates that per acre application rates of nitrogen have decreased 21.8 percent between 1980 and 1987 with no reductions in yield, due to efforts by extension personnel which succeeded in educating farmers of the carryover benefits of previous nitrogen applications; in addition, a recent mass education program to improve Virginia farmers' soil liming practices was highly successful (Hawkins, 1988). Recent surveys of Iowa farm management practices revealed that 40 percent of farmers surveyed in the Big Spring Basin area reported a decrease in rates of nitrogen application between the years 1984 (when educational efforts started) and 1986 (57 percent noted no change over the period). Average rates of application to corn acreage declined about 23 percent over this period (Padgitt, 1987). These results indicate that voluntary programs can be effective in reducing nitrogen use, especially if it can be demonstrated that reduced application rates do not necessarily lead to reduced yields. Finally, the Fertilizer Institute notes that the fertilizer industry must "take the initiative to promote farmer participation in existing voluntary programs" to reduce nitrogen losses to the environment; "ignoring this (nonpoint pollution) problem will only encourage a call for legislation mandating more intense regulation" (Fertilizer Institute, 1984, pp. 17-18).

Potential factors working against the success of voluntary programs stem primarily from the fact that extension, U.S. Department of Agriculture, and university personnel--the groups most likely to be conducting these voluntary programs--are not the primary source of information for most farmers. Rockingham County survey responses revealed that 62 respondents (nearly half of the sample) considered commercial laboratories as their most important source of information for fertilizer application decisions, while 26 considered fertilizer salesmen as their most important source of information. In addition, 34 respondents considered commercial laboratories or fertilizer salesmen as their second most important source of information. Thus, if commercial recommendations differ from those of extension personnel, commercial recommendations may be more likely to be followed. Unfortunately, there is evidence indicating that some commercial laboratories recommend nitrogen applications well in excess of those advocated by Land Grant University soil testing services; one study found that soil testing laboratory recommendations for nitrogen for identical soil samples varied from 0 to 230 pounds[5] (DeVault, 1982; Paul, 1986). In another example, the attorney general for the State of Iowa has threatened to bring suit against soil test laboratories and farm suppliers who recommend excessive applications of plant nutrients; one source found that commercial recommendations (from four different private laboratories) were double the rates of application recommended by university laboratories (Cramer, 1988). Unless commercial concerns and agronomic recommendations coincide, or there is a change in farmers' sources of information on fertilizer use decisions, this contradiction in use recommendations could reduce the effectiveness of any voluntary program.

Mandatory Approaches to Reduce Nitrogen Application

Although approaches designed to induce voluntary reductions in nutrient application have met with some success in Virginia and elsewhere, and are probably relatively attractive from the farmer's point of view since his management practices are not restricted, voluntary programs alone still may not reduce nitrate loadings adequately. In these cases, compulsory programs may need to be considered if the contaminant in question is considered offensive enough to warrant mandatory action. The regulatory approaches used to reduce high-applier rates to low-applier rates are also the same approaches which could be used to effect larger reductions in nitrogen application.

Mandatory programs could be implemented in several ways. First, the regulatory agency could limit the per-acre application rate of nitrogen. Second, a surcharge (similar to a fine) could be added to nitrogen application above certain recommended rates. Finally, a limit on the amount of fertilizer the farmer could apply could be imposed--basically, a permit system for nitrogen purchase based on acreage cultivated.

Limiting per-acre application of nitrogen would require the cooperation of firms which custom apply fertilizer. This approach would be similar to having licensed applicators applying pesticides to insure that recommended rates are followed (or at least, that the applicators understand the regulations). In this way, unless the farmer were somehow able to acquire additional fertilizer elsewhere, a maximum per-acre application rate could be assured. Limits would be designed based on type of soil and manure nutrients available on the farm, perhaps in conjunction with manure testing services.

Applying a surcharge to nitrogen purchases above a recommended application level would encourage the farmer to more closely examine his input purchases. If the charge were high enough, the relationship between the farmer's perceived marginal value product and input price would be altered, so that input purchases would be reduced. If high nitrogen application does not increase yields, the producer would then realize that he can reduce input purchases without loss of net returns (and in fact may experience increased returns).

A permit system would be based on the assumption that a farmer was entitled to a certain rate of nitrogen application on his crop acreage. This would essentially be an emissions permit (Tietenberg, 1984) that relates nitrogen applications to nitrate loadings through means of the nonpoint production function discussed in chapter two. For example, if calculations showed that his cornland should receive 110 pounds of nitrogen, and his manure provided 75 pounds of nitrogen, then he would be issued a permit for 35 pounds of nitrogen per acre. Upon receipt of this permit, the custom applicator would then apply this 35 pounds. In practice, it would probably be more practical for a given farmer to apply all of his manure to a subset of his corn acreage and use his commercial allocation on the remainder, so as to minimize soil compaction and application time. This system would be similar in nature to transferable discharge permits (TDPs) for water pollution control, which are issued by the regulatory agency and have the advantages of allowing permit exchanges, bidding, and direct control of the waste discharge (Eheart, Brill, and Lyon, 1983). However, nitrate permits to manage ground water loadings may not work as effectively as those for surface water contaminants since an increase in per-acre nitrogen application may lead to a more than proportional increase in nitrate loading. Problems could also arise under this system if permits were not transferable; a "black market" for fertilizer permits may develop. Unless the application restrictions covered a large geographic area, fertilizer may also be trucked in from other counties. The additional transaction costs of these averting behavior activities would have the end result of increasing the price per pound of nitrogen applied which is above the recommended level, and so these permits would have the same effect as the nitrogen surcharge.

Administrative and Enforcement Costs

The policies discussed in this chapter differ with respect to distributional impacts and nitrate loadings. All scenarios generated assume compliance with the policy being imposed; this compliance is not always costless, however, and policies will tend to differ in terms of implementation costs.

If the taxation policy were applied on a regional basis so as to achieve a given reduction in nitrogen sales (and application rates), more fertilizer may be shipped in from outside the region. If the tax were high enough to offset the transportation cost differential between regions, the "law of market areas" indicates that market boundaries would shift, and fertilizer would move into Rockingham from other areas (Bressler and King, 1978). Stopping this influx of outside nitrogen would entail significant enforcement costs, although tax revenues could be used to offset these costs. However, transportation costs of this averting behavior would still raise the price of nitrogen, possibly reducing applications in spite of this importation.

Similar importation problems may occur with a permitting system. Finally, restrictions on the purchase of commercial fertilizer would only be effective if there were no available substitutes comparable in price and quality. It has already been shown that poultry litter could become a factor in any nitrogen-limiting scenario. However, disposal of poultry waste is currently a major problem in Rockingham County, so that the hastened development of a litter market could even result in a net improvement in water quality.

DISTRIBUTIONAL EFFECTS OF IMPROVED NUTRIENT MANAGEMENT IN ROCKINGHAM COUNTY

It was initially hypothesized that Rockingham County farmers could, through construction of manure storage facilities with cost sharing assistance, reduce nutrient input costs and nitrate loadings to ground water with essentially no reduction in net returns. However, the representative farm model indicated that this was not the case, as savings generated from higher nutrient recovery levels were not sufficient to offset the cost of constructing manure storage. Widespread adoption of manure storage would thus have an adverse impact on farmers' net returns over variable costs. In addition to the dairy farmers impacted by any type of manure management program, other parties potentially impacted by the widespread adoption of manure storage and nutrient management in the county are the non-farm public, government agencies involved in the program, and the commercial fertilizer industry.

Impacts of Ground Water Management Policies on Rockingham County Dairy Farmers

The representative farm analysis of the manure storage adoption decision indicated that, in the absence of any financial or non-market incentives not captured by the model's objective function, construction of manure storage facilities would entail substantial reductions in net returns. The actual net change in welfare for county farmers will depend on:

- the actual cost of the storage facility (especially regarding site preparation conditions),

- amount of cost sharing available,
- amount of tax savings generated by facility construction,
- market price of N, P, and K,
- expectations of future returns from the improved soil qualities promoted by manure, and
- the value of the three non-market advantages of the facility (annoyance factor, water quality, and bandwagon effect) to each individual farmer.

Of the policies examined, input taxes might have the most severe impact on dairy farmers (due to the substitution possibilities available in the nitrogen ban scenario). If some of these increased costs could be shifted forward onto consumers, some of the reduction in farmers' net returns could be mitigated. Similarly, regulation of nutrient management practices would impose a substantial cost on the farmer which he may not be able to shift forward. Of the three policies, cost sharing would have the least adverse impact on farmers' net welfare. The degree of welfare change to farmers would depend on the amount of cost sharing supplied; whether society experienced an increase in net welfare would depend upon the effects on other elements of society.

<u>Shifts in Comparative Advantage</u>

A possible side effect of regional or state-level policies to manage ground water contamination is that the relative cost structure of the region within the industry may be altered. To the extent that changes in management practices shift supply curves in the region (resulting in increased prices), the boundary between the regulated and unregulated market areas will shift. The unregulated area will then be able to "invade" the regulated market area (Harmston, 1983), reducing the region's pre-regulation sales. Before the cost structure-changing policy was enacted, transport rates prohibited this from occurring.

The Non-farm Public

Effects of promoting and funding manure storage construction may impact the public in three ways: higher taxes (or displacement of other government services) to finance the program may be experienced; increased food prices; and improvements in water quality. These impacts would be mitigated by revenues from corrective taxes (if these taxes were used). Unless a specific tax were applied on consumers for the purpose of water quality improvement, it is doubtful whether consumers would associate programs such as cost sharing with tax increases. Whether or not food prices increased would depend upon whether the tax were applied locally or nationally; if the tax were applied only locally, it is unlikely that consumers would see much change in milk prices (especially since milk prices are federally regulated).

Although decreased nitrate loadings to ground water would have positive benefits to the general population, the magnitude of these benefits is difficult to estimate. No clear dose-response relationship exists between nitrate ingestion and health problems, so that actual impacts of reductions in NO_3 would be hard to identify. In addition, there is no clearly accepted economic method for valuing reduced morbidity and mortality. However, recent public opinion polls indicate that the public is very concerned about ground water quality and is intolerant of even small amounts of chemicals in their drinking water (Center for Community Dynamics, 1985), so that reduced ground water nitrate would likely be perceived as a positive development.

In addition to benefits to drinking water users, improved nutrient management would also improve surface water quality. Improvements to surface water would benefit both those using surface waters for drinking water supply and recreational and commercial users such as those using the Chesapeake Bay for fishing and boating.

The Fertilizer Industry

As the mathematical programming model demonstrated, adoption of manure storage, in addition to reducing nitrate loading to ground water, allowed farmers to substantially reduce their purchases of commercial nitrogen (even when ideal nutrient application practices were being followed for no storage situations). Since the survey confirmed that many area farmers are applying nitrogen in excess of agronomic recommendations, the savings indicated by the representative farm model may be treated as a lower bound.

Using these ideal nutrient management nitrogen use figures, and assuming that 40 percent of county dairy farmers have no manure storage facilities, construction of manure storage coupled with adoption of recommended nutrient management plans would reduce in-county purchases of commercial nitrogen by about 489,000 pounds per year. Assuming an average price of .21/lb. for nitrogen, this translates into sales reductions of $102,690 per year. Additional sales losses would be incurred through reduced purchases of phosphate and potash supplied by increase manure use. This reduction of 244.5 tons represents approximately 13 percent of the 1,891 tons of nitrogen sold in Rockingham County in 1985 (VAS, 1986).

All of the policy options examined would have the effect of reducing commercial nitrogen consumption if storage construction was widely adopted and if nutrient management practices changed as a result of having this storage. If farmers' application rates of commercial nitrogen remained unchanged even with manure storage available, little reduction in commercial fertilizer sales would occur.

Government Programs

The Virginia Division of Soil and Water Conservation budgeted about $750,000 for 1987 to fund cost sharing in Rockingham County. If additional cost sharing funds were allocated to the area, other counties could be denied access to these funds (assuming no increase in overall budget allotments). For example, Accomac and Northampton Counties on the Delmarva Peninsula have been experiencing ground water nitrate contamination problems possibly caused by poultry operations in the area, yet very little cost sharing money is available for nutrient management in these counties (Belote, 1987). Problems thus arise in estimation of the marginal increments to general welfare of allocating these scarce pollution reduction dollars.

Fiscal Impacts of Nitrate Loading Reduction Policies

The dairy industry plays a major role in the agricultural economy of Rockingham County. Therefore, policy initiatives which caused major upheavals in the dairy sector could produce ripple effects which affected the rest of the region. For this reason, a crude fiscal impact analysis of the estimated impacts of the policies discussed was performed, using the Virginia Impact Projection (VIP) model (Johnson and Keeling, 1987). To fully exploit the VIP model's strengths requires much more detailed data input than is provided by the representative farm models; likewise, the VIP output is in much greater detail than is needed to evaluate fiscal impacts of the various policies considered. Ideally, a regional input-output model would be used to evaluate these policies, but such a model has not been developed for the Rockingham County region.

The effects of three alternative scenarios for the county dairy sector were simulated: (1) a baseline scenario, assuming no dairy operations had manure storage facilities in place (in reality, the county has already passed this extreme point); (2) a midpoint scenario, where cost sharing is provided and all farms adopt 120 day manure storage; and (3) regulation, where commercial nitrogen fertilizer is completely banned. From these three scenarios, impacts on farm labor, net returns, and construction costs were used as inputs into VIP.

Annual per capita income for the county was calculated to decrease by about $5 for the 120 day scenario and $40 for the fertilizer ban. On-farm labor hours are reduced by about 30,000 hours for both the 120 day scenario and the ban. Construction costs of about $10,000,000 are incurred to install the facilities; this cost was assumed to be spread out over a 15 year period corresponding to the life of the structure. Using input-output coefficients generated from the Washington State Input-Output model, each $1,000,000 of construction expenditures was assumed to create 36.4 jobs (Bourque, 1987). Therefore, about 364 construction jobs would be generated over the VIP simulation period.

With-without simulations were generated for each of the two alternative policies from 1984-1993. Selected variables under each simulation are presented in table 6.3. As table 6.3 indicates, the economic changes induced by the two policies have barely perceptible effects on the region's economy. County population is unchanged from baseline estimates. The county labor force increases by 2 laborers for each of the policy alternatives. The unemployment rate decreases slightly, from 6.2504 to 6.2305 for 120 day storage and to 6.2323 for the fertilizer ban. This represents a decrease of about .3 percent. Per capita income in the county decreases slightly under both policy scenarios, by $48 for the 120 day scenario and by $4 for the ban. Finally, county tax burden (which represents the amount of tax revenue which would have to be generated to maintain the level of public services assumed by the model) decreases from $7,711,849 to $7,700,674 for both policy scenarios, a decrease of about one tenth of one percent. These results indicate that the nitrate management policies have minimal fiscal impacts on the county economy, and that the more important issues to consider are distributional in nature; that is, they concern

TABLE 6.3. VIP MODEL SIMULATION RESULTS FOR SELECTED VARIABLES UNDER 120 DAY STORAGE AND FERTILIZER BAN SCENARIOS IN ROCKINGHAM COUNTY, VIRGINIA, 1987 - 1993.

		SCENARIO (1993 Estimate)	
	Baseline	**120 Day Storage**	**Fertilizer Ban**
Population Change (%)	.7652	.7652	.7652
Labor Force	31,073	31,075	31,075
Unemployment Rate	6.2504	6.2305	6.2323
Per Capita Income	13,206.73	13,158.80	13,202.39
Tax Burden	7,711,849.00	7,700,674.00	7,700,674.00

which groups within the region are impacted the most heavily.

GENERALIZABILITY OF THE ROCKINGHAM COUNTY STUDY

The generalizability of the Rockingham County study will depend largely on its similarity to other agricultural regions. Specifically, the ease of transferability of study results may depend on the four features discussed below.

Type of Operation. If the Rockingham County situation typifies dairy operations in other parts of the state and region, techniques and findings of the study may be applied to other areas. If herd and farm sizes and nutrient and other farm management practices in the county are unique, then ground water problems generated by county land use practices may be unique also.

Although the agricultural practices examined in the study were narrowly defined (dairy), much of the ground water nitrate problem experienced in Rockingham stems from characteristics common to this type of operation (manure disposal). Other predominantly dairy areas have experienced excessive nutrient use and ground water quality degradation (for example, Lancaster County, Pennsylvania and the Big Spring Basin area of Iowa [Swartz, 1987; Padgitt, 1986]). In addition, nitrate problems from other livestock operations (for example, poultry or hogs) could be mitigated by adaptation of the strategies used to reduce ground water contamination in Rockingham. Virginia extension personnel are currently exploring the option of transporting manure and litter from livestock intensive ("manure surplus") areas to grain producing regions of Virginia (Collins <u>et</u> <u>al</u>., 1988). Therefore, based on the criterion of operation type, it appears that the Rockingham County results provide a useful model for application to other nitrate-contaminated areas of the country.

<u>Hydrogeology</u>. The Shenandoah Valley area is characterized by karst-carbonate geology, which is extremely vulnerable to ground water problems. Surface soil and water characteristics which make the area favorable to dairy activities are not necessarily related to these ground water characteristics, so that nutrient management practices identical to those in Rockingham could be practiced in other (non-karst) areas with much less ground water degradation. However, Hallberg (1987) has noted that a substantial amount of U.S. agricultural land overlies karst areas. Thus it would seem that many other agricultural areas overlying karst and other vulnerable aquifer media would have ground water management problems in common with Rockingham County.

<u>Attitudinal Issues</u>. Attitudes of Rockingham County farmers may or may not be representative of the state or the nation as a whole. Responsiveness to various policy options--especially non-mandatory ones--may depend in part on the receptiveness of area farmers to ground water protection initiatives. Although little survey information is available, results from surveys of Iowa farmers reveal remarkably similar views and attitudes toward the environment and ground water among farmers in Iowa and Virginia (Halstead, Padgitt, and Batie, 1988).

<u>Policy and Funding Options</u>. Much of Rockingham County's cost sharing

money comes from the Chesapeake Bay program; while cost sharing programs for conservation measures are available to the entire country through federal sources, many states may not have access to the type and magnitude of funding that Rockingham County has available. Notable exceptions are provided by the State of Missouri, which uses revenues from a special sales tax to promote water quality protection practices, and the State of Utah, which provides low-interest loans to help farmers pay for conservation practices (Bushwick, Brichford, and Brockway, 1987). Unless a management program is established which does not require substantial infusions of capital (such as taxation or strict regulation), federal, state, and local sources must be relied upon to fund the program. The National Research Council (1986, p. 174) notes that "successful ground water protection programs require adequate legal authority and substantial funding for planning and design as well as implementation."

LIMITATIONS OF THE REPRESENTATIVE FARM/CREAMS MODELING APPROACH

Although the results of the representative farm model approach provide useful information to policy makers and field staff, any results should be interpreted with caution due to several potential problems inherent both in the study and the technique itself. These include: inflexibilities built into the model to accommodate lack of precise knowledge of certain area practices; data problems in model formulation, requiring approximation of certain variables; theoretical difficulties in using the CREAMS model; and transferability problems in applying the study results.

The major inflexibility built into the initial model framework was fixed pasture land acreage. Pasture acreage was fixed so that surplus manure from the no storage regime (that manure which could not be applied to crops) could be evenly distributed over the pasture; this was necessary to simulate the CREAMS runs. However, acreage maintained as pasture is usually a fixed part of the farm, since it is often marginal crop production land (Roller, 1987; Groover, 1988).

Due to a lack of available data and the wide variation in data that were available, a rough estimate had to be obtained for the size and cost of the manure construction activity. However, the approximation used is similar to that being used in the county for appropriating cost sharing assistance. A range of possible facility costs was therefore chosen, rather than one fixed value. In addition, Dairy Herd Improvement Association recommendations which were used to formulate much of the feed ration of the dairy herd apparently may not be followed by many state dairy farmers (Thatcher, 1987), so that recommended rations may overestimate or underestimate certain feed requirements. Finally, much of the data and many of the assumptions of the model were based on aggregate county and state data; it has been demonstrated that county level aggregate data considerably understates the risk experienced by the individual farmer, since this aggregation process has the effect of "smoothing out" the fluctuations in annual yield which the individual farmer faces (Debrah and Hall, 1987). This smoothing could affect the chance constraint coefficients whose derivation relies on historical yield information.

Use of the CREAMS model involved two particular problems in this study. First, since it is not a ground water model, nitrate loadings to ground water were at best an approximation, and no dependable estimate of ground water nitrate concentrations could be generated. This limitation made it impossible to apply the national standard for nitrates in ground water of 10 parts per million to the nitrate loading constraints in the mathematical programming model. Second, CREAMS is not designed to measure actual nutrient and soil losses but to provide a means of comparing the relative losses of alternative scenarios. Due to the lack of any ground water model which would function well in a karst setting, and because relative nitrate loadings across scenarios were of more interest than absolute loadings, CREAMS was considered an adequate model for the purposes of this study.

LESSONS OF THE ROCKINGHAM COUNTY STUDY

The purpose of this dissertation has been to examine potential strategies for managing ground water contamination from agricultural nitrates, and to evaluate the effects of these strategies on the agricultural sector, the general public, and ground water quality. By focusing on a case study of one Virginia county characterized by intensive agriculture, lessons have been learned which can clarify ground water management issues in Rockingham County and provide a model for other agricultural counties contending with ground water quality problems.

Rockingham County is only a small part of the agricultural sector of Virginia, which is itself only a small part of the agricultural sector of the country as a whole. As such, possible solutions to the ground water problems experienced in the county are of limited interest to regional or national policy, except in how they may be generalized to broader areas. This concluding section discusses what the study results mean for Rockingham County agriculture and ground water quality, and the broader implications of the study for ground water quality in other agricultural regions.

First, the results of the representative farm and CREAMS models indicate that the mismanagement of nutrients and the lack of manure storage facilities do contribute substantially to ground water degradation. High application practices may also represent an inefficient use of farmers' capital through wasted inputs (for an opposing view, see Norris and Shabman [1989]). These findings come as no surprise to those familiar with the county's situation; their usefulness is in the fact that they provide a concrete range of both cost and nitrate loading estimates of alternative nutrient management practices which was previously lacking.

The first set of policy initiatives in the conventional practice model examined the short term implications of ground water management in Rockingham County, presuming little structural change in agricultural practices or property rights in the area. It was demonstrated that working with the current cost sharing/nutrient management system, substantial reductions in average nitrate loading to ground water--up to

40 percent annually--could be achieved. Cost sharing was shown to be a viable means of inducing area dairy farmers to construct manure storage facilities.

The nontraditional alternative model demonstrated means of reducing nitrate loadings in the county which are not currently practiced. These policies are restrictive compared to current practices; however, the nontraditional alternative model results indicate that large reductions in nitrate loading could be achieved without driving the county dairy industry out of business. These reductions would come as a result of new, more innovative, and more expensive policy approaches, assuming that farmers would adapt to these management restrictions by changing dairy feed rations, farm management practices, and even traditional methods of raising crops like corn. Model results indicated that the nitrate loading reductions examined would be achieved through shifting feed rations to less nitrogen intensive crops rather than reducing herd size, even though average net returns per cow would be reduced.

The analysis also demonstrated that other sources of revenue could become a factor in county agriculture. Crops like alfalfa would not require substantial deviation from "core" agricultural practices; evidence indicates that demand for alfalfa is strong, and the major element lacking is an area supply structure, which could be motivated by nitrate management policies. Altering the current situation to produce non-traditional crops would require amendments to farm- and county-level expertise and to regional marketing structures.

Many of the policies discussed to achieve these major nitrate loading reductions would require both changes in traditional agricultural policy approaches and reassignment of property rights for water quality. Corrective taxes, though often heralded as economically efficient, are seldom used in practice. Bans on purchase of nitrogen or restrictions on nitrate loading assume that the farmer must bear the cost of protecting ground water quality, while the cost sharing currently practiced imposes the cost on society as a whole. Some of these policy initiatives result in reductions in farmers' net returns over variable costs (in the extreme case of a ban on commercial fertilizer, net returns are reduced by 15 percent, while nitrate loadings are reduced by more than 70 percent), even when cost sharing is provided. Whether these policies are ever enacted may depend on public sentiment over water quality, public attitudes towards farmers' incomes and lifestyles, policy makers' inclination to inflict losses on farmers, and on the results of continuing medical research on the adverse health effects of nitrates.

In the study's second major finding, the survey indicated that storage facilities alone are not necessarily sufficient to induce better nutrient management practices. CREAMS demonstrated that failure to consider manure's nutrient value can lead to nitrate loadings several times those under ideal nutrient management schemes; the survey results confirmed that these high rates of application were not uncommon in Rockingham County. Therefore, continued operation of educational efforts such as the nutrient management program in the county seems warranted.

Third, survey results indicate that small farm owners are less likely to participate in manure testing programs than large farm owners. Furthermore, CREAMS results indicate that these small farms have the potential to generate substantial nitrate contamination of ground water. Therefore, it is important that the education efforts recommended in the previous paragraph be targeted at these small farms owners.

Fourth, regarding policy vehicles for reducing nitrate contamination, cost sharing appears to be the most politically feasible of the those examined. Cost sharing has the disadvantage of not providing any influence on Mennonite farms in the county since these farms do not participate in government sponsored programs; however, the low interest loans often provided within the church are similar in outcome to cost sharing (Groover, 1988). Corrective taxes would require substantial increases in current nitrogen costs before the desired reduction in commercial nitrogen use would be achieved; although this strategy would adversely affect farmers' net returns, it is less expensive (considering the per pound price of nitrate loading reduction) than some of the other strategies considered. Strict regulation (with no cost sharing) would result in substantial reduction in net returns, without the leverage for promoting nutrient management planning that cost sharing gives. Incorporating the effect of uncertainty in the loading process into the model had the effect of substantially increasing the cost of the program. Model results indicate that if the policy situation regarding nitrate loading to ground water were to change so that major reductions were viewed as necessary, other regulatory options are available.

Finally, the survey indicated that Rockingham County farmers are concerned about the quality of their ground water and cognizant that economic tradeoffs may be necessary to protect it. Although the survey did not elicit specific sacrifices which farmers would be willing to make to protect this water quality, and farmers' responses may change when faced with the potential for financial loss, these attitudinal responses do indicate an awareness of the problem and recognition of the costs of mitigating it. These attitudes should favorably affect policy efforts at managing ground water quality.

Need for Further Research

One of the results of the Rockingham County study is a better understanding of the difficulty of the problem of management of agricultural nonpoint contaminants. This dissertation alluded to the possible problems of trading nitrate problems for pesticide problems if policies are too narrowly focused. It is important in the final analyses that the entire ecosystem be considered. Possible undesired side effects of alternative government programs must be accounted for; for example, programs designed to reduce soil erosion may increase leaching, so that surface water quality is improved at the expense of ground water quality (Papendick, Elliot, and Power, 1987).

Although evidence on the medical effects of agricultural chemicals in general is sketchy--in fact, it might be argued that more research is needed on the health effects than the economic effects of managing these chemicals--it appears that pesticides are a more serious threat to human health than nitrates. Future efforts should concentrate on a wider variety of agricultural chemicals and evaluate the implicit tradeoffs involved in many policies.

Finally, the linear programming framework used in the mathematical programming model does not allow consideration of decision makers' risk preferences in the model. For the case at hand, this approach is reasonable because dairy farmers face less price and yield risk than crop farmers. The chance constrained technique does allow incorporation of input risk into the model's technical matrix. However, it would be useful for future studies to demonstrate the effects of risk preferences on ground water management policies through the use of techniques such as quadratic or safety first programming. Failure to include this farm level risk may lead to over- or underestimation of a policy's impacts. The linear programming model also did not consider non-monetary incentives to adopt manure storage, such as water quality or convenience. These factors could be incorporated in future efforts through some kind of multi-attribute objective function.

Importance of a Multidisciplinary Approach

This study has demonstrated that any approach to managing threats to ground water quality (whether nitrates or pesticides) which relies strictly on economics will be somewhat sterile from a policy perspective. The study relied heavily on other disciplines to gain a complete picture of the problem. Physical water quality and chemical transport information was obtained from the agricultural engineering department at VPI & SU; information on the effects of nitrogen on yield values and the potential for alternative revenue producing or nitrogen using crops was provided the agronomy and horticulture departments at VPI & SU; information on alternatives to current dairy practices in Rockingham County came from VPI & SU's dairy science department and the Virginia Maryland Regional College of Veterinary Medicine. In addition to these information sources, interaction with field personnel was essential to the study. Area extension staff both helped characterize the existing situation and provided verification that the assumptions made in the study were correct; Virginia State Water Control Board personnel furnished information on water quality in the county; and Soil and Water Conservation District, Soil Conservation Service, and Division of Soil and Water Conservation personnel provided information on the magnitude and costs of the manure storage program. These sources of information were vital in both assessing the situation as it was and developing scenarios for what it could be. Finally--and certainly not least--county farmers provided information and input through widespread participation in the dairy farm survey. Future efforts at managing ground water quality must maintain and expand this interdisciplinary framework.

CONCLUSIONS

This dissertation has demonstrated a variety of policy approaches which could be used to reduce nitrate contamination of ground water in livestock-intensive areas. Survey and mathematical programming results indicate that substantial reductions in nitrate loading could be achieved via programs which impose minimal financial stress on area farmers. Extreme reductions in nitrate loading, while achievable, would prove costly in terms of lost net farm income. Whether or not these reductions are warranted depends on the value of the losses to society incurred by having high nitrate concentrations in drinking water.

This dissertation furnishes information to ground water policy makers in two principal areas. First, it provides a range of quantified estimates of the effects on income and ground water quality of policies currently practiced or likely to be practiced in Rockingham County in the near future. Second, and perhaps most important, the representative farm analysis provides the means of simulating the effects of various untried policy options on income and water quality. The information thus gained provides guidance to policy makers on the possible outcomes of contemplated policies without actually having to resort to actual trial and error. Towards this end, the dissertation provides a continuum of the explicit economic-environmental tradeoffs involved at each level of nitrate loading reduction.

ENDNOTES

Chapter One

1. Both manure and nitrogen produced per thousand weight varies by animal type; for example, beef cattle produce only 62 pounds of daily manure, poultry produce about 53 pounds/day, and humans 31.2 pounds/day, compared to 85 pounds/day by dairy cattle. Nitrogen per thousand weight is approximately the same for beef and dairy cattle; poultry manure contains about .86 pounds/thousand weight, and humans about .2 pounds/thousand weight (VPI & SU, 1984).

2. The vadose zone is the area that lies between the land surface and the water table.

3. Nitrogen does undergo some attenuation (transformation) in the soil, where it is subject to plant uptake and denitrification. However, once nitrate has reached ground water, it tends to move without further attenuation except for dispersion (Bouwer, 1980). This tendency to remain unaltered is what is meant by conservative.

4. Point sources usually discharge pollutants through a specific location such as a pipe, ditch, or smokestack, while nonpoint sources are characterized by more indirect emissions, usually spread over a large area (Tietenberg, 1984).

5. DRASTIC is an acronym standing for Depth to water table, Recharge area, Aquifer media, Soil type, Topography, Impact of vadose zone, and hydraulic Conductivity. DRASTIC is used to derive a weighted index of an area's relative vulnerability to ground water contamination.

6. Hallberg (1986a) cites evidence that the rate of uptake may actually be lower, in the range of 20 to 30 percent, even at economically optimal application rates.

7. A best management practice is a technique recognized to be a cost effective and practical means to control nonpoint source pollutants which is compatible with the continued productive use of the land (Magette, 1987).

8. An externality--also called a spillover effect--is present whenever some individual's production relationships include real variables, whose values are chosen by others without particular attention to that individual's welfare (Baumol and Oates, 1975).

9. These crop needs are based on the following figures (Hawkins, 1987):
46,900 acres of corn X 135 lbs N/acre
1,200 acres wheat X 80 lbs N/acre
850 acres barley X 80 lbs N/acre
350 acres oats X 80 lbs N/acre

Figures on available nitrogen from manure are based on assuming 77.8 milking cows in confinement (from Rockingham County dairy farm survey) for 291 farms. Cows are assumed to produce an average of 85 lbs. of manure/day (70 percent of which is recoverable) with available N of 4 lbs/ton. These are approximate estimates, and do not include the nitrogen produced by poultry in the county. Nitrogen from this poultry litter may total as much as 8,850 pounds (Bosch, Shabman, and Givens, 1988).

10. These figures are drawn from Virginia state agricultural statistics. However, Harrisonburg serves as a regional distribution point for other counties in the valley and West Virginia, and commercial fertilizer is imported to parts of Rockingham County from neigboring counties (Hawkins, 1987).

11. This method circumvents the problem of estimating the marginal benefit and cost function for the corrective tax.

Chapter Two

1. "Overexploitation" here refers to marginal costs of using an extra unit of the resource exceeding marginal benefits to society. In a common property situation, users view the average cost of resource use rather than the marginal cost, leading to sub-optimal use of ground water.

2. Much recent research has concentrated on predicting the uptake of nutrients and pesticides by plants and insects, and tracing the movement and degradation of the remaining chemicals through the root zone, vadose, and saturated zone (see, for example, Pimentel and Levitan, 1986; Gorelick, 1983; DeCoursey, 1985). However, while it may be technically possible to monitor the flow of chemicals from any given field, the data requirements of monitoring all nonpoint sources tend to render this option economically infeasible.

3. Throughout this dissertation, the term "he" will be used to refer to various farmers. This is merely for simplicity; it is recognized that both men and women are farmers.

4. Standards have been criticized for giving the pollutor no incentive to abate beyond the set limits. Charges (such as taxes per unit of effluent) have the advantage of being "technology forcing," or giving producers the incentive to develop new, more efficient means of pollution control (Randall, 1981).

5. For example, recent Harris polls on the plight of the American farmer indicate that a majority of respondents favor continued government financial assistance to the agricultural sector, both in subsidies and price supports (Harris, 1985a, 1985b). A possible inference from this information is that the public might prefer to see the federal government subsidize farmers to reduce pollution rather than tax them.

Chapter Three

1. Virginia is already credited with having a relatively diverse agricultural base (Virginia Cooperative Extension Service, 1987b); knowledge of this fact may have influenced farmers' responses.

2. A response in agreement with "status quo" questions (SC) is interpreted as indicating that the respondent felt that the status quo--current levels of agricultural input use, labeling, regulation, water treatment ability, environmental standards, and expenditures for agricultural input research and control--is sufficient for protecting the environment and human and animal health and safety. A response in agreement with the CC questions is interpreted as indicating that further research, regulation, or expenditures may be needed to protect ground water quality in the county.

3. Survey information was insufficient to determine whether six respondents owned manure storage facilities; therefore, these six responses were not included in the groupings. These six individuals accounted for a total of 1,280 acres, with an average application rate of 80.7 pounds of nitrogen per acre. Two of these farmers applied 100 pounds or more of nitrogen to a total of 835 acres. Of the other 2,360 acres of corn land identified by the survey, it was not possible to determine what total application rates of commercial nitrogen were being applied, so that these acres were excluded from this part of the analysis.

4. Based on conversations with Pennsylvania State University peronnel involved in Pennsylvania's manure testing program, a value of $20 per sample was chosen (Beegle, 1987). VPI & SU's Agricultural Engineering Department currently provides this service free to state farmers.

Chapter Four

1. In practice, the definitional distinction between risk and uncertainty decidedly deteriorates. Knight (1921) concluded that risk was the appropriate term if the probability of an event could be measured and some sort of outcome probability generated by the decision maker, whereas a decision maker faced with true uncertainty lacked the

information to generate these estimates. Knight's definition has evolved to the point that if decision makers could generate subjective estimates of the probabilities of different outcomes, they were faced with risk rather than uncertainty.

2. Farmers may also face risk from other less important sources, such as health and safety concerns or actions of others (both individuals and institutions) which may affect their own production.

3. It is possible that capital constraints--which may be reflected by interest costs--could stop a farmer from expanding his operation to take advantage of greater profit opportunities. However, this issue was accounted for in the model by placing upper and lower bounds (based on fixed costs and profit expectations) on size of operation. It was assumed that current average herd sizes represented the maximum milking herd which a farmer's physical plant could accomodate; lower bounds on herd size were set so that net returns earned would be equal to the median income which could be earned in Rockingham County by a non-dairy farmer.

4. The term "cross compliance" or "conservation compliance" refers to the requirement that a farmer follow the regulations of certain USDA programs in order to receive benefits from other USDA programs (such as price supports).

5. There is no well-developed market for silage in the area (Roller, 1987; Groover, 1987). Silage can be purchased, but at a very high price, so that farmers view production of sufficient silage for their herd as a high priority.

6. CREAMS simulations were not performed for the barley crop. Crop uptake and leaching for this grain crop were assumed to be in the same range as corn (Heatwole, 1988). Since barley was not chosen under any of the policy scenarios because of high production costs, it was felt that excluding barley from the chance constraint analysis would not bias results.

7. These figures were computed using weekly prices from the Harrisonburg cash market for the years 1975-1981 and the Shenandoah Valley cash market for the years 1982-1986 (The Harrisonburg and Shenandoah Valley market reporting areas were combined in 1982). This series was the only data years available for the individual markets. All price figures were deflated using prices received by farmers index from the Virginia Agricultural Statistics Reports (1977 = 100).

8. Results of the Rockingham County Dairy Farm Survey were used to refine estimates originally furnished by Mr. Harold Roller, Rockingham County agent. Survey responses were divided into two groups, those with total farm size greater than 100 acres, and those with total farm size less than 100 acres. Acreage was used as the basis for dividing the

sample on the advice of Mr. Roller, who felt that it would be less variable than herd size and more representative of the large-small farm operating differences (such as crop production mixes and pasture acreage) which we were trying to capture.

9. Pastureland is generally a fixed portion of farmers' land, due to the fact that it is usually only marginally productivite for crop production. In the representative farm model, the fixed pasture requirement also allowed the manure produced by the model dairy herd to be spread evenly and predictably, so that CREAMS estimates of nitrate loading could be generated.

10. Results of the Rockingham County Dairy Farm survey revealed that 86 percent of respondents followed a corn/rye haylage rotation.

11. It must be realized that alternative crops which cause fewer nitrate problems than those currently grown in the Shenandoah Valley may require heavier applications of pesticides than those required by corn. For example, establishment of alfalfa entails the use of the herbicide 2,4-D, a suspected carcinogen identified as having high leaching potential (Blair and Thomas, 1986; Weaver, 1987); recommended pesticides for conventional strawberry production include the herbicides terbacil and DCPA (also suspected leachers) (National Research Council, 1987). Policy makers concerned with protecting ground water quality must be aware of the potential tradeoffs involved when current practices are altered.

12. Since poultry litter has a much higher nitrogen content than dairy manure, it should be applied in a much thinner cover.

13. Unless otherwise specified, "storage" refers to on-farm liquid manure storage facilities of 60, 120, or 180 days.

Chapter Five

1. This figure represents net returns over variable costs; fixed costs, such as interest payments, were not considered in the model's objective function. Economic theory assumes that fixed costs are not considered in short run profit maximization decisions, so that their omission does not reduce the validity of the model's objective function. However, since the omission of these fixed costs may result in the model overestimating the actual net income of the average Shenandoah Valley dairy farmer, the optimal solution of the model can not be interpreted as a true estimate of net returns. It is a relative measure for purposes of comparing income changes among storage scenarios.

2. The following formula is used to convert pounds of nitrate leached per acre to nitrate concentration (in parts per million) in percolation water:

$$\frac{\text{nitrate loading (kg/ha)}}{\text{percolation flow (cm)}} \times 10 = \text{concentration (ppm)}$$

3. Using a linear objective function assumes that financial compensation for the storage adoption decision is the only consideration in shifting the farmer from one indifference curve to another. The linear programming framework also implicitly assumes risk neutrality on the part of the farmer; that is, only the actual dollar amount of change in income affects his utility, with no explicit consideration of the income variability which might be introduced by alternative management systems. There are, of course, other utility-increasing factors which the farmer may perceive as a result of the storage adoption decision, including improved water quality and the non-monetary benefits of elimination of the need for daily spreading.

4. Borrowed capital necessary to finance construction of the manure storage facility is based on a fifteen year loan at 12 percent interest (Bosch, Taylor, and Ross, 1988). The DAIRYLP program allows consideration of a variety of interest rates from which the farmer can choose; however, since the model used in this study is based on a single year time period, the optimization procedure will always choose the lowest interest rate provided in order to minimize construction costs. For the purposes of this model, a 15 year payback period is chosen to approximate the lifespan of the storage facility.

5. Facilities and practices for which cost sharing has been provided are subject to spot inspection to verify compliance with the terms of the initial agreement. Failure to comply results in the farmer being given a six month period to rectify the problem; if the farmer fails to remedy the situation within that time, he is given 60 days to repay all cost share funds.

6. Net returns in the model when the maximum $11,000 cost sharing was allowed were $54,566 for the large farm with 120 day storage, $53,371.28 for the large farm with 180 day storage, $40,197.16 for the small farm with 120 day storage, and $39,519.30 for the small farm with 180 day storage. All of these cost sharing results assume medium site preparation costs.

7. This result should not be interpreted to mean that 22 cows would be fed an alfalfa-corn grain ration year round while the rest of the herd remained on a silage-based ration. A more plausible explanation is that the whole herd would be fed on an alfalfa-corn grain ration for about two and one-half months (22 percent) of the year, and on silage/ryelage the rest of the year.

8. It may be possible for farmers simply to rent pasture acreage from other area farmers for spreading; in this case, rental rates on pasture

are only in the $15-20 range, so that spreading acreage requirements would have to be much stricter to effect the same change. However, rented pasture would have to be adjacent to the farmer's land and dairy operation to be efficiently utilized.

9. These figures were arrived at by initially multiplying the price of 30 percent nitrogen solution for the period by .3 (to gain a proxy for nitrogen price), then inflating by the price index for all farm commodities using 1986 as a base year. Mean price over the period was 40.61 cents, with a standard deviation of 4.13.

10. This acreage is idled due to the lack of any available nitrogen to use for crop production; the farmer is deprived the use of his nutrient inputs.

11. Unlike the information available for constructing the grain scenarios simulated by CREAMS, limited information on nitrogen uptake by strawberries was available, so that the CREAMS nitrate loading estimates for strawberries should be interpreted with caution (Heatwole, 1988). However, the nitrogen uptake estimates generated by CREAMS are comparable to those estimated in field studies of strawberries (Peterson, Stand, and Krueger, 1986).

Chapter Six

1. The comparative policy cost estimates in tables 6.1 and 6.2 are for the large farms only. This is merely for ease of comparison; since the small farm model's responses to the policies imposed mirror the large farm's, the results would be identical if the small farm were included in this section.

2. Cost sharing provided for manure storage construction is a one-time payment of $11,000 made at the time of facility construction, while the other policy costs and revenues are annual estimated figures. Therefore, the approximate amount of the annual cost sharing outlay over the 15 year life of the facility (with an interest rate of 12 percent) was estimated as
$[\ 733.33 \times (1.12)^{i}]/15$, or $1,822.

3. These estimates assume that about one-third of county farms fall in the 80 acre category and two-thirds fall in the 200 acre category. They also assume that recommended nutrient management practices are followed on all farms.

4. The survey made no attempt to identify Mennonite or non- Mennonite respondents. It was assumed that most of the large farms were not Mennonite operations.

5. The Rodale Research Center study has been criticized for introducing

bias to the results through the method with which the soil samples were submitted to the various laboratories. Some of the laboratories to which samples were submitted maintain that there was not enough information supplied with the sample to make an educated recommendation for nitrogen application needs; however, the variability of the nitrogen application rates recommended from essentially identical samples is still worth noting.

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APPENDIX A

LEGISLATIVE RESPONSE

TO

GROUND WATER CONTAMINATION

LEGISLATIVE RESPONSE TO GROUND WATER CONTAMINATION

Efforts directed at protecting ground water contamination from agricultural sources may emanate from four governmental levels: international, federal, state, and local (Gips, 1987). Although there is no mandatory international regulatory process for agricultural chemicals, a number of actions have been taken on the issue, including: establishment of the International Registry for Potentially Toxic Chemicals (IRPTC) by the United Nations Environmental Program (UNEP); a United Nations resolution calling for countries that export banned or restricted chemicals to make full information on these chemicals available to the purchaser;[1] adoption by the Organization for Economic Cooperation and Development (OECD) of principles of information exchange relating to export of banned or restricted chemicals; and the drafting of an International Code of Conduct on the Distribution and Use of Pesticides by the Food and Agriculture Organization of the U.N. (Gips, 1987). Although these actions and guidelines are important and reflect international concern over pesticide trade and regulation, for the present time the principal constraints on agricultural chemical use will come from state and federal governments within the U.S.

The federal government has substantial regulatory authority to play a major role in the ground water management process. Acts such as the Safe Drinking Water Act (SDWA), the Clean Water Act (CWA), and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) will affect both the handling of agricultural chemicals and the concentrations of contaminants allowed in ground water. The Safe Drinking Water Act requires EPA to develop public drinking water standards for 21 pesticides (in addition to the current six[2]) by 1989 and another 25 by 1991. Typically, the federal agency responsible for administering the law assumes the lead role for developing scientific data, technical standards, and a regulatory framework; states are then given the responsibility (with some federal financial assistance) to develop their own programs to meet federal standards (Henderson, Trauberman, and Gallagher, 1987; NRC, 1986). This definition of state and federal roles can be seen in the 1978 amendments to FIFRA, when responsibility for administration was shifted from EPA to the states, although it is currently uncertain how this situation may change when FIFRA is reauthorized. To date, 39 states have assumed responsibility for administering FIFRA (ICWP, 1987). There is still considerable uncertainty as to the final role which the federal government will play in the ground water management process, and which agency will take the lead role.

Congress is giving increased attention to nonpoint source water pollution in modifications to the recently reauthorized federal Clean Water Act (The Water Quality Act of 1987). Development of nonpoint pollution control programs has been a state and local responsibility; many environmental groups argue that such programs have had little effect. The modification Congress has enacted increases federal authority to require states to implement land use practices to reduce nonpoint source pollution. Suggested strategies include grants to the states, federal assumption of nonpoint control responsibility where these states fail to act, and provision for citizen suits if either federal or state governments fail to act.

Several bills aimed at ground water protection have also been introduced in the 100th Congress. These bills are titled "The Ground Water Protection Act of 1987" (S. 20, H.R. 963) and "The Ground Water Safety Act of 1987" (S. 1419, H.R. 3174). The Ground Water Safety Act, which deals specifically with pesticides, has been the subject of much debate. The bill contains very strong provisions regarding what ground water is to be protected, how pesticides will be classified for leaching potential, and how ground water guidance levels (GRGLs) will be set, and places the onus for testing and monitoring on the pesticide industry. S. 1419, popularly called the Durenburger- Leahy bill, essentially treats all ground water as drinking water, and requires that EPA amend a pesticide's registration if it is detected in ground water at 25 percent of its GRGL (Whitcraft, 1988). If a pesticide reaches 50 percent of its GRGL, either the state or EPA must take steps (including total bans, if necessary) to prevent the contamination level from reaching or exceeding the GRGL (Oberstarr, 1987). The bill has been criticized by industry as being overly restrictive on the agrichemical industry, while environmentalists view the bill as overdue (Whitcraft, 1987). The Ground Water Safety Act would primarily entail amendment of FIFRA; if FIFRA is not acted on in the current session, H.R. 3174 and S. 1419 will not be either (Gabel, 1988).

It is also possible that the Endangered Species act may affect agricultural chemical use. Unlike FIFRA, the Endangered Species Act precludes the use of "economics of jeopardy" in evaluating chemicals. Other federal statutes which may have a impact on ground water management include the Resource Conservation and Recovery Act (RCRA), the Toxic Substances Control Act (TSCA), and the Comprehensive Emergency Response and Liability Act (CERCLA, or "Superfund").

It appears that the most efficient program for ground water management (in terms of each level of government doing what it does best) will incorporate influences from a combination of governmental levels. Henderson, Trauberman, and Gallagher (1987) note that there are four principal reasons why states will play the lead role in ground water management: first, states already have an established and well-developed system of statutory and common law for ground water allocation and use; second, physical characteristics of ground water hydrology, geology, and contamination vary from state to state, making a comprehensive federal approach difficult; third, many solutions to the ground water contamination problem require the use of land use controls, which state and local governments are better prepared to implement; and finally, states are assuming more administrative authority over the federal laws which regulate ground water quality and contamination. It appears likely that primary responsibility for monitoring and managing agricultural ground water pollution will rest with state governments (Dycus, 1984; Tripp and Jaffe, 1979).

Many states are responding by initiating more active roles in the process, and efforts to protect ground water quality have increased over the past several years (O'Hare et al 1985). To date, twenty-seven states have developed policies for protecting ground water quality, while twenty-eight states are either formulating or revising these policies (EPA, 1985). Twelve states have enacted specific ground water protection statutes, while other states rely on existing administrative authority to carry out policies (EPA, 1985). However, the focus of many of these state programs is principally on point sources of pollutants (OTA, 1984), and so may not be as effective in addressing agricultural nonpoint sources such as pesticides and fertilizers. With regard to agricultural chemicals, 21 states have established regulations for use, application, or distributor registration of fertilizers, while 43 have regulations governing use, application, or distributor registration or reporting for pesticides (ICWP, 1987).

ENDNOTES

1. Under FIFRA, EPA is required to notify foreign nations of all pesticide regulation actions regarding exported pesticides (Hearne, 1984). An executive order signed by President Carter also required that notice about health and environmental risks involved with product use be provided with hazardous exports. However, this order was subsequently overturned by President Reagan, who maintained that notification provisions were essentially restrictions of free trade.

2. Federal standards currently exist only for lindane, endrin, 2,4-D, methoxychlor, 2-4-5-TP-Silvex, and toxophene.

APPENDIX B

THE ROCKINGHAM COUNTY DAIRY FARM SURVEY

THE ROCKINGHAM COUNTY DAIRY FARM SURVEY

The Rockingham County dairy farm survey identifies current nutrient and pesticide management practices and farmers' attitudes. All 291 Grade A dairy operations in the county were surveyed, using listings obtained from the Virginia Department of Agriculture.

Survey Design

The initial model for the survey was provided by work performed by Padgitt (1984) in the Big Spring Basin of Iowa. Padgitt's survey was expanded and adapted to reflect Virginia conditions, with input from extension experts (Mr. Fred Givens, Department of Agricultural Engineering, Virginia Tech; Dr. George Hawkins, Department of Agronomy, Virginia Tech; Mr. Harold Roller, Rockingham County Extension Agent) and experts in survey design (Mr. Robert Frary, Virginia Tech).

The survey was implemented using a variant of Dillman's Total Design Method (Dillman, 1978). An initial mailing, which included cover letters from the Department of Agricultural Economics at Virginia Tech and Mr. Harold Roller, and a complementary pen, drew a response of 110 surveys, or about 38 percent. Two weeks after the initial mailing, all dairy farmers on the survey list received a reminder post card. Finally, approximately one month after the initial mailing, those farmers who had not yet responded received a second full mailing. This second mailing elicited 37 more survey returns. In total, 147 of 291 surveys were returned for a response rate of just over 50%. One survey was returned undeliverable while four farmers declined to complete the survey for personal reasons.

SURVEY FORM AND LETTERS

Intitial Mailing

Would you take a few minutes to fill out the enclosed questionnaire about soil nutrient management practices? At a time when farmers are stretched to the limit financially and concerns are being raised about water quality, Virginia Tech research and extension personnel are interested in learning as much as possible about nutrient management. This knowledge should lead to better nutrient management which can improve agricultural profitability and wise stewardship of the land and water.

This survey is being sent to all dairy farmers in Rockingham County. Your individual response is important to us. We know your time is valuable, and we have kept this survey as short as possible. The enclosed pen and addressed envelope is for your convenience in completing and returning the survey. (Please keep the pen.) If you do not make the management decisions asked about in the questionnaire, please have the person who is responsible for these decisions complete the survey.

We assure complete confidentiality. The return envelope has an identification number on it for mailing purposes only. A student will check off your name when the survey is returned, open the envelope, and discard it. Only the student will have access to the identification numbers. Your name will never be placed on the questionnaire, and it will be impossible to trace any responses back to any individual.

You will receive a summary of the survey results at a later date.

Thank you for your help.

Sincerely,

Sandra Batie
Professor

Randall Kramer
Associate Professor

FOLLOWUP LETTER

About four weeks ago we sent you a survey on nutrient management practices on your farm in Rockingham County. As of today we have not yet received your completed questionnaire.

As you know, information on nutrient management in the county is important to Rockingham Dairy farmers, as well as Virginia Tech extension and research faculty. Knowledge of nutrient management practices gained from this study should lead to better management information which can improve agricultural profit.

We are writing to you again because your response is important. In order for the results of this survey to be truly representative of nutrient management practices in Rockingham County, it is important that we have your completed questionnaire.

We assure complete confidentiality. The return envelope has an identification number on it for mailing purposes only. A student will check off your name when the survey is returned, open the envelope, and discard it. Only the student will have access to the identification numbers. Your name will never be placed on the questionnaire, and it will be impossible to trace any responses back to any individual.

In the event your questionnaire has been misplaced, a replacement is enclosed. If for any reason you choose not to return the survey, would you tell us why (you can use the enclosed sheet).

Thank you again for your help.

Sincerely,

Sandra Batie
Professor

Randall Kramer
Associate Professor

ROCKINGHAM COUNTY DAIRY FARM SURVEY

1. Below is a list of issues of concern to Virginians. What priority do you assign to each?

	low priority			high priority
a. profitability in agriculture	1	2	3	4
b. protecting water quality	1	2	3	4
c. preventing soil erosion	1	2	3	4
d. attracting industry to Virginia	1	2	3	4
e. maintaining economic viability of rural communities	1	2	3	4
f. diversifying agriculture in Virginia	1	2	3	4

2. Please describe your farming operation for this year (1987).

a. farm size
- -total acres farmed ___acres
- -acres owned ___acres
- -acres rented ___acres

b. crops
- -corn (conventional till) ___acres
- -corn (minimum till) ___acres
- -alfalfa ___acres
- -killed rye cover ___acres
- -ryelage ___acres
- -pasture ___acres
- -other__________________ ___acres
- __________________ ___acres
- __________________ ___acres

c. livestock
- -dairy (current inventory) ___head
  - -milking herd ___head
  - -replacement heifers ___head
- -beef cattle
  - -stock cows ___head
  - -feedlot steers/heifers ___head
  - -yearling heifers ___head
- -swine ___head
- -poultry (average number

of birds at any
one time)

-chickens ___no. of layers
___no. of broilers

-turkeys ___no. of birds

d. commercial nitrogen fertilizer application

fall rye ___acres
___average pounds Nitrogen/acre

fall corn ___acres
___average pounds Nitrogen/acre

spring corn, preplant ___acres
___average pounds Nitrogen/acre

spring corn, at planting ___acres
__average pounds Nitrogen/acre

sidedress ___acres
___average pounds Nitrogen/acre

e. herbicide application (specify whether lbs. or pints of active ingredients)

-Dual	___acres	_____active ingredients/acre
-Simazine	___acres	_____active ingredients/acre
-2,4-D	___acres	_____active ingredients/acre
-Spreader	___acres	_____active ingredients/acre
-Roundup	___acres	_____active ingredients/acre
-Sinbar	___acres	_____active ingredients/acre
-Sencor	___acres	_____active ingredients/acre
-Atrazine	___acres	_____active ingredients/acre
-Bromoxyln ME-4	___acres	_____active ingredients/acre
-Paraquat	___acres	_____active ingredients/acre
-Banvel	___acres	_____active ingredients/acre
-other____________	___acres	_____active ingredients/acre

f. insecticide application (specify whether lbs. or pints of active ingredients)

-Furadan Flowable 4F	___acres	_____active ingredients/acre
-Furadan Granular (156)	___acres	_____active ingredients/1000
-DiSyston	___acres	_____active ingredients/acre
-Lorsban (4E)	___acres	_____active ingredients/acre
-Lorsban Granular	___acres	_____active ingredients/1000
-Ambush	___acres	_____active ingredients/acre
-Pounce	___acres	_____active ingredients/acre

-Counter	___acres	_____active ingredients/acre
-Lannate	___acres	_____active ingredients/acre
-Pydrin	___acres	_____active ingredients/acre
-Dyfonate	___acres	_____active ingredients/acre
-other__________________	___acres	_____active ingredients/acre

g. If you farm rented land; do your management practices differ between your own land and your rented land (check one)?
___use more soil conservation practices on own land
___use more intensive chemical application on own land
___use less soil conservation practices on own land
___use less intensive chemical application on own land
___manage both the same

3. What are the major crop rotations you use?
___corn/rye haylage
___other (please describe)_____________________

4. Does your land have:
___strip cropping
___grass waterways
___other conservation practices______________________

5. How do you decide how much fertilizer to use?
(1 = most useful source, 2 = second most useful source)
___university soil testing
___extension recommendations
___commercial lab recommendations
___ag fertilizer salesman or dealer recommendations
___my own knowledge
___other (please describe)_______________________________

6. How often do you test your soil for fertilizer needs?
___annually
___every 2 yrs
___every 3 yrs
___every 3-5 yrs
___don't soil test

7. If a manure testing service were available at a reasonable cost (about $20 a sample), would you use it?
___yes
___no

8. Would you be more likely to use the service if it were provided by Virginia Tech than by a private firm?
___yes
___no
___indifferent

9. How do you decide how much pesticide to use?
(1 = most useful source, 2 = second most useful source)
___follow directions on label
___extension recommendations
___my own knowledge
___dealer's recommendations
___other (please describe)___________________________

10. What is your expected average yield for your corn acreage this year?
_____bushels/acre

11. What type of manure storage facilities do you have?
___earthen
___poured concrete
___pre-cast panels
___other______________________________
___none

12. What is the size of your manure storage facility and how often do you empty it (that is, how many gallons of storage capacity do you have)?

a. size____________

b. emptying
___as needed
___twice a year
___three times a year
___monthly
___more often than monthly

c. Do you:
___apply manure yourself
___hire a contractor/hauler to apply it for you

d. For emptying your storage facility, do you:
___own your own manure pump
___own a manure pump jointly with another farmer
___rent a manure pump
___other (please explain)__________________________

13. How do you apply manure? (Complete for each that you use)

	Acres	Rate (specify gallons or tons per acre)
-rowcrop, broadcast	_____	_____
-rowcrop, injected	_____	_____
-alfalfa, broadcast	_____	_____
-pasture, broadcast	_____	_____
-other ____________	_____	_____

14. When do you apply manure? (Check all that apply)
__spring
__summer
__fall
__winter
__year round

15. Do you adjust your fertilizer requirements to reflect the contributions from manure applications?
__yes
__no

If yes, do you consider the nitrogen, phosphorus, and potassium content, or just phosphorus and potassium?
_____nitrogen, phosphorus, and potassium
_____just phosphorus and potassium
_____just nitrogen

16. If you DO NOT consider nutrient contributions from your manure applications, why not (check one)?

___Manure builds good soil structure but is of little use as a fertilizer
___Do not know nutrient value of the manure on my farm that is available for plant use
___Manure on this farm is a waste product to be disposed of, not used as a fertilizer
___I follow fertilizer and lime recommendations on the soil test report to the letter, whether or not allowance has been made for manure
___although manure has significant nutrient values, the costs of considering it outweigh the benefits
___other (specify)_______________________________________

17. Do you treat water for household purposes (other than water softening)?
no__
yes__
If yes, when did you start treatment (year)____

How did you decide you needed water treatment?
__had well tested
__local merchant
__direct sales representative
__general safety concerns
__other________________________

18. If you thought your household water needed treatment, where would you go to obtain information?

__county extension office
__county sanitarian
__local physician
__county health office
__don't know where to go
__other______________________

19. During the past five years have you had your household water tested for bacteria, nitrates, or pesticides (including herbicides)?
__no
__yes

If yes, what were the test conclusions with respect to household use (circle one):

a.	bacteria content	safe	marginally safe	unsafe	don't recall
b.	nitrate content	safe	marginally safe	unsafe	don't recall
c.	pesticide content	safe	marginally safe	unsafe	don't recall

20. Have people or animals suffered any illness or injury from nitrate in water on your farm?
__yes
__no
If yes, please explain ______________________________

21. Have people or animals suffered any illness or injury from pesticides in water on your farm?
__yes
__no
If yes, please explain ______________________________

22. How concerned are you that the use of agricultural chemicals (fertilizers and pesticides) poses a health risk to people:

	not at all concerned	somewhat concerned	very concerned	not sure
a. in the nation as a whole	1	2	3	4
b. in Virginia	1	2	3	4
c. in Rockingham county	1	2	3	4
d. on my farm	1	2	3	4

23. How concerned are you about adverse effects of agricultural fertilizers on:

	not at all concerned	somewhat concerned	very concerned	not sure
a. productivity of land in the years ahead	1	2	3	4
b. entering surface waters and polluting lakes and rivers	1	2	3	4
c. infiltrating the soil and polluting shallow ground water (depth to 100ft.)	1	2	3	4
d. infiltrating through soil and polluting deep, large reservoirs of ground water (depth greater than 100 ft.)	1	2	3	4

24. Please read the following statements and indicate the extent that you agree or disagree with each:

	tend to agree	somewhat agree	somewhat disagree	strongly disagree
a. I am confident that agricultural pesticides, if used as directed are not a threat to the environment	1	2	3	4
b. we cannot be too careful when it comes to putting new pesticides on the market	1	2	3	4
c. should groundwater supplies become contaminated, I am confident scientists will develop ways to purify them	1	2	3	4
d. we already have too much regulation on the use of agricultural pesticides	1	2	3	4
e. so little pesticide residue ever enters the ground water, it could never pose a health risk for humans	1	2	3	4
f. instead of worrying about the should spend more effort in solving				

other problems in farming	1	2	3	4
g. water quality is more an issue for the future--today the threat from agricultural chemicals is quite small	1	2	3	4
h. I worry about the purity of drinking water in Rockingham County	1	2	3	4
i. too much money is being spent in Rockingham County to study agricultural residues in ground water	1	2	3	4
j. pollution control requirements have gone too far; they already cost more than they are worth	1	2	3	4
k. protecting the environment is so important that the requirements cannot be too high, and continuing improvements must be made regardless of costs	1	2	3	4
l. we must relax environmental standards in order to achieve economic growth	1	2	3	4
m. we must accept a slower economic growth in order to protect the environment	1	2	3	4
n. agriculture should be allowed to expand but in a way that will cause minimum damage to the environment	1	2	3	4

25. Farm operator characteristics

a. what is your age

___30 years or less
___31 to 49 years
___50 to 64 years
___65 and older

b. formal education

___some high school (or less)
___high school graduate
___vocational school
___some college

___college graduate or more

c. off farm employment in 1986
yourself ___days
your spouse ___days

d. labor hired in 1986
(not counting immediate family) _____total worker-days

e. years you have farmed_____

Thank you for your help!

APPENDIX C

SURVEY INFORMATION ON NITROGEN APPLICATION RATES IN ROCKINGHAM COUNTY

This appendix contains per acre nitrogen application rates for corn differentiated by the large farm-small farm breakdown. Statistical analysis is then performed on other farm management and attitudinal characterstics.

Large Farm

No statistically significant differences were found between high-appliers and low-appliers regarding farm size (in total acres or milking herd size), percentages of total acreage planted to conventional and no till corn, alfalfa, or pasture, or between acres owned and rented by the group. Likewise, no differences in fertilization techniques were revealed (i.e. the same percentage of both groups used sidedress or split application). Regarding other operating characteristics, no differences were found between off farm employment (self or spouse) or years farmed. However, high-appliers did purchase significantly more worker days (474 vs. 252) than low-appliers.

Attitudinally, no differences were found between the groups for priorities for Virginia farmers, concern over national, regional, or local ground water problems, or knowledge and concern over physical issues. Five of the 14 attitudinal questions were significantly different; dividing these questions into the SC and CC classes used earlier in this chapter, high- appliers consistently saw agricultural chemicals as <u>less</u> of an environmental problem than low-appliers.

All farmers used soil testing services. 22 of 24 high- appliers used some type of conservation practice, compared with 46 of 59 low-appliers. Nineteen high-appliers considered commercial labs their primary source of information for fertilization decisions (6 considered labs their second most important source), while 24 low-appliers considered labs their most important source (3 secondary). Three high-appliers considered fertilizer salesmen their most important information source (3 secondary), while 9 low-appliers considered salesmen most important (9 secondary source).

Discussion

Since no differences were found between herd size, acreage, or pasture size, cow-to-acreage ratios were virtually identical between the two groups. It is possible that the greater number of hired workers by high-appliers could lead to sloppier management practices, due to less supervision of nutrient management practices by the farm operator.

Attitudinal differences revealed that high-appliers were found to be more in agreement with questions such as "I am confident that agricultural pesticides if used as directed are not a threat to the environment," "we already have too much regulation on the use of pesticides," and "too much money is being spent in Rockingham County to study agricultural chemical residues in ground water"; these high-appliers were less in agreement with "we cannot be too careful when it comes to putting new pesticides on the market" and "protecting the environment is so important that the requirements cannot be too high." Differences in means ranged from .32 to .59 (on a scale of four). These results could indicate that high-appliers have less concern over the environmental consequences of their actions than low-appliers; for the other group, this type of concern could lead to moderating influences on their application rates.

Small Farms

Few significant differences were found in the small farm sample. More conventional till corn was grown on low-appliers' farms than on high-appliers; otherwise, none of the farm characteristics differed significantly, nor did workers hired, years farmed, or education. Low-appliers tended to rent more land than high-appliers, although owned land acreage did not differ. High-appliers (the operator him/herself) spent more days working off farm than low-appliers. High-appliers were also less concerned about the health risk of agricultural chemicals both in the county and on their own farm than low-appliers. Only one attitudinal question differed: "we cannot be too careful when it comes to putting new pesticides on the market," with high- appliers less in agreement than low-appliers. Finally, high- appliers were younger on average than low-appliers.

Virtually all farmers used soil testing services. Nine of 15 high-appliers used some type of conservation practices (e.g. strip cropping), compared to 25 of 36 low-appliers. Four high-appliers considered commercial laboratories their primary source of information for fertilization decisions (1 secondary), while 7 considered salesmen their primary source (2 secondary). Fifteen low-appliers considered labs their primary source (none considered labs as second most important), with 7 naming salesmen as primary sources (10 secondary).

Discussion

It is possible that increased hours worked off farm could adversely affect time spent on management and application decisions. However, these averages are based on a very small sample, so that it is hard to draw any general inferences. More land is rented by low-appliers, so that if non-ownership of land were expected to lead to mismanagement, one would see high- appliers being less of a problem in this area.

High-appliers on small farms did see agricultural chemical contamination on their own farm and in the county as a whole to be less of a problem than low-appliers. This could lead to a similar situation as for the large farms, with high-appliers seeing no environmental incentives to closely monitor nitrogen applications.

APPENDIX D

THE QUALITATIVE CHOICE MODEL FOR ANALYZING MANURE TESTING DECISIONS

THE QUALITATIVE CHOICE MODEL FOR ANALYZING MANURE TESTING DECISIONS

The econometric model used in chapter three was constructed to estimate the effects of various socioeconomic factors on the test-adoption decision. Since the dependent variable in this case is binary (0-1)--that is, the only possible answers to the question of "If a manure testing service were available at a reasonable cost, would you use it?" are yes (1) and no (0)--a qualitative choice model was used. This technique has been widely employed for modeling farm-level decision making (Hill and Kau, 1973; Kulshreshtha, 1975), recreation (Miller and Hay, 1981; Hagemann, 1981), demand analysis (Huang and Raunikar, 1982), and participation in various government programs (Capps and Kramer, 1985; Huang, Fletcher, and Raunikar, 1981).

Variable Selection

A total of ten independent variables were selected as having potential impact on the test-adoption decision:

Size of dairy herd (head). It was hypothesized that since a larger milking herd produced more manure (hence more N), a farmer faced a larger potential loss of nutrients by not using manure N. Therefore, herd size would increase the probability that the farmer would adopt manure testing to take greater advantage of this N. (HEAD) Anticipated sign is positive.

Corn acreage (acres). Since corn is the major nitrogen- intensive crop in the area, it was thought that more corn acreage would increase the potential value of the farmers' manure N, thereby increasing the probability of test-adoption. (CORN)

Anticipated sign is positive.

Conservation practices (0-1). It was assumed that if the farmer used conservation practices (such as grass waterways or filter strips) he would be more likely to adopt other practices which more efficiently use available resources.

Anticipated sign is positive. (CONS)

Soil testing (0-1). It was assumed that if the farmer soil tested on an annual basis, he would be more likely to use similar testing services. (SOILT)

Anticipated sign is positive.

Adjust commercial nitrogen (0-1). If the farmer adjusted his commercial fertilizer application rates to reflect the contribution of his manure N, it was assumed that he would value the information gained from a manure test. (NADJ)

Anticipated sign is positive.

Age (1-4). It was hypothesized that older farmers would be less likely to adopt new techniques. These older farmers may as a group be less educated or less likely to change traditional practices. (AGE)

Anticipated sign is negative.

Education (0 = less than high school graduate, 1 = high school graduate or more). It was also hypothesized that farmers who had completed more years of formal education would be more likely to adopt new techniques, due to more developed mangerial skills. (EDUC)

Anticipated sign is positive.

Don't know nutrient value of manure (0-1). If a farmer maintained (in the survey) that he did not take credit for his manure N due to lack of knowledge of its nutrient value, it was assumed that he would value a means of obtaining this information. (DKNOW)

Anticipated sign is positive.

Storage (0-1). Lack of storage facilities on the farm inhibits effective utilization of manure N; therefore, farmers with more storage (hence more recoverable manure N) were deemed more likely to use a testing service. Two 0-1 variables were included, one for 120 days storage and one for 180 days storage (STOR1 and STOR2)

Anticipated sign is positive.

Algorithm Selection

Although ordinary least squares (OLS) can be used to estimate the relationship between the manure testing decision and the aforementioned independent variables via the linear probability model, numerous problems inherent with OLS--among them heteroskedasticity, non-normal distribution of the error term, and the tendency of the model to predict values outside the 0-1 range--tend to negate its usefulness. Therefore, the logit technique was selected to solve the model.[1]

The logit model is based on the cumulative logistic probability function, which is very similar to the t distribution with seven degrees of freedom (which approximates the normal as the number of degrees of freedom grows large). This technique avoids the problems of the linear probability model. In addition, the maximum likelihood parameter estimates generated by both logit have the desirable properties of consistency, asymptotic efficiency, and asymptotic normality of the error terms (Pindyck and Rubinfeld, 1981). This last property is especially attractive since it allows the use of asymptotic t-tests.

Consistency, efficiency, and normality are all large sample properties. Although there is no clear agreement on what sample size constitutes a "large" sample, it was assumed that the survey data set (which consisted of 106 observations after elimination of those responses with missing or uninterpretable values) was large enough to invoke these asymptotic properties. The model was solved using the SHAZAM computer algorithm (White, 1978).

GOODNESS OF FIT

For the case of discrete choice models, the ordinary R^2 measure is of limited usefulness.[2] An alternative measure is McFadden's R^2, which is calculated as

$$1 - \log L(B)/\text{Log } L(B_0)$$

The second term is the likelihood ratio index, which is the ratio of the log of the likelihood function including the estimated B's divided by the log of the likelihood function where all of the B_i's = 0 (excepting the intercept). McFadden's R^2 for the model was .3124.

Calculation of Probability Estimates

One useful result yielded by qualitative choice analysis is a means of assessing the probability that a farmer of given characteristics will participate in a manure testing program. If it is assumed that the representative farmer in Rockingham County is described by the means of the ten variables in the model, the probability that the average farmer will participate in the program can be obtained. For the model, this probability translates to

$$P\ (\text{adopt manure testing} \mid X_i = X_i) \qquad (1)$$

Since the logit model relies on the logistic density function

$$f(z_i) = e^z / (1 + e^z),\ 0 < z_i < oo$$

the value of z_i can be found by

$$z_i = B_i X_i$$

where the B_is are the estimated parameter values and the X_is are the mean values of each variable. Therefore,

$$\begin{aligned} z_i = \ & -2.6674 + .023927\ (78.915) \qquad (2) \\ & - .0070544\ (77.094) - .28350\ (.81132) \\ & + 1.5498\ (.40566) + 2.7188\ (.87736) \\ & - .59182\ (2.0755) + .81910\ (.50) \\ & + 2.1875\ (.05660) - .55793\ (.16038) \\ & + 1.1604\ (.49057) = 1.24783 \end{aligned}$$

and

$$P_i = e^{1.24783} / (1 + e^{1.24783}) = .7769 \qquad (3)$$

so that the probability that the average farmer in Rockingham County will adopt manure testing is approximately 77.7 percent.

Extension of Analysis to the Representative Farm Models

The logit model can also reveal whether farm size and the characteristics of operators on these farms affects the test- adoption decision. As previously described, it was felt that county farms could be roughly divided into two groups, greater than and less than 100 acres. Using the herd size and cropland area averages assumed for the mathematical programming model as proxies for size, the P_i statistic in (3) was then generated for both groups.

For the large farm case, where HERD = 100 and CORN = 90, equation (2) becomes:

$$z_i = -2.6674 + .023927\ (100) - .0070544\ (90) \qquad (4)$$
$$-.28350\ (.81132) + 1.5498\ (.40566) + 2.7188\ (.87736)$$
$$-\ .59182\ (2.0755) + .81910\ (.50) + 2.1875\ (.05660)$$
$$-\ .55793\ (.16038) + 1.1604\ (.49057) = 1.66129$$

and the value of (3) becomes .84062 or about 84.1 percent, so that the larger representative farm is more likely to adopt manure testing than the average size county farm. For a farm with a herd of 60 milking cows and growing 55 acres of corn, z_i = 0.94911, and probability of adoption decreases to 72.1 percent. This result indicates that, other variables held constant, small farmers are <u>less</u> likely to adopt manure testing than the average Rockingham County farmer. This logit result is validated by analysis of survey data, which indicates that farmers with 100 acres or less of cropland are significantly less likely (in statistical terms) to use a manure testing service than farmers with more than 100 acres of cropland. It must be emphasized that these values are generated assuming that all other characteristics built into the model--age, education level, soil testing, nutrient management--are identical between the two farm sizes, which may be an overly restrictive assumption.

Changes in Level of Explanatory Variables

Also of interest to policymakers is how much this probability of test-adoption could be affected by induced changes in the independent variables. Variables used in this model which might be of interest to policymakers are EDUC and STOR2, since variables like age and farm size are not under their direct control. To determine the effect of a change in either variable from the reference case, the value of z_i was calculated for x_i = 0 and x_i = 1, where x_i is the relevant 0-1 variable.

For the STOR2 variable, the value of z_i with no storage is .67857. This translates (using equation 2) to a probability of test adoption of .66342. For STOR2 = 1, z_i = 1.83897 and probability of test adoption increases to .86283. Thus, other variable values remaining the same, a farmer with 180 days storage is about 20 percent more likely to adopt manure testing than one with no storage.

Following similar logic for the EDUC variable, if the respondent is not a high school graduate, the probability of adoption is .6981 or about 69.8 percent. For high school graduates, the probability of adoption is .83989 or about 84 percent. Probability of adoption is then 14 percent higher for high school graduates than for non-graduates.

It must be noted that a substantial amount of financial capital is required to upgrade manure storage facilities, and a major investment in human capital is needed to effect an increase in education level. In addition, formal education is not really a "policy relevant" variable. Still, these figures indicate that improvements in storage capacity and increased formal education levels could help insure success of a manure testing program.

ENDNOTES

1. Other techniques which deal with limited dependent variables are Tobit and discriminant analysis. Tobit (for Tobin's Probit) is used with dependent variables having both quantitative and qualitative characteristics (Tobin, 1958; Ziemer and White, 1981; Norris and Batie, 1987). Discriminant analysis (Anderson, 1958) concentrates on classification while qualitative choice models are more concerned with estimation.

2. Only in extreme cases, where all predicted probabilities are 0 or 1, would a high R^2 be obtained, so that the realistic upper limit of the coefficient of determination is substantially less than one, perhaps as low as .333 (Capps, 1983; Morrison, 1972).

APPENDIX E

MATHEMATICAL PROGRAMMING MODELS USED IN THIS STUDY

The Dairy LP Model

The DAIRYLP model was developed by Groover and Allen (1985) for use by farm management agents in assisting state dairy farmers in evaluating different cropping alternatives, determining optimal herd sizes, and making input mix decisions. The model is a revision of the West Central District dairy model developed by Chapman Huffman.

The model consists of 67 activities and 111 constraints. The major contributions of the DAIRYLP model to the Rockingham County model were labor requirements for the dairy herd and crop activities. Labor in the model was divided into four seasons: December-March, April-May, June-August, and September-November. Hours devoted to dairy herd management were estimated on a per- cow basis, based on the Huffman model. Labor hours devoted to crop production were based on agricultural engineering estimates of field time required on a per-acre basis.

The Rockingham County Mathematical Programming Model

The Rockingham County model was developed as a cooperative effort by John Halstead, Penelope Diebel, Minkang Zhu, Daniel Taylor, and Randall Kramer of the Department of Agricultural Economics, Virginia Polytechnic Institute and State University. The initial structure of the model was obtained from the DAIRYLP tableau and the crop and livestock budgets for the west central region of Virginia. These estimates were refined through consultation with county extension personnel, county engineering firms, Virginia Tech dairy farm personnel, and custom applicators of agricultural chemicals, and through information obtained from the Rockingham County dairy farm survey. The objective function of the model and a breakdown of model constraints by major category follows, along with a brief description of each. Explanation of variable abbreviations are provided in table C.1.

THE REPRESENTATIVE FARM MODEL

A. THE OBJECTIVE FUNCTION

```
MAX  - 0.0025SPRM - 4.31LAB1 - 4.31LAB2 - 4.31LAB3
   - 4.31LAB4 - 775.675DAIRYD - 775.675DAIRY2 - 775.675DAIRY4
   - 775.675DAIRY6 - 777.89DAIRYAD - 777.89DAIRYA2
   - 777.89DAIRYA4 - 777.89DAIRYA6 - 783.27DAIRYACD
   - 783.27DAIRYAC2 - 783.27DAIRYAC4 - 783.27DAIRYAC6
   - 160.43CRSILD - 137.028CSM4 - 137.028CSM6 - 175.39CRSILDA
   - 154.09CSMA4 - 154.09CSMA6 - 140.36CRGRD - 123.862CGM4
   - 123.862CGM6 - 191.89CRGRDA - 140.36CRGRD1 - 140.36CRGRD2
   - 160.43CRSILD1 - 160.43CRSILD2 - 123.862CGM2 - 170.59CGMA2
   - 123.862CGM21 - 170.59CGMA21 - 123.862CGM22 - 170.59CGMA22
   - 123.862CGM41 - 170.59CGMA41 - 123.862CGM42 - 170.59CGMA42
   - 123.863CGM61 - 170.59CGMA61 - 123.862CGM62 - 170.59CGMA62
   - 191.89CRGRDA1 - 191.89CRGRDA2 - 175.39CRSILDA1
   - 175.39CRSILDA2 - 137.028CSM2 - 154.09CSMA2
   - 137.028CSM21 - 154.09CSMA21 - 137.028CSM22 - 154.09CSMA22
   - 137.028CSM41 - 154.09CSMA41 - 137.028CSM42 - 154.09CSMA42
   - 137.028CSM61 - 154.CSMA61 - 154.09CSMA62 - 137.028CSM62
   - 154.09CSMA62 - 170.59CGMA4 - 170.59CGMA6 - 226.62ALFD
   - 226.6ALF2 - 226.26ALF4 - 226.26ALF6 - 18.58PASTD
   - 18.58PASTM - 18.58PASTM2 - 915.44STRAWB2 - 915.44STRAWB4
   - 915.44STRAWB6 - 101.82BARD - 82.02BARM2 - 82.02BARM4
   - 82.02BARM6 - 2.6BYCGR - 120BYHY - 20RNTPASD
   - .21BYFD - .21BYFM2 - .21BYFM4 - .21BYFM6
   - 0.0TAX - BYBIRDD - BYBIRD2 - BYBIRD4 - BYBIRD6
   + 50SLLCLF + 400SLLCULL + 12SLLMK + 120ALFO + .1468WRTOFF
   - 1.5STCSIL - 0.25STCGR - 1.5STRY - 0.1468BORR15
```

B. POLICY CONSTRAINTS

1. TAX - BYFD - BYFM2 - BYFM4 - BYFM6 = 0

An accounting row which sets TAX equal to total commercial fertilizer purchase. The objective function value of TAX is thus the amount of a corrective tax imposed.

TABLE E.1. ABBREVIATIONS OF VARIABLE NAMES USED IN THE REPRESENTATIVE FARM MATHEMATICAL PROGRAMMING MODEL.

DAIRYD	One dairy cow/year, no storage, silage ration (head)
DAIRY2	One dairy cow/year, 60 day storage, silage ration (head)
DAIRY4	One dairy cow/year, 120 day storage, silage ration (head)
DAIRY6	One dairy cow/year, 180 day storage, silage ration (head)
DAIRYAD	One dairy cow/year, no storage, alfalfa-barley ration (head)
DAIRYA2	One dairy cow/year, 60 day storage, alfalfa-barley ration (head)
DAIRYA4	One dairy cow/year, 120 day storage, alfalfa-barley ration (head)
DAIRYA6	One dairy cow/year, 180 day storage, alfalfa-barley ration (head)
DAIRYACD	One dairy cow/year, no storage, afalfa-corn grain ration (head)
DAIRYAC2	One dairy cow/year, 60 day storage, alfalfa-corn grain ration (head)
DAIRYAC4	One dairy cow/year, 120 day storage, alfalfa-corn grain ration (head)
DAIRYAC6	One dairy cow/year, 180 day storage, alfalfa-corn grain ration (head)
CRSILDA	Corn silage, no till, no storage, 17 ton yield (acres)
CRGRDA	Corn grain, no till, no storage, 110 bushel yield (acres)
CRSILD	Corn silage, conventional till, no storage, 15 ton yield (acres)
CRGRD	Corn grain, conventional tillage, no storage, 100 bushel yield (acres)
CRSILDA1	Corn silage, no till, no storage, 14.8 ton yield (acres)
CRGRDA1	Corn silage, no till, no storage, 95.8 bushel yield (acres)
CRSILD1	Corn silage, conventional tillage, no storage, 13.5 ton yield (acres)
CRGRD1	Corn grain, conventional till, no storage, 92.7 bushel yield (acres)
CRGRD2	Corn grain, no till, no storage, 85.4 bushel yield (acres)
CRSILD2	Corn silage, no till, no storage, 12 ton yield (acres)
CRSILDA2	Corn silage, no till, no storage, 12.4 ton yield (acres)

TABLE E.1. (continued) ABBREVIATIONS OF VARIABLE NAMES USED IN THE REPRESENTATIVE FARM MATHEMATICAL PROGRAMMING MODEL.

CRGRDA2	Corn grain, no till, no storage, 88.5 bushel yield (acres)
CSMA2	Corn silage, no till, 60 day storage, 17 ton yield (acres)
CGMA2	Corn grain, no till, 60 day storage, 110 bushel yield (acres)
CSM2	Corn silage, conventional till, 60 day storage, 15 ton yield (acres)
CGM2	Corn grain, conventional tillage, 60 day storage, 100 bushel yield (acres)
CSMA21	Corn silage, no till, 60 day storage, 14.8 ton yield (acres)
CGMA21	Corn silage, no till, 60 day storage, 95.8 bushel yield (acres)
CSM21	Corn silage, conventional tillage, 60 day storage, 13.5 ton yield (acres)
CGM21	Corn grain, conventional till, 60 day storage, 92.7 bushel yield (acres)
CGMA22	Corn grain, no till, 60 day storage, 88.5 bushel yield (acres)
CSMA22	Corn silage, no till, 60 day storage, 12.4 ton yield (acres)
CSM22	Corn silage, conventional till, 60 day storage, 12 ton yield (acres)
CGM22	Corn grain, conventional till, 60 day storage, 85.4 bushel (acres)
CSMA4	Corn silage, no till, 120 day storage, 17 ton yield (acres)
CGMA4	Corn grain, no till, 120 day storage, 110 bushel yield (acres)
CSM4	Corn silage, conventional till, 120 day storage, 15 ton yield (acres)
CGM4	Corn grain, conventional tillage, 120 day storage, 100 bushel yield (acres)
CSMA41	Corn silage, no till, 120 day storage, 14.8 ton yield (acres)
CGMA41	Corn silage, no till, 120 day storage, 95.8 bushel yield (acres)
CSM41	Corn silage, conventional tillage, 120 day storage, 13.5 ton yield (acres)
CGM41	Corn grain, conventional till, 120 day storage, 92.7 bushel yield (acres)
CSMA42	Corn grain, no till, 120 day storage, 88.5 bushel yield (acres)
CGMA42	Corn silage, no till, 120 day storage, 12.4 ton yield (acres)

TABLE E.1. (continued) ABBREVIATIONS OF VARIABLE NAMES USED IN THE REPRESENTATIVE FARM MATHEMATICAL PROGRAMMING MODEL.

CSM42	Corn silage, conventional till, 120 day storage, 12 ton yield (acres)
CGM42	Corn grain, conventional till, 120 day storage, 85.4 bushel (acres)
CSMA6	Corn silage, no till, 180 day storage, 17 ton yield (acres)
CGMA6	Corn grain, no till, 180 day storage, 110 bushel yield (acres)
CSM6	Corn silage, conventional till, 180 day storage, 15 ton yield (acres)
CGM6	Corn grain, conventional tillage, 180 day storage, 100 bushel yield (acres)
CSMA61	Corn silage, no till, 180 day storage, 14.8 ton yield (acres)
CGMA61	Corn silage, no till, 180 day storage, 95.8 bushel yield (acres)
CSM61	Corn silage, conventional tillage, 180 day storage, 13.5 ton yield (acres)
CGM61	Corn grain, conventional till, 180 day storage, 92.7 bushel yield (acres)
CSMA62	Corn grain, no till, 180 day storage, 88.5 bushel yield (acres)
CGMA62	Corn silage, no till, 180 day storage, 12.4 ton yield (acres)
CSM62	Corn silage, conventional till, 180 day storage, 12 ton yield (acres)
CGM62	Corn grain, conventional till, 180 day storage, 85.4 bushel (acres)
ALFD	Alfalfa hay, no storage (acres)
ALF2	Alfalfa hay, 60 day storage (acres)
ALF4	Alfalfa hay, 120 day storage (acres)
ALF6	Alfalfa hay, 180 day storage (acres)
PASTD	Pasture, no storage (acres)
PASTM	Pasture, 60 day storage (acres)
PASTM2	Pasture, 120 or 180 day storage (acres)
STRAWB2	Strawberries, 60 day storage (acres)
STRAWB4	Strawberries, 120 day storage (acres)
STRAWB6	Strawberries, 180 day storage (acres)
BARD	Barley, no storage (acres)
BARM2	Barley, 60 storage (acres)
BARM4	Barley, 120 day storage (acres)
BARM6	Barley, 180 day storage (acres)
BYCGR	Buy corn grain (bushels)
BYFD	Buy N fertilizer, no manure storage (pounds/N)
BYFM2	Buy N fertilizer, 60 day storage (pounds/N)
BYFM4	Buy N fertilizer, 120 day storage (pounds/N)

TABLE E.1. (continued) ABBREVIATIONS OF VARIABLE NAMES USED IN THE REPRESENTATIVE FARM MATHEMATICAL PROGRAMMING MODEL.

BYFM6	Buy N fertilizer, 180 day storage (pounds/N)
SLLCLF	Sell dairy calves (head)
SLLCULL	Sell cull cows (head)
SLLMK	Sell milk (cwt)
ALFO	Sell alfalfa hay (tons)
SURPH	Surplus hay (tons)
STHY	Store alfalfa hay (tons)
STRY	Store rye (tons)
BYHY	Buy alfalfa hay (tons)
RNTPASD	Divert cropland to pasture for manure spreading (acres)
TAX	Number of pounds of commercial fertilizer purchased
STCSIL	Store corn silage (tons)
STCGR	Store corn grain (bushels)
LAB1	Labor requirements, December-March (hours)
LAB2	Labor requirements, April-May (hours)
LAB3	Labor requirements, June-August (hours)
LAB4	Labor requirements, September-November (hours)
BORR15	Borrow capital, 15 year payback (dollars)
BY2	Buy 60 days manure storage (gallons)
BY4	Buy 120 days manure storage (dollars)
BY6	Buy 180 days manure storage (dollars)
MTND	Conversion of manure (tons) to available nitrogen (pounds)
MTN4	Conversion of manure (gallons) to available nitrogen (pounds)
MTN6	Conversion of manure (gallons) to available nitrogen (pounds)
SPRM	Spread manure from two, four or six month storage (gallons)
WRTOFF	Net present value (at 12 percent interest) of tax advantages of siting a manure storage facility. This figure is deducted from the post-cost sharing (if any) purchase price of the storage structure.
CSTSHARE	Amount of cost sharing assumed in the specific version of the representative farm model
BYBIRDD	Buy one pound of poultry litter nitrogen, no storage
BYBIRD2	Buy one pound of poultry litter nitrogen, 60 day storage
BYBIRD4	Buy one pound of poultry litter nitrogen, 120 day storage
BYBIRD6	Buy one pound of poultry litter nitrogen, 180 day storage
TREV	Tax revenue generated

TABLE E.1. (continued) ABBREVIATIONS OF VARIABLE NAMES USED IN THE REPRESENTATIVE FARM MATHEMATICAL PROGRAMMING MODEL.

STMD	Integer constraint. Choose no manure storage option.
STM2	Integer constraint. Choose 60 day storage option.
STM4	Integer constraint. Choose 120 day storage option.
STM6	Integer constraint. Choose 180 day storage option.

2. .00TAX - TREV = 0
Accounting row to determine the amount of tax revenue generated.

3. 11000STM4 + 11000STM6 - CSTSHARE = 0
Allows for cost sharing of $11,000 if the model chooses either 120 or 180 day storage.

4. .3572BORR15 - WRTOFF = 0
Allows for tax writeoff of 35.72% of total financed for manure storage structure.

5. PASTD - 00DAIRYD - 00DAIRYAD - 00DAIRYACD < 0
Policy constraint to set minimum per cow acreage required if daily manure spreading routine is followed.

6. PASTD - RNTPASD - 85STMD < 0
Requires that acreage required for daily spreading in excess of the 85 acres of assumed pasture be drawn from active cropland.

C. HERD CONSTRAINTS

1. DAIRYD + DAIRY2 + DAIRY4 + DAIRY6
+ DAIRYACD + DAIRYAC2 + DAIRYAC4 + DAIRYAC6
+ DAIRYAD + DAIRYA2 + DAIRYA4 + DAIRYA6 < 100 (60)
Upper limit on herd size, based on survey results.

2. DAIRYD + DAIRY2 + DAIRY4 + DAIRY6
+ DAIRYACD + DAIRYAC2 + DAIRYAC4 + DAIRYAC6
+ DAIRYAD + DAIRYA2 + DAIRYA4 + DAIRYA6 > 67 (43)
Lower limit on herd size, based on minimum number of cows to keep profit level of operation at or above $15,000 annually.

D. ACREAGE CONSTRAINTS

1. PASTD + PASTM2 + PASTM > 85
Sets pasture acreage equal to 85 acres.

2. CRSILD + CSM4 + CSM6 + CRSILDA + CSMA4
+ CSMA6 + CRGRD + CGM4 + CGM6 + CRGRDA + CGMA4
+ CGMA6 + ALFD + ALF2 + ALF4 + ALF6
+ CSM2 + CSMA2 + CGM2 + CGMA2 + CRGRD1 + CRGRDA1 + CRSILD1
+ CRSILDA1 + CRGRD2 + CRGRDA2 + CRSILD2 + CRSILDA2 + CGM21
+ CGMA21 + CSM21 + CSMA21 + CGM22 + CGMA22 + CSM22
+ CSMA22 + CGM41 + CGMA41 + CSM41 + CSMA41 + CGM42
+ CGMA42 + CSM42 + CSMA42 + CGM61 + CGMA61 + CSM61
+ CSMA61 + CGM62 + CGMA62 + CSM62 + CSMA62 + STRAWB2
+ STRAWB4 + STRAWB6 + BARD + BARM2 + BARM4 + BARM6
+ RNTPASD < 115 (55)
Total cropland constraint.

3. ALFD + ALF2 + ALF4 + ALF6 < 85 (44)
Sets maximum acreage of cropland which can be planted to alfalfa due to disease problems to 80% of total cropland.

E. DAIRY HERD FEED REQUIRMENTS

1. 106.78DAIRYD + 106.78DAIRY2 + 106.78DAIRY4 + 106.78DAIRY6
+ 152.17DAIRYACD + 152.17DAIRYAC2 + 152.17DAIRYAC4
+ 152.17DAIRYAC6 - BYCGR - STCGR = 0
Corn grain requirements (bushels) per cow in the feed rations for silage and alfalfa-corn grain. Deficit of on-farm production is made up for by market purchase.

2. 6.42DAIRYD + 6.42DAIRY2 + 6.42DAIRY4 + 6.42DAIRY6
- STCSIL = 0
Silage requirements (tons) per cow on silage ration. No off-farm purchase allowed.

3. 0.796DAIRYD + 0.796DAIRY2 + 0.796DAIRY4 + 0.796DAIRY6
+ 4.38DAIRYAD + 4.38DAIRYA2 + 4.38DAIRYA4 + 4.38DAIRYA6
+ 4.74DAIRYACD + 4.74DAIRYAC2 + 4.74DAIRYAC4 + 4.74DAIRYAC6
+ SURPH (-.5STRYA) - STHY - BYHY = 0
Alfalfa requirements per cow in silage, alfalfa-barley, and alfalfa-corn grain rations (tons). Allows substitution of rye for alfalfa in silage ration herd for small farm on a two-to-one ratio. STRYA = rye produced, stored, and fed as alfalfa.

4. 3.196DAIRYD + 3.196DAIRY2 + 3.196DAIRY4 + 3.196DAIRY6
- STRY (STRYR) = 0
Per cow ryelage requirements for silage ration herd (tons).

5. 195.3DAIRYAD + 195.3DAIRYA2 + 195.3DAIRYA4 + 195.3DAIRYA6
- BARST = 0
Per cow barley requirements for alfalfa-barley ration herd.

F. CROP PRODUCTION ACTIVITIES

1. 100CRGRD + 100CGM4 + 100CGM6 + 110CRGRDA
+ 95.8CRGRDA1 + 88.5CRGRDA2
+ 92.7CRGRD1 + 85.4CRGRD2 + 100CGM2 + 110CGMA2 + 92.7CGM21
+ 95.8CGMA21 + 85.4CGM22 + 88.5CGMA22 + 92.7CGM41
+ 95.8CGMA41 + 85.4CGM42 + 88.5CGMA42 + 92.7CGM61
+ 95.8CGMA61 + 85.4CGM62 + 88.5CGMA62 + 110CGMA4
+ 110CGMA6 - STCGR = 0
Corn grain produced and stored on farm (bushels).

2. 5ALFD + 5ALF2 + 5ALF4 + 5ALF6 - STHY - ALFO = 0

Alfalfa hay produced and stored/sold (tons).

3. 5CRSILDA + 5CSMA4 + 5CSMA6 + 5CRGRDA
+ 5CRSILDA1 + 5CRSILDA2 + 5CSMA2 + 5CSMA21
+ 5CSMA22 + 5CSMA41 + 5CSMA42 + 5CSMA61
+ 5CSMA62 + 5CRGRDA1 + 5CRGRDA2 + 5CGMA2
+ 5CGMA21 + 5CGMA22 + 5CGMA41 + 5CGMA42
+ 5CGMA61 + 5CGMA62 + 5CGMA4 + 5CGMA6 - STRY = 0

Ryelage produced and stored on farm (tons).

4. 70BARD + 70BARM2 + 70BARM4 + 70BARM6 - BARST = 0

Barley produced and stored on farm (tons).

5. (STRYR + STRYA = STRY)

Requires that total rye fed as alfalfa and total rye fed as rye not exceed total production in small farm model.

G. DAIRY PRODUCTION ACTIVITIES

1. .39(.78)DAIRYAD + .39(.78)DAIRYA2 + .39(.78)DAIRYA4
+ .39(.78)DAIRYA6 + .39(.78)DAIRYACD + .39(.78)DAIRYAC2
+ .39(.78)DAIRYAC4 + .39(.78)DAIRYAC6 + 0.39(.78)DAIRYD
+ 0.39(.78)DAIRY2 + 0.39(.78)DAIRY4 + 0.39(.78)DAIRY6
- SLLCLF = 0

Male calves produced and sold on farm. Large farms are assumed to keep cow calves for herd replacement, while small farms sell all calves.

2. .33DAIRYAD + .33DAIRYA2 + .33DAIRYA4 + .33DAIRYA6
+ .33DAIRYACD + .33DAIRYAC2 + .33DAIRYAC4 + .33DAIRYAC6
+ 0.33DAIRYD + 0.33DAIRY2 + 0.33DAIRY4 + 0.33DAIRY6
- SLLCULL = 0

Cull rate of .33 per cow per year, so that dairy herd is replaced on a three year average.

3. 160DAIRYD + 160DAIRY2 + 160DAIRY4 + 160DAIRY6
+ 160DAIRYAD + 160DAIRYA2 + 160DAIRYA4 + 160DAIRYA6
+ 160DAIRYACD + 160DAIRYAC2 + 160DAIRYAC4 + 160DAIRYAC6
- SLLMK = 0

Production of 160 hundredweight per cow per year.

H. MANURE PRODUCTION ACTIVITIES

1. - .25MTND + 9.85DAIRYD + 9.85DAIRYAD + 9.85DAIRYACD = 0

Nitrogen produced by dry manure from dairy cows when no manure storage is available.

2. - 113.64MTN2 + 6119DAIRY2 + 6119DAIRYA2
+ 6119DAIRYAC2 = 0

Nitrogen produced by liquid manure from dairy cows when 60 day storage is available.

3. - 83.3MTN4 + 5680DAIRY4 + 5680DAIRYA4 + 5680DAIRYAC4 = 0
Nitrogen produced by liquid manure from dairy cows when 120 day storage is available.

4. - 83.3MTN6 + 5383DAIRY6 + 5383DAIRYA6 + 5383DAIRYAC6 = 0
Nitrogen produced by liquid manure from dairy cows when 180day storage is available.

I. CROP NITROGEN BUDGETS

1. - MTN2 + 100CGM2 + 170CGMA2 + 90CGM21 + 150CGMA21
+ 80CGM22 + 140CGMA22 + 100CSM2 + 170CSMA2
+ 90CSM21 + 150CSMA21 + 80CSM22
+ 140CSMA22 + 100BARM2 + 150STRAWB2 - BYFM2 - BYBIRD2
+ 50STRAWB2 - 12.5ALF2 = 0
Nitrogen required by crops produced when 60 day storage is adopted. Deficits from manure and legume nitrogen are made up for with commercial N purchase.

2. - MTN4 + 90CSM41 + 150CSMA41 + 80CSM42 + 140CSMA42
+ 90CGM41 + 80CGM42 + 150CGMA41 + 140CGMA42
+ 100CSM4 + 170CSMA4 + 100CGM4 + 170CGMA4 + 100BARM4
+ 50STRAWB4 - BYFM4 - BYBIRD4 - 12.5ALF4 = 0
Nitrogen required by crops produced when 120 day storage is adopted. Deficits from manure and legume nitrogen are made up for with commercial N purchase.

3. - MTN6 + 100CSM6 + 170CSMA6 + 100CGM6
+ 170CGMA6 + 150CGMA61 + 140CGMA62 + 90CGM61
+ 80CGM62 + 90CSM61 + 150CSMA61 + 80CSM62 + 140CSMA62
+ 100BARM6 + 50STRAWB6 - BYFM6 - BYBIRD6 - 12.5ALF6 = 0
Nitrogen required by crops produced when 180 day storage is adopted. Deficits from manure and legume nitrogen are made up for with commercial N purchase.

4. - 0.5MTND + 100CRSILD + 170CRSILDA + 100CRGRD
+ 170CRGRDA + 90CRSILD1 + 150CRSILDA1 + 90CRGRD1
+ 150CRGRDA1 + 80CRSILD2 + 140CRSILDA2 + 80CRGRD2
+ 140CRGRDA2 + 100BARD - BYFD - BYBIRDD - 12.5ALFD = 0
Nitrogen required by crops produced when no manure storage is adopted. Deficits from manure and legume nitrogen are made up for with commercial N purchase.

J. BORROWING/FINANCE/VARIABLE COST FOR MANURE STORAGE

1. - 37.08BY2 + 6119DAIRY2 + 6119DAIRYA2 + 6119DAIRYAC2 = 0
Total variable cost of 60 day manure storage facility.

2. - 17.19BY4 + 5680DAIRY4 + 5680DAIRYA4 + 5680DAIRYAC4 = 0
Total variable cost of 120 day manure storage facility.

3. - 11.96BY6 + 5383DAIRY6 + 5383DAIRYA6 + 5383DAIRYAC6 = 0
Total variable cost of 180 day manure storage facility.

4. - BY2 - BY4 - BY6 - 8000STM2 - 8000STM4 - 8000STM6
+ CSTSHARE + BORR15 = 0
Total dollar amount of manure storage facility financed. Includes variable and fixed costs less cost sharing.

K. LIQUID MANURE SPREADING

1. - SPRM + 6119DAIRY2 + 5680DAIRY4 + 5383DAIRY6
+ 6119DAIRYA2 + 5680DAIRYA4 + 5383DAIRYA6 + 6119DAIRYAC2
+ 5680DAIRYAC4 + 5383DAIRYAC6 = 0
Per gallon cost of spreading liquid manure.

L. NITRATE LOADINGS TO GROUND WATER

1. OOCRSILD + OOCSM4 + OOCSM6
+ OOCRSILDA + OOCSMA4 + OOCSMA6 + OOCRGRD
+ OOCGM4 + OOCGM6 + OOCRGRDA + OOCGMA4
+ OOCGMA6 + OOPASTD + OOCRGRD1 + OOCRGRD2 + OOCRSILD1
+ OOCRSILD2 + OOCGM2 + OOCGMA2 + OOCGM21 + OOCGMA21
+ OOCGM22 + OOCGMA22 + OOCGM41 + OOCGMA41 + OOCGM42
+ OOCGMA42 + OOCGM61 + OOCGMA61 + OOCGM62 + OOCGMA62
+ OOCRGRDA1 + OOCRGRDA2 + OOCRSILDA1 + OOCRSILDA2
+ OOCSM2 + OOCSMA2 + OOCSM21 + OOCSMA21 + OOCSM22
+ OOCSMA22 + OOCSM41 + OOCSMA41 + OOCSM42 + OOCSMA42
+ OOCSM61 + OOCSMA61 + OOCSMA62 + OOCSM62
+ OOCSMA62 + OOCGMA4 + OOCGMA6 + OOPASTM2 + OOSTRAWB2
+ OOSTRAWB4 + OOSTRAWB6 + OOBARD + OOBARM2 + OBARM4
+ OOBARM6 - LOADING = (<) 0
Average per acre loadings of nitrate to ground water. Parameters will vary with level of chance constraint imposed.

M. LABOR CONSTRAINTS

1. - LAB1 + 29.77DAIRYD + 29.39DAIRY2 + 29.39DAIRY4
+ 29.39DAIRY6 + 0.6CRSILD + 0.6CSM4 + 0.6CSM6
+ 29.77DAIRYAD + 29.39DAIRYA2 + 29.39DAIRYA4 + 29.39DAIRYA6
+ 29.77DAIRYACD + 29.39DAIRYAC2 + 29.39DAIRYAC4 + 29.39DAIRYAC6
+ 0.6CRGRD + 0.6CGM4 + 0.6CGM6

+ 0.6CSM2 + 0.6CGM2 + 0.6CGM21 + 0.6CGM22
+ 0.6CSM21 + 0.6CSM22
+ 0.6CRSILD1 + 0.6CSM41 + 0.6CSM61
+ 0.6CRGRD1 + 0.6CGM41 + 0.6CGM61
+ 0.6CRSILD2 + 0.6CSM42 + 0.6CSM62
+ 0.6CRGRD2 + 0.6CGM42 + 0.6CGM62 < 816

December-March labor requirements. 816 hours assumed available on farm with deficit purchased.

2. - LAB2 + 14.69DAIRYD + 14.48DAIRY2 + 14.48DAIRY4
+ 14.48DAIRY6 + .8CRSILD + .8CRSILD1 + .8CRSILD2
+ 14.69DAIRYAD + 14.48DAIRYA2 + 14.48DAIRYA4 + 14.48DAIRYA6
+ 14.69DAIRYACD + 14.48DAIRYAC2 + 14.48DAIRYAC4 + 14.48DAIRYAC6
+ 0.8CSM4 + 0.8CSM41 + 0.8CSM42 + 0.8CSM6 + 0.8CSM61
+ 0.8CSM62 + 2CRSILDA + 2CRSILDA1 + 2CRSILDA2 + 2CSMA4
+ 2CSMA41 + 2CSMA42 + 2CSMA6 +2CSMA61 + 2CSMA62 + 1.43CRGRD
+ 1.43CRGRD1 + 1.43CRGRD2 + 1.43CGM4 +1.43CGM41 + 1.43CGM42
+ 2CSMA21 + 2CSMA22 + 2CSMA2 +2CGMA2 + 2CGMA21
+ 2CGMA22 + 1.43CGM2 + 1.43CGM21 + 1.43CGM22
+ .8CSM2 + .8CSM21 + .8CSM22
+ 1.43CGM6 + 1.43CGM61 + 1.43CGM62 + 2CRGRDA + 2CRGRDA1
+ 2CRGRDA2 + 2CGMA4 + 2CGMA41 + 2CGMA42 + 2CGMA6 + 2CGMA61
+ 2CGMA62 + 4ALFD + 4ALF2 + 4ALF4 + 4ALF6
+ 3.16BARD + 3.16 BARM2 + 3.16 BARM4
+ 3.16BARM6 + 51STRAWB2 + 51STRAWB4 + 51STRAWB6 < 432

April-May labor requirements. 432 hours assumed available on farm with deficit purchased.

3. - LAB3 + 22.97DAIRYD + 22.65DAIRY2 + 22.65DAIRY4
+ 22.65DAIRY6 + 22.97DAIRYAD + 22.65DAIRYA2 + 22.65DAIRYA4
+ 22.65DAIRYA6 + 22.97DAIRYACD + 22.65DAIRYAC2 + 22.65DAIRYAC4
+ 22.65DAIRYAC6 + 8ALFD + 8ALF2 + 8ALF4 + 8ALF6
+ 0.1PASTD + .1PASTM2 + 0.1PASTM + 180STRAWB2
+ 180STRAWB4 + 180STRAWB6 < 624

June-August labor requirements. 624 hours assumed available on farm with deficit purchased.

4. - LAB4 + 23.55DAIRYD + 23.23DAIRY2 + 23.23DAIRY4
+ 23.23DAIRY6 + 23.55DAIRYAD + 23.23DAIRYA2 + 23.23DAIRYA4
+ 23.23DAIRYA6
+ 23.55DAIRYACD + 23.23DAIRYAC2 + 23.23DAIRYAC4 + 23.23DAIRYAC6
+ 4.4CRSILD + 4.4CRSILD1 + 4.4CRSILD2
+ 4.4CSM4 + 4.4CSM41 + 4.4CSM42 + 4.4CSM6 + 4.4CSM61
+ 4.4CSM62 + 5.75CRSILDA + 5.75CRSILDA1 + 5.75CRSILDA2
+ 5.75CSMA4 + 5.75CSMA41 + 5.75CSMA42 + 5.75CSMA6
+ 5.75CSMA61 + 5.75CSMA62 + 2.83CRGRD + 2.83CRGRD1
+ 2.83CRGRD2 + 2.83CGM2 + 2.83CGM21 + 2.83CGM22
+ 5.75CSMA2 + 5.75CSMA21 + 5.75CSMA22 + 4.4CSM2
+ 4.4CSM21 + 4.4CSM22 + 5.75CGMA2 + 5.75CGMA21
+ 5.75CGMA22 + 2.83CGM4 + 2.83CGM41 + 2.83CGM42

+ 2.83CGM6 + 2.83CGM61 + 2.83CGM62 + 5.75CRGRDA
+ 5.75CRGRDA1 + 5.75CRGRDA2 + 5.75CGMA4 + 5.75CGMA41
+ 5.75CGMA42 + 5.75CGMA6 + 5.75CGMA61 + 5.75CGMA62
+ 1.06BARD + 1.06BARM2 + 1.06BARM4 + 1.06BARM6
+ 4ALFD + 4ALF2 + 4ALF4 + 4ALF6 + 20STRAWB2
+ 20STRAWB4 + 20STRAWB6 < 624

September-November labor requirements. 624 hours assumed available on farm with deficit purchased.

N. INTEGER CONSTRAINTS

All integer constraints serve the function of insuring that the model cannot mix manure storage options; otherwise, the model could produce crops based on assumptions of manure P and K credits without purchasing manure storage facilities. All integer constraints are tied into the choose manure facility constraint (1).

1. STM6 + STM4 + STM2 + STMD = 1
2. .000001BYFD - STMD < 0
3. .000001BYFM2 - STM2 < 0
4. .000001BYFM4 - STM4 < 0
5. .000001BYFM6 - STM6 < 0
6. .000001BYBIRDD - STMD < 0
7. .000001BYBIRD2 - STM2 < 0
8. .000001BYBIRD4 - STM4 < 0
9. .000001BYBIRD6 - STM6 < 0
10. .001ALFD - STMD < 0
11. .001ALF2 - STM2 < 0
12. .001ALF4 - STM4 < 0
13. .001ALF6 - STM6 < 0
14. .0001PASTD - STMD < 0
15. .0001PASTM2 - STM2 < 0
16. .0001PASTM - STM4 - STM6 < 0
17. 9.85DAIRYD + 9.85DAIRYAD + 9.85DAIRYACD - 10000STMD < 0
18. 6119DAIRY2 + 6119DAIRYA2 + 6119DAIRYAC2 - 1000000STM2 < 0
19. 5680DAIRY4 + 5680DAIRYA4 + 5680DAIRYAC4 - 1000000STM4 < 0
20. 5383DAIRY6 + 5383DAIRYA6 + 5383DAIRYAC6 - 1000000STM6 < 0

A brief schematic of the model in tableau form is presented in table C.2. This tableau aggregates the principal sectors of the model into four activities and 15 constraints. Activity groups are crop production, selling, labor, and finance. The dairy selling activity is aggregated to include milk, cull, and calf sales. Constraints include two size constraints (herd and acreage), six crop transfer activities, four labor transfers, one feed ration constraint, one manure storage constraint, and one nitrate loading constraint.

TABLE E.2. TABLEAU OF REPRESENTATIVE ROCKINGHAM COUNTY DAIRY FARM.

		ACTIVITIES								
		PRODUCTION								
		CORNGR	CORNSIL	ALFALFA	RYE	PASTURE	STRAWB	COWS	BUYN	MANN
C	OBJ	-C	-C	-C	-C	-C	-C	-C	-C	-C
O	HERD							1		
N	LAND	1	1	1	1	1	1			
S	TCGR	A								
T	TCSIL		A							
R	TALF			A						
A	TRYE				A					
I	TSTRAWB						A			
N	TCOWS							A		
T	NFERT	-N	-N		-N		-N		B	M
S	LDECMAR	D	D	D	D	D	D	D		
	LAPRMAY	E	E	E	E	E	E	E		
	LJUNAUG	J	J	J	J	J	J	J		
	LSEPNOV	S	S	S	S	S	S	S		
	HERDFEED	F	F	F	F			-G		
	MSTOR							W		-Q
	NO3LOAD	NO3	NO3	NO3	NO3	NO3	NO3			

TABLE E .2. TABLEAU OF REPRESENTATIVE ROCKINGHAM COUNTY DAIRY FARM (CONTINUED).

		ACTIVITIES											
		SELLING			LABOR				FINANCE				RHS
		MLKCLCF	ALFALFA	STRAWB	DECMAR	APRMAY	JUNAUG	SEPNOV	BORROW	CSTSHARE	WRTOFF		
C	OBJ	+P	+P	+P	-L	-L	-L	-L	-F	+S	+R		
O	HERD											LE	100
N	LAND											LE	200
S	TCGR											=	0
T	TCSIL											=	0
R	TALF		-1									=	0
A	TRYE											=	0
I	TSTRAWB			-1								=	0
N	TCOWS	-1										=	0
T	NFERT											=	0
S	LDECMAR											GE	0
	LAPRMAY											GE	0
	LJUNAUG											GE	0
	LSEPNOV											GE	0
	HERDFEED											=	0
	MSTOR								F	S	R	=	0
	NO3LOAD											LE	L

TABLE E.2. TABLEAU OF REPRESENTATIVE ROCKINGHAM COUNTY DAIRY FARM (CONTINUED).

Variable Definitions

CORNGR = corn grain
CORNSIL = corn silage
STRAWB = strawberries
BUYN = buy commercial nitrogen fertilizer
MANN = recover (produce) manure nitrogen
MLKCLCF = aggregate dairy selling activity, milk-cull-calf
FECMAR = December-March labor
APRMAY = April-May labor
JUNAUG = June-August labor
SEPNOV = September-November labor
BORROW = borrow capital to construct manure storage facility
CSTSHARE = cost sharing to defray manure storage cost
WRTOFF = tax writeoff for constructing manure storage
TCGR = transfer corn grain
TCSIL = transfer corn silage
TALF = transfer alfalfa
TRYE = transfer ryelage
TSTRAWB = transfer strawberries
TCOWS = transfer cows
NFERT = nitrogen fertilizer requirements
HERDFEED = dairy herd ration requirements
MSTOR = store manure (includes 60 day, 120 day, 180 day, and no storage options)
NO3LOAD = nitrate loading constraint

Definitions of Surrogate a_{ij}s

A = yield transfer to selling activities
B = purchase of commercial nitrogen
C = activity cost
D = December-March labor requirment
E = April-May labor requirement
F = dairy herd feed ration requirement transfer
G = herd ration feeding
L = labor cost
M = manure nitrogen produced and recovered
N = crop nitrogen requirments NO3 = per acre nitrate loadings
P = output price received
Q = manure stored and converted to nitrogen
R = tax writeoff for manure storage construction
S = cost sharing for manure storage construction
W = manure stored
X = borrowing to finance manure storage

APPENDIX F

DERIVATION OF THE CHANCE CONSTRAINTS OF SILAGE PRODUCTION AND NITRATE LOADING

DERIVATION OF THE CHANCE CONSTRAINTS OF SILAGE PRODUCTION AND NITRATE LOADING

The Chance Constraint for Silage Production

Dairy farmers in Rockingham County have experienced considerable variation in per acre silage yields over the past several decades. Since silage is a necessary component of dairy cattle feed, and since no well established market for purchasing silage exists in the county, it is essential that farmers produce enough to satisfy their dairy herd ration requirements. Simply treating the mean value per acre yield as a constant and making crop production decisions accordingly may therefore result in feed shortages.

Farmers in the county typically plant enough acreage to corn so that silage needs can be met even in poor years; in high yield years, this extra corn acreage is simply harvested as grain and used as feed or sold (Groover, 1987). In order to incorporate this risk into the model, the chance constrained programming method was used.

This method, rather than mandating that constraints be met with certainty, establishes confidence intervals (chosen by the decision maker) within which the constraint will be met. This appendix describes both the general method and the construction of the chance constraint for silage production.

Data Detrending

In order to construct the probabilistic constraint for silage production on the dairy farm, historical estimates for per acre silage yield (tons) were used to characterize the yield distribution over the

1961-85 period (Virginia Agricultural Statistics, 1961-85). Silage yields on a per acre basis have only been maintained for Virginia since 1974; prior to that, only data on corn grain yields were available. To standardize the data, it was assumed that five bushels of corn were equivalent to one ton of silage (Brann, 1987).

It was suspected that technological practices had altered average yields over this period; therefore, detrending was performed on the data. The first detrending model used ordinary least squares to estimate a simple quadratic equation which regressed yield against time (1-25) and time-squared. In this way, the influence of time (as a proxy for technical change) on average yields was obtained. Results of this model showed no evidence of significance in either independent variable (table F.1).

The second model dropped the quadratic term and simply regressed yields against time. Based on these results, it was determined that time played a significant role in increasing yields, with silage production trending upward by about .23 tons per year (Table F.1). Therefore, new detrended estimates were obtained by using parameter estimates for the year beyond the data period (26) and adding each year's residual value to the estimated value. The resulting data set yielded a detrended mean of 17.404 and a variance of 9.8829.

TABLE F.1. RESULTS OF DETRENDING OF PER ACRE SILAGE YIELD (TONS) FOR ROCKINGHAM COUNTY, VIRGINIA.

QUADRATIC FUNCTIONAL FORM

Variable	Parameter Estimate	T-Value (standard error)
intercept	10.235	4.835** (7.117)
year	0.466	1.241 (0.375)
$(year)^2$	-0.0088	-0.630 (.014)

R^2: .2479

LINEAR FUNCTIONAL FORM

Variable	Parameter Estimate	T-Value (standard error)
intercept	11.268	8.522** (1.32223)
year	0.236	2.653* (0.08894)

R^2: .2344

* = significant at 95% level
** = significant at 99% level
Mean of Dependent Variable: 14.336

<u>The Constraint</u>

Since per acre yield of silage was assumed to vary from year to year due to weather, plant disease, and other random elements outside of the farmer's control, the chance constraint was designed to reflect a risk-averse decision maker's behavior to insure that his dairy herd demand for silage feed was met. This was considered especially important because there is no market for silage in the Rockingham area, so that substitutes for silage in the feed ration would be difficult to find.

Using the method of Charnes and Cooper (1963), the general constraint was of the form

$$\{ Pr(a_{ij}X_1) > b_i \} > z_i \qquad (1)$$

where

X_1 = acres of silage corn grown

a_{ij} = silage yield, tons per acre

b_i = minimum silage feed required for dairy herd

z_i = specified confidence level at which constraint is to be met

and a_{ij} is assumed to have mean u and variance σ^2.

This constraint is linearized following Segarra, Kramer and Taylor (1985) by the transformation

$$((u)x_1 - [x_1^2 (\sigma^2)]^{1/2}D^*) > b_i \qquad (2)$$

where

u = mean value, silage production/acre

σ^2 = variance of silage production

D^* = value from standard normal distribution

Since it is assumed that $a_{ij} \sim N(17.404, 9.8829)$,[1] this constraint explicitly becomes

$$17.404x_1 - D^*(x_1^2[9.8829])^{1/2} > b_i \qquad (3)$$

The constraint is then derived for confidence intervals of 90 percent and 95 percent (Table F.2). Unfortunately, county level data used to generate the detrended distribution do not differentiate between corn silage grown using conventional tillage and corn silage grown using no-till, as the representative farm model does. Therefore, an approximation of the effect of risk on the model's a_{ij}'s is obtained by extrapolating from the aggregated county data. It is thus assumed that percentage reductions of the a_{ij}'s are the same for both cases.

The results indicate substantial reductions in the technical coefficients for silage yields, necessitating devotion of more acreage to silage production. However, for average or better than average years of silage yields, the farmer will not be penalized, since the extra acreage can be harvested as corn grain and used to offset purchases of grain in the feed rations.

A Note on Covariance Terms Between the Chance Constraints

When using the chance constrained programing method with multiple constraints, it is possible that the factors causing variability in the a_{ij}'s in different constraints may be related (Taha, 1976). In the case of the Rockingham County representative farm model, the principal factor generating variability in both corn yields and nitrate loadings

TABLE F.2. DERIVATION OF THE CHANCE CONSTRAINT FOR ALTERNATIVE CONFIDENCE INTERVALS.

Confidence Interval	D* Value	a_{ij}	Percent Reduction[a]
90%	1.280	13.38	23.1
95%	1.645	12.23	29.7

[a]from the mean of the distribution

MODEL PARAMETERS

No-till	Mean Value	Adjusted Value
90%	17	13.1
95%	17	12.0

Conventional Tillage		
90%	15	11.5
95%	15	10.6

to ground water is rainfall (or the lack thereof). In this case, it would typically be appropriate to consider the covariance terms of the random elements. However, it is assumed in this model that the farmer is not specifically considering the chance constraint on nitrate loading. Rather, he considers this constraint to be exogenously imposed by regulation of his management options. Since he is only explicitly considering the variability of his corn production, it is not necessary in this case to include consideration of the covariance terms in the model, since they do not affect his cropping and management decisions (Segarra, 1988).

THE CHANCE CONSTRAINT FOR NITRATE LOADING

Examination of the nitrate leaching parameter over the 20 year simulation period reveals that average loadings for all of the crop types grown are subject to large standard deviations, indicating that loadings for any given year may fluctuate widely about the mean. In order to reflect this randomness inherent in agricultural nonpoint contamination, the chance constraint for nitrate loading explicitly considers the variability of the a_{ij} in the A matrix of the model.

Derivation of the constraint is similar to the technique used in equation (2), except that for a less than or equal to constraint the second term ($- [x_1^2 \sigma^2]^{1/2} D^*$) is positive rather than negative, so that the effect of the variance factor is to discount the a_{ij} up by a factor proportional to the confidence interval chosen (D^*) and the standard deviation (σ^2). The chance constraint for nitrate loadings thus becomes

$$((u)x_1 + [x_1^2 (\sigma^2)]^{1/2}D^*) < b_i \qquad (4)$$

Adjusted parameter values are presented in text table 5.12.

Consequences of the Normality Assumption

The assumption of normality in the chance constraints was made so that the constraints could be linearized in the model. Due to software limitations, the mixed integer option used in the representative farm model cannot be used with nonlinear constraints (such as the inherently nonlinear forms of the chance constraints), so that this linearization was a necessity. However, any symmetric distribution could be linearized in a similar fashion.

Examination of the nitrate leaching data for the 20 year simulation indicates that loadings are not distributed symmetrically; in fact, loadings are skewed towards zero in a logarithmic fashion. This skewing is consistent with other CREAMS simulations and the inherent assumptions of the CREAMS model itself (Heatwole, 1988).

If the normal distribution is assumed when nitrate loadings are actually logarithmically distributed, the result will be a greater probability of satisfying the imposed loading reduction; that is, using the normal distribution actually biases the results toward the conservative side (less nitrate loading)(Segarra, 1988). Although the normality assumption is somewhat unrealistic, it has the effect of improving ground water quality even further.

APPENDIX G

ALTERNATIVE FEED RATIONS FOR ROCKINGHAM COUNTY DAIRY COWS.

TABLE G.1. ALTERNATIVE FEED RATIONS FOR ROCKINGHAM COUNTY DAIRY COWS.

Ration Components	Annual Requirements
CORN SILAGE/CORN GRAIN/RYELAGE/ALFALFA (DAIRY)[a]	
Corn silage	5.60 tons
Corn Grain	85.00 bushels
Ryelage	2.80 tons
Alfalfa	.73 tons
ALFALFA/CORN GRAIN (DAIRYAC)	
Alfalfa	4.74 tons
Corn Grain	152.17 bushels
ALFALFA/BARLEY (DAIRYA)	
Alfalfa	4.38 tons
Barley	195.30 bushels

[a]Term in parentheses represents model variable name for each feed ration. The alfalfa/oats/corn ration was not used, so this ration is not included here.

Source: Thatcher (1988); Remillard (1988)

APPENDIX H

THE MANURE STORAGE FACILITY

THE MANURE STORAGE FACILITY

Size of Facility

Once herd size in the model is chosen, it is necessary to estimate the size of manure storage facility that the farm will require if 60, 120, or 180 day storage is constructed. This requires consideration of four principal sources of liquid waste:[1] manure produced by the cows; washwater from the parlor, milkhouse floor, and cow washing activity; surface runoff from the paved lot area; and precipitation on the storage structure. Estimates of manure production (assuming average weight of 1300 lbs./cow), washwater, and surface runoff were obtained from the Soil Conservation Service (SCS) estimates for storage capacity needs (SCS, 1984). Estimation of precipitation on the storage structure was obtained by assuming a 50′ diameter tank (Roller, 1987), 1.24′ of rainfall for 120 days storage, and 1.52′ of rainfall for 180 days storage. The structure as designed includes 1.5 feet of freeboard. Storage requirements for both herd sizes (60 and 100 cows) for 60, 120 and 180 days are presented in tables H.1, H.2, and H.3.

Facility Costs

Generation of cost estimates for storage facilities required three elements: type of facility; cost of particular facility per square foot; and site preparation costs. The first two figures were obtained from Mr. William Patterson, Soil Conservation Service director for Rockingham County, while site preparation estimates were provided by Mr. James Blodgett, district Soil Conservation Service, USDA.

Farmers have four principal options for manure storage: earthen pits, poured concrete tanks, tanks of precast concrete panels, and glass-lined tanks. Facilities for which the Virginia Division of Soil and Water Conservation in 1985-86 provided cost- sharing assistance ranged in price from $5,524 to $71,987 (Virginia Division of Soil and Water Conservation, 1987). In general, earthen facilities are the least expensive and glass- lined structures are the most expensive. For the purpose of this study, it is assumed that the typical farmer will <u>not</u> purchase a glass-lined structure due to excessive cost. While many would likely prefer to construct an earthen storage facility, geology in Rockingham County has effectively removed that option due to thinness of soil; therefore, it is assumed that the typical farmer will purchase either poured concrete or precast panel structures, which are comparable in performance, lifespan, and cost. Lifespan of the facility is conservatively estimated to be 15 years.

Due to the presence of shallow layers of rock beneath the land surface in most of Rockingham County, site preparation costs are often a substantial part of construction costs, principally due to blasting requirements. Using rough estimates provided by SCS as a proxy, preparation costs are estimated as $2,500 for sites requiring light preparation, $8,000 for sites requiring heavy preparation, and $18,000 for heavy site preparation (Blodgett, 1987; Patterson, 1988). Cost estimates were generated for the low and medium site preparation options.

"Average" costs per square foot for manure storage facilities constructed in the Shenandoah Valley area are difficult to derive due to differences in type of facility, size of herd serviced, length of storage constructed, site preparation required, and other factors such as whether the particular farmer chooses to build excess capacity into his facility to absorb possible future herd expansion. Therefore, estimates were obtained from SCS figures used in the Linville Creek Water Treatment Project in the county. These figures, which are used to generate estimates of cost sharing payments to farmers participating in the program, were $25,000 for a 60 cow/120 day storage facility, and $40,000 for a 100 cow facility with more than 120 days storage (but less than 180 days)(Patterson, 1988).

The $25,000 figure was combined with the storage requirement estimates in table H.1 to obtain a cost per gallon estimate, which was extrapolated to generate total cost figures (exclusive of site preparation costs) for each of the four facilities. Site preparation costs were then added to obtain the total costs displayed in table H.4. It is strongly emphasized that these figures would likely vary widely in practice, due to differences in site preparation costs, type of facility, and other factors; however, they are treated as reasonable averages over the entire area.

NUTRIENT MANAGEMENT PLANS

In order to estimate cost savings from adopting alternative manure management practices (especially manure storage), nutrient management plans were developed for a 200 acre dairy farm with a herd of 100 cows

TABLE H.1. WASTE STORAGE REQUIREMENTS FOR 60 COW DAIRY HERD.

		120 days	180 days
MANURE PRODUCTION[a]		8,976 ft^3	13,464 ft^3
WASHWATER			
Bulk Tank	60 gal/day		
Pipeline	125 gal/day		
Parlor Floor	75 gal/day		
Washing Cows	60 gal/day		
Milkhouse Floor	20 gal/day		
Total	340 gal/day (45.33 ft^3)	5,440 ft^3	8,160 ft^3
SURFACE RUNOFF			
Paved Lot		3,720 ft^3	4,560 ft^3
VOLUME of PRECIPITATION on STORAGE STRUCTURE			
1.24′ X 3.14 X $(25)^2$		2,435 ft^3	
1.52′ X 3.14 X $(25)^2$			2,983 ft^3
STORAGE REQUIRED		20,571 ft^3	29,167 ft^3

[a]Assumes 1,300 lbs. average weight, 1.37 ft^3/day/1,000 lbs live weight manure production (solid and liquid), 70% confinement

Sources: Garst, 1987; Roller, 1987

TABLE H.2. WASTE STORAGE REQUIREMENTS for 100 COW DAIRY HERD.

		120 days	180 days
MANURE PRODUCTION[a]		14,960 ft^3	22,441 ft^3
WASHWATER			
Bulk Tank	60 gal/day		
Pipeline	125 gal/day		
Parlor Floor	75 gal/day		
Washing Cows	100 gal/day		
Milkhouse Floor	20 gal/day		
Total	380 gal/day (50.67 ft^3)	6,080 ft^3	9,120 ft^3
SURFACE RUNOFF			
Paved Lot		3,720 ft^3	4,560 ft^3
VOLUME of PRECIPITATION on STORAGE STRUCTURE			
$1.24' \times 3.14 \times (25)^2$		2,435 ft^3	
$1.52' \times 3.14 \times (25)^2$			2,983 ft^3
STORAGE REQUIRED		27,195 ft^3	39,104 ft^3

[a]Assumes 1,300 lbs. average weight, 1.37 ft^3/day/1,000 lbs live weight manure production (solid and liquid), 70% confinement

Sources: Garst, 1987; Roller, 1987

TABLE H.3. 60 DAY WASTE STORAGE REQUIREMENTS FOR 60 AND 100 COW DAIRY HERDS.

		60 Cows	100 Cows
MANURE PRODUCTION[a]		4,488.12 ft^3	7,480.2 ft^3
WASHWATER			
Bulk Tank	60 gal/day		
Pipeline	125 gal/day		
Parlor Floor	75 gal/day		
Washing Cows	60/100 gal/day		
Milkhouse Floor	20 gal/day		
Total	340/380 gal/day (45.33/50.67 ft^3)	2,720 ft^3	3,040 ft^3
SURFACE RUNOFF			
Paved Lot		1,860 ft^3	1,860 ft^3
VOLUME OF PRECIPITATION ON STORAGE STRUCTURE			
$.62' \times 3.14 \times (25)^2$		1,216.75 ft^3	
STORAGE REQUIRED		10,285.62 ft^3	13,597.7 ft^3
(gallons)		77,142.15	101,982.75
STORAGE COSTS			
Low Site Preparation		15,000	19,025
Medium Site Preparation		20,500	24,500
COST PER GALLON			
Low Site Preparation		.1944	.1866
Medium Site Preparation		.2657	.2402

[a]Assumes 1,300 lbs. average weight, 1.37 ft^3/day/1,000 lbs live weight manure production (solid and liquid), 70% confinement

Sources: Garst, 1987; Roller, 1987

TABLE H.4. APPROXIMATE COST PER GALLON and SITE PREPARATION COSTS OF MANURE STORAGE FACILITIES in ROCKINGHAM COUNTY, VIRGINIA[a]

Site Preparation Costs ($)		
Low Preparation	2,500	
Medium Preparation	8,000	
High Preparation	18,000	
Total Storage Facility Costs, Low Site Preparation		
	Total Estimated Costs	Final Cost per Gallon
60 Cows/120 Day Storage	$27,500	.1782
60 Cows/180 Day Storage	$37,946	.1735
100 Cows/120 Day Storage	$35,550	.1743
100 Cows/180 Day Storage	$47,500	.1620
Total Storage Facility Costs, Medium Site Preparation		
	Total Estimated Costs	Final Cost per Gallon
60 Cows/120 Day Storage	$33,000	.2139
60 Cows/180 Day Storage	$43,445	.1986
100 Cows/120 Day Storage	$41,050	.2013
100 Cows/180 Day Storage	$53,000	.1807

[a]Assumes precast panel or poured concrete storage facility.

Sources: Patterson, 1988; Blodgett, 1987 and an 80 acre dairy farm with a 60 cow herd. These plans were designed with the assistance of Mr. Fred Givens of the Department of Agricultural Engineering at VPI & SU, following the guidelines of the nutrient management program being conducted in Rockingham County. The plans were designed assuming three scenarios: no manure storage facilities; storage facilities for 120 days; and storage facilities for 180 days. The absence of storage facilities necessitates spreading manure on pastureland during corn season, resulting in both loss of valuable nutrients and increased nitrate loadings to ground water.

Management plans were developed considering corn and rye, production, which is typical of Rockingham County dairy farms. Manure and commercial fertilizer requirements for each crop (assuming yields compatible with type II soil) are provided in table H.5. Assumed nutrient content per 1000 gallons of liquid manure is 12 pounds available nitrogen, 14 pounds phosphate, and 23 pounds potash (Virginia Cooperative Extension Service, 1984). Assumed nutrient content per ton of dry manure is 4 pounds nitrogen, 3 pounds phosphorus, and 8 pounds potassium (Virginia Cooperative Extension Service, 1984).

Nitrogen was treated as the limiting element in liquid manure application; that is, given soil tests for Rockingham County, farmers following the nutrient management plan would be overapplying P and K. However, nitrogen is both the most expensive nutrient applied and the major environmental problem (after its conversion to nitrate) in the county. These factors, coupled with the fact that P and K tend not to leach, provide the rationale for this focus on nitrogen.

TABLE H.5. CROPS INCLUDED IN ROCKINGHAM COUNTY REPRESENTATIVE FARM MODEL AND NUTRIENT REQUIREMENTS.

	Yield	N	P_2O_5	K_2O
Corn grain/ryelage/no till	110bu/5 t	170	95	130
Corn grain/conventional till	100 bu	110	50	50
Corn silage/conventional till	15 t	110	60	90
Corn silage/ryelage/no till	17 t/5 t	170	95	130
Alfalfa	5 t	0	60	160
Pasture	--	*	20	20

t = tons
bu = bushels

All yields are on a per acre basis. Nutrient requirements are in pounds/acre.

* N applied to pasture depends on storage option chosen by model.

Cost Sharing

Rockingham County farmers are eligible through the Virginia Agricultural Best Management Practice Cost Share Program to be subsidized for a portion of the cost of construction of manure storage facilities. This cost sharing is limited to 75% of facility cost up to a maximum of $7,500. The farmer is required to maintain these facilities for at least ten years. These cost sharing funds can not be used for pumping equipment, buildings, spreading equipment, or spreading animal wastes on the land (DSWC Specification No. WP-4). This is a potentially important issue since farmers who adopt a liquid storage practice must either buy or rent a pump for draining the facility, and must either buy application equipment or contract out to have the manure spread, adding to the operation's variable costs. Farmers who participate in the Agricultural Stabilization and Conservation Service cost sharing plan are eligible for an additional $3,500, so that the maximum cost sharing funds available to the Rockingham County farmer is $11,000.

ENDNOTES

1. Although generally referred to as manure storage facilities, these structures actually contain washwater, runoff, and precipitation, as well as manure. The actual waste product in long-term storage then becomes a liquid combination of these four elements, rather than the more solid product which would result if only the manure were stored.

APPENDIX I

TAX ADVANTAGES AVAILABLE FOR SITING MANURE STORAGE FACILITIES

This appendix illustrates a specific example of how tax advantages may be obtained for farmers constructing manure storage facilities. A storage facility cost of $16,500-- equivalent to the post-cost sharing expense of a 120 day storage facility for a 60 cow herd--is assumed.

Three potential writeoff plans are available, based on different assumptions of length of operation of dairy facility and previous tax deduction strategies. Plan B assumes that the dairy plant was in operation prior to 1976, and is a new identifiable treatment facility used for abatement or control of water or atmospheric pollution, certified by state and federal authorities. Plans B and C assume that the facility is single purpose. Plan A can be viewed as the minimum writeoff available.

All strategies assume that the farmer will stay in the same tax bracket over the relevant periods, and that the opportunity cost of the farmers' capital is the same as the interest rate at which he borrowed capital to construct the facility. All facilities begin amortization or depreciation midway through the first year of facility installation, either by tax restriction (A and C) or by assumption (B) (see table I.1).

The net present value of these writeoffs was calculated assuming that the opportunity cost of the farmer's capital was identical to the interest paid on capital borrowed to finance the facility at 12 percent (table I.2), then subtracted from the model's objective function. Therefore, although the model still assumes that the farmer must borrow

TABLE I.1. TAX WRITEOFF PLANS AND TOTAL DEDUCTIONS FOR MANURE STORAGE FACILITIES.

	WRITEOFF TYPE			DEDUCTION		
FACILITY COST	A	B	C	A	B	C
16500	0.033333	0.1	0.1429	549.994	1650	2357.85
16500	0.066667	0.2	0.2449	1100.005	3300	4040.85
16500	0.066667	0.2	0.1749	1100.005	3300	2885.85
16500	0.066667	0.2	0.1249	1100.005	3300	2060.85
16500	0.066667	0.2	0.0893	1100.005	3300	1473.45
16500	0.066667	0.1	0.0892	1100.005	1650	1471.8
16500	0.066667		0.0893	1100.005		1473.45
16500	0.066667		0.0446	1100.005		735.9
16500	0.066667			1100.005		
16500	0.066667			1100.005		
16500	0.066667			1100.005		
16500	0.066667			1100.005		
16500	0.066667			1100.005		
16500	0.066667			1100.005		
16500	0.066667			1100.005		
16500	0.033333			549.994		

ANNUAL TAX WRITE OFF

a28	a15	b28	b15	c28	c15
257.1224	181.4981	771.375	544.5	778.090	778.090
514.2525	363.0018	1542.75	1089	1333.480	1333.480
514.2525	363.0018	1542.75	1089	952.330	952.330
514.2525	363.0018	1542.75	1089	680.080	680.080
514.2525	363.0018	1542.75	1089	486.238	486.238
514.2525	363.0018	771.375	544.5	485.694	485.694
514.2525	363.0018			688.838	486.238
514.2525	363.0018			344.033	242.847
514.2525	363.0018				
514.2525	363.0018				
514.2525	363.0018				
514.2525	363.0018				
514.2525	363.0018				
514.2525	363.0018				
514.2525	363.0018				
257.1224	181.4981				
7713.80	5445.021	7713.80	5445	7713.80	5445

A = 15 YEAR STRAIGHT LINE WRITEOFF USING 1/2 YR CONVENTION
B = 60 MONTH AMORTIZATION (ASSUMES FARM OPERATION PRE-1976)
C = 7 YEAR 200% DECLINING BALANCE, 1/2 YR CONVENTION
*28 = ASSUMES 28% FEDERAL TAX BRACKET, 5.75% STATE TAX BRACKET
*15 = ASSUMES 15% FEDERAL TAX BRACKET, 5% STATE TAX BRACKET

TABLE I.2. NET PRESENT VALUES OF THREE WRITEOFF STRATEGIES FOR MANURE STORAGE FACILITIES.

Net Present Value, 15 year straightline @ 12% interest

28% bracket: 3712.65
15% bracket: 2620.69

Net Present Value, 5 year amortization

28% bracket: 5894.44
15% bracket: 4161.14

Net Present Value, 7 year declining balance

28% bracket: 5883.80
15% bracket: 4152.76

the entire post-cost sharing amount, he is awarded a credit in the amount of the net present value times the borrowing coefficient.

APPENDIX J

SHADOW PRICES OF BINDING CONSTRAINTS IN THE LARGE AND SMALL REPRESENTATIVE FARM MODELS

Shadow prices for the unconstrained (no storage/baseline) conventional practice large and small farm models are listed in table J.1. The dual prices listed in the table represent the amount which the objective function would be increased or decreased by if the constraint were relaxed by one unit. As the table indicates, shadow prices are almost identical for both large and small farms. This is as expected since the crop production and herd feed requirements are the same for each model. The key difference is in the shadow price for an additional cow. Results indicate that one additional 1,600 pound dairy cow would increase the large farm's net returns by about $505, while one more cow would increase the small farm's net returns by about $456. This difference is attributed to the fact that the small farm would have to purchase a higher percentage of the corn grain needed to feed the additional cow than the large farm, due to acreage limitations.

TABLE J.1. SHADOW PRICES OF SELECTED CONSTRAINTS IN THE UNCONSTRAINED (CP) REPRESENTATIVE FARM MODEL.

UNCONSTRAINED LARGE FARM MODEL.

Constraint	Unit	Dual Prices
HERD SIZE (upper limit)	cows	504.601300
PASTURE	acres	-19.011000
LAND	acres	52.693390
BUY CORN GRAIN	bushels	2.600000
SILAGE PRODUCTION	tons	15.735290
RYELAGE PRODUCTION	tons	12.537180
STORE CORN GRAIN	bushels	-2.350000
STORE CORN SILAGE	tons	-14.235290
STORE RYE	tons	-11.037180
SELL CALF	head	-50.000000
SELL CULL	head	-400.000000
SELL MILK	cwt	-12.000000

UNCONSTRAINED SMALL FARM MODEL.

Constraint	Unit	Dual Prices
HERD SIZE (upper limit)	cows	456.239200
PASTURE	acres	-19.011000
LAND	acres	52.693390
BUY CORN GRAIN	bushels	2.600000
SILAGE PRODUCTION	tons	15.735290
RYELAGE PRODUCTION	tons	12.537180
STORE CORN GRAIN	bushels	-2.350000
STORE CORN SILAGE	tons	-14.235290
STORE RYE	tons	-11.037180
SELL CALF	head	-50.000000
SELL CULL	head	-400.000000
SELL MILK	cwt	-12.000000

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