FRAMEWORK FOR EVALUATING IMPACT OF A CONFINED ANIMAL FEEDING OPERATION INSIDE A WELLHEAD PROTECTION AREA

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FRAMEWORK FOR EVALUATING IMPACT OF A CONFINED ANIMAL FEEDING OPERATION INSIDE A WELLHEAD PROTECTION AREA

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Tables Page

CHAPTER I

INTRODUCTION

Background

Over the past few decades, concern for ground water quality degradation has increased and become a major environmental issue. Ground water serves as a source of drinking water for more than 40% of the population, or 95% of rural residents (Canter, 1997; USDA, 1999). Therefore, protecting the quality of ground water is important as it significantly affects public health (US EPA, 1987), economic growth, and the community development (Christenson & Parkhurst, 1987).

Ground water quality can change and deteriorate either naturally or anthropogenically. According to the 1998 National Water Quality Inventory (US EPA, 2000), the major contributor to ground water contamination is from agricultural nonpoint sources (NPS). As the population grows, the use of land for agriculture increases causing a localized contamination of ground water (Ribaudo *et al.*, 1999; USDA, 1999). This type of pollution can be minimized if properly managed (US EPA, 2000).

One problem associated with agriculture practice that has prominently affected water quality is the increase of concentrated animal feeding operations (CAFOs), a large and specialized animal operations. CAFOs generate large amounts of animal wastes that are generally managed by storage in waste piles or lagoons and/or by land application. Management of the wastes require a large and sophisticated manure handling and large storage systems as well as a sufficient amount of cropland for application of manure (Ribaudo *et al.*, 1999; Copeland & Zinn, 1998; Letson & Gollehon, 1996).

Concerns with CAFOs are associated with failures in the waste management systems. CAFOs frequently treat large quantities of manure in lagoons prior to land application or other disposal. Most of these lagoons are lined with clay or designed to be "self-sealed" by manure solids that prevent leaking or infiltration of pollutants into the ground water. Other types of failures include spills due to overfilling; washouts in floods; failures of dikes, pipes or other aboveground structures; and accidental and intentional operator-related releases (US EPA, 2001c; Ribaudo *et al.*, 1999; Copeland & Zinn, 1998; Letson & Gollehon, 1996).

Wastes produced by the animals contain nitrogen and other valuable nutrients. These nutrients are essential to plant growth when applied without exceeding the crop agronomic rate. However, nitrogen pollution is a concern to ground water (US EPA, 2001c). In the subsurface, nitrogen in the form of ammonium (NH_4^+) is converted to nitrate (NO_3^-), a form that is mobile and moves easily with soil water. Excessive application of manure to land can cause accumulation of nitrate that will eventually percolate into the ground water system thus elevating the nitrate level (Ribaudo *et al.*, 1999; Copeland & Zinn, 1998; Letson & Gollehon, 1996). The concentration of nitrate in ground water used as a source of drinking water is of primary concern since high levels of nitrate can adversely affect infants. Consumption of high levels of nitrate causes infants to lose oxygen transport/transfer capabilities in the blood, a disorder called methemoglobinemia, or blue baby syndrome (Canter, 1997).

To preserve ground water quality from further degradation, Kneese and Bower (1968) addressed three main issues related to its management. The first issue relates to the determination of the water quality that is acceptable by the public that does not adversely affect human health. In order to protect public health, the Safe Drinking Water Act (SDWA) requires the Environmental Protection Agency (EPA) to set standards for drinking water quality and water treatment of public water systems (Morandi, 1989; Ribaudo *et al.*, 1999; USDA, 1999). The EPA established a maximum contaminant level (MCL) for NO_3-N in drinking water as 10 mg/liter, of which Public Water Systems (PWSs) are to be in compliance with as specified in 42 U.S.C.§ 300g (USDA, 1999).

The second issue concerns best management systems to protect water quality. The relationship between agricultural enterprises such as CAFOs and damages to water quality is complex. Best management practices for CAFOs involve many aspects such as the physical, biological, economical, and societal aspects (Ribaudo *et al.*, 1999). The physical and biological aspects include pollution transport processes between the facility and the public well, the type of crops, and the amount of land required for manure application. The economic aspects include how contamination or degradation of water quality affects the community's economic development. The societal aspect, which will not be discussed in this study, entails whether such agricultural practices are acceptable by the community (Ribaudo *et al.*, 1999; Gilley & Jensen, 1983).

Modern agriculture such as CAFOs creates a situation where producers are challenged to develop management practices that allow them to minimize production cost and optimize high productivity and quality while minimizing environmental and societal impacts (Ribaudo *et al.*, 1999; Gilley & Jensen, 1983). Farmers or producers do not generally account for the cost of pollution to others, referred to as externalities, when making their production decision. Those externalities cause inefficiently high levels of nonpoint source pollution (Ribaudo *et al.,* 1999; USDA, 1999).

Alternatively, the optimal level of water quality protection is often determined by economics. Society does not benefit from overly stringent or costly water quality goals. Measuring the benefits of water quality protection for water users in economic terms is often difficult, since many benefits occur outside easily observable market conditions. Even when water quality impacts on markets are observed, it can be difficult to conclude exactly how much water pollution affects the ability of this resource to provide economic good (USDA, 1999; Ribaudo *et al.,* 1999).

The third issue involves the best institutional or organizational arrangements for managing water quality. Provisions of management require the use of information on alternatives provided by engineering-economic analysis. It also involves implementation of an effective and efficient management program. A management program specifically designed to protect public drinking water derived from ground water was developed under the Safe Drinking Water Act Amendment 1986, called the Wellhead Protection (WHP) program. The protection of ground water is based on the concept of landuse controls and other preventive measures (Ribaudo *et al.,* 1998; USDA, 1999). The program requires participation of the community in protecting their wellhead protection areas – the surface and subsurface areas surrounding a well or wellfields supplying a public water system (US EPA, 1987).

All the above three issues discussed by Kneese and Bower (1968) are related. The choice of water quality level depends on the cost of achieving that level and depending on how effective the management agency is.

Statement of the Problem

Various investigations on interactions between agricultural production associated with confined animal feeding operations and ground water quality have been conducted intensively over the past years (Christensen, 1983). Additionally, studies on best management practices have also been conducted to provide information to producers or farmers to achieve maximum production while protecting water quality. However, intensified CAFOs encounter a challenge in agriculture to find sufficient land for disposing manure, or in finding economic alternatives, especially if the supply of land for disposal is insufficient. The solutions for these problems are highly site-specific, depending of many variables such as location, topography, and applied best management practices (US EPA, 1994).

On the other hand, the Wellhead Protection program was developed specifically to protect the quality of ground water from degradation. The program is a proactive effort designed to apply proper management techniques and various preventive measures to protect ground-water supplies. Such protection prevents the need for expensive treatment of wells to comply with drinking water standards, and thereby ensures public health. The underlying principle of the program is that it is much less expensive to protect ground water than it is to restore it once it becomes contaminated (US EPA, 1994).

To minimize ground water contamination from point and nonpoint sources of pollution in a wellhead protection area requires participation of not only individual farmers, but also the community. Yet it is difficult to encourage the people to participate in such efforts due to their minimal understanding and limited available information on the importance to protect their source of water supply.

Oklahoma is becoming a major state for swine production. Over the past decade, swine production in Oklahoma has been growing exponentially (NRDC, 1998). Specifically swine facilities in Kingfisher County have been increasing since 1990. The county, located within the Turkey Creek watershed, derives its source of water supply from the Cimarron alluvial and terrace aquifer, which is known for its elevated nitrate concentration.

Pierce and Key (1998) conducted a study in Turkey Creek Educational Assessment Project. The research concluded that people would be willing to adopt and consider alternative best management practices to protect their water quality, if they had more information on the technical feasibility and economic efficiency of the approach.

This research focuses on the contamination of nitrate from swine facilities (lagoon and effluent application areas) and their effect on ground water in a wellhead protection area. The result of this study will suggest a framework for farmers producers, decision-makers and the community as a whole to assess PS and NPS management specifically from swine facilities in or near a wellhead protection area. The assessment will emphasize on the effectiveness and efficiency of a wellhead protection program as a policy tool of a community, considering a CAFO that implements BMPs in its operation. In addition, the study will provide a visual educational tool using a geographic information system to increase the understanding of wellhead protection areas and the surrounding landuse of the community. Societal acceptance of the wellhead protection program will not be discussed in this assessment.

Purpose and Objectives

The purpose of the study is to develop a means of assessing the risk of nitrogen (or other pollutants) contamination of a public well and the benefits to society from controlling NPS, such as a CAFO in a wellhead protection area. The scope of the study will focus on nitrate contamination to ground water resulting from the CAFO, used as a source of drinking water to rural communities. This research focuses on the effectiveness and efficiency of Best Management Practices (BMPs) of a CAFO. BMPs considered are the animal waste lagoon and land application management. BMPs associated with lagoon designs include the specific thickness of the liner and the permissible hydraulic conductivity while taking into consideration the geologic settings of the location. BMPs related to land application practices of disposing effluent from waste lagoon, which include the land application rate, land application timing, land acreage, and the type of crops, such as Bermudagrass - a common crop found in Kingfisher County.

The information obtained will present a more thorough understanding of the quality of ground water as a source of drinking water, the processes resulting in ground water contamination, and evaluation of possible control measures or management practices. The significance of the study is to provide comprehensive information to encourage communities to implement wellhead protection, to explain the potential economic benefit from controlling NPS, and the possible cost avoidance to communities from finding other resources should their public wells become contaminated. The analysis framework is illustrated in Figure I-1.

The specific objectives are to;

- Estimate the concentration of NO_3^--N leaching into the ground water from an animal waste lagoon of a CAFO with BMPs implemented,
- Estimate the concentration of NO_3^--N leaching from a grassland area applied with effluent from an animal waste lagoon of a CAFO with BMPs,
- Estimate and evaluate the concentration of NO_3^--N reaching a public well system located inside and outside a wellhead protection area in Kingfisher as a case study,
- Determine whether or not the concentration of NO_3^--N at the selected public well exceeds the Maximum Contaminant Level (MCL),
- Determine whether a CAFO with BMPs in a wellhead protection area in Kingfisher can be beneficial to the community, and
- Determine whether the benefits out weigh the future cost to the community from an animal feeding operation.

Disclaimer

The CAFO facility used in this study was selected due to its proximity to a public well system. Facility Operation and best management practice scenarios are based on a hypothetical 2000 Animal Unit CAFO facility. This study does not consider current facility parameters or waste management practices adopted by any CAFO facility.

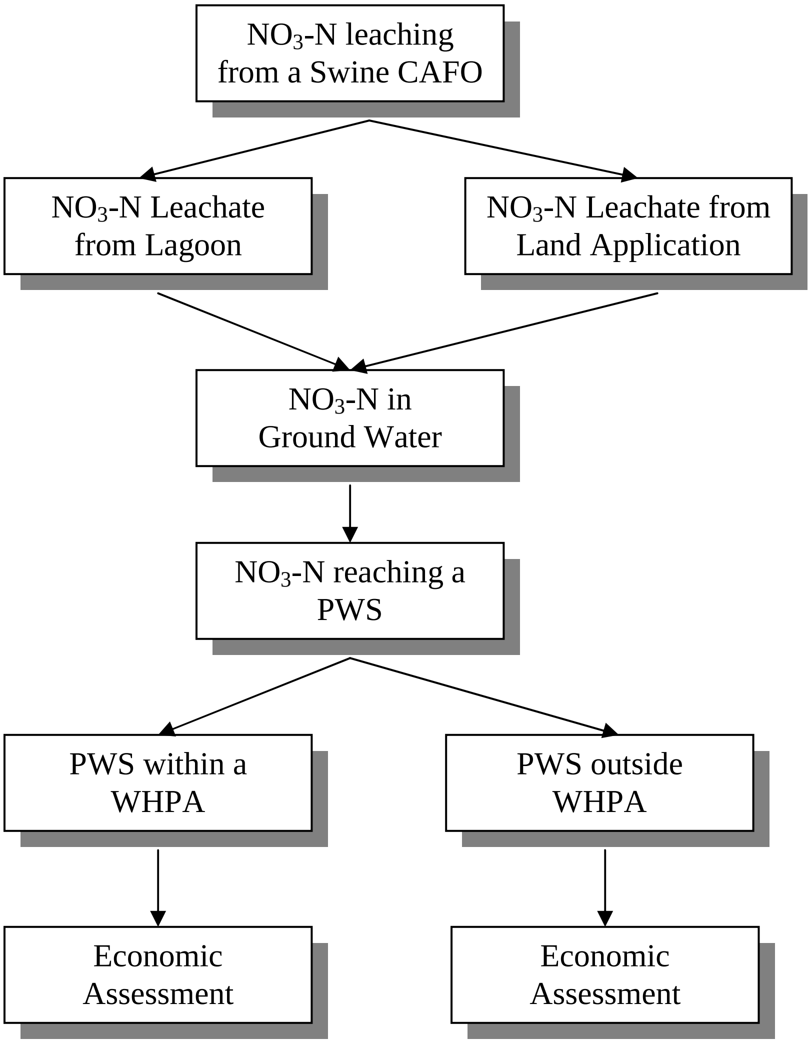

Figure I-1. Diagram of NO_3-N Assessment Framework

Hypothesis

The hypothesis tested in this thesis may be stated as;

- H0: A CAFO with BMPs in a Wellhead Protection Area can protect the water quality without restricting economic growth, and
- H1: A CAFO with BMPs in a Wellhead Protection Area cannot protect water quality without restricting economic growth.

CHAPTER II

LITERATURE REVIEW

Ground Water Quality Issues

Ground water is frequently used as a source of water supply and is defined as subsurface water that occurs beneath the water table where the soils and geologic formations are fully saturated (Freeze & Cherry, 1979). Hence, the occurrence of ground water is related to its geologic setting, and the chemical composition is related to the precipitation and the solubility of aquifer constituents.

The quality of ground water can be altered by contaminants (Christenson 1987), defined as “solutes that are introduced into the hydrologic environment, regardless of whether or not the concentrations reach levels that may cause significant degradation of water quality” (Freeze & Cherry; 1979). The contamination of ground water could be caused by many point or non-point sources, either naturally or human induced (Barton *et al.*, 1987; Timmons, 1983). Point sources are considered as “any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation or other floating craft, from which pollutants are or may be discharged” (WPCF, 1987; CH2M Hill, Inc., 1990). Examples of point sources of contaminants include landfills, industrial spills, liquid waste lagoons, storage, and animal feedlots (EPA, 1994).

Nonpoint sources are defined as “pollutants that arise from sources associated with the land and human use of it”. Nonpoint source pollutants are transported from the land by individual, or combined aerial, surface water, and ground water mechanisms. Examples of nonpoint sources include domestic septic systems, application of pesticides and fertilizers, leakage, illegal discharges (EPA, 1994), and contaminated ground water as it enters the surface as a diffuse source (CH2M Hill, Inc., 1990; WPFC, 1987; Christensen, 1983).

Contaminants may enter ground water through infiltration, recharge from the surface, direct migration, and inter-aquifer exchange (EPA, 1994). Thus, naturally occurring contaminants, as well as human activities related to land-use, can contribute to the contamination of ground water systems (Senior, 1996; Christenson & Parkhurst, 1987). Human activities are commonly associated with agriculture, industrialization, and urbanization. A recent trend in agriculture is the increase of confined animal feeding operations (CAFOs). These facilities pose potential point source of pollution from leakage/seepage from lagoons and nonpoint source of pollution from improper or over application of manure (Grady, 1994; Freeze & Cherry, 1979).

Issues in ground water quality management are complex, involving water quality standards, best management practices and best institutional policy. Water quality standards serve as a basis to determine the suitability of its use (Crowe, 1993). The most important standards are those established for drinking water where contamination of ground water may result in unacceptable risk to human health or the environment (Copeland & Zinn, 1998; Crowe, 1993; Freeze & Cherry, 1979). The National Primary Drinking Water Regulations (NPDWR), also called the primary standards, defined the maximum contaminant levels (MCL) as the permissible concentration limits in drinking water (Freeze & Cherry, 1979). This primary standard protects drinking water quality by setting the limits of specific contaminants that are considered to have significant potential harm to human health at concentrations above the specified limits (EPA, 1998; Freeze & Cheery, 1979). MCLs are set by EPA and are enforceable at Public Well Systems: " a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals" (EPA, 1998). Ground water contaminated with nitrate-nitrogen above the specified MCL (10 mg/L) could adversely affect human health when used as drinking water (EPA, 1998; Canter, 1997; Freeze & Cheery, 1979; and Kneese & Bower, 1968).

The focus to control agricultural non-point source pollution is by the identification and evaluation of best management practices. Best Management Practices (BMPs) is defined as "A practice or combination of practices that are determined by a state or designated area wide planning agency to be the most effective and practicable." This practice(s) includes technological, economic, and institutional considerations to control point and non-point pollutants at a level compatible with environmental quality goals (SCSA, 1982; Christensen, 1983).

Water quality problems often require the use of several BMPs depending on the type and location of the activity. CAFOs require BMPs to ensure there is no discharge of manure or wastewater into waters of the State. BMPs for this activity should consist of guidance for controlling runoff, wastewater and manure discharges to watercourses, as well as other practices that will help to protect ground water. Therefore, it is important to analyze and evaluate the systems of BMPs that includes environmental effectiveness, economic feasibility, as well as social acceptability and implementability (Bailey & Swank, 1983; Christensen, 1983).

The best institutional policy to manage ground water quality requires the implementation of an effective and efficient management program using information provided by engineering-economic analysis (Kneese & Bower, 1968). Agricultural and environmental policies as economic tools have been emerging together for over a decade, though the process has been difficult. Intricasies arise due to the differing perceptions about what the problems are and how to view them, differing concepts of environmental quality and responsibilities to maintain that quality, as well as differing institutional perspectives (Copeland & Zinn, 1998).

Ground Water Policies and the Wellhead Protection Program

Since 1970, deterioration of ground water quality has been increasing, mainly related to chlorides, nitrates, and bacterial contamination. Enforcement of ground water quality protection laws continues to be primarily a state and local responsibility. Nonetheless, federal regulation of ground water has become increasingly important over the past two decades, resulting in interactions, overlapping or even conflicts between federal and state regulation. There are many laws related to ground water protection, including the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA) (Copeland, 2001; EPA OWOW, 2000).

The Clean Water Act or the Federal Water Pollution Control Act, originally enacted in 1948, is the principal law governing pollution in the nation's streams, lakes, and estuaries. In 1972 (P.L. 92-500), the CWA was amended and consists of two major parts. The first part provides regulatory provisions that impose progressively more stringent requirements on industries and cities in order to meet the statutory goal of zero discharge of pollutants. The second part provides provisions that authorize federal financial assistance for municipal wastewater treatment construction. Industries were to meet pollution control limits first by use of Best Practicable Technology and later by improved Best Available Technology (Copeland, 2001). In 1987, the amendments added Section 319 to the Act, under which states were required to develop and implement programs to control nonpoint sources of pollution, or rainfall runoff from farm and urban areas, as well as construction, forestry, and mining sites (Copeland, 2001; EPA OWOW, 2000).

The Safe Drinking Water Act (SDWA) focuses on the quality of public drinking water supplies and ground water protection by regulating "maximum contaminant levels" (MCLs). These MCLs serve as the minimum standards for the nation's drinking water, and are important for assessing liability for ground water contamination (Feitshans, 1996). Under Section 1428 of the Safe Drinking Water Act Amendments of 1986, each State is required to develop and implement a Wellhead Protection program (EPA 1994). The WHP program is a pollution prevention strategy designed to protect and preserve ground water-based sources of drinking water from threats of contamination and/or further degradation of its quality. The program is focused on community-based approach for the protection of ground water that supplies public wells and wellfields. The overall goal of the program is to delineate Wellhead Protection Areas (WHPA), "a surface and subsurface area surrounding a water well or wellfield, supplying a public water system through which contaminants are likely to move toward and reach such well or wellfield"

(EPA, 1995; US EPA, 1987). Within the protection areas, landuse controls and other preventive measures are recommended (USDA, 1999; Ribaudo *et al.*, 1998).

The Wellhead Protection program can be used in conjunction with agriculture resource conservation programs. Both programs are voluntary and rely on the combination of education, technical assistance and cost sharing payments to attract participation of the community (Copeland & Zinn, 1998).

Ground Water Quality and CAFOs

Confined Animal Feeding Operations concentrate animals, feed, manure and urine, dead animals, and production operations on a relatively small area where feed is brought to the animals rather than the animals grazing or seeking feed in pastures, fields, or on rangeland (Sutton, 2000; USDA & EPA, 1999; Copeland & Zinn, 1998). These facilities produce a large amount of manure that require complicated storage and handling systems for wastes such as lagoons, as well as sufficient land acreage for disposal of wastes. Both lagoon and land application of waste may become point or nonpoint source of pollution to ground water (Copeland & Zinn, 1998).

Confined Animal Feeding Operation

A Confined Animal Feeding Operation (CAFO) is defined under the Title 40 of the Code of Federal Regulations, part 122.23 (40CFR122.23) Appendix B, as an animal feeding operation with more than 1,000 animal units in a confined facility, or an animal feeding operation with 300 to 1,000 animal units in a confined facility for 45 days or longer in any twelve month period where vegetative cover is not maintained.

An animal feeding operation (AFO) is defined as a "lot or facility" where animals "have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12 month period and crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility" (USDA & EPA, 1999; Executive Order, 2000).

Swine Wastes: Nutrients and Management

Waste management consists of five components; production, storage, treatment, the environment, and transportation (OSU Extension Facts F1734).

Production of Animal Waste

Production of animal waste, usually in the form of solid and liquid, is the result of feed converted by animals to feces and urine. Other sources of waste (non-animal production) include flush water, spilled feed, bedding, leaking waters, and captured rainfall, which could be controlled with careful management and regular equipment maintenance (Copeland & Zinn, 1998; OSU Extension Facts F1734).

The production of manure varies within the animal type, feed ration, health, animal age, and climate (US EPA, 2001; Copeland & Zinn, 1998). The Natural Resource Conservation Service (NRCS) estimated the amount of manure produced on an animal unit equivalent basis for various livestock sectors. Swine manure contains nitrogen and other nutrients such as phosphorus and potassium that can be good for crop production (Table II-1) (Copeland & Zinn, 1998).

Ammonium is one of the dominant inorganic chemical constituents and represents almost 99 percent of soluble N in swine waste with concentration generally ranging from 550 – 1000 mg L^{-1} (Ham *et al.,* 1999). In addition to nutrients, manures also contain organic solids, trace heavy metals, salts, bacteria, viruses, other microorganisms, and sediment that can adversely affect water quality due to its oxygen-demanding characteristics (Sutton, 2000; Copeland & Zinn, 1998; NCCES, 1993).

Table II-1. Nutrient Composition of Swine Manure

Type of Manure	Dry Matter	Total N^3	Ammonium (NH_4)	Phosphorus (P_2O_5)	Potassium (K_2O)
Solid Handling Systems	%	lb/ton			
Fresh[1]		12	7	9	9
Scrapped[1,4]		13	7	12	9
Without bedding[2]	18	10	6	8	8
With bedding[2)]	18	8	5	7	7
Liquid Handling Systems		lb/1000 gal			
Liquid slurry[1,5]		31	19	22	17
Anaerobic lagoon sludge[1]		22	6	49	7
Liquid pit[2]	4	36	26	27	22
Lagoon[2,6]	1	4	3	2	7
		lb/acre-inch			
Anaerobic lagoon liquid[1)]		136	111	53	133

[1] Source: SoilFacts, N. Carolina Cooperative Extension Service, 1993 (Abridged from N. Carolina Agricultural Chemicals) and Tyson, 1996.
[2] Source: Colorado State University Cooperative Extension Bulletin 552 A, 1992.
[3] Total N = total nitrogen in the form of ammonium N plus organic N.
[4] Collected within one week
[5] Six to twelve months accumulation of manure, urine, and excess water usage; does not include fresh water for flushing or lot runoff.
[6] Application conversion factors: 1000 gal = 4 tons; 1 acre-inch = 27,154 gal

Swine Waste Storage

A swine facility as a CAFO requires adequate storage capacity for animal and other wastes. The type of storage is determined by the intended use of the waste, and the structure of the storage must be designed to prevent waste from seeping into the soil and groundwater. Greater storage capacity is needed for longer periods of storage, especially through the winter to avoid spreading while the ground is frozen and crop growth and nutrient requirements are low, preventing surface water pollution (Sutton, 2000; Copeland & Zinn, 1998, Tyson, 1996; OSU Extension Facts F1734).

To prevent lagoon overflow, excess lagoon liquid should be pumped and applied to grassland, cropland, or woodland to maintain enough storage space. Application to the fields should be during the growing season and at rates within the soil infiltration capacity and the crop fertilizer requirement (Copeland & Zinn, 1998, Tyson, 1996).

Common methods for collecting and storing liquid wastes are earthen basins (lagoons and pits) and holding ponds (Sutton, 2000; Copeland & Zinn, 1998). A lagoon is a lined earthen basin used to treat raw organic waste, and store treated solids and liquids. Lagoons are designed to hold diluted waste for six to 24 months allowing wastes to decompose more organic matter per unit volume. Pits are smaller than lagoons, and are capable of storing liquid manure for one to six months. Little decomposition occurs because of the short holding time and little dilution. Consequently, nutrient levels are higher in pits than in lagoons (Sutton, 2000; Tyson, 1996).

Holding pond is another type of storage that is smaller than lagoons and allows very little decomposition. Holding ponds can be used for short-term storage of feedlot runoff for application to cropland through irrigation systems. Other methods used for waste storage include above or below ground tanks of concrete or steel, which generally have smaller risks in impacting water quality (Sutton, 2000).

The location of the lagoon is generally down-slope from the swine housing unit to allow drainage of waste by gravity, and the distance should be close enough for easy access to recycle the lagoon water for flushing waste from buildings. The American Society of Agricultural Engineering (ASAE) Engineering Practice 403.3 recommends that lagoons should be greater than 300 feet from any water wells to prevent water supply contamination. The Natural Resources Conservation Service (NRCS) recommends 500 feet, but will tolerate 150 feet from an upslope well (Tyson, 1996).

Proper design of a lagoon system requires the calculation of the volume that will be needed to accommodate waste accumulation over the desired treatment period. The total lagoon volume is composed of treatment, manure wastewater, surface runoff, net rainfall (actual precipitation minus surface evaporation, including the 25 year-24-hour storm), sludge, and freeboard volume (Tyson, 1996; OSU Extension Facts F-1736). Figure II-1 illustrates the schematic of zones and operating levels of a lagoon.

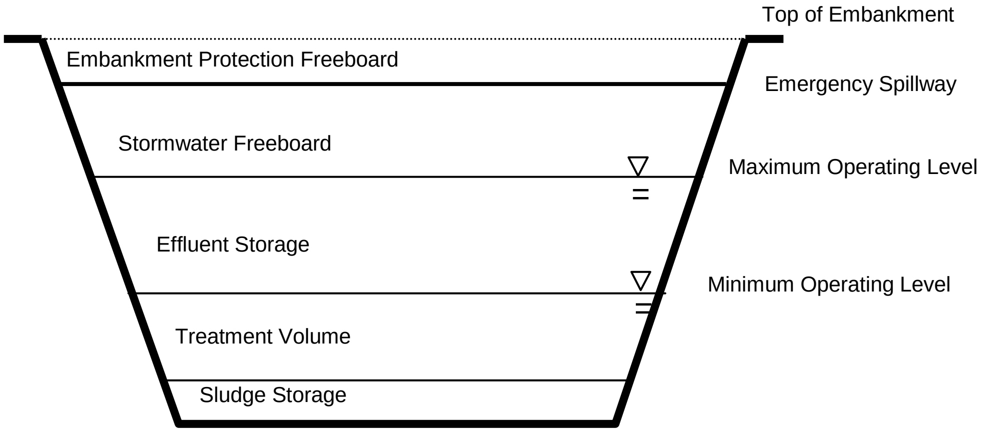

Figure II-1.   Zones and Operating Levels of a lagoon

Modified from Hamilton, F-2245 and Tyson, 1996

Treatment volume is not removed from the lagoon during pumpdown operations to allow enough dilution for the breakdown of volatile solids by bacteria. This volume is based on volatile solid daily loading rate in pounds per day per thousand cubic feet. Manure wastewater volume provides storage of wastewater to accumulate manure equal to the volume of the designed treatment period. Surface runoff volume provides storage for rainfall runoff plus any wash water or other fresh water that may be used for cleaning buildings or lot areas. Net rainfall volume provides storage for the net gain of rainfall minus lagoon surface evaporation plus the 25-year-24-hour storm. Both surface runoff and net rainfall volume are removed when the lagoon is pumped. Sludge volume is the storage volume for solids retained in the lagoon, mostly in the bottom of the lagoon. Freeboard volume provides the minimum extra depth above the total full pool level, usually one foot, after all other volume requirements are met (Tyson, 1996). Table II-2 provides information on average feeder-to-finish lagoon liquid accumulation rates.

Table II-2. Lagoon Liquid Accumulation Rates of Swine Feeder-to-Finish

Total Lagoon Liquid		
Capacity	270	ft^3/animal
To be irrigated */animal/year	972 (0.034)	gallons (acre-inch)

*Estimated total lagoon liquid includes total liquid manure plus average surface rainfall surplus; does not account for seepage

Source: Tyson, 1996. Planning and Managing Lagoons for Swine Waste Treatment

Earthen basins are either constructed with liner in heavy-textured and clayey soils, or lined with clay or plastic, controls downward nutrient leaching. Earthen basins constructed in sandy, well-drained soils, in high water table areas or where bedrock containing usable ground water is within thirty feet of the surface require additional precaution to prevent leaching of nutrients (Sutton, 2000).

Swine Waste Treatment

Waste treatment is necessary to reduce pollution potential by altering the characteristics of manure using physical, chemical or biological methods. Treatment components include lagoons, composters, oxidation ditches, solid separators and chemical additives with lagoons as the common treatment facility (OSU Extension Facts F1734). Holding capacities of storage and treatment facilities are recommended based on the estimated time period the anticipated volume of waste may have to be retained.

With proper lagoon design, manure undergoes biological treatment that allows anaerobic decomposition of organic matter as shown in Figure II-2.

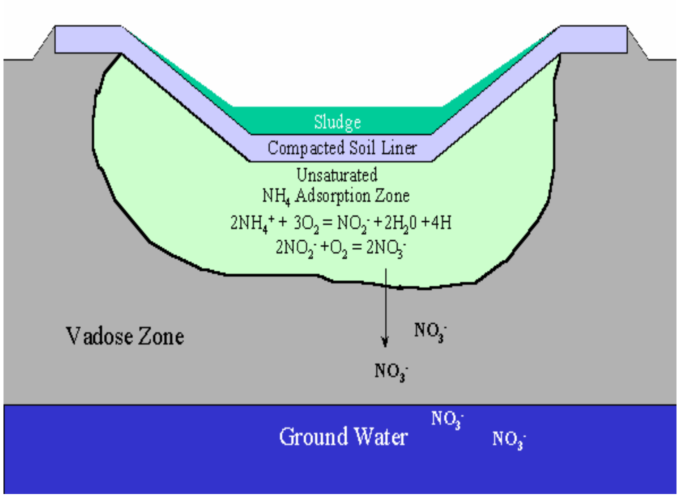

Figure II-2. Potential Lagoon Condition

Source: Ham *et al.*, 1999. Seepage Losses From Animal Waste Lagoons: Potential Impacts on Ground Water Quality.

Swine Wastes Impact to the Environment

Good nutrient management planning is an integral part of a system of practices that conserve and enhance natural resources to eliminate and minimize environmental risks (NCEES, 1993). Application of the proper amount of manure to cropland may improve the soil's water holding capacity, help control erosion, and greatly reduces the amount of commercial fertilizer required to grow a crop (Copeland & Zinn, 1998; OSU Extension Facts F1734; NCEES, 1993).

Swine manure must be analyzed to determine proper application based on the nutrient content of the manure, the percentages of those nutrients that are available to the plants and the nutrient requirement of the plants. The total nutrient content reported from a manure analysis is not the amount immediately available to crops when the manure is applied. Some elements are only released when soil microorganisms decompose the organic matter. Other elements can combine with soil constituents and be made unavailable. Nitrogen is removed by plant uptake and in crop harvest. In addition, N is lost from manure management systems in gaseous forms – the volatilization of ammoniacal N as ammonia gas and the loss of N gases through denitrification, depending on the application method and soil moisture sampling (Lowrance & Hubbard, 2001; NCEES, 1993).

Land application rates of manure are generally determined by matching the available nitrogen or phosphorus content of the wastes to the nutrient requirements of the crops. In most cases, nitrogen determines the application rate unless the area is designated "nutrient sensitive" and indicates that phosphorus movement off-site could contaminate surface waters (Lowrance & Hubbard, 2001; NCEES, 1993). Moreover, excessive manure application causes high nitrate concentrations in feed and forage crops that can harm livestock (through nitrate poisoning) and promote nutrient imbalances (Extension Facts F1734).

In addition to application rate, land availability and land coverage also needs to be carefully determined to assure crop utilization of nutrients (USDA & SCS, 1999). It is important to use a type of crop(s) that removes a maximum level of nutrients, especially the specific nutrient of concern in the area. Forage crops that are commonly used are those that have a high dry matter yield potential or that have higher nutrient uptake for specific nutrients. The most efficient nutrient removal forage system uses a combination of both warm and cool-season forage species to enhance nutrient removal on a year-round basis (OSU Extension Facts F-2251). Table II-3 lists the plant available nutrients contained in effluent. It also provides guidelines on application rates and minimum land areas needed for irrigation using effluent from swines from feeder-to-finish and application for Bermudagrass, a common crop field in Kingfisher.

Table II-3. Plant Available Nutrients, Land Area and Application Rate for Irrigated Swine Feeder-to-Finish Lagoon Liquid for Bermudagrass

	Plant Available Nutrients by Irrigation*		Land Area and Application Rate for Irrigated Swine Feeder-to-Finish Lagoon Liquid for Bermudagrass		
Rate-Limiting Nutrients	lb/ac-in	lb/Animal/ Yr	Maximum lb/acre/ year	Inches/ acre/ year	Minimum acres/ animal
N	68	2.3	400	5.90	0.0058
P2O5	37	1.3	100	2.70	0.0130
K2O	93	3.2	300	3.20	0.0110

* Irrigated: sprinkler irrigated liquid, uncovered for 1 month or longer. Soil incorporated: sprinkler irrigated liquid, plowed or disked into soil within 2 days
Source: Tyson, 1996. Planning and Managing Lagoons for Swine Waste Treatment

Swine Waste Transportation

The process of storage ends when the stored waste is transferred and used or disposed. The most common use is to spread it across the farm fields as a soil amendment and nutrient supplement (Copeland & Zinn, 1998; OSU Extension Facts F1734).

Ground Water Quality and Nitrogen

Nitrogen (N) is an essential nutrient required by all living organisms. Nitrogen occurs in the environment in many forms. In the atmosphere, nitrogen is in gaseous form of elemental nitrogen (N_2); nitrogen oxide compounds (N_2O and NOx); and ammonia (NH_3), which compose 80 percent of the air we breathe. In the soil, nitrogen is in the inorganic and organic forms. Nitrogen in the inorganic form is water soluble as ammonia (NH_3); ammonium (NH_4^{2-}), nitrite (NO_2^-) and nitrate (NO_3^-). Nitrogen in the organic form is bound up in the proteins of living organisms and decaying organic matter (US EPA, 2001; Ribaudo *et al.,* 1999; Canter, 1997; Kellogg *et al.*, 1992; Brady, 1990).

Nitrogen exists in manure in organic and inorganic form (NCAES, 1982). In fresh manure, sixty to ninety percent of total nitrogen is in the organic form, and is unavailable to plants. However, through microbial processes, organic nitrogen is transformed to ammonium (NH_4^+) and nitrate (NO_3^-), which are bioavailable, and therefore, have fertilizer value. In an anaerobic lagoon, the organic fraction is about 20 to 30 percent of total nitrogen (USDA, 1992).

Manure from swine is usually collected in lagoons outside the barns of the raised animals and is degraded by anaerobic bacteria in the lagoons. Organic nitrogen in the solid content of animal feces is mostly in the form of complex molecules associated with digested food, while organic nitrogen in urine is mostly in the form of urea $(NH2)_2$ CO). Carbon-containing compounds decompose and are converted into carbon dioxide and methane, and organic nitrogen is converted into ammonia and ammonium (Kellogg *et al.,* 1992; Ribaudo *et al.,* 1999). The ammonia content of manure may increase as organic matter breaks down, and may decrease when volatilization occurs or when nitrite oxidizes to nitrite under aerobic conditions (US EPA, 2001; USDA, 1992). Subsequent anaerobic conditions can result in denitrification (transformation of nitrates/nitrites to gaseous nitrogen forms). Therefore, between 30 to 90 percent of nitrogen excreted in manure can be lost due to evaporation before it can be used as fertilizer (US EPA, 2001; Vanderholm, 1975).

Nitrogen is often applied in large quantities. Residual nitrogen on cropland (nitrogen from commercial fertilizer, manure, and natural sources in excess of plant needs) is an indicator of potential nitrate availability for runoff to surface water or leaching into ground water. Nitrate-nitrogen is particularly susceptible to leaching due to its solubility in water. High levels of NO_3^--N below the root zone will leach into the ground water contaminating wells supplying drinking water (Helwig *et al.,* 2002; Ribaudo *et al.,* 1999; Nolan *et al.,* 1996; Kellogg *et al.,* 1992).

The risks of nitrate contamination depend on the aquifer vulnerability. The vulnerability and characteristics of an aquifer is based on the characteristics of the soil, precipitation, the depth to the water table, and the types of crops (Ribaudo *et al.*, 1999; Nolan *et al.*, 1996; Kellogg *et al.*, 1992). Areas with a high risk of ground water contamination by nitrate generally have high nitrogen loading or high population, well-drained soils, and less woodland relative to cropland. Nitrate concentration in ground water generally increases with higher nitrogen input (Helwig *et al.*, 2002; US EPA, 2001; Nolan *et al.*, 1996) and higher aquifer vulnerability. Poorly drained soils have reduced the risk of ground water contamination, even in areas with high nitrogen input (Nolan *et al.*, 1996).

The risk of nitrate pollution generally increases at higher rates of application. Even when farmers land apply manure at agronomic rates, nitrogen transport to surface and ground water can still occur for the following reasons: (1) nitrate is extremely mobile and may move below the plant root zone before being taken up; (2) ammonia may volatilize and be redeposited in surface water; (3) the waste may be unevenly distributed, resulting in local “hot spots”; (4) it may be difficult to obtain a representative sample of the waste to determine the amount of mineralized (plant-available) nitrogen; (5) there are uncertainties about the estimated rate of nitrogen mineralization in the applied waste; (6)

transport is affected by uncontrollable environmental factors such as rainfall and other local conditions (Follett, 1995 in US EPA 2001).

Nitrogen concentration in groundwater is of primary concern due to potential human health impacts from groundwater usage, especially as a source of drinking water. The toxicity of nitrate to humans is due to the body's reduction of nitrate to nitrite. This reaction takes place in the saliva of humans of all ages and in the gastrointestinal tract of infants during their first 3 months of life. The toxicity of nitrite has been demonstrated to have vasodilatory/cardiovascular effects at high dose levels and methemoglobinemia or "blue baby syndrome", at lower dose levels (Canter, 1997; Federal Register, 1985).

Ground Water Economics

Ground water is usually considered a "free" good. In the past, ground water has been undervalued, resulting in the depletion and/or pollution of the resource. Valuation of ground water resource can be accomplished by recognizing and quantifying the resource's total economic value (TEV). TEV includes extractive value and in situ value of ground water (NRC, 1997).

Extractive values are derived from the municipal, industrial, commercial, and agricultural demands met by ground water. In situ values are services or values that occur or exist as a consequence of water remaining in place within the aquifer. This value includes the capacity of ground water to protect its quality by maintaining the capacity to dilute and assimilate contaminants, also to facilitate habitat and ecological diversity.

Determination of TEV requires the understanding of the hydrology and ecology of the ground water resource. Hydrologic information includes factors such as rainfall, runoff, infiltration, and water balance data, depth to ground water, type of aquifer (confined or unconfined), geologic settings, and ground water flow as well as direction (NRC, 1997). Ground water systems create ecological services by providing discharge for the maintenance of stream flows, wetlands, and lakes. These discharges support general ecological functions that provide their own services of economic value, thus providing a derived value through its contributions to the larger environment (NRC, 1997).

Qualities of water affected by humans would constitute contamination that may diminish or preclude use for its original purpose. Contamination or degradation of water quality is a supply-related concept, changing a characteristic(s) of a particular water supply. Ground water may be used for many purposes where the use of water for one function may leave a residue or an effluent affecting its quality. The affected quality precludes or diminishes its potential use for other purposes, thus increasing the cost of subsequent use of the same water. This would constitute water pollution, which is a supply-related concept. In economic terms, water pollution means a change in a characteristic(s) of a particular water supply. Water pollution generates additional costs, either monetary or non-monetary, that must be borne by the next use and the next user. The additional costs occur either through diminishing or precluding the next use or through forcing the next use to absorb more costs in cleaning up the residue left by the initial use or to develop a new source of water supply (Timmons, 1983).

Economic Analysis of Ground Water Contamination

Water quality is valued based on its usefulness for many purposes and is determined by its acceptability for a particular use. Therefore, a quality problem occurs when water is contaminated to a level where it is no longer acceptable for that particular use. Water quality parameters are important due to its beneficial uses for domestic, industrial, and agricultural water supplies. Of the domestic purposes, only a small amount is used for drinking water. However, it is of the greatest concern as it affects human health, thus involving the most stringent quality requirements (Ribaudo *et al.*, 1999).

Pollution from point and nonpoint sources is considered an externality, a consequence of production that is not considered when production decisions are made. Farmers and other producers do not take into account social welfare or social costs of pollution when making production decisions. Economic theory suggests several ways to design policies that provide the appropriate incentives for farmers to account for the costs of their pollution and make socially efficient solutions. An efficient solution is an ideal goal of policy to control such pollution by recommending farmers to consider these external costs (Ribaudo *et al.*, 1999).

Ribaudo *et al*. (1999) described that an efficient solution is defined by three conditions. First, for each input and each site, the marginal net private benefits from the use of the input on the site equal the expected marginal external damages from the use of the input. Second, a site should be brought into practice as long as profits on this site are larger than the resulting expected increase in external damage. Third, technologies or environmental policy, should be adopted on each site such that the incremental impact of each technology (relative to the next best alternative) on expected social net benefits is greater than or equal to the incremental impact on expected damages. The three efficiency conditions represent economic tradeoffs involving farm profitability (net returns) and water quality (Figure II-3).

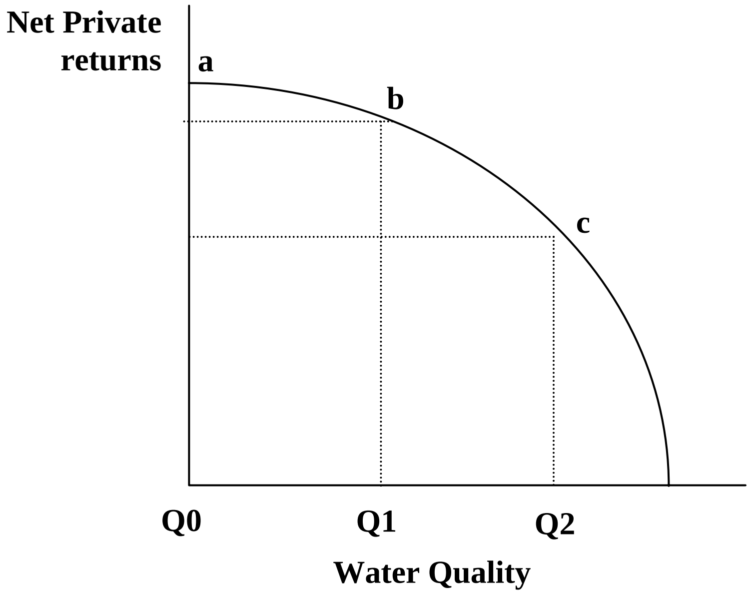

Figure II-3. Farm-level Tradeoff between Net Returns and Water Quality, Given Known Technology or Policy

Source: Modified from Ribaudo *et al.*, 1999.

Movement along the curve represents changes in inputs and policies familiar to the farmer that achieve increasing levels of water quality, where higher level of water quality protection can be achieved with a loss of net returns. Point "**a**" maximizes net private returns without consideration of water quality. Any movement away from point "**a**" results in a profit loss. A farmer may have an economic incentive (taxes, subsidies, permit trading) to pollute less if affected by on farm practices, such as contaminating a drinking water well. Such consideration, without any incentives, may lead to the adoption of practices at point "**b**", which corresponds to a water quality level of "**Q1**". Essentially, the policy tools such as the wellhead protection programs, aim to move the farmers to point "**c**", with water quality of "**Q2**". Point "c" can be justified if the values to avoid pollution damages exceed the decline in net private returns.

Water quality protection is costly to those who must pay for pollution reduction. Consequently, policies can produce net social economic gains only if their impact is to reduce the expected damages from pollution. Reducing expected damages may not always constitute a measurable policy goal, however, because damages from pollution, specifically from nonpoints sources of pollution often remain largely unquantified (Ribaudo *et al.,* 1999).

Environmental policies are cost-effective if they achieve some measurable objectives or goals at the least costs. Therefore, an overall strategy for water quality protection relies on the choice of both policy goals and the instruments to achieve them. Depending on the goals, it may not be possible to attain the least-cost solution with some types of policy instruments (Ribaudo *et al.,* 1999).

Economics of Wellhead Protection Program

The basis of a ground water protection program is to delineate areas surrounding public water system wells where ground water recharge will likely become the source of drinking water. Within these protected areas, good management can reduce the threat of contaminants entering the well recharge areas and polluting public water supplies. Protection of ground water resources require good planning and challenging efforts. Ground water contamination is often irreversible at least in the short run, therefore preventing contamination is usually more effective and less costly than remediation (Ribaudo *et al.,* 1999).

The wellhead Protection Program sets forth its purpose, identifies management concerns, provides technical assistance, issues guidance for identifying contaminant sources, leads to contingency planning, and helps communities site new wells. It is a structured, organized means of focusing federal, state, and local government resources on pollution prevention. The cost of prevention can overburden a municipality in terms of capital outlay. However, the expense is reasonable if compared to the enormous cost of Superfund cleanups (from $70 thousand to over $2.3 million), the cost of a new well, or new connections to an existing supplier. Cleanup of contaminated ground water sites costs about $5.9 million to $7.3 million per site. The preventive aspects of the wellhead protection program that are designed to preclude the need for these measures, save users money in the long run (US EPA, 1995).

Little information exists about trends on nitrate in ground water, especially within the protection area, due to the lack of monitoring programs designed to look at the quality of ground water over time.

Economics of Swine Waste Management

Waste management is a critical component of a CAFO. Failure in such management could cause nutrients runoff to surface water or leachate to groundwater, adversely affecting land, water, and air resources, as well as farm income (Rausch & Sohngen, 1998; Copeland & Zinn, 1998). The word “waste” has the connotation of being something left over that has little or no value. The value of manure can be difficult to determine, although from an agronomic perspective, it has many benefits. The benefit, however, is by utilizing the nutrients from wastes as soil building amendments. If wastes are used for application of nutrients, then purchased inputs (commercial fertilizers) could be reduced (Copeland & Zinn, 1998; USDA & SCS, 1992).

Several options exist for disposing of animal waste, but land application has always been the preferred option by producers or throughout the farm community (Copeland & Zinn, 1998). Alternative methods include composting, burning, and biotech changes to feed that alter the characteristics of the waste (Copeland & Zinn, 1998). Many of these options require large initial investment costs. The constituents and moisture content of the manure are important qualities in determining which disposal techniques to use. Shipping costs constrain many options because manure is of low economic value on a volume or weight basis, so it is uneconomic to ship it long distances unless the waste can be concentrated so as to decrease the volume or increase the value.

Uncertainties in Valuing Ground Water Contamination

The decision-maker attempting to value ground water faces significant uncertainties regarding hydrologic, institutional, economic, and human health aspects of ground water management. One source of uncertainty lies with the problem of predicting the consequences of environmental policies and actions. A related restrain or challenge is the difficulty to assess ground water benefits in the future and the irreversible nature of some present ground water management decisions and impacts. Economic uncertainties regarding non-market goods and services are even more substantial because there is no accurate documentation of monetary values when markets are absent (NRC, 1997).

Ground Water Quality Studies related to Swine Facilities

Many researchers have studied the effects of contamination from CAFOs to ground water quality. Their purposes include finding alternative approaches or best management practices (BMPs) for producers to minimize the pollution to the environment while maximizing their production. These BMPs take into consideration physical characteristics of the site, technology effectiveness and economic efficiency.

Physical characteristics of a site entail the types of soil that determine the seepage/ infiltration rates of water movement, the distance to the aquifer, and the climate affecting the amount of water percolating into the ground. Numerous manure storage facilities have been constructed with minimal compacted clay liners or no liners at all. Many studies have been conducted to determine the effect of seepage/leakage from these lagoons, in which some investigations expected seepage to occur (Hart & Turner, 1965; Loehr, 1968; Scalf *et al.,* 1973; and Ciravolo *et al.*, 1977).

Seepage from lagoons into the ground water could increase the concentration of nitrate and other contaminants, particularly if the distance to the water table is close. Besides the distance, soils with high permeability (sandy soil), high water tables, shallow or unconfined aquifers are susceptible to contamination (Pote *et al.*, 2001; US EPA, 2001 - Attachment B; Ham & DeSutter, 1999; Lichtenberg & Shapiro, 1997; Lindsey, 1997; Ciravolo *et al.*, 1977). The overall results show a positive correlation between animal manure production and elevated nitrate in ground water (US EPA, 2001; North Carolina Division of Water Quality, 1998; Ritter & Chirnside, 1990; Ciravolo *et al.*, 1977; Miller *et al.*, 1976; Scalf *et al.*, 1973; Loehr, 1968; and Hart & Turner, 1965). Contradicting this statement, there have been experiments that indicated seepage from animal waste lagoons is negligible and has only a slight effect on ground water quality (Ciravolo *et al.*, 1977; Swell *et al.*, 1975; Davis *et al.*, 1973; and Nordstedt *et al.*, 1972). Seepage or infiltration from lagoons also depends on the management of the lagoon and the thickness of the liner. Thickness of the liner is also important due to the retardation, decay, and saturation levels of NH_4-N in clay liners Reddi *et al.*, 1999).

Furthermore, well depth found is also found to be a small but significant factor contributing to elevated nitrate concentrations in groundwater (CDC, 1998; Nolan *et al.,* 1998 - Attachment B; Carleton, 1996; Richards *et al.,* 1996). Swistock et al. (1993) reported that wells deeper than 100 feet have the tendency to have significantly lower nitrate concentrations, whereas Kross et al. (1993) found that wells less than 45 feet generally had higher nitrate concentrations.

Associated with the seepage/infiltration rate is the application rate and timing of manure. Most studies have shown that increased application rate of nutrients will not only increase the dry matter yield of crops, but also increase the concentration of NO_3-N in the subsoil (Adeli & Varco, 2001; Lowrance & Hubbard, 2001; Pote *et al.,* 2001; Sanderson *et al.,* 2001; Smith, 1999; Schmidt, 1998; Liu, 1996; Kranz et al. 1995). Split application will lower the application rate at one time. However, such practice would not reduce yearly production, but it would greatly reduce the concentrations and loads of nutrients to the environment would have to assimilate at one time (Hardeman, *et al.,* 2001; Pote *et al.,* 2001; Smith, 1999). Proper timing of nutrient application during the growing season could significantly lower leachate of contaminant as compare to the dormant season or in the winter (Knappe & Meissner, 2002; Pote *et al.,* 2001).

Method of effluent application is another aspect that was studied. Spalding et al. (2001) assessed the impact of improved irrigation and nutrient practices on ground water quality. The results demonstrate that the conversion from furrow to well-managed sprinkler irrigation would significantly benefit shallow ground water quality. Uniform water application and the ability to apply supplemental N on an as-needed basis through fertigation substantially controlled NO_3 leaching beneath the pivot-irrigated management field. Center pivot or linear spray irrigation techniques, and best nutrient and water management practices could lower and maintain ground water NO3 at or near compliance level without significantly lowering yield goals.

In addition, the types of landuse and agricultural practices are found to be influencing factors for the increase of nitrate in the ground water. The US Geological Survey studied the differences in nutrient conditions related to the type of land use. As reported, high concentrations of nitrate in shallow ground water were widespread and strongly related to agricultural land use, but there were no apparent regional patterns. Based on the comparisons with background concentrations, human activities have increased nitrate concentrations in ground water for about two-thirds of agricultural areas studied, compared to about one-third of urban areas (US Geological Circular 1225: Nutrient conditions differ by land use).

Several studies determined that crops such as corn are connected with the higher nitrate level in ground water. This is because corn demands higher fertilizer input and excess irrigation, which increases the rate at which nitrate leaches to the ground water (Lichtenberg & Shapiro, 1997; Stuart *et al.*, 1995; Swistock *et al.,* 1993; Spalding & Exner, 1993). On the contrary, Rausch (1992) found that planting vegetation with nitrogen-fixing legumes as part of crop rotation cycle was associated with lower levels of nitrate in ground water. Tillage practices change the amount of organic matter in the root zone and decrease the quantity of nitrate available for leaching (US EPA, 2001-Attachment B).

The type of crops determines the amount of nitrogen leachate. Alfalfa is a better target crop for swine effluent as compared to corn. Alfalfa utilizes more nitrogen, with flexible irrigation scheduling that is year round, allowing more advantage of land application due to a long growing season and frequent harvest crop (Anderson *et al.,* 1998; Kranz et al. 1995; Shapiro et al. 1989). Therefore, alfalfa is found to be environmentally safer than corn if land is limited, which could be an advantage to producers who do not have enough sufficient land to apply effluent at agronomic rates to corn or other row crops (Knappe & Meissner, 2002; Kranz *et al.,* 1995; Shapiro et al. 1989).

A different aspect of ground water quality study related to CAFOs is the economic impacts of ground water quality affected by CAFOs. Some studies revealed that crops such as corn and alfalfa would be economically feasible for swine effluent application. Corn is found to be a more economical crop if land is not limited, and alfalfa would be more environmentally safe if land is limited, which affects the production costs (Kranz et al. 1995).

Parker (2000) studied the economic impacts of manure alternatives as nutrient management, a part of surface Water Quality Improvement Act (WQIA) of Maryland. The Act regulates the quantities of nutrients that may be applied to cropland, taking into considerations input reduction, improved irrigation management, and cover cropping in winter months. Parker discussed other alternatives to local land application such as compost for wholesale and retail markets; energy conversion, and transportation to agricultural lands out of the area. He suggested that the distribution of costs between groups of growers might vary significantly across different scenarios. In the cases of composting and energy conversion, the majority of costs are almost certain to be borne by the poultry growers. A small number of poultry growers may still be able to apply litter on their own fields, but with little or no economic impact. Some litter could be used on other fields within the county, generating fertilizer savings. If a strong market for poultry litter were to arise, the poultry growers could capture the fertilizer savings from the in-county use. If a weak market exists, the benefits from the fertilizer savings may go to the crop grower. In the case of transporting litter for land application outside the county, the allocation of the benefit is unclear. If a strong market in poultry litter arises, then poultry growers will capture much of the savings, and crop growers will break even. If there is a weak market, then poultry growers could bear significantly higher costs while crop growers could make significant profits. Overall, the WQIA provides a good function in balancing the need for Maryland to maintain a healthy agricultural economy.

Manure handling systems encompass the characteristics of structural (storage), equipment & labor (land application and handling), and nutrient benefit of manure as a substitute for commercial fertilizer. Rausch & Sohngen (1998) presented an overview of the types of costs and benefits that producers should consider before investing in capital for manure handling systems using representative operations. Structures and application method considered were: earthen holding pond with a drag-line direct injection toolbar, earthen holding pond with a tanker spreader, and stacking pad with a conventional spreader. The analysis suggests that for this facility, the earthen holding pond with a drag-line injection toolbar produces the highest Net Annual Cost (Annual Cost – Nutrient Benefit), while a stacking pad with conventional spreader produces the least Net Annual Cost. In general, site specific management of nitrogen application could substantially reduce the economic variability (variability of net returns), reduce nitrate pollution and maintain profitability (Rejesus & Hornbaker, 1999).

In addition to technical and economical aspects of the studies, education can be used as an instrument to provide producers with information on how to farm more efficiently with current or new technologies that generate less pollution and are more profitable. However, education cannot be considered as a strong tool for water quality protection. The success of the effort depends on alternative practices being more profitable than conventional practices, or the notion that producers value cleaner water enough to accept potentially lower profits. Evidence suggests that net returns are the main concern of producers when they adopt alternative management practices (Ribaudo *et al.*, 1999). Education is a nonpoint strategy approach that has been effective in getting producers to adopt certain environmentally friendly practices (Ribaudo *et al.*, 1999; Knox *et al.*, 1995; Gould *et al.*, 1989).

Richert *et al.*, (1995) conducted a study to evaluate pork producer's general knowledge regarding waste production and management to help better focus future Extension educational programs. The results of the survey indicate that many producers are not concerned with swine waste as an environmental issue. However, younger producers with higher educational background tend to realize the impact of their operations on the environment and adopt nutritional and management practices to help minimize swine waste production. This suggests that educational programs are necessary to inform pork producers that waste management is an important environmental concern. The program should include local and state regulations for waste storage, amounts and composition of waste produced, and effects of different storage and application methods on fertilizer value. In addition, programming would be to implement technology to reduce swine waste production.

Ground Water Modeling

Ground Water Modeling of Nitrogen Leachate using HYDRUS 1D

Ground water can be adversely affected by the influx of nutrients from agricultural lands. Nitrogen applied to the soil surface prior to and immediately after the planting operation are particularly susceptible to loss through surface runoff or leaching to groundwater through the soil profile (Helwig *et al.*, 2002; Kumar *et al.*, 1998; Canter, 1997; Addiscott *et al.*, 1992).

Canter (1997) explained the three main processes of nitrogen leaching. First, water flowing through the soil tends to dilute the nitrate. Second, microbes in the soil produce nitrate as they break down nitrogen-containing organic material. These microbes could also remove nitrate from the system by locking it up in soil organic material or by converting it to gaseous nitrogen or nitrous oxide. Third, crops growing on the soil can take up nitrate and lessen the risk of leaching. These three processes are interrelated where a shortage of water in the soil could restrain the production of nitrate by the microbes and its uptake by the crops, while a shortage of nitrate in the soil restricts crop nutrient uptake.

Vulnerability of ground water to contamination is determined by characteristics of the aquifer. To evaluate the vulnerability of the aquifer, a standardized systems called DRASTIC was developed. DRASTIC considers seven hydrologic factors: depth to water, net recharge, aquifer media, soil media, topography (slope), impact of the vadose zone media, and hydraulic conductivity of the aquifer.

The DRASTIC model computes the relative vulnerability of ground water to contamination from surface sources of pollution with assumptions that: (1) the contaminant is introduced at the ground surface; (2) the contaminant is transported into the ground water by precipitation; (3) the contaminant has the mobility of water; and (4) the area being evaluated by DRASTIC is 100 acres or larger. However, these parameters are not inclusive and were not designed to deal with pollutants introduced in the shallow or deep subsurface, by methods such as leaking underground storage tanks, animal waste lagoons, or injection wells (Osborn *et al.*, 1999).

Computer models have been used to evaluate the risk of contamination of water resources by agricultural chemicals from cropping systems. These models use nutrient transport equations to assess water quality, predicting contamination of surface and ground water. HYDRUS 1D program is a finite element model for simulating the one-dimensional movement of water and multiple solutes in variably saturated media. The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media by solving Richards' equation. The model consists of flow equations that incorporate a sink term to account for water uptake by plant roots and the solute transport. The root growth is simulated by means of a logistic growth function where water and salinity stress response functions can be defined according to functions proposed by Feddes et al. (1978) or van Genuchten (1987). The model also contains solute transport equations that include linear equilibrium reactions between the liquid phase, diffusion in the gaseous phase, and nonlinear and/or nonequilibrium reactions between the solid and liquid phases. The flow and transport region may be composed of nonuniform soils, occurring in the vertical, horizontal, or a generally inclined direction. The water flow part of the model can deal with (constant or time-varying) prescribed head and flux boundaries, boundaries controlled by atmospheric conditions, as well as free drainage boundary conditions. Soil surface boundary conditions may change during the simulation from prescribed flux to prescribed head type conditions (and vice-versa). The analytical functions are related to each soil hydraulic characteristics of a reference soil, described using van Genuchten type (1980) with the governing flow and transport equations that are solved numerically using Galerkin type. These computations are based on theoretical equations and need to be verified against field measurements in order to evaluate the accuracy and viability of the given method (Jabro *et al.,* 2001).

Ground Water Modeling of Public Water Systems Delineation using WHPA 3.0

The US EPA has listed several criteria as a technical base to delineate protection areas. These criteria include distance, drawdown, time-of-travel (TOT), flow boundaries and assimilative capacity. The ODEQ delineates the WHPAs based on the TOT criteria. Therefore, to assist local technical staff with the delineation, the WHPA ground water model was used. The WHPA model is a time-related, semi-analytical ground water flow model developed by Hydrogeologic Inc. for the U.S. EPA Office of Ground Water (ODEQ 1994). The model simulates the ground water flow conditions and determines the boundary of the protection areas based on the TOT, which is the time required for a ground water contaminant to reach a well (Blanford and Huyakorn, 1991; ODEQ, 1994).

As described in the U.S. EPA WHPA’s user guide (EPA, 1991), the model contains four major computational modules: RESSQC, Multiple Well Capture Zone (MWCAP), General Particle Tracking (GPTRAC), and Uncertainty Analysis

(MONTEC). The GPTRAC (General Particle Tracking Module) was selected for this assessment. The module consists of two options: semi-analytical and numerical. The semi-analytical option delineates time-related capture zones for pumping wells in the homogenous aquifers with steady and uniform ambient ground water flow. The aquifer may be confined, unconfined or unconfined with recharge area. The extent of the aquifer may be infinite or bounded by one or two streams and/or boundaries. The numerical option delineates time-related capture zones of pumping wells for steady ground water flow fields. This option uses numerical ground water flow modeling, types of boundary, as well as aquifer heterogeneity.

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Geographic Information System (GIS)

Many scientists have used Geographic Information Systems (GIS) to analyze spatial data to depict the environment. GIS system can perform three important functions: organize and store data layers (record keeping), integrate data layers using spatial analysis tools within the GIS, and integrate data layers by linking other softwares to the GIS. Information or spatial data includes soil survey data, digital orthophoto quadrangles (DOQs), and the digitized elevation model (DEM), could be used in conjunction with other models such as ground water models.

GIS maintains the spatial location of wells and other potential sources of contaminants to the wells that could be used in generating maps. The maps generated can provide a better illustration to communicate and explain water resource concepts, land cover maps, the relations between landuse and water quality. Such information contains results of data analysis that could be beneficial to decision makers.

Contaminants Mixing in Aquifer

Chemicals leaching through soils to the ground water mix with water present in the system. The concentration of chemicals that reach the aquifer varies depending on the inflow concentration of the chemical, the recharge rate, and the initial concentration of chemicals in the aquifer itself. The inflow concentration is associated with the concentration of chemicals in the soil profile. The recharge rate is the rate at which water enters the aquifer. The initial concentration is the concentration of chemical already mixed with water in the saturated zone or the aquifer (Nofziger & Wu, 2002).

The concentration of chemical affecting the concentration in the aquifer can be determined by using the mass balance equation below. The mass balance equation describes the time variation of average concentration in an aquifer under constant recharge from the surface soil, hence can be solved by:

$$\mathbf{C(t) = C_o\, e^{-qt/nH} + C_{in}\,(-e^{-qt/nH})}$$

Where :
$C(t)$ = the average concentration in the aquifer at time t
C_0 = the initial concentration in the aquifer
q = the flux density of water entering the aquifer or the aquifer recharge rate
t = time
n = the effective porosity of the aquifer
H = the average thickness of the aquifer

The assumptions and simplifications of the equations consider that the aquifer is an ideal mixer or a constantly stirred tank with water entering the aquifer at a constant recharge rate (q) and constant concentration (Cin).

CHAPTER III

METHODOLOGY OVERVIEW AND SELECTION OF STUDY AREA

The study to develop a framework for evaluating impact of a CAFO in a wellhead protection area comprises of 4 components. The first component covers the selection of the study area, which includes the selection of the CAFO facility and the public well systems. This component will be discussed in this chapter. The second component deals with the simulation of nitrate leaching from an animal waste lagoon and from land application of effluent. This section will be discussed in Chapter IV. The third component consists of Cost Benefit analysis of a CAFO, discussed in Chapter V. The fourth component contains the evaluation of the impact of a CAFO in a wellhead protection area, discussed in Chapter VI.

Methodology Overview

I. Selection of study area, swine CAFO, and Public Water Systems
    A. Select a study area: Kingfisher County
    B. Select a CAFO and PWS for case study
        1. Identify Public Well Systems (PWSs) in Kingfisher County
        2. Identify swine CAFOs in Kingfisher County
        3. Select a PWS that is located down-gradient from a CAFO
        4. Select the closest CAFO located upgradient from the PWS
        5. Determine the size of the CAFO
        6. Delineate the wellhead protection area of the PWS

II. Simulations of nitrate leaching from a CAFO
   A. Simulation of nitrate leaching from a lagoon
      1. Determine the nitrate concentration in the soil profile flux water
      2. Determine the time when MCL is reached in the soil profile
      3. Determine the time that nitrate plume reaches the aquifer
      4. Determine the concentration of nitrate reaching the aquifer
      5. Determine whether or not the concentration will exceed the MCL
   B. Simulation of nitrate leaching from effluent application to land
      1. Estimation of nitrate leaching from effluent application to land
         a. Determine the time that nitrate plume reaches the aquifer
         b. Determine the maximum leachate concentrations
         c. Determine practice(s) that generates the lowest concentration of nitrate leachate over time
         d. Determine practice(s) that provide the longest period of time before nitrate reaches the MCL in the soil profile
      2. Calculation of nitrate mixing in the aquifer
         a. Determine the nitrate concentrations in the aquifer
         b. Determine the time when MCL in ground water is reached
   C. Calculation of time required for nitrate to reach a Public Well(s) from the facility to the periphery of the delineated area.
      1. Determine whether or not nitrate level in the PWSs reaches the MCL
      2. Determine the time that nitrate reaches the MCL at the PWS

III. Cost Benefit Analysis of a CAFO
   A. Analysis of the costs of waste management systems of a CAFO incorporating the net revenue from Bermudagrass hay production to compensate partial waste management costs.
      1. Determine the costs of waste management systems of a CAFO using the same size of lagoons for all scenarios.

    2. Determine the costs of waste management of a CAFO by incorporating net revenue from Bermudagrass production to compensate partial costs of waste management systems.
    3. Determine alternative least cost of waste management systems by using smaller size of lagoon for scenarios that recycles water from lagoon (D-2, lYG-2, HYG-2, and SA-2) to minimize waste systems expenses.
    4. Determine alternative least cost of waste management incorporating the net revenue from Bermudagrass production.

B. Evaluation of potential costs of alternative water sources
    1. Determine the potential costs to drill new wells to replace the current operating wells.
    2. Determine the potential costs to purchase water from another source (the city of Hennessey).

C. Cost Benefit Analysis of the cost of waste management incorporating externality costs at the time nitrate concentration in the PWS reaches the MCL
    1. Determine the costs of waste management with replacing new wells using the same size of lagoon for all scenarios.
    2. Determine the least cost of waste management with replacing new wells using different lagoon sizes for scenarios D-2, lYG-2, HYG-2, and SA-2.
    3. Determine the cots of waste management with purchasing water from the city of Hennessey using the same lagoon sizes for all scenarios.
    4. Determine the least cost of waste management with purchasing water from the city of Hennessey using different lagoon sizes for scenarios D-2, lYG-2, HYG-2, and SA-2.
    5. Determine the benefit from a CAFO, which includes the costs of waste management
    6. Determine the benefit from a CAFO incorporating the potential costs to replace new wells.
    7. Determine the benefit from a CAFO incorporating the potential costs to purchase water from the city of Hennessey.

E. Cost Benefit analysis of a CAFO in a wellhead protection area, considering the time of nitrate concentration at a PWS reaches the MCL at an earlier stage.
    1. Determine the benefit from a CAFO in a WHPA, incorporating the potential costs to replace new wells.
    2. Determine the benefit from a CAFO in a WHPA, incorporating the potential costs to purchase water from the city of Hennessey.

IV. Evaluation of impact of a CAFO in a Wellhead Protection Area
- Determine the practice and benefit that would satisfy both preservation of water quality and beneficial to the producers.

Selection of Study Area, CAFO Facility, and Public Water Systems

Study Area: Kingfisher County, Oklahoma

Kingfisher County was selected for this study because of elevated nitrate concentrations in the public well systems and the increasing number of CAFOs. The geologic setting of the Kingfisher area is dominated by Permian red beds composed of sands, siltstones, shales, and evaporite sequences. The City of Kingfisher depends on ground water produced from the Cimarron Alluvium and Terrace Aquifer for its municipal water supply (Figure III-1).

The Cimarron Alluvium and Terrace aquifer is an unconfined aquifer with an average saturated thickness of 28 ft. The structure of the aquifer consists of unconsolidated deposits of sand, silt, clay, and gravel. This aquifer has shallow water depths and is very permeable. Estimated recharge to the aquifer is 207 cubic feet per second. Yields of wells in these aquifers range from 10 to 1,200 gpm (Osborn *et al.,* 1998, Adams & Bergman, 1996). Shallow and unconfined aquifers are vulnerable to contamination from deep percolation of precipitation, irrigation, and subsurface inflow through alluvium (Adams & Bergman, 1996).

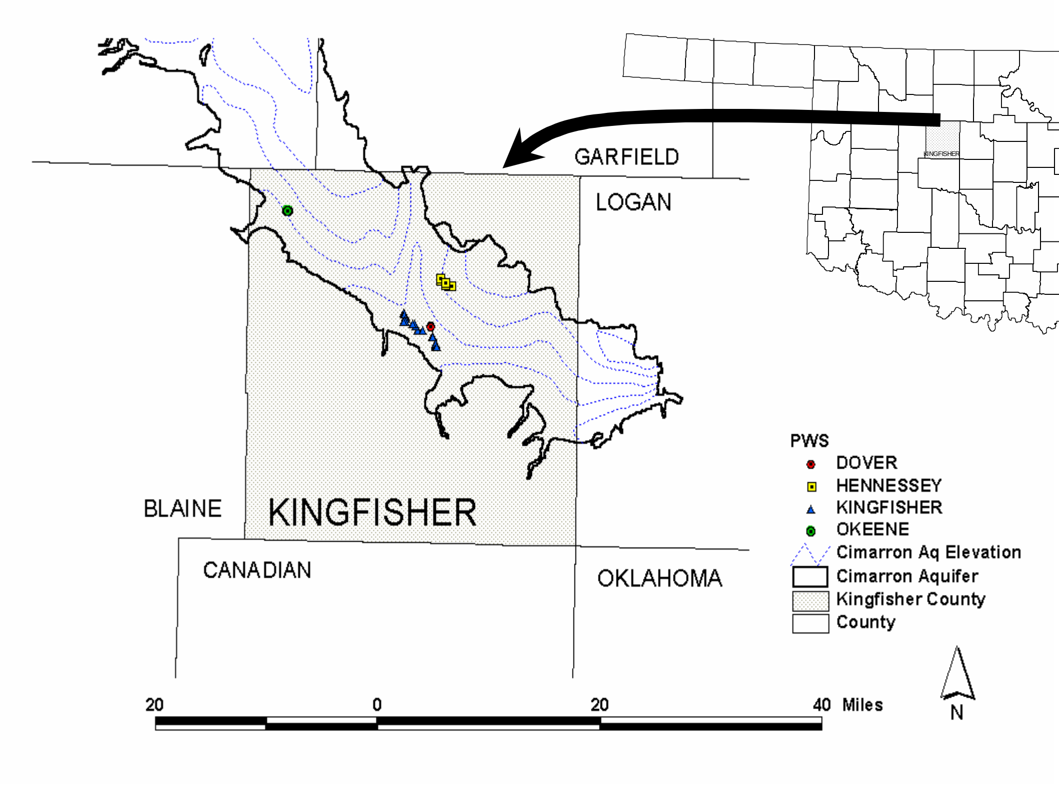

Figure III-1. Kingfisher County, Oklahoma Overlying the Cimarron Aquifer

Selection of a Public Well Systems and Swine CAFO Facility

Public Well Systems in the Kingfisher County were displayed using ArcView. The data were obtained from the Oklahoma Department of Environmental Quality, in the latitude and longitude format (shown in Appendix A). In the area, there are four PWSs that overly the Cimarron Aquifer in the Kingfisher County. These PWSs are: Okeene, Dover, Kingfisher, and Hennessey. These PWSs are shown in Figure III-2.

Swine facilities in Kingfisher County were identified based on the data obtained from ODEQ. The data consists of information on the types of CAFO operation, the sizes of the facility, and their locations (shown in Appendix B). These positions were then displayed using ArcView to visualize their locations with respect to public wells and the underlying Cimarron Aquifer in Kingfisher (Figure III-3).

Based on the information provided in Figure III-3, it can be seen that several Kingfisher wells are located down gradient from a CAFO facility. Other public wells are found to be hydrologically isolated from the existing CAFOs. Therefore, both the wells and the CAFO that are hydrologically related are selected for this study. The black circle shows the CAFO selected.

Additional information on the map, such as the aquifer elevation (Cimarron aquifer elevation) and the hydraulic conductivity, provides us better understanding to examine the movement of groundwater. This information could be useful for future decision-making to assign areas for new CAFOs or other landuse.

Other information presented on the map, such as the distance between a PWS to another could also be beneficial. This detail could be used to resolve problems in selecting which of the PWS would be more reliable to purchase water from, should the wells or wellfield become contaminated.

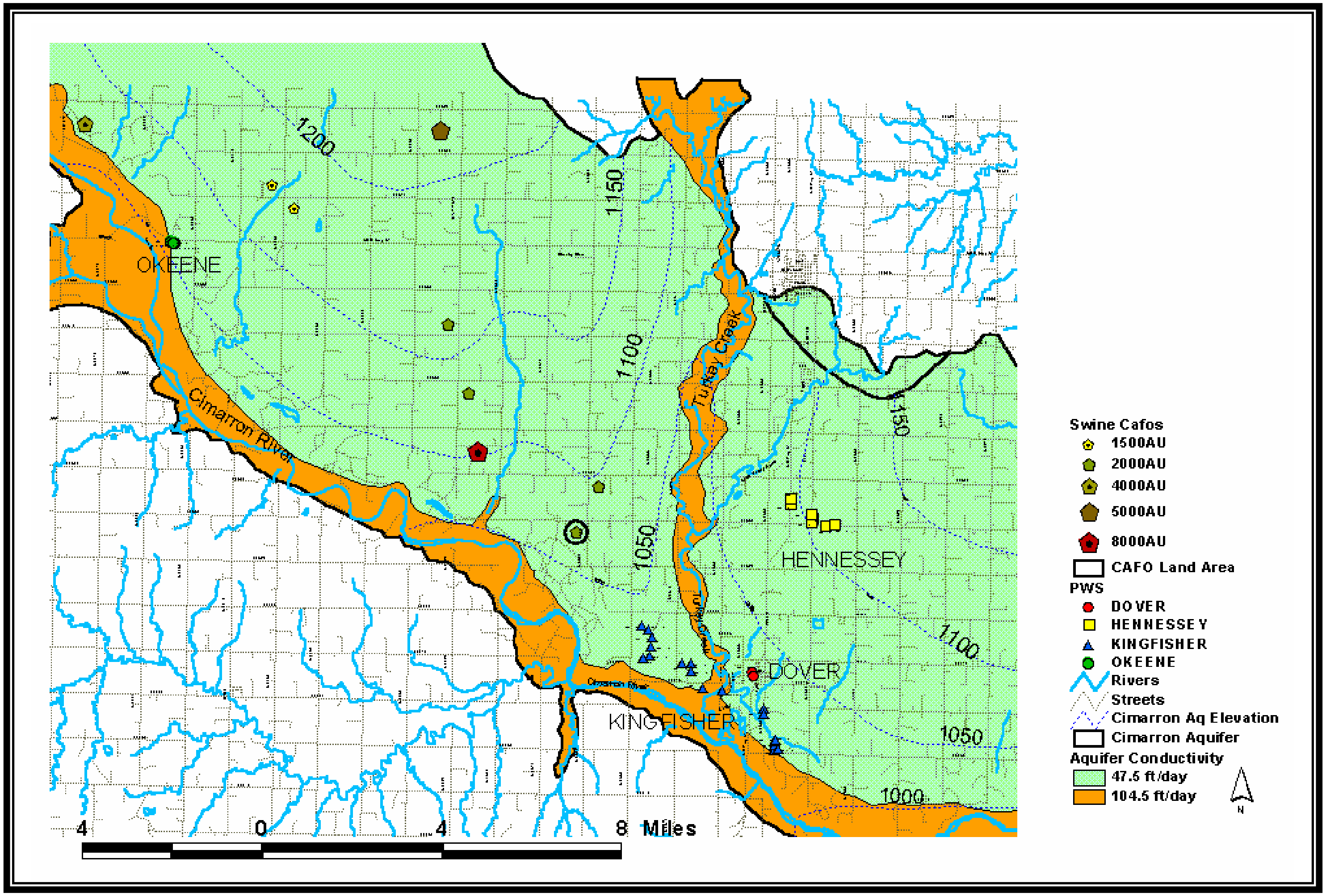

Figure III-2. Public Water Systems and Swine CAFO facilities overlying Cimarron Terrace Aquifer in Kingfisher, OK

After the wells were positioned, the wellhead protection areas were delineated using WHPA code version 3.0. Within the code, the GPTRAC module was selected for each site. This option delineates time-related capture zones for pumping wells in homogenous unconfined aquifers with steady and uniform ambient ground water flow, using a 10 year TOT. Parameters used in WHPA code are included in Appendix C. The results from WHPA were also included as another layer in ArcView to depict the boundaries, shown in Figure III-3. The combination of CAFO, public wells and delineated areas on the map illustrates the linkage between the potential source of contaminants, the protected area, and the public wells.

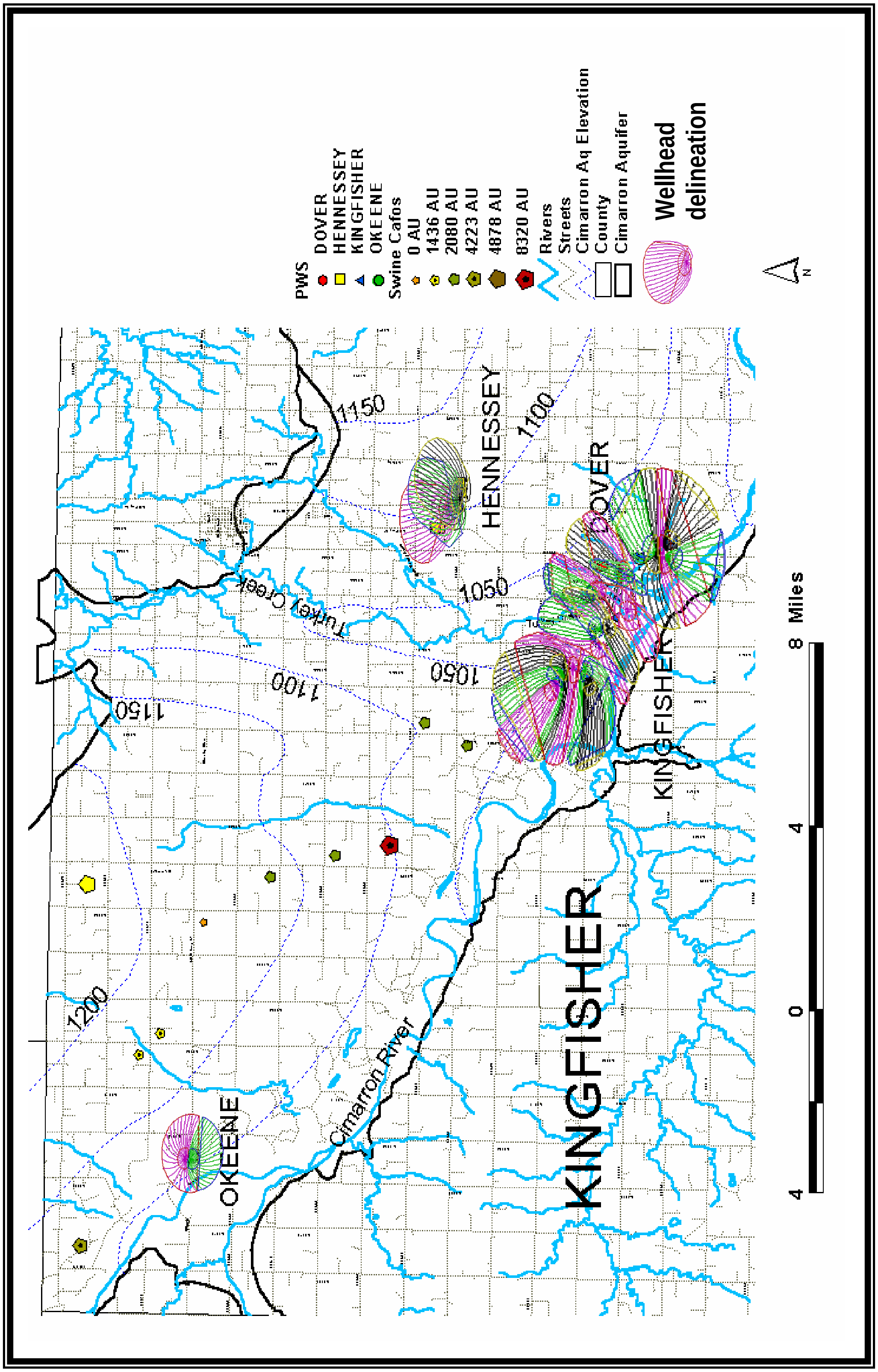

Figure III-3. Swine Facilities and Delineated Public Wells

CHAPTER IV

SIMULATIONS OF NITRATE LEACHING FROM A CAFO

Confined Animal Feeding Operations (CAFOs) pose both point and nonpoint sources of pollution. Point sources of pollution is generated from the leaching of nitrate from underneath the waste lagoon, whereas nonpoint sources are generated from leaching of nitrate resulted from effluent application to land. This chapter will discuss the second component of the framework: simulations of nitrate leachate from the bottom of a waste lagoon and land application of effluent.

The purpose of this part of the study is to provide information regarding the leaching of nitrate from a CAFO facility. This component consists of 3 parts: 1) simulation of nitrate leaching from beneath a waste lagoon; 2) simulation of nitrate leaching from effluent application to land, which include the calculation of nitrate mixing in the aquifer; and 3) calculation of the time required for nitrate to reach PWSs.

Simulations of Nitrate Leaching from Beneath a Waste Lagoon

Purpose and Objectives

Lagoons are designed to provide storage and treatment of animal waste and other types of waste. The design includes clay liner in the construction to prevent or impede seepage to ground water. In Oklahoma, the liner of a lagoon is required to have a minimum thickness of one and one half (1.5) feet with a maximum hydrostatic head of ten and one half (10.5) feet or permeabilities of 1x 10^{-7} cm/sec (Title 35). The purpose of this study is to determine whether or not nitrate leaching from underneath a waste lagoon will reach the underlying aquifer with a distance of 70 ft. The specific objectives are to determine:

1. the nitrate concentration in the soil profile flux water,
2. the time when MCL is reached in the soil profile,
3. the time that nitrate reaches the aquifer,
4. the concentration of nitrate reaching the aquifer, and
5. whether or not the concentration of nitrate reaching the aquifer will reach the MCL.

Methodology

1. Parameters of the lagoon to be used for HYDRUS 1D simulations were determined. The parameters include the head of the water level, the thickness of the clay liner, and the hydraulic conductivity of the clay liner. The head of the water level in the lagoon was determined to be 3m (approximately 10 ft), taking the conservative assumption that the lagoon is full at all times. The bottom of the lagoon is assumed to be layered with clay liner with a thickness of 0.5m (1.5 ft) and a hydraulic conductivity of 10^{-9} m/s (0.04 ft/d) as determined by the Oklahoma standards. The Total Nitrogen concentration in the bottom of the lagoon was assumed to be 600 mg/L.
2. Geologic parameters used were determined. Geologic parameters include: soil types and hydraulic conductivity, soil thickness, and the distance from the bottom of the lagoon to the aquifer. The soil type used is loamy sand, obtained from the USDA & SCS (1962) for soil types in Kingfisher. Loamy sand in the area has a thickness of about 27m (87 ft). This thickness is the distance between the bottom of the lagoon and the aquifer. The hydraulic conductivity for this layer is $4\text{x}10^{-5}$ m/s (11.5 ft/d), obtained as a default value from HYDRUS 1D. The summary of these parameters is illustrated in Figure IV-1 below.

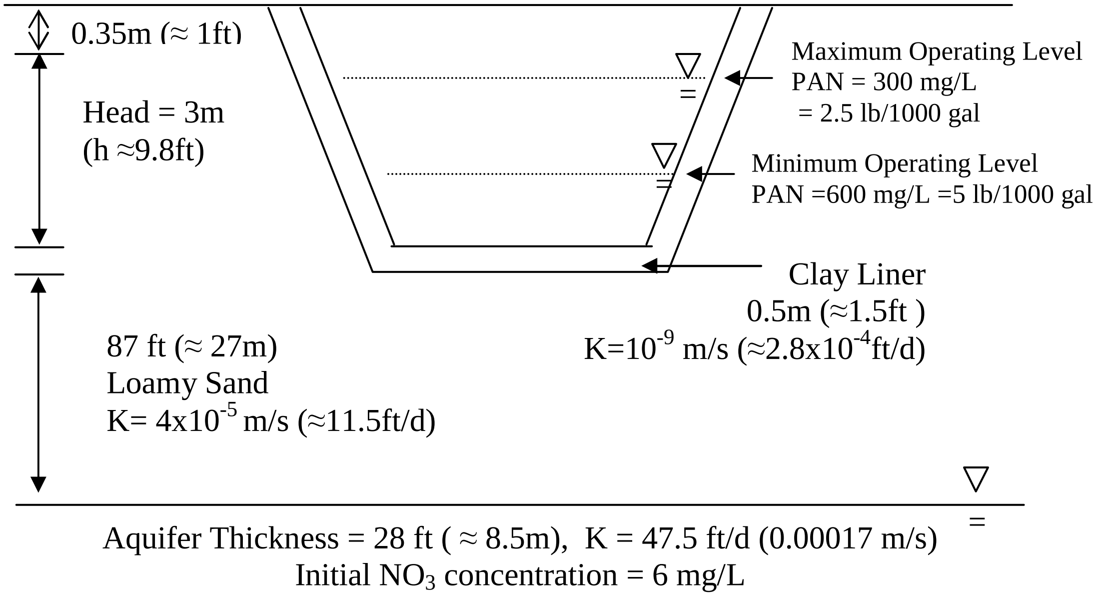

Figure IV-1. Lagoon and Soil Profile Input Parameters for Nitrate Leachate Simulation beneath a Waste Lagoon

3. Leaching of nitrate from the lagoon was simulated using HYDRUS 1D. The simulation was performed for a duration of 50 years to observe the leaching of nitrogen through the soil column into the ground water.

Results and Discussions

The results of the simulations are shown in Figures IV-2 and IV-3. The graphs display the vertical movement of nitrate into the underlying aquifer. Figure IV-2 shows the actual scale of leaching from the bottom of the lagoon to the aquifer with a distance of 27m (70ft). Each curve in this graph represents the profile at the end of five years of simulations. It can be seen that the leachate from the lagoon does not reach the underlying aquifer by year 50.

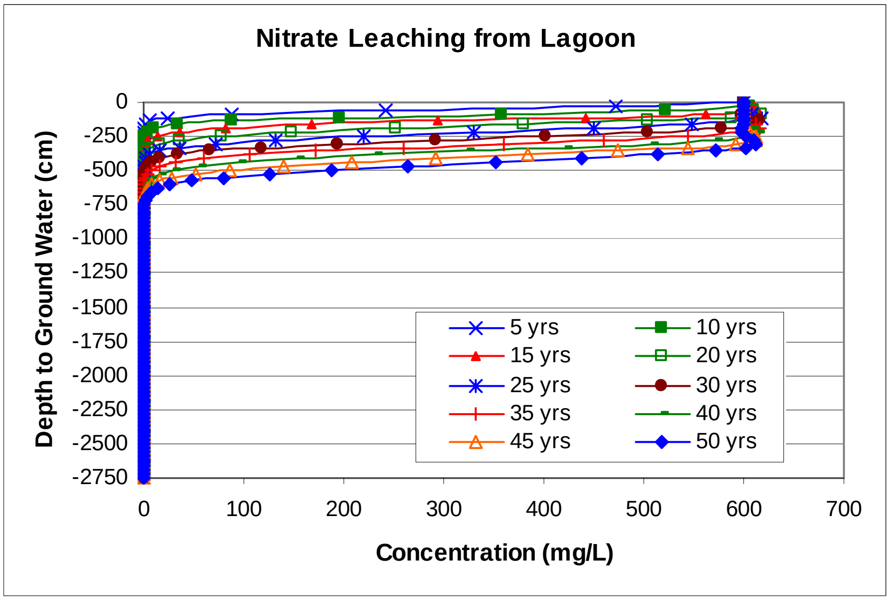

Figure IV-2. Nitrate Leaching from Below a Waste Lagoon

(Clay thickness = 0.5 m, K = 10^{-9} m/s, Distance to aquifer = 27 m)

Figure IV-3 shows the same results but with a larger scale to better illustrate the seepage of contaminant occurring at the end of every five-year interval. The concentration of total nitrogen in the effluent (on top of the liner) was assumed to be 600 mg/L. The model considers transformation from NH_4^+ to NO_2^- to NO_3^-, but with small concentrations of ammonia and nitrite. Therefore, only the concentration of nitrate-nitrogen is presented.

From this figure it can be seem that the clay layer becomes saturated within the 5 years of simulation. After 5 years, the nitrate has seeped through the clay layer to a depth of about 1.5m (4.9ft) where the concentration of 10mg/L can be found at a depth of 1.25m (4.1ft). After 10 years, the plume reaches a depth of about 2.5 m (6.5 ft), an increase of about 1 m (3 ft) in five years. After 15 years the contaminant has seeped to depth of about 3.25 m (10.66 ft), an increase of 0.75 m (2.5 ft) every five years. After 20 years, the seepage increased at a rate of about 0.5 m (1.6 ft) every five years. At the end of year 50, the contaminant has seeped to a depth of about 7 m (23ft).

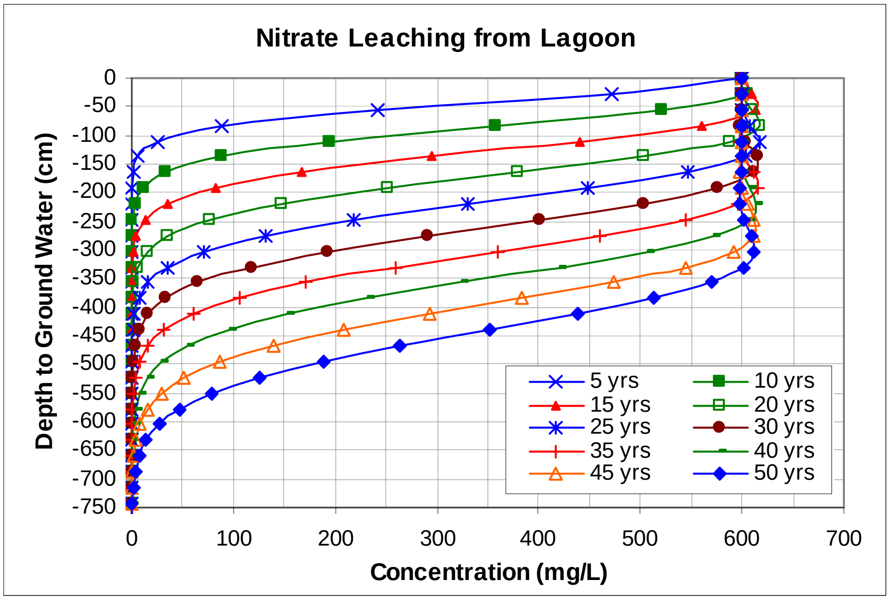

Figure IV-3. **Nitrate Leaching from Below a Waste Lagoon (expanded scale)**

The percolation of nitrate through the liner into the deeper soil profile depends on the pressure head in the lagoon and the hydraulic conductivity of the clay liner at the bottom of the lagoon. The flux of nitrate seeping through the soil profile depends on effluent concentration, the thickness of the clay layer and the type of soil under the lagoon (loamy sand in this case). The simulation was based on a worst-case scenario assuming the lagoon was full at all time (3 m), providing constant nitrate flux into the deeper soil profile. The results can be seen in Figure IV-2 where effluent with nitrate concentration of 600 mg/L seeps through the 0.5 m (1.5 ft) clay liner. The NO_3^- does not reach the underlying aquifer in the 50 years of simulation.

Water generally travels vertically towards the saturated zone. This movement can be slowed due to the characteristics of clay liners beneath the lagoon. The clay liner has a smaller hydraulic conductivity and higher moisture content than the underlying native soil. In Figure IV-3, it can be seen that the effluent has moved to a depth of about 1.5 m (4.9 ft), a rate of about 0.008 m/d (0.003 ft/d) after the first five years of operation. Within this period, the concentration of 10mg/L can be found at a depth of 1.25m (4.1 ft).

The only source of nitrate considered here is that from the lagoon, and the lower part of the unsaturated zone is assumed to contribute no nitrate. Therefore, NO_3-N concentration decreases as it percolates towards the saturated zone. This agrees with previous studies showing that nitrate concentration is highest close to the compacted liner and decreases with depth (Zhu, 2002; Ham *et al.,* 1997).

The time required for NO_3-N to reach the groundwater depends on the distance from the lagoon to the aquifer, depth of water in the lagoon, and the soil properties along its path. Underneath the lagoon, NO_3-N reached a depth of about 7 m (23 ft) in 50 years, an average rate of approximately 0.45 ft/yr (0.14 m/yr). At this rate, the time required for nitrate to reach an aquifer of 70 ft (27m) would be approximately 190 years. Therefore, the contribution of NO_3-N to the aquifer is considered insignificant during the first 50 years.

The rate of nitrate leaching through the soil profile is summarized in Figure IV-4. From this graph it can be seen that nitrate seeps faster during the first 20 years after and slows down thereafter.

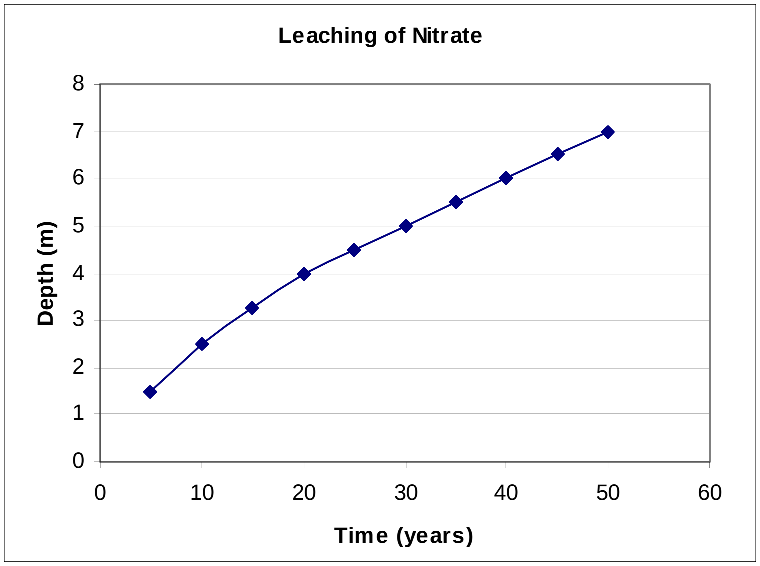

Figure IV-4. The Rate of Nitrate Leaching in the Soil Profile

Based on the figure above, if the distance to the aquifer had been 3.5 m (10 ft), as allowed in Oklahoma regulations, the MCL of NO_3 in the groundwater would have been contaminated in about 20 years.

HYDRUS 1D is a one-dimensional model that simulates vertical movement of water in the soil profile. Uncertainties in the model may be due to the consideration of only vertical inflow and outflow below the lagoon. In addition, other sources of nitrogen that could affect the nitrate concentration in the soil were not considered in the simulation.

High nitrogen concentration in the soil profile does not necessarily indicate ground water pollution. Horizontal flow, which is not considered in this model, may affect nearby and shallow drinking wells. The impact depends on the distance between the source and the wells. Although the risk of nitrate contamination from the waste lagoon to this underlying aquifer is not imminent, nitrate existence in the soil profile should not be totally excluded in future assessment of the area.

Conclusions

1. The nitrogen plume has saturated the clay liner in the first five years after operation.
2. Nitrate concentration has reached the MCL (10 mg/L) in the soil profile at depth of 1.25 m (4.1 ft), in five years of operation.
3. Nitrate leaching from the bottom of the lagoon does not reach the underlying aquifer with a distance of 27 m (70 ft) in 50 years.
4. The nitrate plume would require approximately 190 years to reach the underlying aquifer.
5. Shallow aquifers laying 10 ft below the lagoon liner would be impacted in about 20 years.
6. The NO_3 plume would reach the water table and raises the concentration to the MCL in 20 years.

Simulation of Nitrate Leaching from Effluent Application to Land

Purpose and Objectives

Waste lagoons usually fill to design capacity within 2 to 3 years of start-up with the accumulation of wastewater and rainfall on the open lagoon surface. To prevent the lagoon from overflowing, excess lagoon liquid is applied to cropland at rates within the soil infiltration capacity and the fertilizer requirement for the vegetation.

Application of effluent may cause leaching of nitrate into the groundwater if applied excessively. Leaching of nitrate from a field that is applied with effluent depends on several factors (Canter, 1997). First, the amount of nitrogen source applied to plants, which is associated to agricultural management and practices. This involves the type of crops, the rate, amount, and time of application. Second, the amount of percolating water, which depends on the amount of precipitation and evapotranspiration, the physical characteristics of the soil materials, as well as the depth to the water table. Third, the potential for nitrate reduction and/or denitrification, which was not considered and would not be discussed in this study.

The purpose of this study is to determine whether or not effluent application to land generates nitrate leaching and degrades the quality of groundwater. The specific objectives are to determine:

1. The time required for nitrate plume to reach the aquifer,
2. Practice(s) that generate the highest nitrate leachate concentrations,
3. Practice(s) that generate the lowest concentration of nitrate leachate over time,
4. Practice(s) that provide the longest period of time before nitrate reaches the MCL in the soil profile,
5. The nitrate concentrations in the aquifer, and
6. The time when MCL in ground water is reached.

Methodology

Estimate nitrate leaching from effluent application to land

1. Determine the geologic parameters. Geologic parameters include: soil types and hydraulic conductivity, soil thickness, and the distance from the surface to the aquifer. The soil types used are sandy clay loam and loamy sand, obtained from the (USDA & SCS, 1962) for soil types in Kingfisher. Sandy clay loam in the area has a thickness of about 2 m (6.5 ft) and overlies loamy sand of about 28.5 m (94 ft). The combined thickness, 30.5 m (100ft), is the distance between the surface and the aquifer. The default hydraulic conductivity values for sandy clay loam and loamy sand are $3.6\text{x}10^{-6}$ m/s (1.03 ft/d) and $4\text{x}10^{-5}$ m/s (11.5 ft/d), obtained as default values from HYDRUS 1D. The summary of these parameters is illustrated in Figure IV-5 below.

2. Determine the type of vegetation receiving effluent application. The type of vegetation mostly found in the area is Bermudagrass. Bermudagrass is perennial vegetation that has a root growth zone of about 1.5m (4.9ft) (Ball *et al*., 1991).

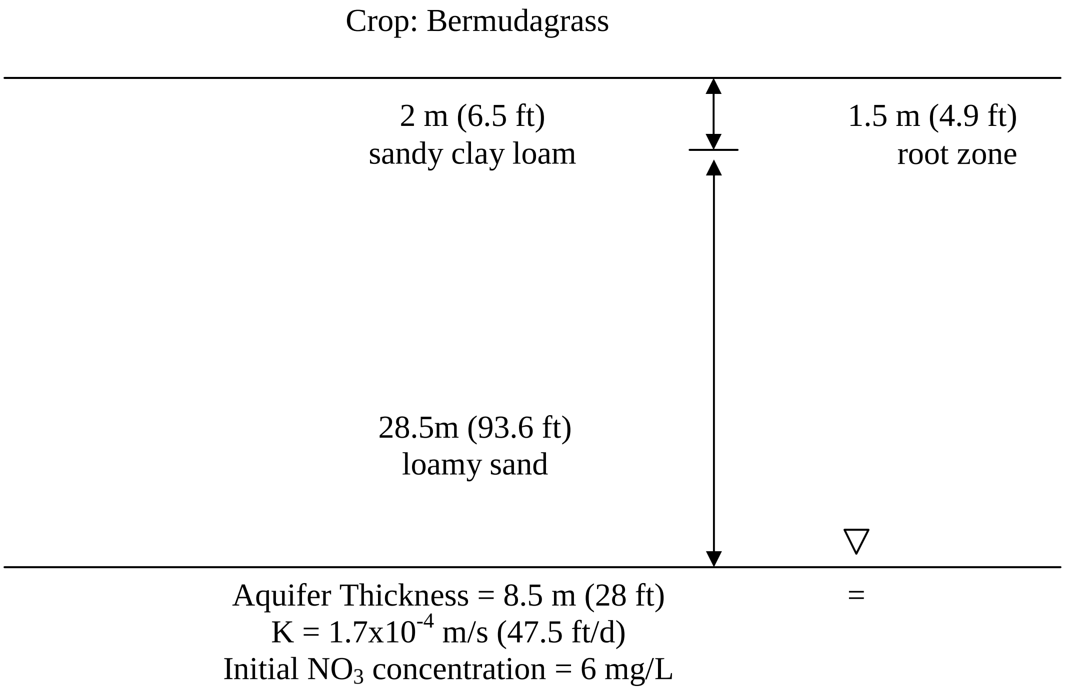

Figure IV-5. Soil Profile Input Parameters for Nitrate Leachate Simulation from Effluent Application to Land

3. Determine the water balance parameters, which include precipitation, runoff, and evapotranspiration.
    a. Daily rainfall data for five years was obtained from the National Climatic Data Center (NCDC) (http://ftp.ncdc.noaa.gov/pub/upload/982421179820dat.html). These data (1990 – 1994) were used repeatedly ten times to run the 50 years of simulation.
    b. Runoff was calculated using the Curve Number Approach (Haan, 1994 p. 63)

$$\mathbf{Q\ (in) = (P-0.2S)^{\wedge}2\ /\ P+0.8S}$$

Where:
Q = accumulated runoff volume
P = accumulated precipitation
S = maximum soil water retention parameter given by S,
where $S = (1000/CN) - 10$

CN = Curve Number
Hydrologic Group for Sandy clay loam = C
CN for pasture – good condition = 74

c. Evapotranspiration was determined using the SCS Blaney-Criddle Method (ASCE No. 70, p. 104). The result of the calculation is tabulated in Appendix D.

$$\mathbf{U = KF = \Sigma\ kf}$$

Where:
U = estimated evapotranspiration (consumptive use)
K = empirical consumptive use coefficient
F = sum of monthly consumptive use factors,
f , for the season or growing period

$$\mathbf{f = tp/100}$$

Where:
t = mean monthly air temperature in F degree (obtained from NDCC)
p = pan coefficient (ASCE No. 70, p. 105)
= mean monthly percentage of annual daytime hours
k = monthly consumptive use coefficient

$$\mathbf{k = kt*kc}$$

Where:
kt = $0.0173t - 0.314$
kc = monthly crop growth stage coefficient – for grass
(Haan, 1994, p. 97)

4. Determine the irrigation water required to meet the growth of Bermudagrass (obtained from the National Engineering Handbook, part 652 for Irrigation Guide).
5. Determine the amount of effluent to be applied. This includes the calculations of the number of animals in the facility, the plant available nitrogen (PAN) generated, the amount of PAN to be applied, and the land area for application.

a. Number of animals

Based on the facility selected, the size of the CAFO contains 2000 Animal Unit (AU), which is equivalent to 16,000 hogs (finishers). The calculation is shown below:

$$\#\ of\ Animals\ = (\ Finishers) = AU * \left(\frac{1000\, lb\, LV}{1\, AU} \right) * \left(\frac{1\, hog}{125\, lb\, LV} \right) = 16{,}000\, hogs$$

where:
LV = Live weight; 1AU = 1000 lb Live weight

b. Plant Available Nitrogen (PAN)

One hog generates 2.7 lb (1.2273 kg) of Plant Available Nutrients (PAN) after storage, handling, and application by irrigation (Tyson, 1996). For a CAFO of 2000 AU, 16 thousand hogs generate 43,200 lb (19636.4 kg) of PAN.

c. Land area for effluent application

The land area required for disposing the effluent depends on the suggested N application to meet a specific yield goal for Bermudagrass. To achieve a yield goal of 3 tons/acre, the suggested N application is 200 lb/ac, whereas the suggested N application to achieve a higher yield goal of 6 tons/ac is 320 lb/ac. Therefore the land area required:

$$at\ 200 \frac{lb}{ac} = 43{,}200 \frac{lb\ PAN}{yr}\ x \frac{yr - ac}{200\, lb\ PAN} = 216\, ac\ \approx\ 250\, ac\ \left(1{,}018{,}500\, m^2\right)$$

$$at\ 320 \frac{lb}{ac} = 43{,}200 \frac{lb\ PAN}{yr}\ x \frac{yr - ac}{320\, lb\ PAN} = 135\, ac\ \approx 125\, ac\ \left(509{,}250 m^2\right)$$

d. Amount of effluent for land application

The amount of effluent to be applied depends on the PAN concentration in the effluent. Several assumptions were made:

1. Effluent concentration of Total Nitrogen (TN) in the lagoon generally ranges from about 600 to 1000 mg/L (Ham *et al*., 1999). The concentration depends on the amount of fresh and recycled water used to flush the barn and the amount of precipitation accumulated in the lagoon. More fresh water use would reduce effluent concentration.
2. The concentration of TN in the lagoon is related to the Plant Available Nitrogen, depending on the volatilization after storage, handling, and application.
3. Effluent is more concentrated toward the minimum operating level and is less concentrated toward the maximum operating level.
4. PAN concentrations selected are 300 (near maximum operating level) and 600 mg/L (near minimum operating level), considering the range of TN (600-1000 mg/L) and loss of nitrogen after volatilization (ranging from 20 to 80%) (Tyson, 1996).
5. Lagoon stores effluent until the maximum operating level. When the maximum level of that lagoon is reached, effluent is to be pumped until the minimum operating level (Figure IV-6).

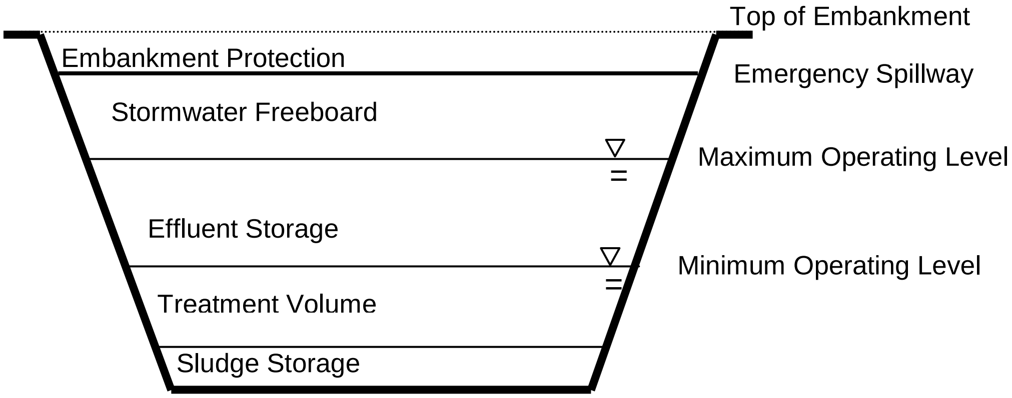

Figure IV-6. Lagoon Profile and Effluent Concentration in Lagoon

The amount of effluent containing 300 mg/L of PAN is:

$$300\frac{mg}{L}*3.785\frac{L}{gallon}x\frac{1kg}{1x10^{6}mg}x\frac{2.2\,lb}{1\,kg}x1000=\frac{2.5\,lb\,PAN}{1000\,gallon}\ or\left(0.30\frac{kg}{m^{3}}\right)$$

$$43{,}200\,lb\,PAN\ x\frac{1000\,gallons}{2.5\,lb\,PAN}x\frac{1\ ft^{3}}{7.48\,gallons}=2{,}310{,}160\ ft^{3}\ \left(65{,}416.8\,m^{3}\right)$$

$$2{,}310{,}160\,ft^{3}\ x\frac{1\,ac}{43{,}560\ ft^{2}}x\frac{12\ in}{1\,ft}=\ 636.40\,ac-in\left(64{,}732.5\ m^{3}\right)$$

Therefore, the amount of effluent to be applied:

$$\frac{630\,ac-in}{250\,ac}=2.52\,in\ \left(6.4\,cm\right)\ or\ \frac{630\,ac-in}{125\,ac}=5.04\,in\ \left(12.8\,cm\right)$$

The amount of effluent containing 600 mg/L of PAN is:

$$600\frac{mg}{L}*3.785\frac{L}{gallon}x\frac{1kg}{1x10^{6}mg}x\frac{2.2\,lb}{1\,kg}x1000=\frac{5\,lb\,PAN}{1000\,gallon}\ or\left(0.60\frac{kg}{m^{3}}\right)$$

$$43{,}200\,lbs\,PAN\ x\frac{1000\,gallons}{5\,lb\,PAN}x\frac{1\ ft^{3}}{7.48\,gallons}=1{,}155{,}080\ ft^{3}\ \left(32{,}708.4\,m^{3}\right)$$

$$1{,}155{,}080\,ft^{3}\ x\frac{1\,ac}{43{,}560\,ft^{2}}x\frac{12\,in}{1\,ft}=318.20\,ac-in\left(32{,}880.5\,m^{3}\right)$$

Therefore, the amount of effluent to be applied:

$$\frac{320\,ac-in}{250\,ac}=1.28\,in\ \left(3.25\,cm\right)\ or\ \frac{340\,ac-in}{125\,ac}=2.52\,in\ \left(6.4\,cm\right)$$

6. Determine the scenarios consisting of different practices with the combinations of depth of effluent applied, effluent concentration and frequency of application.
   a. Depths of effluent application: 5 in (125 mm), 2.5 in (62.5 mm), and 1.25 in (31.3 mm). Hydrus 1D does not take into consideration land area and yield goal of a crop, however the calculations to determine the amount for application depend on the land area.
   b. PAN concentrations in effluent: 300 mg/L and 600 mg/L,
   c. Frequency of application: 2 times per year (in April and October), and 4 times per year (in April, June, August, and October). Two applications per year were performed in April, assuming that the lagoon fills up during the winter period, and in October to allow storage for winter precipitation. Four applications per year, referred to as split application, were performed in April, June, August, and October, considering the growing season of the crop.
   d. Supplemental irrigation water was added to meet the crop requirement based on the National Engineering Handbook-Part 652, for Irrigation, 1998.
      Table IV-1 summarizes the descriptions of the scenarios used for modeling, and Table IV-2 summarizes the parameters of the scenarios used. Disposal scenario was modeled using only lagoon effluent without additional irrigation water, where other scenarios were modeled with supplemental irrigation water
7. Simulation of nitrate leaching using HYDRUS 1D with different scenarios. Assumptions considered:
   a. The aquifer is in a steady-state condition, with an average flow or recharge rate into the aquifer of 2.3 in/yr (1.85×10^{-5} m/sec) (Adams, *et al* 1996).
   b. The background NO_3^- - N concentration of the aquifer is 6 mg/L, where previous flux of total nitrogen mass-balance is not considered.
   c. Bermudagrass was harvested 50 percent after the growing season.

Table IV-1. Description of Effluent and Irrigation Application Scenarios

Scenarios	Sub group*	Effluent and Irrigation Application (in)														Description
		Apr		May		Jun		Jul		Aug		Sep		Oct		
		Eff	H_2O	Eff	H_2O	Eff	H_2O	Eff	H_2O	Eff	H_2O	Eff	H_2O	Eff	H_2O	
Disposal	D-1	1.25	-	-	-		-	-	-	-	-	-	-	1.25	-	Disposal of effluent
	D-2	0.63	-	-	-		-	-	-	-	-	-	-	0.63	-	
Low Yield Goal	LYG-1	1.25	-	-	-		3.13	-	5.79	-	5.18	-	2.37	1.25	-	Effluent + Irrigation H_2O to meet a yield goal of 3 tons/ac
	LYG-2	0.63	-	-	-		3.13	-	5.79	-	5.18	-	2.37	0.63	-	
High Yield Goal	HYG-1	2.50	-	-	-		3.13	-	5.79	-	5.18	-	2.37	2.50	-	Effluent + Irrigation H_2O to meet a yield goal of 6 tons/ac
	HYG-2	1.25	-	-	-		3.13	-	5.79	-	5.18	-	2.37	1.25	-	
Split Application	SA-1	1.25	-	-	-	1.25	1.88	-	5.79	1.25	3.93	-	2.37	1.25	-	Effluent + Irrigation H_2O to meet a yield goal of 6 tons/ac, with more frequent application and less depth of application
	SA-2	0.63	-	-	-	0.63	2.50	-	5.79	1.25	4.55	-	2.37	0.63	-	

*The numbers 1 and 2 in each subgroup refer to the concentration of NO_3 in effluent as applied; number 1corresponds to 300 mg/L and number 2 corresponds to 600 mg/L)

Table IV-2. Effluent Application Parameters used for Simulations

SCENARIOS		PAN C		Land A[2]		Total D[3]		AppD[4]		NA[5]	Mass[1]		Yield Goal[1]
Group	Sub Group	mg/L	lb/ac-in	ac	m2	in	mm	in	mm		lb	kg	tons/ac
Disposal	D-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	42,469	19,111	3
	D-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	42,469	19,111	3
Low Yield	LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	42,469	19,111	3
	LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	42,469	19,111	3
High Yield	HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	42,469	19,111	6
	HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	42,469	19,111	6
Split Application	SA-1	300	68	125	509,250	5.00	125.0	1.25	31.25	4	42,469	19,111	6
	SA-2	600	136	125	509,250	2.50	62.5	0.63	15.63	4	42,469	19,111	6

[1] PAN C = Plant Available Nitrogen Concentration (conversion for pounds per acre-in = ppm (mg/L) * 0.2265 (EQ215, 2000)
[2] Land A = Area required to apply Nitrogen on Bermudagrass
[3] Total D = Total depth of effluent applied per year to meet the expected yield goal
[4] AppD = each depth = depth of effluent application per treatment
[5] NA = Number of application applied per year; 2 applications (April and October); 4 applications (April, June, August, October)
[6] Total PAN = Total PAN applied per year to meet the expected yield goal

Calculation of nitrate mixing in the aquifer

1. Determine the NO_3 concentration in the aquifer by using the mass-balance equation:

$$\mathbf{C(t) = C_o\, e^{-qt/nH} + C_{in}\, (-e^{-qt/nH})}\text{..}\mathbf{(1)}$$

Where :
$C(t)$ = the average concentration in the aquifer at time t
C_0 = the initial concentration in the aquifer
q = the flux density of water entering the aquifer or the aquifer recharge rate
t = time
n = the effective porosity of the aquifer
H = the average thickness of the aquifer
C_{in} = Concentration of nitrate influx at time t

Assumptions considered:

   a. NO3 is assumed to mix and undergo dilution in the aquifer once it reaches the water table.
   b. The aquifer is an ideal mixer or a constantly stirred tank.
   c. The flux density of water entering the aquifer varies over time causing fluctuations of nitrate concentrations entering the aquifer. However, for simplifications, a conservative measure of constant recharge rate (q) into the aquifer was used.
   d. Background level (6 mg/L) is assumed to be constant, where previous flux of nitrate is not considered.

2. Determine the time for nitrate in the aquifer to reach the maximum contaminant level (MCL) of 10 mg/L.

Assumptions considered:

   a. Water used for irrigation is assumed to be from the same aquifer.

b. The returning irrigation water leaches additional nitrate from the unsaturated zone and transports it back to the aquifer.
c. Irrigation return increases NO3 concentration in the aquifer from its background level.

Results and Discussions

There was a total of eight scenarios examined. The scenarios present management practices with combinations of effluent concentration, number of applications, and effluent application depths. The results of waste-water disposal simulations with HYDRUS 1D are shown in the graphs as the concentration influx or input of NO_3-N to the top of the water table. The concentration of nitrate flowing into the groundwater is referred to as C(in) in Figures IV-7, IV-9, and IV-11. Once the nitrate reaches the top of the water table, it is assumed to mix and undergo dilution in the aquifer. The NO_3-N concentration in the aquifer after dilution at time t is referred to as C(t), in figures IV-8, IV-10, and IV-12. The graphs for C(in) and C(t) are presented adjacent to each other, where each graph consists of 4 curves comparing 2 groups of scenarios. The number in each subgroup refers to the concentration of NO_3 in effluent as applied. Number 1 corresponds to 300 mg/L and number 2 corresponds to 600 mg/L. This arrangement applies to all scenarios in this study. The Disposal group is the only group without supplemental irrigation water. The three other groups have added irrigation water to meet the requirement of the crop.

The first comparison is between Disposal (D) and Low Yield Goal (LYG) scenarios, comparing practices that dispose effluent without additional irrigation water (D) and practices that use effluent as fertilizer with supplemental irrigation water for growth of crops (LYG). The difference between the two groups is supplemental irrigation water.

D-1 received total application of 2.5 in of effluent with PAN 300mg/L, applied twice per year, and without additional irrigation water. D-2 received 1.25 in of effluent at 600 mg/L. LYG-1 receives effluent with PAN of 300mg/L and with additional irrigation water. LYG-2 received the same treatment as LYG-1, but with a higher PAN concentration in the effluent, 600mg/L. These parameters are shown in Table IV-3 along with the summary of the results. The illustrations of the output of simulations, C(in), are shown in Figure IV-7. After dilution in the saturated zone, the flux affects the initial NO_3 concentration in the aquifer, C(t), shown in Figure IV-8.

From Figure IV-7 it can be seen that NO_3 leachate reaches the ground water earliest under the LYG-1 scenario, followed by LYG-2, D-1 and D-2. The years required for NO_3 leachate to reach the aquifer are 10, 12, 18, and 21 years respectively. Consequently, the MCL in the soil is reached in the same manner, within 15, 18, 26, and 31 years. This sequence also applies to the time required for each scenario to reach the maximum concentration of NO3 leachate: 20, 22, 40 and 45 years. However, the order of scenarios generating the maximum NO_3 flux concentration is different. LYG-2 has the lowest maximum NO3 leachate concentration (15mg/L), followed by LYG-1 (17mg/L), D-1 (23mg/L), and D-2 (25mg/L).

Table IV-3. Descriptions and Results of Simulations for Scenarios Disposal (D) and Low Yield Goal (LYG)

											SOIL PROFILE				AQUIFER		
Scenarios	PAN Conc		Land Area		Total Depth		Application Depth		Number Apply	Yield Goal	Time to GW	Time to MCL	Max C(in)	Time to Max C(in)	Lag	Time to MCL	Max C(t) at yr 60
	mg/L	lb/ ac-in	ac	m2	in	mm	in	mm		tons/ ac	yrs	yrs	mg/L	yrs	yrs	yrs	
D-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	18.5	26.0	23.6	40	20.8	27.2	19.8
D-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	21.2	31.0	24.8	45	22.0	32.4	20.3
LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	10.2	15.0	17.6	20	12.3	19.3	16.1
LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	12.3	18.2	15.2	22	14.0	21.9	15.1

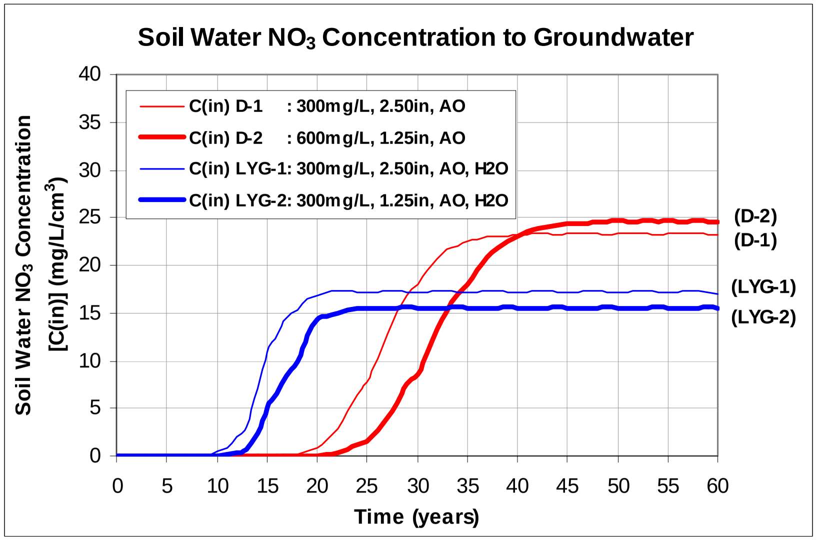

Figure IV-7. Soil Water NO$_3$ Concentration to Groundwater (Scenarios: D & LYG)

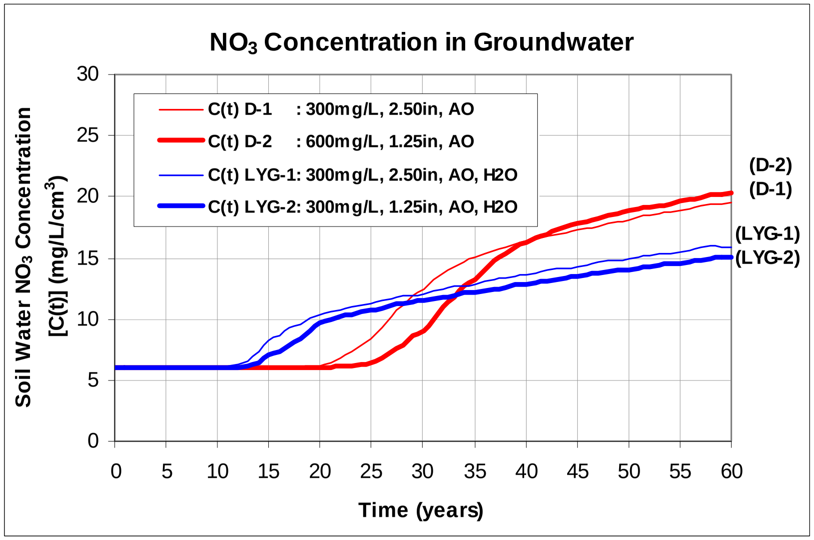

Figure IV-8. NO$_3$ Concentration in Groundwater (Scenarios: D & LYG)

When D-1 and D-2 are compared, it can be seen that D-1 affected the aquifer three years earlier and reached its maximum concentration five years earlier. This early delivery to the water table raised the NO3 concentration in the soil to reach the MCL within 26 years, a difference of five years with the D-2 scenario. During the first 40 years, D-1 generates higher NO_3 concentration to the groundwater. After 40 years, the situation reverses and D-2 generates higher NO_3 flux concentration. This situation could be due to the amount of liquid applied annually (2.5 in), which is twice more than the D-2 scenario (1.25in). More liquid serves as a means of transportation for nitrate to travel in the unsaturated zone, reaching the vadose zone earlier. However, after 40 years, the situation reverses such that the nitrate leachate generated under the D-2 practice is higher than D-1. This situation is possible due to the initial high concentration of D-2 accumulated in the soil. A build up of N in the soil can occur when total water applied does not exceed the water-holding capacity, and plant-uptake (Black, 1968 in Lauriat et al, 2002). As time elapses, nitrate accumulated in the soil profile eventually moves downward to the groundwater, supplying high concentration of nitrate.

When LYG-1 and LYG-2 are compared, it can be seen that LYG-1 affects the ground water and reaches its maximum concentration 2 years earlier. Unlike D-1 and D-2, there was no intersection between these two curves. In addition, the concentration of NO_3 flux generated is higher for LYG-1 (17.6 mg/L), reaching a steady-state condition after 20 years. These effects are also due to the doubled depth of effluent applied (2.5in) when compared to LYG-2 (1.25in). In this case, the soil could be saturated from the application of effluent, exceeding the water holding capacity of the soil, and thereby moving NO_3 downward.

Additionally, comparison between the two groups reveals that the LYG group generates lower concentrations of nitrate leachate than the D group. However, nitrate leachate under the LYG group reaches the aquifer sooner than the D group. This is caused by the supplemental irrigation water that facilitates earlier delivery of contaminant to the deeper soil profile. The additional irrigation water dilutes the nitrate concentration in the soil, resulting in lower concentration of nitrate flux to the ground water.

In general, flux of nitrate increases with time until it reaches a steady state, and the maximum nitrate concentration leached into the ground water depends on the practice employed. Between the four practices, LYG-2 generates the least NO_3 flux concentration, followed by LYG-1, D-1, and D-2.

As a consequence, the initial NO_3 concentration in the aquifer (6 mg/L) increases in the same manner according to the practices employed. Figure IV-8 shows that during the sixty years of simulation, LYG-2 causes the lowest maximum NO_3 concentration in the aquifer. Under this scenario, the NO_3 concentration increased after a lag of about 14 years, reaching a maximum concentration of 15.1 mg/L. The maximum concentration level (MCL) of NO_3-N of 10 mg/L was reached within 21.9 years. LYG-1 generates relatively higher concentration of NO3 after 12.3 years, increasing the background level to 16.1 mg/L. Under this practice, the MCL can be reached within 19.3 years. D-1 contributes a lower nitrate concentration at the end of 60 years of simulation than D-2. The groundwater concentration increased to 19.5 mg/L after 20.8 years and the MCL was reached within 27.2 years. D-2, the highest nitrate contributor, increased the nitrate concentration to 20.3 mg/L after 22 years, reaching the MCL within 32.4 years.

Based on the results, LYG-2 generates the least amount of nitrate leachate into the vadose zone because of the lower depth of effluent applied and additional irrigation water to allow dilution. However, due to the added irrigation water, the time for NO_3 in the aquifer to reach the MCL is also least due to its initial high effluent concentration. On the other hand, D-2 was the highest supplier of NO_3 flux due to its high initial effluent concentration, more depth of effluent applied, and no supplemental irrigation water to dilute the contaminant. Nonetheless, the lack of irrigation water for mobilization of nutrient allows practice under D-2 to have longer period of time before the MCL in the aquifer is reached.

Uncertainty needs to be considered for the Disposal scenario. Under these practices, there may be more leachate occurring due to the lack of irrigation water to support the growth of Bermudagrass. The lack of supplemental irrigation water provides less growth and thus less forage to uptake the nutrients. As a result of the simulations, it can be concluded that disposal of effluent without additional irrigation water (D) could be effective in minimizing leachate of NO_3-N in the shorter time period. However, after about 40 years, the accumulated nitrate in the unsaturated zone resulted in a higher nitrate concentration in the aquifer than if LYG management were employed. Therefore, for short-term consideration to delay NO_3 leachate into the groundwater, D-2 may be considered. However, to consider long-term minimal contamination, LYG-2 may be employed.

The next comparisons are between scenarios Low Yield Goal (LYG) and High Yield Goal (HYG). The difference between LYG and HYG scenarios is related to the application of effluent with respect to the expected yield goal of Bermudagrass hay production. HYG scenario was designed for application of effluent in a smaller land area to achieve a higher yield goal of crop production (6 tons/ac), and LYG scenario for low yield goal (3 tons/ac).

As described previously, LYG-1 receives lower effluent concentration (300mg/L) and more effluent applied (1.25in) than LYG-2. HYG-1 also receives lower effluent concentration (300mg/L) and more effluent application (5in) than HYG-2. HYG-2 receives effluent containing PAN at 600mg/L and application depth of 2.5in. Effluent was applied twice a year under both scenarios. These parameters are shown in Table IV-4 along with the summary of the results from simulations. The output of the NO3 flux, C(in), is illustrated in Figure IV-9 and the impact of NO_3 leaching to groundwater, C(t), is shown in Figure IV-10. The purpose of this observation was to determine which practice would be preferred, taking into consideration the amount of NO_3 leachate generated with respect to the expected yield goal.

Table IV-4. Descriptions and Results of Simulations for Scenarios Low Yield Goal (LYG) and High Yield Goal (HYG)

											SOIL PROFILE				AQUIFER		
Scenarios	PAN Concentration		Land Area		Total Depth		Application Depth		Number Apply	Yield Goal	Time to GW	Time to MCL	Max C(in)	Time to Max C(in)	Lag	Time to MCL	Max C(t) at yr 60
	mg/L	lb/ ac-in	ac	m2	in	mm	in	mm		tons/ ac	yrs	yrs	mg/L	yrs	yrs	yrs	
LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	10.2	15.0	17.6	20	12.3	19.3	16.1
LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	12.1	18.2	15.2	22	14.0	21.9	15.1
HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	6	7.6	11.2	36.2	15	9.83	13.3	27.7
HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	6	8.2	13.6	35.2	20	11.5	15.0	26.2

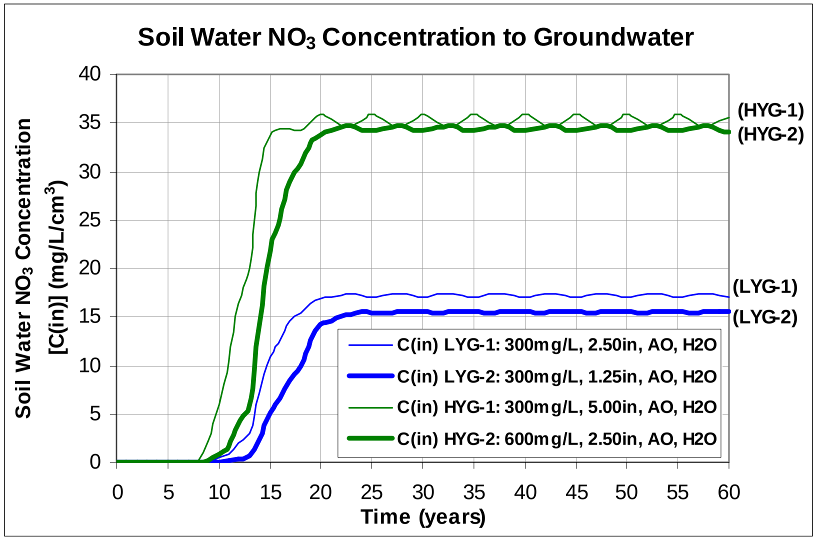

Figure IV-9. NO_3 Flux to Groundwater (Scenarios: LYG & HYG)

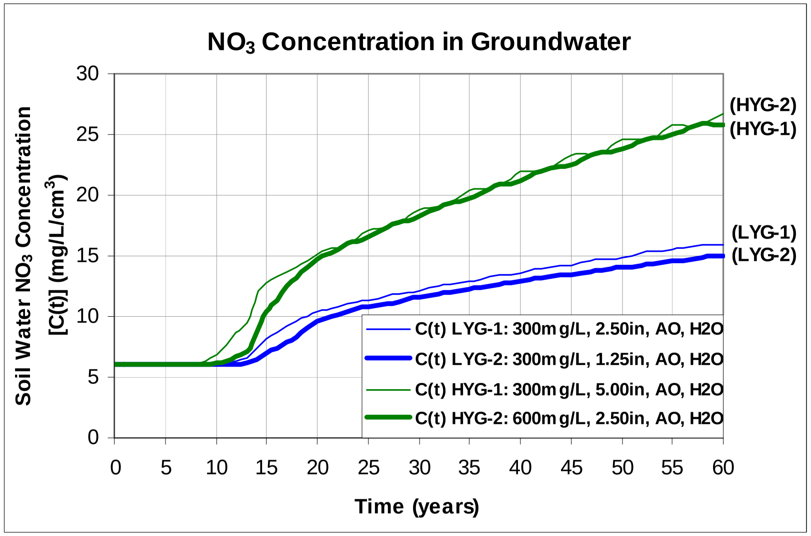

Figure IV-10. NO_3 Concentration in Groundwater (Scenarios: LYG & HYG)

From Figure IV-9 it can be seen that NO_3 reaches the ground water earliest (7 yrs) under the HYG-1 scenario, followed by HYG-2 (8 yrs), LYG-1 (10 yrs) and LYG-2 (12 yrs). The time to reach the maximum NO_3 concentration was reached first under HYG-1 (15 yrs), reaching a max concentration of 36mg/L. HYG-2 follows five years later (20 years), with a max NO_3 concentration of 35mg/L. LYG-1 also reaches its maximum NO_3 concentration within 20 years. However, the NO_3 concentration generated is half than HYG-2 (17mg/L). LYG-2 reaches its maximum NO_3 concentration 2 years later (22yrs) with a concentration of 15.2 mg/L.

As previously discussed, NO_3 flux generated under LYG-1 scenario affected the ground water about two years later than LYG-2. The cause was assumed to be the difference in the depth of application. LYG-1 receives more effluent, serving as a means of transport for contaminant to travel in the unsaturated zone.

Likewise, when HYG-1 is compared to HYG-2, it can be seen that NO_3 flux generated by HYG-1 reached the top of the water table a year earlier. This situation is similar to LYG scenarios, where more depth of effluent resulted in earlier arrival to the aquifer and increases the MCL In addition, the pulse of NO_3 flux generated is more obvious and fluctuates greater than HYG-2.

Consequently, the aquifer is also impacted in the same nature, shown in Figure IV-10. It can be seen that LYG-2 has the least effect on the aquifer, followed by LYG-1. HYG-1 reached MCL in 13.8 years after a lag of 9.83 yrs, reaching 27.7 mg/L at year 60. HYG-2 reached MCL in 15 yrs after a lag of 11.5 years, reaching 26.2 mg/L at year 60.

Between ten to twenty years, NO_3 flux concentration produced by HYG-1 is higher than HYG-2. After twenty years, the build up of NO_3 in the unsaturated zone from HYG-2 results in a breakthrough and convergence of concentrations between the two different practices. This indicates that in the long run (after 20 years), either practice would affect the groundwater the same way. Therefore, to obtain a high yield goal, HYG-2 management would be preferred in the short term.

Overall, LYG scenarios are preferred to HYG scenarios because they take longer to reach the MCL. Of the four scenarios, LYG-2 produced NO_3 leachate the latest, providing longer period of time for operation, and also generated the lowest NO_3 concentration. These effects propose a better management to preserve the quality of groundwater.

The next observation concern scenarios HYG and SA. These scenarios have the same expected high yield goal of 6 tons/ac. The difference lies in the frequency of effluent application. HYG scenarios received effluent twice annually, while SA scenarios were split to receive four applications per year.

The split application (SA) treatment was intended to minimize the leaching of NO_3-N into the saturated zone while obtaining high yield goal of Bermudagrass hay production. The SA group received the same amount of total PAN applied four times per year; April, June, August, and October. SA-1 received effluent with PAN concentration of 300 mg/L, total application of 5 in. SA-2 received the same treatment with a higher PAN concentration, 600 mg/L and effluent application of 2.5 inches instead of 5 in.. These parameters are summarized in Table IV-5 along with the summary of the simulation results. Illustrations of the simulation output, C(in), are shown in Figures IV-11 and the impact to groundwater after dilution, C(t), is shown in Figure IV-12.

Figure IV-11 shows that NO_3 leachate reached the ground water earliest also under HYG-1 scenario (7 yrs), 1 year earlier than HYG-2 (8 yrs). SA-1 arrives at the water table approximately the same time as HYG-2 (8 yrs), followed by SA-2 (9 yrs). This is consistent with LYG and D results suggesting that higher effluent application depth resulted break through and higher concentration of NO_3 flux.

Table IV-5. Descriptions and Results of Simulations for Scenarios High Yield Goal (HYG) and Split Application (SA)

											SOIL PROFILE				AQUIFER		
Scenarios	PAN Concentration		Land Area		Total Depth		Application Depth		Number Apply	Yield Goal	Time to GW	Time to MCL	Max C(in)	Time to Max C(in)	Lag	Time to MCL	Max C(t) at yr 60
	mg/L	lb/ ac-in	Ac	m2	in	mm	in	mm		tons/ ac	yrs	yrs	mg/L	yrs	yrs	yrs	
HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	6	7.6	11.2	36.2	15	9.83	13.3	27.7
HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	6	8.2	13.6	35.2	20	11.5	15.0	26.2
SA-1	300	68	125	509,250	5.00	125.0	1.25	31.25	4	6	8.2	13.6	28.6	20	11.8	15.6	22.5
SA-2	600	136	125	509,250	2.50	62.5	0.63	15.63	4	6	8.6	14.6	28.0	25	12.6	17.3	22.0

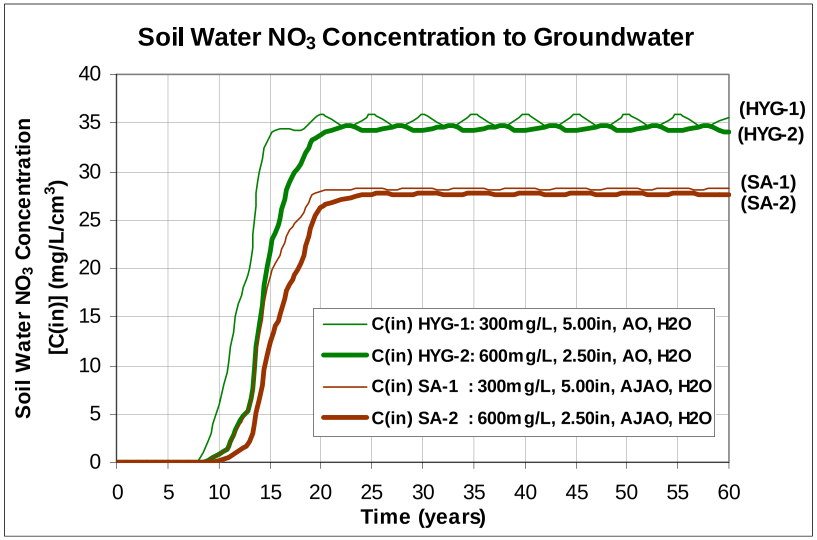

Figure IV-11. NO_3 Flux to Groundwater (Scenarios: HYG & SA)

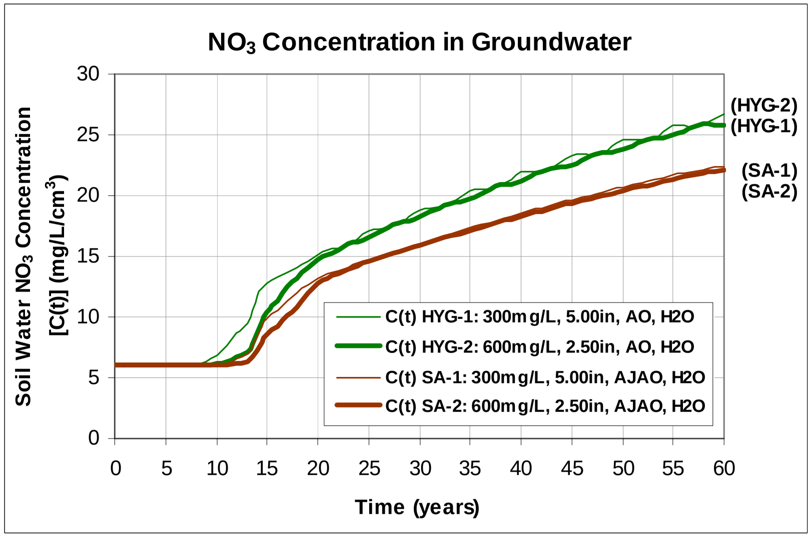

Figure IV-12. NO_3 Concentration in Groundwater (Scenarios: HYG & SA)

The maximum NO_3 flux concentration of 36mg/L was first reached under HYG-1, in 15 years. HYG-2 follows five years later (20 years), with a max NO_3 concentration of 35mg/L. During the first 15 years of operation, HYG-2 and SA-1 are approximately the same. SA-1 generated NO_3 flux that reached the MCL in the soil profile and water table at the same time as HYG-2. However, the maximum NO_3 concentration is lower (20mg/L) and reached at a later time (29 yrs). SA-2 produced NO3 that reached the MCL in the soil profile in 15 years, with a maximum concentration of 25mg/L, reached in 28 years.

The difference of NO_3 flux in the soil profile between SA-1 and SA-2 occurs during the first 25 years. After 25 years, the two curves merged indicating that there is no difference between the two practices in the long run. Consequently, the NO_3 in the aquifer is affected in the same way, as shown in Figure IV-12. In the figure, HYG-1 produced NO_3 leachate that reached the MCL in 13 years after a lag of 9.8 years. The maximum concentration at year 60 is 27.7 mg/L. Under HYG-2, NO_3 leachate reached the MCL in 15 years after a lag of 11.5 years with a maximum concentration of 26mg/L in 60 years.

Similar to the previous analysis, during the first 15 years of operation, HYG-2 and SA-1 show comparable trends after a lag of about 11 years, reaching MCL in the aquifer in 15 years. The maximum concentration at year 60, however, is different; SA-1 increased the NO_3 concentration to 22.5mg/L and HYG-2 reached 26 mg/L. SA-2 reached the MCL in the aquifer after a lag of 17 years, increasing the background NO_3 concentration to 22mg/L at year 60. These differences are distinctive between 10 to 20 years. After 20 years, curve SA-1 merged with SA-2, and HYG-1 merged with HYG-2, implying that, in the long run, applications of effluent with lower initial PAN concentration and higher initial PAN application would show the same outcome.

Comparisons between the two groups, show that SA management would be preferred over HYG. SA management applies smaller amounts of effluent at one time with less downward movement of soil-water. Effluent application in June and August provides an advantage due to high evapotranspiration rate. These factors increase N uptake in soil water thus decreasing the water movement through the root zone, and decreasing the soil nitrate level. Specifically, SA-2 would be the most preferred of the four practices with higher expected yield goal of Bermuda production.

The results of all eight practices are summarized in Table IV-6 and shown in Figure IV-14. From Figure IV-14, it can be seen that Disposal scenarios would be the most preferred to preserve the quality of groundwater. This management allows producers to operate for about 20 years before the NO_3 plume reaches the water table and between 27 to 37 years before NO_3 concentration in the aquifer reaches the MCL.

The next preferred scenarios would be LYG, specifically LYG-2 because it provides a period of 12 years before the aquifer is affected and allows 22 years before NO_3 concentration in the aquifer reaches the MCL.

Table IV-6. Descriptions and Results of Simulations for Scenarios High Yield Goal (HYG) and Split Application (SA)

											SOIL PROFILE				AQUIFER		
Scenarios	PAN Concentration		Land Area		Total Depth		Application Depth		Number Apply	Yield Goal	Time to GW	Time to MCL	Max C(in)	Time to Max C(in)	Lag	Time to MCL	Max C(t) at yr 60
	mg/ L	lb/ ac-in	Ac	M2	in	mm	in	mm		tons/ ac	yrs	yrs	mg/L	yrs	yrs	yrs	
D-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	18.5	26.0	23.6	40	20.8	27.2	19.8
D-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	21.2	31.0	24.8	45	22.0	32.4	20.3
LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	10.2	15.0	17.6	20	12.3	19.3	16.1
LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	12.3	18.2	15.2	22	14.0	21.9	15.1
HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	6	7.6	11.2	36.2	15	9.83	13.3	27.7
HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	6	8.2	13.6	35.2	20	11.5	15.0	26.2
SA-1	300	68	125	509,250	5.00	125.0	1.25	31.25	4	6	8.2	13.6	28.6	20	11.8	15.6	22.5
SA-2	600	136	125	509,250	2.50	62.5	0.63	15.63	4	6	8.6	14.6	28.0	20	12.6	17.3	22.0

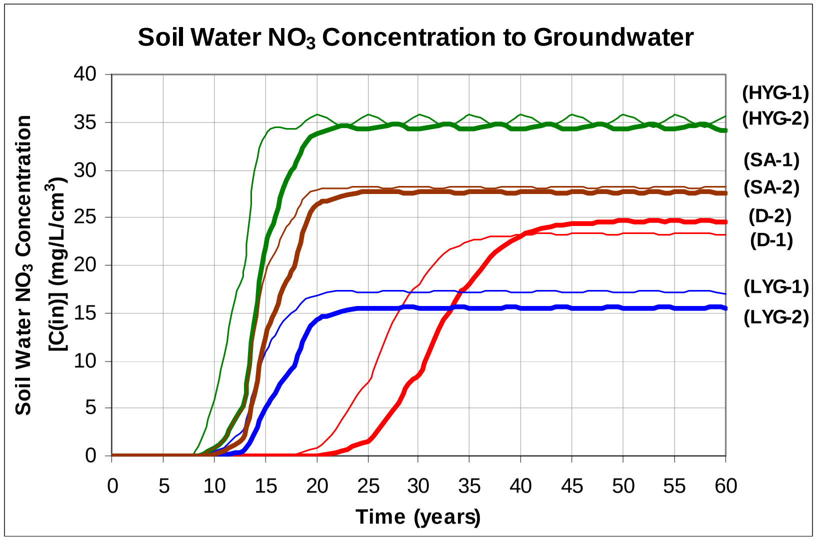

Figure IV-13. NO$_3$ Flux to Groundwater (All Scenarios)

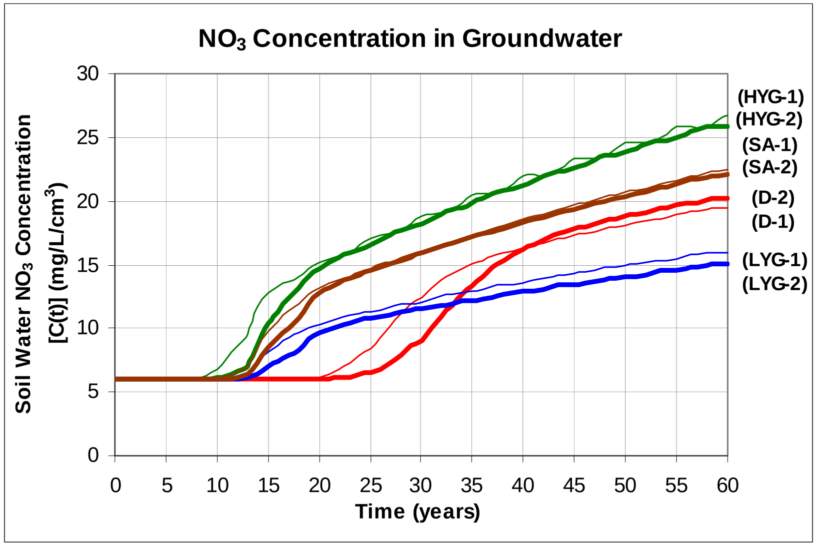

Figure IV-14. NO$_3$ Concentration in Groundwater (All Scenarios)

HYG and SA scenarios generate NO3 fluxes that raise the NO_3 concentration in the aquifer to reach the MCL in less than 20 years. These scenarios receive more depth of effluent applied over a smaller land area, illustrating higher application of nitrogen. Many studies have confirmed that higher application rates of nitrogen result in higher leaching of NO_3-N into the aquifer (Adeli et al., 2003; Smith, 1999; Schmidt, 1998, King et al., 1985). Furthermore, N concentrations applied in combination with the frequency of effluent applied are important in minimizing the concentration of leachate, as stated by Lauriat et al., 2002.

Due to many uncertainties, it is difficult to accurately determine the level of nitrate that could be released into the ground water to prevent exceeding the MCL. These uncertainties include the properties and characteristics of soil, the existence of bacteria in the soil, as well as the precipitation and the temperature affecting evapotranspiration of the crops. HYDRUS 1D model considers crop uptake of nutrients from the root zone (up to 750 mm for Bermudagrass). However, nutrient build up from the previous years could not be exactly determined, where a fraction of the organic N could gradually be mineralized and remain as inorganic N in the soil (Smith, 1999). The inorganic N in soil could be stored for many years, thus providing a residual source of nitrate in percolating water. In contrast, dilution may reduce the concentration of nitrate in the percolating water and the final concentration in the groundwater (Harter et al., 2001).

Most studies have used lysimeters to determine the concentration of N leached in the unsaturated zone underneath agricultural fields or to analyze water quality of shallow wells (Smith, 1999). These results suggest that residual soil NO_3-N increases with increasing N rate applied. As mentioned previously, distance to the aquifer is correlated with the time required for nitrate to travel and reach the saturated zone, possibly more than 10 years. In these simulations, the time for nitrate to travel 30.5m (100ft) vertically to the aquifer differs according to the practices employed, and to the soil water nitrate flux generated. The arrival of the plume can be as early as 7.6 years with the time to reach the MCL in the aquifer as early as 13.3 years under the HYG-1 scenario.

According to the Oklahoma CAFO regulations, the distance from the bottom of a lagoon to the aquifer should be a minimum of 3.5 m (10 ft). Based on this requirement, if the distance to the underlying aquifer were only about 7m (23ft), the plume would reach the aquifer in about 1.7 years and reach the MCL in approximately 3.05 years. Therefore, site-specific investigation is necessary to minimize uncertainties.

Conclusions

1. To delay the impact to groundwater, waste management under the D scenarios would be preferred because d scenarios generated NO_3 leachate 10 to 20 years later than other scenarios.
2. Waste management under the D-2 scenario provides the longest period of time, 32.4 years, before the aquifer reaches the nitrate MCL.
3. For long-term operation, more than 30 years, scenario LYG would be preferred. Low Yield Goal (LYG) management produced nitrate flux with concentration that is 10 mg/L lower than Disposal managements.
4. Waste management under High Yield Goal, specifically the HYG-1 scenario generated NO_3 the earliest, affecting the aquifer to reach the MCL in 13.3 years.
5. A shallow aquifer lying 3.5m (10ft) below the lagoon with a clay liner or a total of 7m (23ft), would be affected earlier. Under HYG-1 scenario the NO_3 plume would reach the aquifer in about 1.7 years, increasing the NO_3 in the aquifer to reach the MCL I about 3.05 years.
6. To obtain a high yield of Bermudagrass hay production, Split Application (SA) practices would be preferred over High Yield Goal practices.

7. HYG generated NO3 flux that reached the aquifer about the same time as SA. However, the affected aquifer reached the MCL 2 years earlier under HYG scenarios.
8. Overall, higher initial PAN concentration in the effluent (600mg/L) is preferred over the lower initial PAN concentration in the effluent (300mg/L).

Calculations of time required for NO_3 to reach Public Well Systems

Purpose and Objectives

Nitrate leaching from effluent application to land was assumed to percolate and move vertically downward towards the underlying aquifer. Once nitrate reached the aquifer, its movement was assumed to be horizontal or down gradient with the movement of groundwater. The purpose of this analysis is to observe the effect on a nearby public well system (PWS). The specific objectives are to determine:

1. whether or not the nitrate level in the PWSs reaches the MCL, and
2. the time for nitrate to reach the MCL at the PWS

Methodology

1. Determine the time required for nitrate leaching from the facility to the public wells by using the time-of-travel equation.

$$v = Ki/n \qquad (2)$$

where:
v = average velocity (ft/d) = 0.76 ft/d
K = hydraulic conductivity (ft/d) = 47.5 ft/d
i = hydraulic gradient = (difference in elevation/distance)
= 1100-1050/2.7 mi *5,280 ft = 0.0035
n = effective porosity = 0.22

$$t = d/v/365 \qquad (3)$$

where:
t = time of travel (years)
d = distance (feet)

Assumptions considered:

a. Once NO_3-N reaches the ground water, it will eventually reach a down-gradient PWS, depending on the distance and conductivity of media between the source and the PWS.

b. Once NO_3-N reaches the periphery of the delineated area, the time it requires to reach the wellhead depends on the TOT delineation (i.e. 10 years for this delineation).

2. Determine the time that nitrate reaches the MCL at the PWS

Results and Discussions

Based on the map of Kingfisher County, the CAFO selected was the closest to the Kingfisher Public Well Systems. Figure IV-15 below review the location of the facility and the PWS selected. The PWS was delineated to illustrate the protected area.

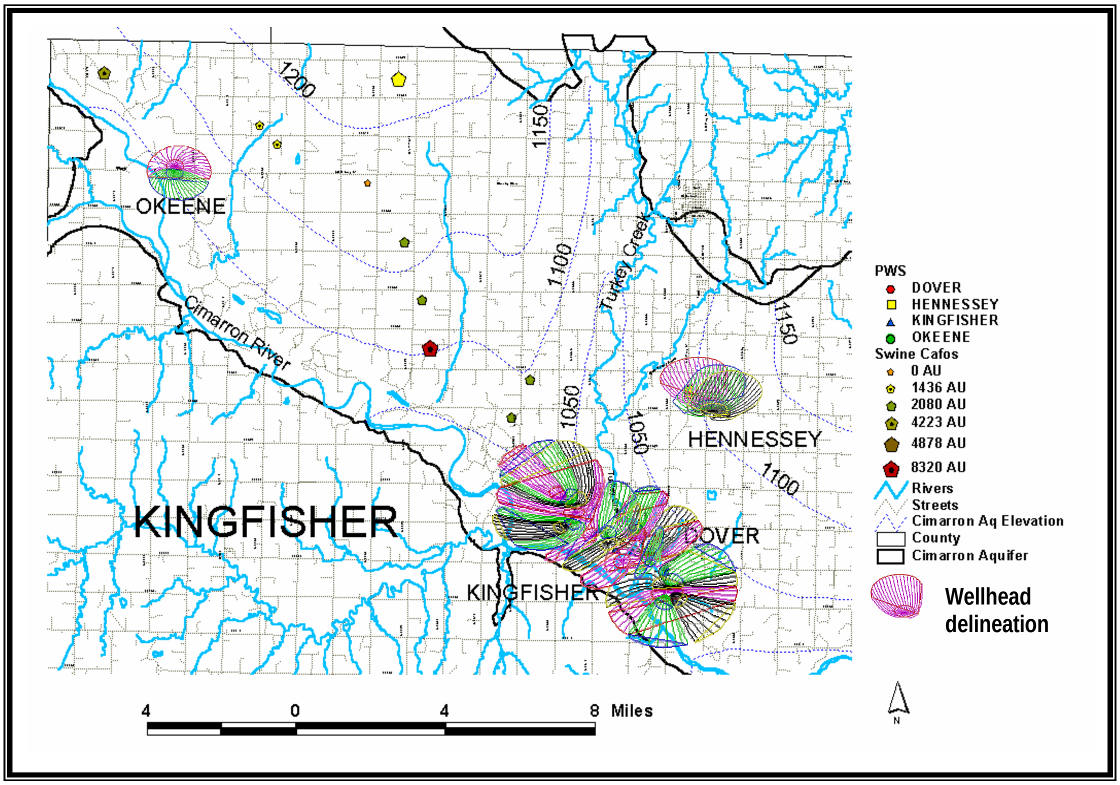

Figure IV-15. Location of CAFO and PWS

The CAFO facility selected for this study is located outside the wellhead delineation area. The distance is about 0.8 km (0.5 mi) from the Kingfisher PWS delineation. The delineation of the PWS indicates that contaminants require 10 years to travel in the aquifer to the well. Due to the proximity of the CAFO and the peripheries of the delineated area an additional four years beyond the 10 yr TOT is needed before the well becomes contaminated. Therefore, 14 years is added to the time for vertical leaching to determine the total time required for NO3 to reach the MCL in the PWS. If the CAFO selected for observation were located inside the delineation area, the additional 14 years would not be included. This assumption was derived considering the possible draw-down effect of the wells. The results of the analysis is summarized and shown in Table IV-7.

Table IV-7. Time NO_3 Reached MCL in Groundwater and PWS

Scenarios	PAN Concentration		Land Area		Total Depth		Application Depth		NA	Yield Goal	WHPA	
	mg/ L	lb/ ac-in	ac	m2	in	mm	in	mm		tons/ ac	In[1]	Out[2]
D-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	27.2	41.2
D-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	32.4	46.4
LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	19.3	33.4
LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	21.9	35.9
HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	6	13.3	27.3
HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	6	15.0	29.0
SA-1	300	68	125	509,250	5.00	125.0	1.25	31.25	4	6	15.6	29.6
SA-2	600	136	125	509,250	2.50	62.5	0.63	15.63	4	6	17.3	31.3

[1] In = MCL in PWS, CAFO is located inside a Wellhead Protection Area = MCL in aquifer
[2] Out = MCL in PWS, CAFO is located outside a Wellhead Protection Area

From Table IV-7 it can be seen that in general, a CAFO located inside a wellhead protection area would cause the NO_3 concentration in PWS to reach the MCL 14 years earlier than if the CAFO were located outside the wellhead protection area.

A PWS deriving its water supply from the same aquifer underlying the CAFO facility could become contaminated as early as 13.3 years if the CAFO were located inside the WHPA. The same management, HYG-1, would allow 27.3 years before the PWS reaches the MCL if the CAFO were located 0.5 miles outside the WHPA. This time period is about the same as for scenario D-1 located inside a WHPA. Therefore, this is one trade-off factor to consider for CAFOs that anticipate applying effluent at high rate.

Depth to the aquifer is also a major factor. Previous analysis regarding shallow aquifers of 7 m (23 ft) show that the required time for NO_3 (under the HYG-1 scenario) to reach the water table was 1.7 years and the time required to reach the MCL was 3.05 years. Based on these estimations, if the CAFO were located in a WHPA, the PWS would be contaminated and the MCL reached in 3 years. If the CAFO were located outside a WHPA, then 17 years would be required before the MCL is reached at the PWS.

The longest period for PWS to attain the MCL is 32.4 years under the D-2 scenario with the CAFO located inside the WHPA. If the CAFO were located outside the WHPA, the time for PWS to reach the NO_3 MCL would be even longer, 46.4 years. Therefore, to preserve the quality of groundwater, CAFOs should be located outside a wellhead protection area to prolong the time before PWS become contaminated and reaches the maximum contaminant level. CAFOs located outside a WHPA would have more options of waste management practices.

If the CAFO were already in existence and located inside a WHPA, the management employed would be critical. In this case, scenarios LYG would be most preferred to sustain the quality of groundwater.

Conclusions

1. CAFOs located outside the Kingfisher PWS wellhead protection area affected the NO_3 concentration at the PWS 14 years later than if the CAFO were located inside.
2. CAFOs located outside a WHPA have more options to manage their wastes.
3. The type of waste management employed in a wellhead protection area is critical to maintain both the practice and the quality of groundwater.
4. High Yield Goal (HYG) scenarios located 0.8 km (0.5 mi) outside the Kingfisher PWS wellhead protection area can be sustained for about 27 to 29 years before the NO_3 in the PWS increases to the MCL. This time period is approximately the same for Disposal (D) scenarios located inside a wellhead protection area.
6. A shallow aquifer 7m (23 ft) or 3.5m (10ft) below the lagoon liner would be affected by HYG-1 in 1.7 years, raising the NO3 concentration to the MCL in 3.05 years. If the CAFO were located one-half mile outside the wellhead protection area, the MCL at the PWS could be reached in 17 years.
7. Combinations of distance to the aquifer and to the PWS are important factors to consider. Shallow aquifers in combination with close or nearby PWS would be detrimental to drinking water derived from the contaminated PWS.

CHAPTER V

COST BENEFIT ANALYSIS OF A CONFINED ANIMAL FEEDING OPERATION

Cost Benefit Analysis (CBA) can be used as a tool to provide information to decision-makers. In this study, the CBA method is used to examine the benefits and costs associated with waste management of a Confined Animal Feeding Operation (CAFO). The costs related to waste management in the analysis include the costs incurred due to externalities as a result of waste management of the CAFO operation. The current analysis does not attempt to determine what level of costs and benefits are acceptable to the community. It is also not intended to determine the loss in the local taxes resulting from a decline in property values.

The purpose of this part of the study is to provide information to decision-makers on the costs and benefits analysis associated with a CAFO operating inside versus outside of a wellhead protection area under different scenarios. The cost and benefit analysis of a CAFO consists of 4 parts: 1) Cost analysis of waste systems, 2) Evaluation of costs of potential alternative water resources, 3) Least cost alternative to minimize waste management costs, and 4) Cost Benefit Analysis of a CAFO in a wellhead protection area.

Cost analysis of waste management systems

Purpose and Objectives

This study analyzes the costs of waste management systems of a CAFO under different scenarios, which consists of 2 parts. The first part of the study evaluates the waste management systems using the same lagoon sizes. The second part assesses the waste management systems to find the least cost of waste management practices, using different lagoon sizes.

The framework for this analysis is as follows:

1. Determine the costs of waste systems of a CAFO using the same size of lagoons for all scenarios.
2. Determine the costs of waste management of a CAFO by incorporating net revenue from Bermudagrass production to offset partially the costs of waste management systems.
3. Determine alternative least cost of waste systems by using a smaller size of lagoon for scenarios that recycle water from lagoon (D-2, lYG-2, HYG-2, and SA-2) to minimize waste systems expenses.
4. Determine alternative least cost of waste management incorporating the net revenue from Bermudagrass production.

The analysis includes estimation of expenses associated with the costs of lagoon construction and management, the costs of effluent application and the cost of the center pivot system. In addition, the net revenue from Bermudagrass hay production is also considered to compensate partially the waste management costs.

Methodology

The first part of the study analyzes the costs of waste management systems under eight different scenarios described previously. The assumptions for the waste management systems are:

1. An anaerobic waste lagoon is used to store wastes.
2. The size of the lagoon is the same for all scenarios, disregarding the option to keep a lower or higher effluent concentration in the lagoon.
3. Waste management systems consist of lagoon, effluent application and center pivot irrigation systems.
4. The costs of the lagoon (construction and liner) are amortized over 20 years at 8% rate (based on a 5% annual rate and 3% risk factor).
5. The costs of the center pivot effluent application system include the costs for pump, motor, pipe, maintenance, repair and labor. The costs for the pump and motor were amortized over 10 years while the cost for the pipe was amortized over 20 years.
6. Estimated costs are associated with waste management systems only without considering the net revenue from swine production.

In addition to the waste management systems, a supplemental irrigation practice was selected to dispose the effluent and produce a crop with the nutrient. Therefore, additional irrigation equipment was also accounted for (including wells, pump, motor, and pipe). The pump and motor costs are amortized for 10 years, while the costs of the pipes are amortized for 20 years. Irrigation is employed to support specific Bermudagrass yield goals. Scenarios HYG-1, HYG-2, SA-1 and SA-2 were designed to attain a yield goal of 6 tons/acre. D-1, D-2, LYG-1 and LYG-2 were projected to achieve a yield goal of 3 tons/acre. Disposal scenarios (D-1 and D-2) did not receive supplemental irrigation water, and therefore, irrigation costs are not incurred. The expected yields for D-1 and D-2 were based on the average of grass production from dry land in Kingfisher County, about 1.7 tons/acre.

Calculations were determined based on:

1) total annual waste systems costs, consist of:
    - annual cost of lagoon construction and operation,
    - annual cost of effluent application, which include the costs of pump, motor, fuel, maintenance and labor
    - annual costs of center pivot systems that includes the cost of the equipment, fuel and maintenance
2) total annual irrigation costs, consist of annual payment of irrigation wells, pivot fuel maintenance, pump, and labor.
3) total annual expenses, consist of the total annual costs of waste systems and irrigation
4) total annual net revenue from Bermuda hay production
5) total annual waste management costs, consisting of total annual expenses and total annual net revenue from Bermuda hay production.

The second part of the study evaluates the least cost of waste management systems using the same eight scenarios. All assumptions and parameters related with the calculations are the same as the above analysis. The difference in this evaluation lies in the size of the lagoon. Scenarios D-2, LYG-2, HYG-2, and SA-2 were designed to recirculate water from the lagoon, thereby decreasing the size of the lagoon required and minimizing the costs of fresh water usage. In addition to reducing the fresh water costs, those practices do not require as large a lagoon as scenarios D-1, LYG-1, HYG-1, and SA-1. The lagoon size for D-1, LYG-1, HYG-1 and SA-1 is the same as in the previous analysis.

Results and Discussions

The result of these calculations to determine the costs of waste management is shown in Table V-1.

a. Total Annual Waste Systems Costs

From Table V-1 it can be seen that the total annual waste systems cost is least under scenarios HYG-2 and SA-2 (about $115,000), followed by D-2 and LYG-2 (about $120,000). As previously assumed, D-2, LYG-2, HYG-2, and SA-2 recirculate effluent from the lagoon to flush the animal house, thus increasing the effluent concentration in the lagoon.

Therefore, the use of fresh water is less, resulting in the lower cost of using fresh water. The highest annual waste management cost is for the D-1 and LYG-1 scenarios (about $150,000), followed by HYG-1 and SA-1 scenarios (about $144,000). Scenarios D-1 and LYG-1 use more fresh water, and therefore keep a lower effluent concentration in the lagoon. Consequently, the cost of fresh water is about twice as much as the HYG-2 and SA-2 scenarios. In addition to fresh water expenses, the cost for the pivot systems is also doubled due to the larger land area. The waste systems costs for scenarios D-2, LYG-2, HYG-1, and SA-1 are within the range of the highest and lowest costs. Overall, the combination of lagoon expenses, effluent application, and pivot system expenses influence the variation in the cost of total waste management.

Table V-1. Waste Management Cost Analysis

Scenarios	D-1	D-2	LYG-1	LYG-2	HYG-1	HYG-2	SA-1	SA-2
Lagoon recirculate (1=yes; 0=no)	0	1	0	1	0	1	0	1
Land area (ac)	250	250	250	250	125	125	125	125
REVENUE								
Swine (Capacity Head)	16176	16176	16176	16176	16176	16176	16176	16176
Revenue @								
Less Variable Costs								
Swine Net Revenue								
Bermuda Yield (ton/ac)	1.7	1.7	3	3	6	6	6	6
Variable Cost ($/ac)	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94
Fixed Cost ($/ac)	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70
Bermuda Net Revenue	*$ (17,207)*	*$ (17,207)*	*$ 893*	*$ 893*	*$ 21,446*	*$ 21,446*	*$ 21,446*	*$ 21,446*
TOTAL ANN. NET REVENUE	**$ (17,207)**	**$ (17,207)**	**$ 893**	**$ 893**	**$ 21,446**	**$ 21,446**	**$ 21,446**	**$ 21,446**
EXPENSES								
Lagoon Size								
Length (ft)	1461	1461	1461	1461	1461	1461	1461	1461
Width (ft)	529	529	529	529	529	529	529	529
Initial Lagoon Cost	$ 775,097	$ 775,097	$ 775,097	$ 775,097	$ 775,097	$ 775,097	$ 775,097	$ 775,097
Annual Payment	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945
Recirculation cost	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576
Fresh Water cost	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812
Total Ann. Lagoon Costs	*$ 135,047*	*$ 106,333*	*$ 135,047*	*$ 106,333*	*$ 135,047*	*$ 106,333*	*$ 135,047*	*$ 106,333*
Effluent Application								
Pump and Motor	$ 6,891	$ 6,891	$ 6,891	$ 6,891	$ 6,377	$ 6,377	$ 6,377	$ 6,377
Pipe	$ 20,969	$ 20,969	$ 20,969	$ 20,969	$ 12,675	$ 12,675	$ 12,675	$ 12,675
Initial Cost	$ 27,860	$ 27,860	$ 27,860	$ 27,860	$ 19,052	$ 19,052	$ 19,052	$ 19,052
Annual Payment	$ 3,163	$ 3,163	$ 3,163	$ 3,163	$ 2,241	$ 2,241	$ 2,241	$ 2,241
Fuel, Main.,Rep, Labor	$ 1,175	$ 719	$ 1,175	$ 718	$ 1,887	$ 986	$ 1,887	$ 986
Total Ann. Effluent App Costs	*$ 4,338*	*$ 3,881*	*$ 4,337*	*$ 3,881*	*$ 4,128*	*$ 3,227*	*$ 4,128*	*$ 3,227*
Pivot System (acres)	250	250	250	250	125	125	125	125
Initial Cost	$ 67,010	$ 67,010	$ 67,010	$ 67,010	$ 33,663	$ 33,663	$ 33,663	$ 33,663
Annual Payment	$ 6,825	$ 6,825	$ 6,825	$ 6,825	$ 3,429	$ 3,429	$ 3,429	$ 3,429
Pivot: Fuel, Main., Rep.	$ 3,320	$ 3,320	$ 3,320	$ 3,320	$ 1,653	$ 1,653	$ 1,653	$ 1,653
Total Ann. Pivot Sys Costs	*$ 10,145.56*	*$ 10,145.56*	*$ 10,145.56*	*$ 10,145.56*	*$ 5,081.79*	*$ 5,081.79*	*$ 5,081.79*	*$ 5,081.79*
Total Ann. Waste Syst Costs	**$ 149,530**	**$ 120,360**	**$ 149,530**	**$ 120,360**	**$ 144,257**	**$ 114,642**	**$ 144,257**	**$ 114,642**
Irrigation Wells total no	0	0	6	6	3	3	3	3
Total GPM	0	0	1200	1200	600	600	600	600
Initial Cost, Wells	$ -	$ -	$ 61,800	$ 61,800	$ 30,900	$ 30,900	$ 30,900	$ 30,900
Pipe	$ -	$ -	$ 20,271	$ 20,271	$ 10,135	$ 10,135	$ 10,135	$ 10,135
Ann Cap Cost	$ -	$ -	$ 8,359	$ 8,359	$ 4,180	$ 4,180	$ 4,180	$ 4,180
Pivot Fuel, Maint., Repair	$ -	$ 0	$ 1,233	$ 1,233	$ 616	$ 616	$ 616	$ 616
Pump Cost	$ -	$ -	$ 6,872	$ 6,872	$ 3,435	$ 3,435	$ 3,435	$ 3,435
Labor Cost	$ -	$ -	$ 8	$ 8	$ 4	$ 4	$ 4	$ 4
Total Ann. Irrigation Costs	*$ 0*	*$ 0*	*$ 16,473*	*$ 16,473*	*$ 8,235*	*$ 8,235*	*$ 8,235*	*$ 8,235*
TOTAL ANN. EXPENSES	$ 149,530	$ 120,360	$ 166,002	$ 136,832	$ 152,492	$ 122,877	$ 152,492	$ 122,877
TOTAL ANN. WASTE MGMT	**$ 166,738**	**$ 137,568**	**$ 165,110**	**$ 135,940**	**$ 131,046**	**$ 101,431**	**$ 131,046**	**$ 101,431**

Total Annual Net Revenue = Total Annual Net Revenue from Bermuda production
Total Waste Systems Costs = Total Annual Lagoon Costs + Total Annual Effluent Application Costs + Total Annual Pivot Systems Costs
Total Irrigation Costs = Total annual well, pump, motor and pipe costs + fuel, maintenance, repair, and labor costs.
Total Annual Expenses = Total Annual Waste Management Systems Costs + Total Annual Irrigation Costs
Total Annual Waste Management = Total Annual Expenses and Total Annual Revenue

b. Total Annual Irrigation Costs

Supplemental irrigation is intended to meet crop needs beyond that provided by effluent and natural rainfall. With additional irrigation, an annual cost required for irrigation wells, pumps and pipes is incurred. Scenarios D-1 and D-2 do not acquire additional expenses for irrigation. LYG-1 and LYG-2 are the scenarios requiring the highest annual irrigation expenses ($16K). This is because management practices under the two scenarios require more irrigation wells to cover the larger area (250 ac). On the other hand, scenarios HYG-1, HYG-2, SA-1, and SA-2 require half the total annual irrigation costs ($8K). The lower cost is related to the number of wells installed in the field, based on smaller land coverage (125 ac).

c. Total Annual Expenses

In addition to waste systems costs, the costs for irrigation practices were incorporated in the Total Annual Expenses. From this total, it can be seen that scenarioD-2 would acquire the least total annual expenses (about $123K) when compared to other scenarios. This is again because D-2 does not have additional irrigation costs. In contrast, the highest total annual expenses are acquired under the LYG-1 scenario. Under this management practice, a sum of the costs for the center pivot and the additional irrigation adds up to about $166K. The total annual expenses under other scenarios lie within this range, depending on the combinations of systems required.

d. Total Annual Waste Management Costs

Irrigation practice is anticipated to provide water required for the crop growth. In return, crop growth would produce net revenue based on the yield attained. The yield depends on the amount of nitrogen in the effluent applied over the field. Scenarios D-1, D-2, LYG-1, and LYG-2 receive less effluent because it is applied over a larger acreage with expected realistic yield goal of 3 tons/acre. This expected yield goal might be attained if the crops receive supplemental irrigation water. In the case of the Disposal scenarios (D-1 and D-2), irrigation water was not added, thus eliminating the possibility for the grass to reach an average yield of 3 tons/acre. Therefore, a value of 1.7 tons/acre was used based on the average of grass production over dry land in Kingfisher County.

With an average yield of 1.7 tons/acre, the net revenue for Bermuda production under the disposal scenarios returns a negative value. This indicates that the net revenue from Bermuda production is not sufficient to cover the costs (fixed and variable costs) for growing the crops. Alternatively, scenarios LYG-1 and LYG-2 receive a positive return of annual net value of $893. Although the benefits under these two scenarios are not much, the expenses associated with its production are covered. This low benefit is related to the fixed and variable costs required covering a larger land area.

Nonetheless, when the net revenues from the Low Yield Goal scenarios (LYG-1 and LYG-2) are compared to those of the High Yield Goal scenarios (HYG-1 and HYG-2), it can be see that the benefits of LYG are much smaller. Scenarios HYG-1, HYG-2, SA-1, and SA-2 receive more effluent applied over a smaller land area, increasing the expected yield goal to about 6 tons/acre. With a higher yield goal and a smaller land area, the expenses related with Bermuda production are lower, therefore providing a higher net return of about $21,500 for each scenario.

The total net revenue from Bermudagrass production functions as an additional income to the producers. This additional income could be used to compensate the cost of waste management. The combined total annual expenses and revenues from crop production present a different outcome. With the higher net revenue from Bermudagrass, the more recovery of the costs of waste management systems. Accordingly, scenarios HYG-2 and SA-2 receives the most recovery from the net revenue of Bermuda production, thereby reducing the already least cost waste management to $100,000. Conversely, scenarios D-1 and LYG-1 receive the least recovery net revenue from Bermuda production, which consequently offsets the least from the total annual expenses, retaining the total waste management costs of about $165 – $166,000.

Differing from the above results, scenarios D-2, LYG-2, HYG-1 and SA-1 require about the same amount of waste management costs, approximately $130,000. This similarity is a result of combinations from the total annual waste systems costs, the total annual irrigation costs, and the total annual net revenue from Bermuda production. Therefore, based on the scenarios considered, practices under the HYG-2 and SA-2 are the most preferable options for producers. Nonetheless, this study strictly analyzes the potential annual revenue from Bermudagrass production to be incorporated in the waste management analysis. The study of potential revenue does not take into consideration the marketing aspect associated.

The result of the second part of the study shows least cost of waste management practices, summarized in Table V-2.

Table V-2. Alternative Least Cost Waste Management Analysis

Scenario	D-1	D-2	LYG-1	LYG-2	HYG-1	HYG-2	SA-1	SA-2
Lagoon Recirculate (1=Yes;0=No)	0	1	0	1	0	1	0	1
Land Area (acre)	250	250	250	250	125	125	125	125
REVENUE								
Swine (Capacity Head)	16176	16176	16176	16176	16176	16176	16176	16176
Revenue @								
Less Variable Costs								
Swine Net Revenue								
Bermuda Yield (ton/ac)	1.7	1.7	3	3	6	6	6	6
Variable Cost ($/ac)	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94
Fixed Cost ($/ac)	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70
Bermuda Net Revenue	*$ (17,207)*	*$ (17,207)*	*$ 993*	*$ 993*	*$ 21,496*	*$ 21,496*	*$ 21,496*	*$ 21,496*
TOTAL ANN. REVENUE	**$ (17,207)**	**$ (17,207)**	**$ 993**	**$ 993**	**$ 21,496**	**$ 21,496**	**$ 21,496**	**$ 21,496**
EXPENSES								
Lagoon Size								
Length (feet)	1461	1190	1461	1190	1461	1190	1461	1190
Width (feet)	529	438	529	438	529	438	529	438
Initial Lagoon Cost	$ 775,097	$ 525,938	$ 775,097	$ 525,938	$ 775,097	$ 525,938	$ 775,097	$ 525,938
Annual Payment	$ 78,945	$ 53,568	$ 78,945	$ 53,568	$ 78,945	$ 53,568	$ 78,945	$ 53,568
Recirculation cost	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576
Fresh Water cost	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812
Tot. Ann. Lagoon Costs	*$ 135,047*	*$ 80,956*	*$ 135,047*	*$ 80,956*	*$ 135,047*	*$ 80,956*	*$ 135,047*	*$ 80,956*
Effluent Application								
Pump and Motor	$ 6,891	$ 6,891	$ 6,891	$ 6,891	$ 6,377	$ 6,377	$ 6,377	$ 6,377
Pipe	$ 20,969	$ 20,969	$ 20,969	$ 20,969	$ 12,675	$ 12,675	$ 12,675	$ 12,675
Initial Cost	$ 27,860	$ 27,860	$ 27,860	$ 27,860	$ 19,052	$ 19,052	$ 19,052	$ 19,052
Annual Payment	$ 3,163	$ 3,163	$ 3,163	$ 3,162	$ 2,241	$ 2,241	$ 2,241	$ 2,241
Fuel, Main.,Rep, Labor	$ 1,175	$ 719	$ 1,175	$ 719	$ 1,887	$ 986	$ 1,887	$ 986
Tot. Ann. Effluent App. Costs	*$ 4,338*	*$ 3,881*	*$ 4,337*	*$ 3,881*	*$ 4,128*	*$ 3,227*	*$ 4,128*	*$ 3,227*
Pivot System (acres)	250	250	250	250	125	125	125	125
Initial Cost	$ 67,010	$ 67,009	$ 67,010	$ 67,009	$ 33,663	$ 33,663	$ 33,663	$ 33,663
Annual Payment	$ 6,825	$ 6,825	$ 6,825	$ 6,825	$ 3,429	$ 3,429	$ 3,429	$ 3,429
Pivot: Fuel, Main., Rep.	$ 3,320	$ 3,320	$ 3,320	$ 3,320	$ 1,653	$ 1,653	$ 1,653	$ 1,653
Total Ann Piv Syst Costs	*$ 10,146*	*$ 10,145*	*$ 10,146*	*$ 10,146*	*$ 5,082*	*$ 5,082*	*$ 5,082*	*$ 5,082*
Tot. Ann. Waste Syst Costs	**$ 149,530**	**$ 94,982**	**$ 149,530**	**$ 94,982**	**$ 144,257**	**$ 89,265**	**$ 144,257**	**$ 89,265**
Irrigation Wells total no	0	0	6	6	3	3	3	3
Total GPM	0	0	1200	1200	600	600	600	600
Initial Cost, Wells	$ -	$ -	$ 61,800	$ 61,800	$ 30,900	$ 30,900	$ 30,900	$ 30,900
Pipe	$ -	$ -	$ 20,271	$ 20,271	$ 10,135	$ 10,135	$ 10,135	$ 10,135
Ann Cap Cost	$ -	$ -	$ 8,359	$ 8,359	$ 4,180	$ 4,180	$ 4,180	$ 4,180
Pivot Fuel, Maint. Repair	$ -	$ -	$ 1,233	$ 1,233	$ 616	$ 616	$ 616	$ 616
Pump Cost	$ -	$ -	$ 6,872	$ 6,872	$ 3,435	$ 3,435	$ 3,435	$ 3,435
Labor Cost	$ -	$ -	$ 8	$ 8	$ 4	$ 4	$ 4	$ 4
Total Ann. Irrigation Cost	*$ 0*	*$ 0*	*$ 16,473*	*$ 16,473*	*$ 8,236*	*$ 8,236*	*$ 8,236*	*$ 8,236*
TOTAL ANN. EXPENSES	$ 149,530	$ 94,982	$ 166,002	$ 111,455	$ 152,493	$ 97,501	$ 152,493	$ 97,501
TOTAL ANN. WASTE MGMT	**$ 166,738**	**$ 112,190**	**$ 165,010**	**$ 110,462**	**$ 130,996**	**$ 76,004**	**$ 130,996**	**$ 76,004**

In this evaluation, two different lagoon sizes were used. Practices with lower PAN effluent concentration (D-1, LYG-1, HYG-1, SA-1) utilize more fresh water to keep a lower effluent concentration, and therefore require a bigger storage volume. Practices with higher PAN effluent concentration (D-2, LYG-2, HYG-2, and SA-2) recirculate the water from the lagoon, require less fresh water, and thus, require less storage volume.

a. Total Annual Waste Systems Costs

From Table V-2, it can be seen that the total annual waste systems cost is least under scenarios HYG-2 and SA-2. This is consistent with previous analysis. The difference, however, is in the lower costs of the lagoon systems, bringing the total annual waste systems costs down to $89K. Likewise, scenarios D-2 and LYG-2 are the next lowest cost of scenarios. The difference form previous setting is also associated with the costs needed for a smaller size of lagoon, a total of $95K. Other scenarios require the same expenses for the waste management systems as the previous analysis because they have the same size lagoons.

b. Total Annual Irrigation Costs

The total annual irrigation costs for all the scenarios are the same as in the previous analysis, as irrigation expenses are not related to the size of the lagoon.

c. Total Annual Expenses

The total annual expenses are the sum of the total annual waste systems costs and total annual irrigation costs. Therefore, the overall results are affected according to the changes in the total waste systems costs. In this analysis, the total annual expenses for scenarios D-2, LYG-2, HYG-2, and SA-2 differ from the previous analysis as a result of the lower cost of lagoons.

The amount of the total annual expenses is least under scenario D-2 ($95K), followed by HYG-2 and SA-2 ($98K), LYG-2 ($111K), D-1 ($150K), SA-1 ($152K), and HYG-1 ($153K). The highest cost is required under the LYG-1 scenario ($166K), which is the same as previous calculations.

d. Total Annual Waste Management

As in the previous analysis, the revenue from Bermudagrass production offsets the total operation cost of waste management for all scenarios except Disposal scenarios. The revenue from Bermudagrass under the Disposal scenarios (D-1 and D-2) is insufficient to pay for the expenses associated with hay production. Hence, the annual waste management cost is also lowest under HYG-2 and SA-2 ($76K) followed by LYG-2 ($110K), D-2 ($112K), HYG-1 and SA-1 ($131K), and LYG-1 ($165K) and D-1 ($166K) being the highest.

Based on the total annual expenses and revenue of waste management systems, the cumulative cost was calculated over 60 years to analyze the differences under the different scenarios. The comparisons between annual costs management using the same lagoon sizes for all scenarios and the costs of waste management using the smaller lagoon size for scenarios D-2, LYG-2, HYG-2 and SA-2 are illustrated in Figures V-1 and V-2.

In Figure V-1, it can be seen that the cumulative waste management cost is highest under scenarios D-1 and LYG1, where the least cost is under scenarios HYG-2 and SA-2. Scenarios D-2, LYG2, HYG-1, and SA-1 are in the middle range between the lowest and highest costs, accruing similar waste management costs over the first 20 years. Therefore, to minimize the cost of waste management practices under HYG-2 and SA-2 may be considered.

Table V-3. Summary of Cost Analysis of Waste Management

Scenario	PAN Conc		Land Area		Total Depth		App Depth		No. App	Yield Goal	Costs of Waste Management				Least Costs of Waste Management			
	lb/ L	lb/ ac	ac	m2	in	mm	in	mm		tons/ ac	Net Rev	Annual Waste System	Annual Exp	Annual Waste Mgmt	Net Rev	Annual Waste System	Annual Exp	Annual Waste Mgmt
D-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	(17,207)	149,530	149,530	166,738	(17,207)	149,530	149,530	166,738
D-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	(17,207)	120,360	120,360	137,568	(17,207)	94,982	94,982	112,190
LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	893	149,530	166,002	165,010	893	149,530	166,002	165,010
LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	893	120,360	136,832	135,940	893	94,982	111,455	110,462
HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	6	21,446	144,257	152,492	131,046	21,446	144,257	152,493	130,996
HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	6	21,446	114,642	122,877	101,431	21,446	89,265	97,501	76,004
SA-1	300	68	125	509,250	5.00	125.0	1.25	31.25	4	6	21,446	144,257	152,497	131,046	21,446	144,257	152,493	130,996
SA-2	600	136	125	509,250	2.50	62.5	0.63	15.63	4	6	21,446	114,642	122,877	101,431	21,446	89,265	97,501	76,004

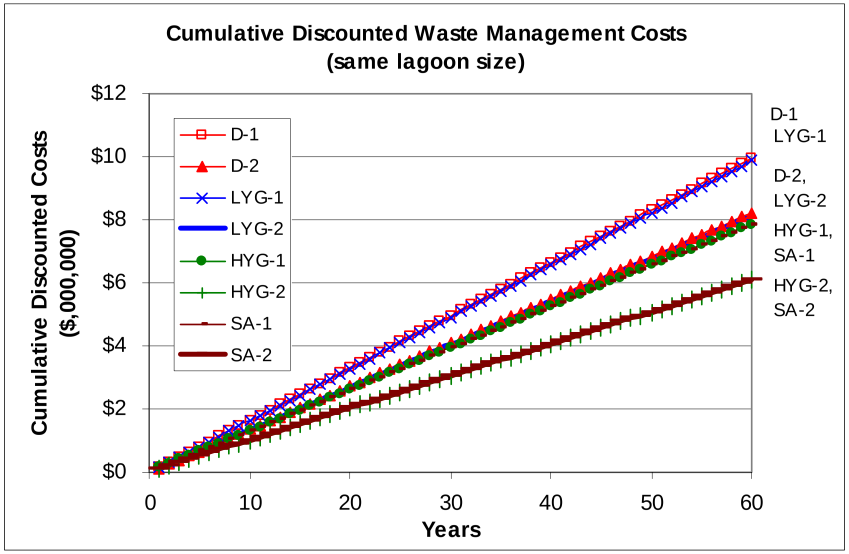

Figure V-1. Cumulative Discounted Waste Management Costs

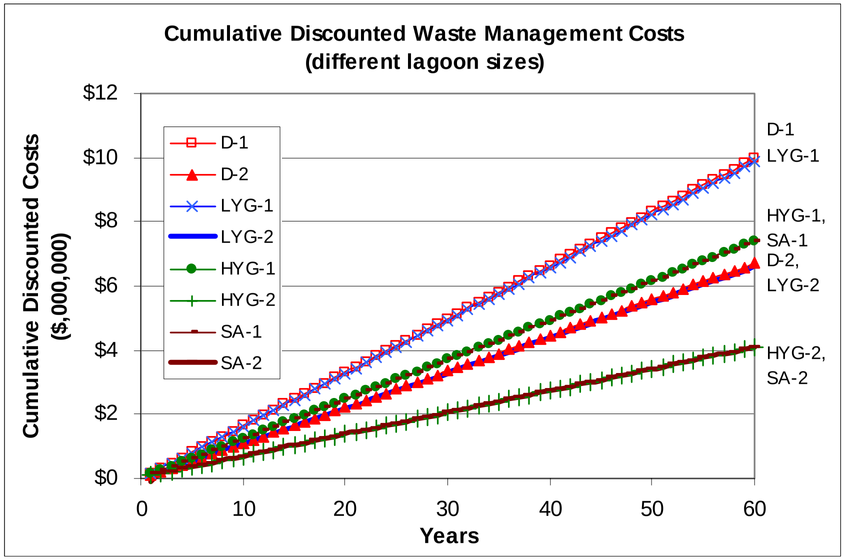

Figure V-2. Cumulative Discounted Waste Management Costs (smaller lagoon size for D-2, LYG-2, HYG-2, SA-2)

Figure IV-12 illustrates the cumulative cost of waste management systems using different sizes of lagoons. From this figure, it shows that scenarios HYG-2 and SA-2 also accrue the lowest cost of waste management. The difference from the previous analysis is in the higher cost associated with a bigger lagoon. The highest cumulative costs, is again, under the D-1 and LYG-1, with the same value as previous analysis.

Other dissimilarities are shown with scenarios D-2 and LYG-2. In previous analysis, the cumulative costs for the scenarios D-2, LYG-2 show the same trend with scenarios HYG-1 and SA-1. This graph, however, shows that smaller lagoon size lowered the cumulative waste management costs for the D-2 and LYG-2. Therefore, to reduce the cost of waste management, scenarios HYG-2 and SA-2 would be preferred with a smaller lagoon size.

Conclusions

Based on the evaluations, conclusions derived are:

1. The net annual costs of waste management is lowest under the HYG-2 and SA-2 scenarios ($114,642) and highest under D-1 and LYG-1 scenarios ($149,530).
2. Annual costs of waste management is lowest under the HYG-2 and SA-2 scenarios ($89,265) and highest under the D-1 scenario ($166,738). The high cost is due to lower compensation from Bermuda hay production.
3. Annual least costs of waste systems is lowest under HYG-2 and SA-2 scenarios ($89,265) and highest under D-1 and LYG-1 scenarios ($149,530).
4. Annual least costs of waste systems for HYG-2 and SA-2 are less than the annual costs of waste systems. This is due to the smaller lagoon size used in the least cost analysis.
5. Annual least cost of waste management is lowest under HYG-2 and SA-2 scenarios ($ 76,004) and highest under D-1 ($166,738). The lower cost is also due to the smaller size of lagoon used.

Evaluation of costs of potential alternative water sources

Purpose and Objectives

High application of nitrogen from lagoon effluent can result in nitrogen leaching. In the case that effluent is over applied, nitrate along with other nutrients can contaminate the groundwater. Groundwater is used by many communities as a source of drinking water. Once the aquifer is contaminated, public well systems (PWS) may also become contaminated, depending on the location and distance of the wells from the source of contaminants. PWSs (city or private entity) that contain NO_3-N over the MCL of 10 mg/L must consider alternative water sources.

Alternatives considered in this study were to (1) find other sources of water by drilling new wells in a location that is hydraulically isolated from the source of contaminants and (2) purchase water from another source/city. The purpose of this evaluation is to find the least cost to replace the existing PWSs. The objectives are to:

1. Determine the potential costs to drill wells to replace the current operating wells.
2. Determine the potential costs to purchase water from another source (the city of Hennessey).
3. Determine which of the two alternatives provide the least cost source of water.

Methodology

1. Find new location to drill new wells by referring to the map of Kingfisher and its underlying aquifer by selecting a location that is upgradient, further downgradient, or hydraulically isolated from the current source of contaminant (CAFO facility).
2. Determine the distance from the old wells to the potential location.

3. Determine the wells to be replaced.
4. Calculate the potential costs to drill new wells in the selected location. The calculations consisted of fixed and variable costs associated with the purchase and installation of the new wells. Fixed costs include the purchase and installation of new wells, pump, motor, and pipelines. The length of pipelines to be purchased depends on the depth of the wells and also the distance from the water reservoir to the new wells. Variable costs include the costs for maintenance, repair, and electricity for the equipment.
5. Select the source/city to purchase water from.
6. Determine the distance from the current water tower to the alternative source (the city of Hennessey).
7. Calculate the potential costs to purchase water from the city of Hennessey. The calculations also consisted of fixed and variable costs. Fixed costs include the purchase and installation of pipe, pump and motor. The length of pipe depends on the distance from the current water tower to the new source/city. Variable costs include the cost for pump and motor maintenance, electricity, and the price to purchase water.

Results and Discussions

Based on the map of Kingfisher and its underlying aquifer, the potential location to drill new wells would be further from the Dover Public Well Systems. This location is hydraulically isolated from the current CAFO facility and three miles from the existing Kingfisher wellfield. The wells to be replaced, six wells, were determined to be those closest to the CAFO facility. The selected wells are shown in Figure V-5 below.

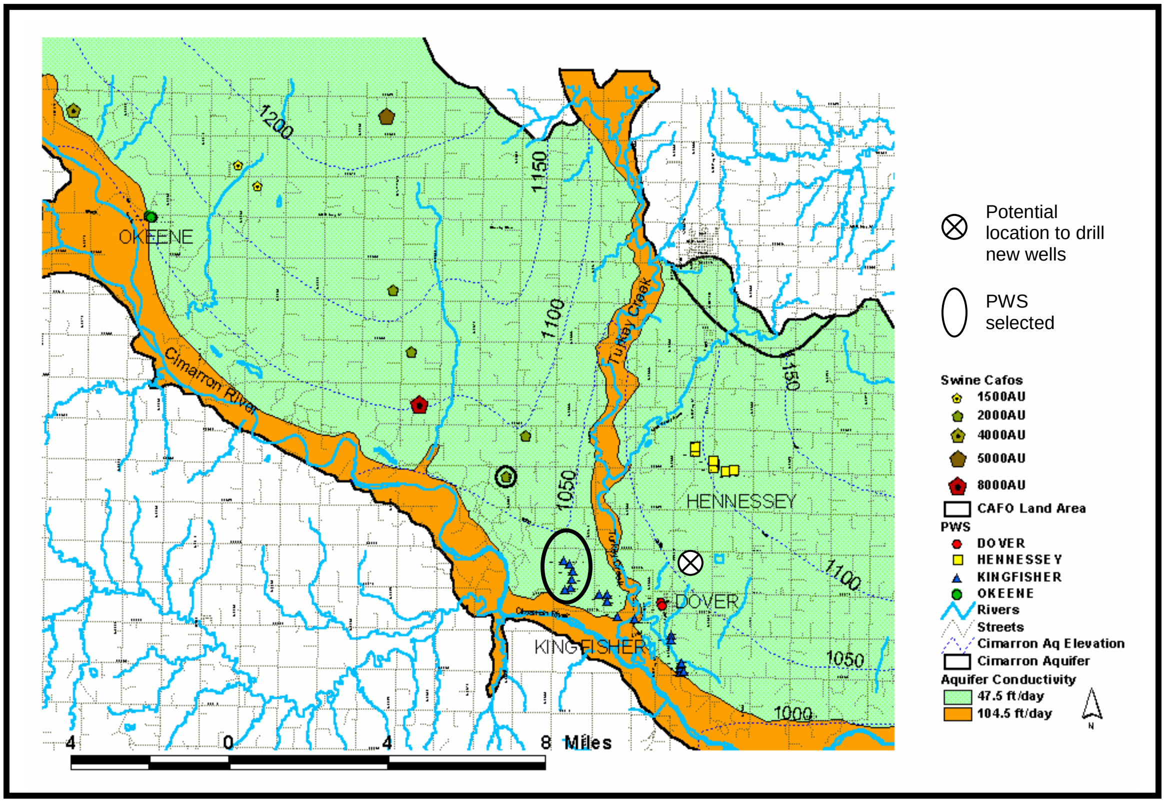

Figure V-3 . Public Well Systems selected for potential replacement

The cost of drilling wells at the new location is shown in Table V-3. From the calculation, the annual payment to replace six wells is about $160,000. This amount is an approximation, provided that ground water supply in the area (about 3 miles from current wellfield location) is sufficient and the quality is acceptable.

Table V-4. Potential Costs to Drill New Wells

Parameters:	Unit	Description	Amount
Well, Casing, Drilling			
Depth to Static Water Table	ft	140	
Pressure at well head	psi	40	
Well Pipe diameter	in	6	
Friction loss in Well Pipe	ft	0.86	
Friction loss other	ft	10	
Total pressure head	ft	243	
Cost of Drilling and casing (Purchase Price)	($/ft)	$ 24.00	
Total Cost of Well Casing (6 wells)	$	$ 3,360.00	$ 20,160.00
Annual Well Casing Cost	20 yrs		**$2,053.34**
Total Cost of Well (Purchase price)	$/well	$ 840.00	$ 5,040.00
Annual Well Cost	20 yrs		**$513.34**
Total Annual Cost of Well, Casing & Drilling			**$2,566.68**
Pump			
Pump Capacity	gpm	300	
Min bhp Required	bhp	29	
Qt Groundwater Pumped	gal/yr	558450000	
Annual Hours of Operation/well	hrs/well	8760	
Years Life	yrs	2	
Submersible Pump (Purchase price for 30 hp)	$	6100	$ 36,600.00
Annual pump payment	$		$20,524.15
Pump Maintenance & Repair (3%)	$/yr	6	$ 6,588.00
Kwph	kwph/hr	0.83	
Kwh		7265.77	
Electricity Cost (per well)	$/kwh	0.07	$ 15,621.47
Total Electricity Cost (for 6 wells)		6	$ 93,728.80
Total Annual Cost of Pump	**$/yr**		**$79,792.65**
Pipe Installation			
Distance to new location (3 miles)	ft	15840	
Pipe cost per linear ft (diameter = 14 in)	ft	$ 44.50	
Trench and backfill			
width	in	17.5	
depth	in	43	
Cost per linear ft	ft	$ 1.67	
Labor	hr	0.421	
Wage	$/hr	$ 15.00	
Labor Cost (=0.421*wage $/hr *0.1)	$	$ 0.63	
OVH rate		1.39	
Total cost per linear foot		$ 48.19	
Total Cost of Pipe & installation			$ 763,353.36
Annual Payment for Pipe & Installation	20 yrs		$77,749.23
Total Annual Cost of Pipes and Installation			**$77,749.23**
TOTAL ANNUAL COST OF NEW WELLS			**$160,108.55**

Annual payment of pipes were amortized over 20 years

Table V-5. Potential Costs to Purchase Water from Hennessey

Parameters:	Unit	Description	Amount
Pipes and installation			
Distance to new location (5 miles)	ft	26400	
Pipe cost per linear ft (diameter = 14 in)	ft	$ 44.50	
Trench and backfill			
width	in	17.5	
depth	in	43	
Cost per linear ft	ft	$ 1.67	
Labor	hr	0.421	
Wage	$/hr	$ 15.00	
Labor Cost (=0.421*wage $/hr *0.1)	$	$ 0.63	
OVH rate		1.39	
Total cost per linear foot		$ 48.19	
Total costs of pipes and installation			$ 1,272,255.60
Annual Payment of Pipe Installation	20 yrs		$129,582.04
Total Annual Cost of Pipes & Installation (Fixed)			**$129,582.04**
Pump and motor (Fixed Costs)			
Pump Capacity	gpm	1600	
Min bhp Required	bhp	156	
Final Head	ft	10	
Head loss	ft	133	
Pump cost	$	1	$ 7,470.00
Total pressure head	ft	243.26	
HP Required		74.6	
Motor Cost	$		$ 11,525.00
Total costs of pump and motor (Fixed Cost)			$ 18,995.00
Annual Payment of Pipe Installation	yrs	4	$5,734.99
(Variable Costs			
Annual Hours of Operation	hrs	8760	
Kwph	kwph/hr	0.83	
Kwh		7265.77	
Electricity Cost	$/kwh	0.07	$ 79,347.13
Total Annual Fixed and Variable Cost			**$ 73,612.15**
Purchase water			
Price per 4000 gallons	$/ 4000 gallons	2.3	
Gallons required	gal/day	1530000	
	gal/yr	558450000	
Annual cost of purchasing water			**$ 321,108.75**
TOTAL ANNUAL COST OF PURCHASE WATER			**$524,302.94**

Table IV-5 continued.

Desriptions of calculations:

Friction loss in well pipe
=(10.46*(Pump capacity/150)^1.852/well pipe diameter)^4.87)*depth to static water table

Total Pressure head
=depth to static water table + Presure at wellhead * 2.31 + Friction loss in well pipe + firction loss in other

Cost of well & casing
=Cost of drilling * depth to static water table

Min bhp required
= (pump capacity * total pressure head)/(3960*0.9*0.7)

Cost for pipe and installation per linear ft
= (cost per linear ft + labor cost) * 1.39

Number of wells required
= (amount of fresh water required (cuft/yr) * 7.5/ pump capacity 860)/(150+0.99))

Annual hours of operation/well
=quantity of freshwater * 7.5 / (pump capacity 8 60) / number of wells

Years life
= min (20000/annual hours of operation)

Electricity required
= ((headloss* pump capacity)/(3960*friction loss))*(annual hrs of operation * 2547 /(3412*0.9)*number of wells

Maintenance & repair
= 0.03 * submersible pump * number of wells

Total cost of wells, pipe, and pump
= (cost of well & casing + cost of well pipe + submersible pump) * number of wells

Annual payments
= interest rate (8%; 5% base rate + 3% risk), amortized over life years of equipment, and the cost for the equipment(s)

Total Annual Cost of Wells, Pipe and Pump
= (Total Annual Well, Casing & Drilling) + (Total Annual Cost of Well pipe & installation) + (Total Annual cost of pump)

Another alternative was to purchase water from another source, the city of Hennessey. The distance from the current water tower to the city is approximately 5 miles, 2 miles further than the possible location to drill new wells. Table V-5 shows the potential annual cost to purchase water from Hennessey is about $525,000. This cost includes the additional expense to purchase water, $2.30 per 4000 gallons. This estimation also depends on the availability and the quality of water supply in the future. Comparison between the two alternatives shows that although purchasing water does not acquire new wells, the annual cost is about 3 times higher than to drill new wells. This is due to the cost of pipe that is more and the additional expense to purchase water.

Conclusions

1. The potential annual cost to drill new well that is 3 miles further is approximately $160,000.
2. The potential annual cost to purchase water from Hennessey is approximately $525,000.
3. The potential annual cost to purchase water from Hennessey is about 3 times more than to drill new wells.

Least Cost Alternative to Minimize Waste Management Costs

Purpose and Objectives

Many CAFOs do not take into consideration the externalities caused by effluent application practices. Therefore, to consider these externalities, the potential costs to the public wells are incorporated into the waste management costs. The externality factor increases the total annual costs of the waste management. The magnitude of externality costs depends on the time for the PWS to reach the MCL level, which in turn depends on the practices employed.

This analysis includes evaluation of practices that provide the least cost method of waste management taking consideration the cost of externalities at the time that a PWS become contaminated. The objectives are to:

1. Analyze the cumulative discounted cost of waste management (using the same lagoon size) with the cost of externality by incorporating the cost of to drill new wells at the time NO_3-N at PWS reaches the MCL.
2. Analyze the cumulative discounted cost of waste management (using the same lagoon size) with the cost of externality by incorporating the cost to purchase water from Hennessey.
3. Analyze the cumulative discounted cost of waste management (using smaller lagoon size for D-2, LYG-2, HYG-2, and SA-2) with the cost of externality by incorporating the cost of to drill new wells at the time NO_3-N at PWS reaches the MCL.
4. Analyze the cumulative discounted cost of waste management (using smaller lagoon size for D-2, LYG-2, HYG-2, and SA-2) with the cost of externality by incorporating the cost to purchase water from Hennessey.
5. Determine the least cost of waste management with externality.

Methodology

1. Combine the potential annual cost of drilling six new wells to the cumulative discounted costs of waste management from previous analysis. This applies to both waste management using the same lagoon size and different lagoon sizes. The addition occurs at the time that the NO_3-N in the PWS reach the MCL, depending on the practices employed.
2. Combine the potential annual cost of purchasing water from Hennessey to the cumulative discounted costs of waste management, also from previous analysis. This again applies to both waste management approaches; using the same and different

lagoon sizes. The addition also occurs at the time that the NO_3-N in the PWS reach the MCL, depending on the practices employed.

Results and Discussions

Figure V-4 shows the cumulative costs accrued with new wells drilled after 30 years, the date where alternative water is needed. The left graph illustrates the costs if the same lagoon size for all waste management practices were employed. The result shows a similar ranking of cumulative discounted waste management costs with waste management scenarios as shown previously in Figure V-1. The cost due to externality was included in the scenarios, but the effects are not obvious. The right graph illustrates the cumulative discounted costs with new wells for scenarios using smaller lagoon sizes for scenarios (D-2, LYG-2, HYG-2, and SA-2). Again, the graphs show similar results to those in Figure V-2 with an increase in the cumulative costs that is not so apparent. This indicates that drilling new wells will not have much impact on the costs of waste management. The overall illustrations also suggest that a high yield goal management (scenarios HYG-2 and SA-2) is preferable from economic perspective.

Figure V-5 shows the cumulative discounted costs with expenditures to purchase water. The left graph represent the cost if all scenarios use the same lagoon size. The overall trend is again similar to previous graphs. Scenarios D-1 and LYG-1 require the same cost of waste management until the new water source is needed. By incorporating externality costs at the time NO_3-N at the PWS reached the MCL, the two curves differ with LYG-1 increasing earlier than D-1. This is due to the earlier delivery of NO_3-N to the water table under LYG-1, increasing the concentration in the aquifer, and thereby reaching the MCL earlier. The cost increase is more obvious due to the more costly expenditure needed to purchase water.

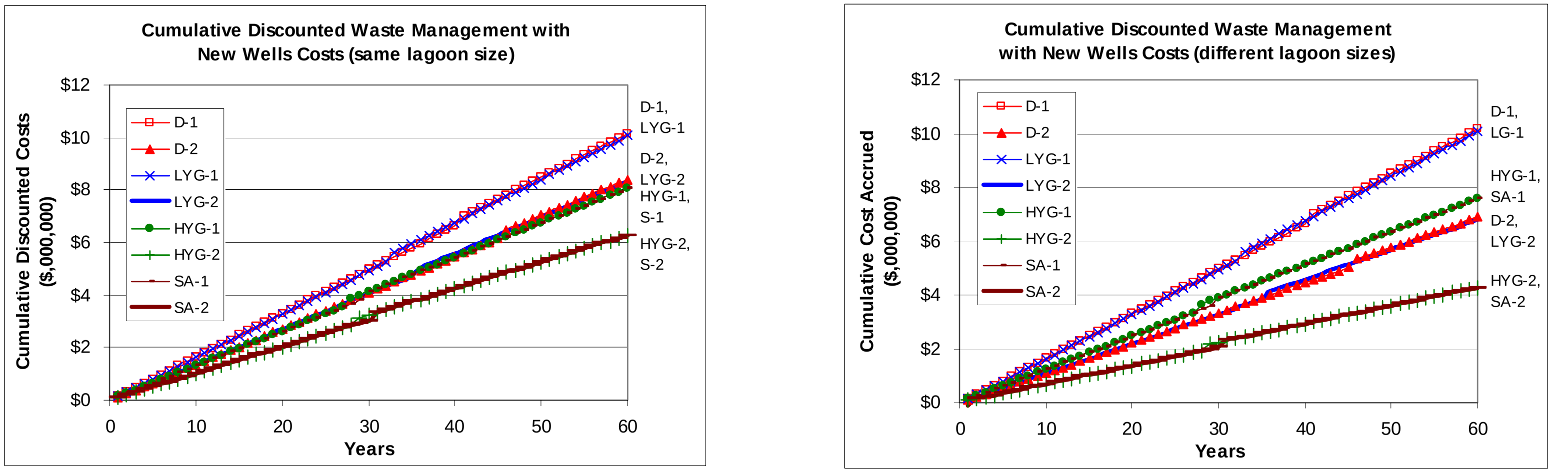

Figure V-4. Cumulative Discounted Waste Management with New Wells Costs: same lagoon size (left), smaller lagoon size for D-2, LYG-2, HYG-2, SA-2 (right)

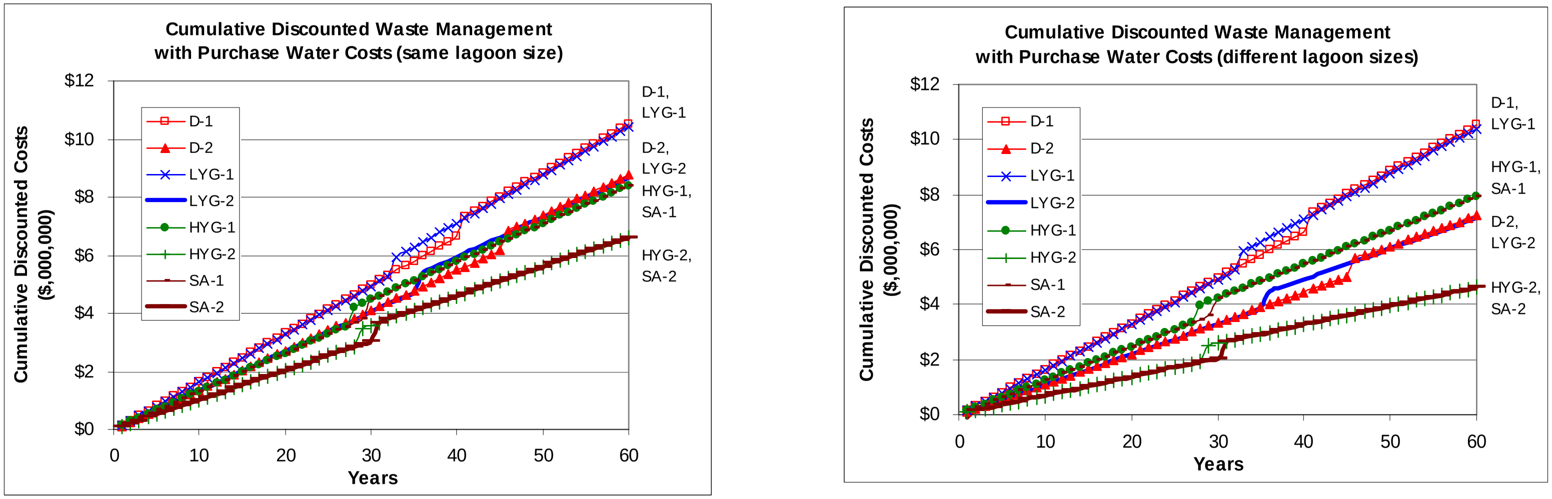

Figure V-5. Cumulative Discounted Waste Management Costs with Purchase Water from Hennessey: same lagoon size (left), smaller lagoon size for D-2, LYG-s, HYG-2, SA-2 (right)

Scenarios D-2, LYG-2, HYG-1 and SA-1 generate approximately the same amount of cumulative discounted cost of waste management (Figure V-5, left). After externality, the graphs differ with HYG-1 increasing first, followed by SA-1, LYG-2, and D-2. Scenarios that require the least cost of waste management, HYG-2 and SA-2 also differ subsequent to the increase due to pollution with HYG-2 increasing earlier. Overall, even with the externality costs, Scenarios HA-2 and SA-2 are still preferable, showing the least cost of waste management systems.

Figure V-5 right shows the cumulative discounted costs of purchasing water from different scenarios using the different lagoon sizes. In this figure, the increase between D-2, LYG-2, HYG-1, and SA-1 are more noticeable. The cumulative waste management costs under HYG-1 increases first than SA-1. Likewise, the cumulative waste management costs also increases earlier for LYG-2. Overall, the trends suggest that HYG-2 and SA-2 scenarios are the most preferred.

Conclusions

1. The effects of the cost to drill six new wells to the cumulative discounted cost of waste management are not obvious for both scenarios using the same and different lagoon sizes.
2. The effects of the cost to purchase water from Hennessey to the cumulative discounted cost of waste management are more apparent than the affects from drilling new wells.
3. The least discounted waste management cost is under HYG-2 and SA-2, with SA-2 more preferred when externality is included.

Cost Benefit Analysis of a CAFO in a Wellhead Protection Area

Purpose and Objectives

Cost benefit of analysis of a CAFO is assessed to determine whether or not the benefit from CAFO production out weighs the cost of waste management to both public and private sectors. In addition, the cost to obtain alternative sources of water supply is also incorporated to determine whether or not the benefit from the CAFO would compensate the cost of either drilling new wells or purchasing water from another source should the drinking water wells become contaminated. If the potential benefit from the CAFO exceeds the cost of waste treatment and the cost of potential alternative sources of water, then the CAFO would be beneficial to the community. However, if the CAFO's net revenue is less than the cost of waste treatment plus the cost of a new source of water, then the community may not consider permitting the CAFO to exist.

The location of a CAFO is important in preventing the nitrate concentration in ground water from reaching the MCL. Once the contaminant reaches the saturated zone, it will travel horizontally and reach a public well system. The time required for the contaminant to reach the PWS depends on the distance from the source to the well. Wellhead protection area (WHPA) in this study was based on a 10-year Time-of-Travel delineation, allowing 10 years for contaminants to travel from the periphery of the zone to the well. A CAFO located up-gradient and outside a wellhead protection area would require a longer period of time before it contaminates a public well system. The CAFO selected lies about 0.5 miles to the periphery of the delineated zone, allowing an additional 4 years for contaminants to reach the periphery of the Kingfisher wellfields delineation. The additional 4 years would delay the expenditures, should a PWS becomes contaminated and reach the maximum contaminant level for nitrate. The two alternatives considered are assessed towards the different scenarios based on the time (years) that the well becomes contaminated.

The objectives of this analysis are:

1. Determine the benefit from a CAFO production
2. Evaluate the benefit from a CAFO production after incorporating externality
3. Determine whether or not the benefits out weigh the cost of waste management.
4. Determine whether or not CAFOs located inside a wellhead protection area would be beneficial to the community.

Methodology

1. Calculate the potential benefit from CAFO production for practices using the same lagoon size.
2. Calculate the potential benefit from a CAFO production for practices using smaller lagoon size for D-2, LYG-2, HYG-2 and SA-2.
3. Determine whether or not the benefits out weigh the cost of waste management.
4. Determine the most profitable scenario for the CAFO.
5. Calculate the Net Present Benefit from scenarios using the same and different lagoon sizes and incorporating the cost of externalities (drill new wells and purchase water).

Results and Discussions

The benefit of a CAFO production was estimated using the Swine Budget Revenue adopted from Kansas State University (shown in Table V-6). Parameters considered are: fixed (building, equipment, office) and variable costs. Variable costs consists of:

- Gross revenue per pig based on the sales finished per unit price (average taken from sales from 1997 to 2001). The sales finished price includes the feed costs and less death costs.
- Non-feed costs include the labor costs, veterinary drugs, professional costs, transportation and market costs, equipment interests, and depreciation value for buildings and equipments.

The estimation showed that the Total Annual Net Revenue generated from a swine production facility of 2000 AU is about $229,000. This value was added to the total annual revenue from Bermudagrass to determine the total revenue of the CAFO. From this total annual revenue, the total annual expenses from waste management were deducted to determine the total annual benefit of the CAFO. The comparisons of benefits from a CAFO employing different waste management practices while using the same lagoon size are shown in Table V-7.

From Table V-7, it can be seen that practices (scenarios) that require the least cost of waste management systems resulted in higher total annual benefit. This is consistent with previous observation, in which CAFOs that employ waste management practices under the HYG-2 and SA-2 would attain a higher benefit ($127,000). On the contrary, CAFOs that employ practices in scenarios LYG-1 and D-1 would have the least total annual benefit due to the high cost of waste management ($62,000) with only half as much potential profit from sale of hay.

In addition, benefit analysis of a CAFO employing different waste management systems while using the least cost alternative (different lagoon sizes) are shown in Table

V-8. Again, HYG-2 and SA-2 are the most profitable management, gaining more benefit from reducing the size of the lagoon to about $153,000.

Table V-6. Swine Budget Revenue

Investments	Dollars/ Pig Space	Pig/Spaces	Total		
Bldings	$ 140.00	16176	$ 2,264,640.00	DeathLoss	1%
Equipment	$ 25.00		$ 404,400.00	Turn over	2.8
Office			$ 15,000.00	Total Pigs	44840
Total			**$ 2,684,040.00**		

	Unit price	Total
Sale finished	37.74	$ 98.12
Less Cost Fd Pig	41.66	41.66
Less Death Loss		3.79
Gross Revenue per Pig		**$ 60.25**
FEED COSTS		
Grain tons		$ 22.18
Protein tons		$ 11.84
Other Ingredients		$ 1.87
Complete feeds tons		
Feed Processing tons		$ 3.81
Total Feed Costs		**$ 39.70**
NON-FEED COSTS		
Labor (person years)	34000	$ 2.10
Veterinary drugs		$ 1.80
Utilities, fuel, oil		$ 0.46
Transport and market cost		$ 3.00
Building and Eq Rep (% inv)	0.02	$ 1.32
Professional costs (acct)		$ 0.74
Depreciation on Buildings, equip		$ 2.16
Interest on building and Equipment		$ 2.86
Insurance on building and Equip		$ 1.01
Total NonFeed Costs		**$ 15.45**
Total Cost/Pig		$ 55.15
Net Returns/Pig		$ 5.10
Total Annual Net Revenue (Total net returns per pig * total pigs sold)		**$ 228,862.71**

Swine Budget, Adapted for Grower to Finisher Budget by Kansas State University

Price Received Hogs by farmers in Oklahoma

1997	50
1998	32
1999	28.1
2000	38.4
2001	40.2
Average	37.74

Table V-7. Benefits from of a CAFO using the same lagoon size for all scenarios

Scenarios	**D1**	**D2**	**L1**	**L2**	**H1**	**H2**	**S1**	**S2**
Lagoon Recirculate (1=yes;0=No)	0	1	0	1	0	1	0	1
Land Area (acre)	250	250	250	250	125	125	125	125
REVENUE								
Swine(Capacity Head)	16176	16176	16176	16176	16176	16176	16176	16176
Revenue @	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
Less Var Cost	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55
Swine Net Revenue	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*
Bermuda Yield (ton/ac)	1.7	1.7	3	3	6	6	6	6
Variable Cost ($/ac)	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94
Fixed Cost ($/ac)	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70
Bermuda Net Revenue	*$ (17,207)*	*$ (17,207)*	*$ 993*	*$ 993*	*$ 21,496*	*$ 21,496*	*$ 21,496*	*$ 21,496*
Total Revenue	**$ 211,477**	**$ 211,477**	**$ 229,677**	**$ 229,677**	**$ 250,180**	**$ 250,180**	**$ 250,180**	**$ 250,180**
EXPENSES								
Lagoon Size								
Length (feet)	1461	1461	1461	1461	1461	1461	1461	1461
Width (feet)	529	529	529	529	529	529	529	529
Initial Lagoon Costs	$ 775,096	$ 775,096	$ 775,096	$ 775,096	$ 775,096	$ 775,096	$ 775,096	$ 775,096
Annual Payment	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945	$ 78,945
Recirculation cost	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576
Fresh Water cost	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812
Tot. Ann. Lagoon Costs	*$ 135,046*	*$ 106,333*	*$ 135,046*	*$ 106,333*	*$ 135,046*	*$ 106,333*	*$ 135,046*	*$ 106,333*
Effluent Application								
Pump and Motor	$ 6,891	$ 6,891	$ 6,891	$ 6,891	$ 6,377	$ 6,377	$ 6,377	$ 6,377
Pipe	$ 20,969	$ 20,969	$ 20,969	$ 20,969	$ 12,675	$ 12,675	$ 12,675	$ 12,675
Initial Cost	$ 27,860	$ 27,860	$ 27,860	$ 27,860	$ 19,052	$ 19,052	$ 19,052	$ 19,052
Annual Payment	$ 3,163	$ 3,163	$ 3,163	$ 3,163	$ 2,241	$ 2,241	$ 2,241	$ 2,241
Fuel, Main.,Rep, Labor	$ 1,175	$ 719	$ 1,175	$ 719	$ 1,887	$ 986	$ 1,887	$ 986
Tot. Ann. Eff App Cost	*$ 4,338*	*$ 3,881*	*$ 4,337*	*$ 3,881*	*$ 4,128*	*$ 3,227*	*$ 4,128*	*$ 3,227*
Pivot System (acres)	250	250	250	250	125	125	125	125
Initial Cost	$ 67,010	$ 67,010	$ 67,010	$ 67,010	$ 33,663	$ 33,663	$ 33,663	$ 33,663
Annual Payment	$ 6,825	$ 6,825	$ 6,825	$ 6,825	$ 3,429	$ 3,429	$ 3,429	$ 3,429
Pivot: Fuel, Main., Rep.	$ 3,320	$ 3,320	$ 3,320	$ 3,320	$ 1,653	$ 1,653	$ 1,653	$ 1,653
Total Ann. Piv Syst Cost	*$ 10,146*	*$ 10,146*	*$ 10,146*	*$ 10,146*	*$ 5,082*	*$ 5,082*	*$ 5,082*	*$ 5,082*
Tot. Ann. Waste Syst Costs	**$ 149,529**	**$ 120,360**	**$ 149,529**	**$ 120,360**	**$ 144,256**	**$ 114,642**	**$ 144,256**	**$ 114,642**
Irrigation Wells total no	0	0	6	6	6	6	6	6
Total GPM	0	0	1200	1200	600	600	600	600
Initial Cost, Wells	$ -	$ -	$ 61,800	$ 61,800	$ 30,900	$ 30,900	$ 30,900	$ 30,900
Pipe	$ -	$ -	$ 20,271	$ 20,271	$ 10,135	$ 10,135	$ 10,135	$ 10,135
Ann Cap Cost	$ -	$ -	$ 8,359	$ 8,359	$ 4,180	$ 4,180	$ 4,180	$ 4,180
Pivot FOR	$ -	$ -	$ 1,233	$ 1,233	$ 616	$ 616	$ 616	$ 616
Pump Cost	$ -	$ -	$ 6,872	$ 6,872	$ 3,435	$ 3,435	$ 3,435	$ 3,435
Labor Cost	$ -	$ -	$ 8	$ 8	$ 4	$ 4	$ 4	$ 4
Total Ann. Irrigation Cost	*$ 0*	*$ 0*	*$ 16,473*	*$ 16,473*	*$ 8,235*	*$ 8,235*	*$ 8,235*	*$ 8,235*
TOTAL ANN. EXPENSES	$ 149,529	$ 120,360	$ 166,002	$ 136,832	$ 152,491	$ 122,877	$ 152,491	$ 122,877
TOTAL ANN. BENEFIT	**$ 61,947**	**$ 91,117**	**$ 63,675**	**$ 92,844**	**$ 97,689**	**$ 127,303**	**$ 97,689**	**$ 127,303**

Table V-8. Benefit Analysis of a CAFO using smaller lagoon sizes for scenarios D-2, LYG-2, HYG-2, SA-2

Scenarios	D1	D2	L1	L2	H1	H2	S1	S2
Lagoon Recirculate	0	1	0	1	0	1	0	1
Land Area	250	250	250	250	125	125	125	125
REVENUE								
Swine (Capacity Head)	16176	16176	16176	16176	16176	16176	16176	16176
Revenue @	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
Less Var Cost	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55
Swine Net Revenue	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*	*$ 228,684*
Bermuda Yield (ton/ac)	3	3	3	3	6	6	6	6
Variable Cost ($/ac)	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94	$ 94
Fixed Cost ($/ac)	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70	$ 70
Bermuda Net Revenue	*$ 993*	*$ 993*	*$ 993*	*$ 993*	*$ 21,496*	*$ 21,496*	*$ 21,496*	*$ 21,496*
TOTAL ANNUAL REVENUE	**$ 229,677**	**$ 229,677**	**$ 229,677**	**$ 229,677**	**$ 250,180**	**$ 250,180**	**$ 250,180**	**$ 250,180**
EXPENSES								
Lagoon Size								
Length	1461	1190	1461	1190	1461	1190	1461	1190
Width	529	438	529	438	529	438	529	438
Initial Lagoon Cost	$ 775,097	$ 525,938	$ 775,097	$ 525,938	$ 775,097	$ 525,938	$ 775,097	$ 525,938
Annual Payment	$ 78,945	$ 53,568	$ 78,945	$ 53,568	$ 78,945	$ 53,568	$ 78,945	$ 53,568
Recirculation cost	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576	$ -	$ 1,576
Fresh Water cost	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812	$ 56,101	$ 25,812
Tot. Ann. Lagoon Costs	*$ 135,047*	*$ 80,956*	*$ 135,047*	*$ 80,956*	*$ 135,047*	*$ 80,956*	*$ 135,047*	*$ 80,956*
Effluent Application								
Pump and Motor	$ 6,891	$ 6,891	$ 6,891	$ 6,891	$ 6,377	$ 6,377	$ 6,377	$ 6,377
Pipe	$ 20,969	$ 20,969	$ 20,912	$ 20,912	$ 12,675	$ 12,675	$ 12,675	$ 12,675
Initial Cost	$ 27,860	$ 27,860	$ 27,803	$ 27,803	$ 19,052	$ 19,052	$ 19,052	$ 19,052
Annual Payment	$ 3,163	$ 3,163	$ 3,157	$ 3,157	$ 2,241	$ 2,241	$ 2,241	$ 2,241
Fuel, Main.,Rep, Labor	$ 1,175	$ 719	$ 1,175	$ 718	$ 1,887	$ 986	$ 1,887	$ 986
Tot. Ann. Effluent App Costs	*$ 4,337.79*	*$ 3,881.46*	*$ 4,331.62*	*$ 3,875.29*	*$ 4,128.25*	*$ 3,227.17*	*$ 4,128.25*	*$ 3,227.17*
Pivot System (acres)	251	251	251	251	124	124	124	124
Initial Cost	$ 67,010	$ 67,010	$ 67,010	$ 67,010	$ 33,663	$ 33,663	$ 33,663	$ 33,663
Annual Payment	$ 6,825	$ 6,825	$ 6,825	$ 6,825	$ 3,429	$ 3,429	$ 3,429	$ 3,429
Pivot: Fuel, Main., Rep.	$ 3,320	$ 3,320	$ 3,320	$ 3,320	$ 1,653	$ 1,653	$ 1,653	$ 1,653
Total Ann Piv Syst Cost	*$ 10,146*	*$ 10,146*	*$ 10,146*	*$ 10,146*	*$ 5,082*	*$ 5,082*	*$ 5,082*	*$ 5,082*
Tot. Annual Waste Syst Costs	**$ 149,530**	**$ 94,983**	**$ 149,524**	**$ 94,977**	**$ 144,257**	**$ 89,265**	**$ 144,257**	**$ 89,265**
Irrigation Wells total no	0	0	6	6	3	3	3	3
Total GPM	0	0	1200	1200	600	600	600	600
Initial Cost, Wells	$ -	$ -	$ 61,800	$ 61,800	$ 30,900	$ 30,900	$ 30,900	$ 30,900
Pipe	$ -	$ -	$ 20,271	$ 20,271	$ 10,135	$ 10,135	$ 10,135	$ 10,135
Ann Cap Cost	$ -	$ -	$ 8,359	$ 8,359	$ 4,180	$ 4,180	$ 4,180	$ 4,180
Pivot FOR	$ -	$ -	$ 1,233	$ 1,233	$ 616	$ 616	$ 616	$ 616
Pump Cost	$ -	$ -	$ 6,872	$ 6,872	$ 3,435	$ 3,435	$ 3,435	$ 3,435
Labor Cost	$ -	$ -	$ 8	$ 8	$ 4	$ 4	$ 4	$ 4
Total Ann. Irrigation Cost	*$ 0*	*$ 0*	*$ 16,473*	*$ 16,473*	*$ 8,235*	*$ 8,235*	*$ 8,235*	*$ 8,235*
TOTAL ANNUAL EXPENSES	$ 149,530	$ 94,983	$ 165,996	$ 111,449	$ 152,492	$ 97,500	$ 152,492	$ 97,500
TOTAL ANNUAL BENEFIT	**$ 80,146**	**$ 134,694**	**$ 63,680**	**$ 118,227**	**$ 97,688**	**$ 152,680**	**$ 97,688**	**$ 152,680**

Table V-9. Summary of Benefit Analysis of a CAFO

Scenarios	PAN Conc		Land Area		Total Depth		App Depth		No. App	Yield Goal	Benefits of CAFO (same lagoon size)				Benefits of CAFO (different lagoon size)			
	lb/ L	lb/ ac	ac	m2	in	mm	in	mm		tons/ ac	Net Rev	Annual Waste System	Annual Exp	Annual Benefits	Net Rev	Annual Waste System	Annual Exp	Annual Benefits
D-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	211,477	149,530	149,530	61,947	211,477	149,530	149,530	61,947
D-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	211,477	120,360	120,360	91,117	211,477	94,982	94,982	116,494
LYG-1	300	68	250	1,018,500	2.50	62.5	1.25	31.25	2	3	229,677	149,530	166,002	63,675	229,677	149,524	165,996	63,680
LYG-2	600	136	250	1,018,500	1.25	31.3	0.63	15.63	2	3	229,677	120,360	136,832	92,844	229,677	94,977	111,449	118,227
HYG-1	300	68	125	509,250	5.00	125.0	2.50	62.50	2	6	250,180	144,256	152,491	97,689	250,180	144,257	152,493	97,688
HYG-2	600	136	125	509,250	2.50	62.5	1.25	31.25	2	6	250,180	114,642	122,877	127,303	250,180	89,265	97,501	152,680
SA-1	300	68	125	509,250	5.00	125.0	1.25	31.25	4	6	250,180	144,256	152,491	97,689	250,180	144,257	152,493	97,688
SA-2	600	136	125	509,250	2.50	62.5	0.63	15.63	4	6	250,180	114,642	122,877	127,303	250,180	89,265	97,501	152,680

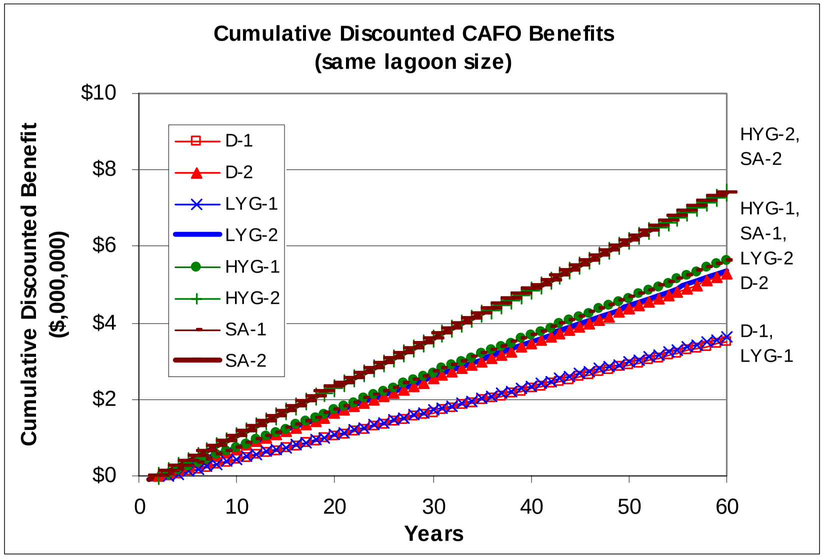

Figure V-6. Cumulative Discounted CAFO Benefits (same lagoon size)

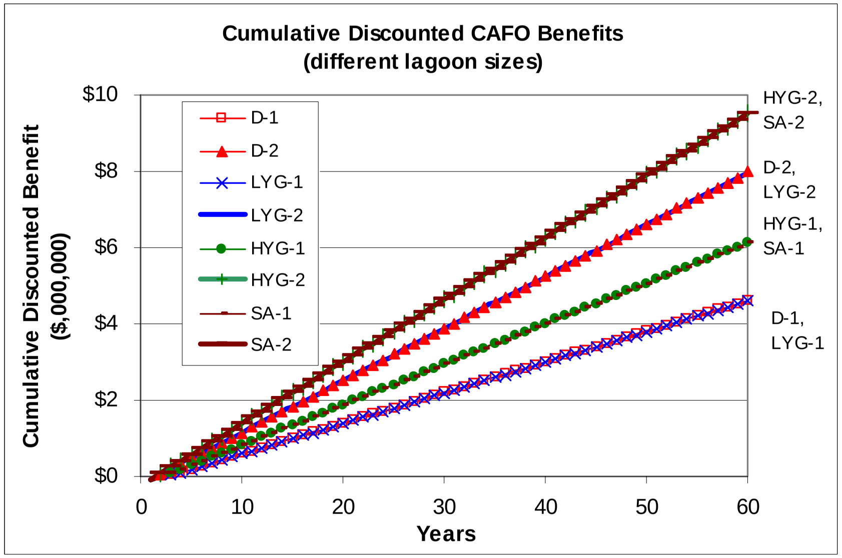

Figure V-7. Cumulative Discounted CAFO Benefits (smaller lagoon size for D-2, LYG-2, HYG-2, SA-2)

Similar to previous assessment, the cumulative discounted benefit from the CAFO is shown in Figures V-6 and V-7. Figure V-6 illustrates the benefit of a CAFO implementing waste management practices using the same size of lagoon. The benefits of CAFOs are related to the cost of waste management acquired. It can be seen that scenarios previously acquiring the least cost of waste management (HYG-2 and SA-2) is now generating the highest benefit to the industry. Scenarios acquiring the highest cost of waste management systems (D-1 and LYG-1) propose the lowest benefit. Other scenarios lay within the range of the highest and lowest benefits.

Figure V-7 shows the benefit of a CAFO using smaller lagoon size for scenarios D-2, LYG-2, HYG-2 and SA-2. By utilizing a smaller lagoon size minimizes the waste system costs, thus offers a higher benefit. As with previous results, HYG-2 and SA-2 present the highest benefit. This cumulative discounted benefit is not much different during the first 10 years. However, after 10 years, the differences between scenarios D-2, LYG-2, HYG-1, and SA-1 are obvious with D-2 and LYG-2 presenting more benefits.

In addition, the benefit after the cost of incorporating externalities is evaluated. Related to previous results where externalities increase the costs of waste management, the proposed benefit also decreases at the same time. Again, the declines in the proposed benefits differ for each scenario depending on the time that NO_3-N at the PWS reach the MCL. The cumulative of discounted benefits of CAFO with externalities are shown in Figure V-8.

Figure V-8 left graph shows the cumulative discounted benefit of a CAFO using the same lagoon size for all scenarios incorporating the cost of installing new wells. Figure V-8 right graph shows the cumulative discounted benefit of a CAFO utilizing smaller lagoon size for scenarios D-2, LYG-2, HYG-2, and SA-2. The difference between the 2 figures is the same with previous graphs where HYG-1 and SA-1 propose lower benefits than D-2 and LYG-2. In both figures, the affects of the cost of installing new wells to the proposed benefits under all scenarios are not that apparent due to the lower cost of installing new wells, but the ranks of the highest benefit are still under scenarios HYG-2 and SA-2.

The effects of expenditures in purchasing water to the benefit of CAFOs are shown in Figures V-9. Figure V-9 left graph illustrates the decline in the benefit to CAFOs using the same size of lagoon for its waste systems. In this figure, the plunge due to externalities is noticeable. This is due to the annual cost for PWS to purchase water that is 3 times more than to install new wells. Likewise in Figure V-9 right, the plunge is also apparent. In both figures, the declines occur after 25 years. Again, the difference between the two graphs (V-9 left and V-9 right) is the lower potential benefit under HYG-1 and SA-1.

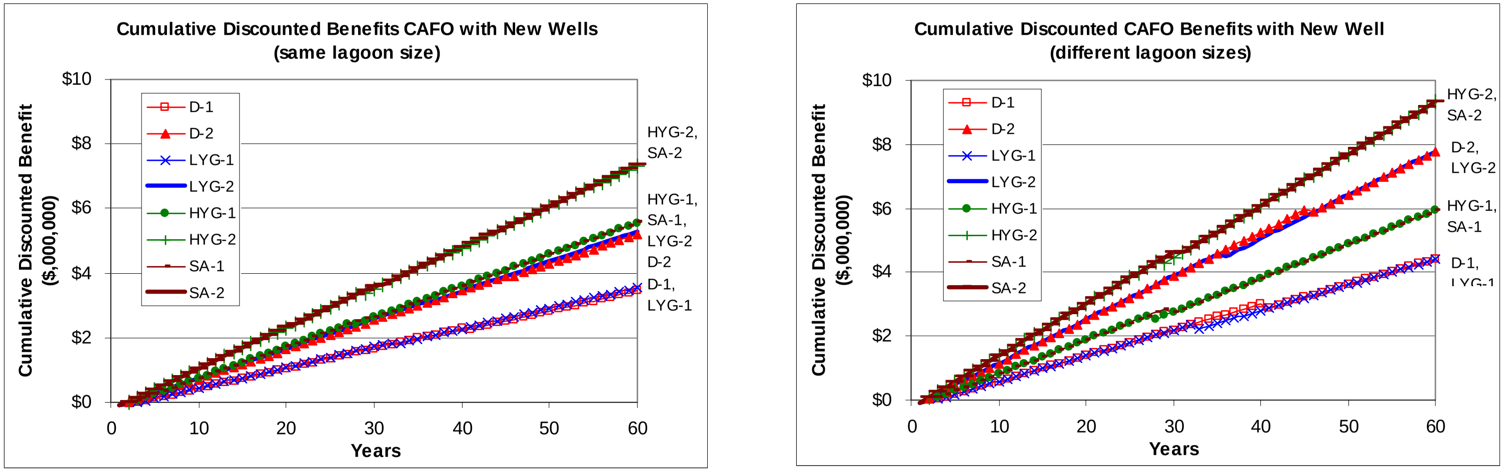

Figure V-8. Cumulative Discounted Benefits of a CAFO with New Wells: same lagoon size (left), smaller lagoon size for D-2, LYG-s, HYG-2, SA-2 (right)

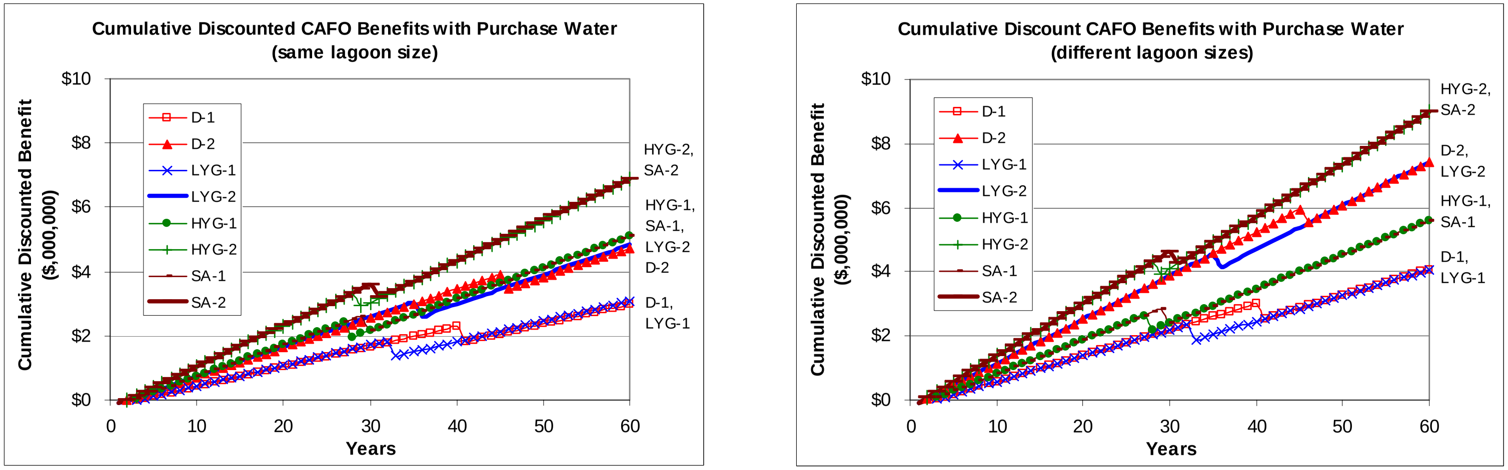

Figure V-9. Cumulative Discounted Benefits of a CAFO with Purchase Water from Hennessey: same lagoon size (left), smaller lagoon size for D-2, LYG-s, HYG-2, SA-2 (right)

A CAFO located inside a WHPA will increase nitrate at the PWS sooner than if it were located outside the delineated area. The illustrations for a CAFO located inside a protected area are shown in Figures V-10 and V-11.

Figure V-10 left graph shows the cumulative discounted benefit of a CAFO using the same lagoon size for all scenarios that is located inside a WHPA after incorporating new wells installation. Although the reduction in the benefit is not visible because it is small, it occurs at about 14 years. This drop is much earlier than if the CAFO were located outside the delineated area.

Figure V-10 right graph shows the cumulative discounted benefit of a CAFO located inside a WHPA using different lagoon sizes and after including the cost to drill new wells. The drop in the potential benefit is also not apparent, occurring after about 14 years.

Figure V-11 left graph shows the cumulative discounted benefit of a CAFO inside a WHPA utilizing the same lagoon size for all scenarios with the expenses to purchase water. The effect and the occurrence of the drop are more apparent. The right graph shows the cumulative discounted benefit of a CAFO inside a WHPA using different lagoon sizes with the expenses to purchase water. Again, similar trend can be seen where earlier drop take place.

Figure V-14 shows the cumulative discounted benefit of a CAFO using the same lagoon size for all scenarios that is located inside a WHPA after incorporating new wells installation. Although the decline in the benefit is not visible, the trend in general shows that the decline occurs after about 14 years. This drop is much earlier than if the CAFO were located outside the delineated area.

Figure V-10 right graph shows the cumulative discounted benefit of a CAFO located inside a WHPA using different lagoon sizes and after including the cost to drill new wells. The drop in the potential benefit is also not apparent, however, the overall trend is also the same, occurring after about 14 years.

Figure V-11 left graph shows the cumulative discounted benefit of a CAFO inside a WHPA utilizing the same lagoon size for all scenarios with the expenses to purchase water. The effect and the occurrence of the drop are more apparent. The right graph shows the cumulative discounted benefit of a CAFO inside a WHPA using different lagoon sizes with the expenses to purchase water. Again, similar trend can be seen where earlier plunges take place.

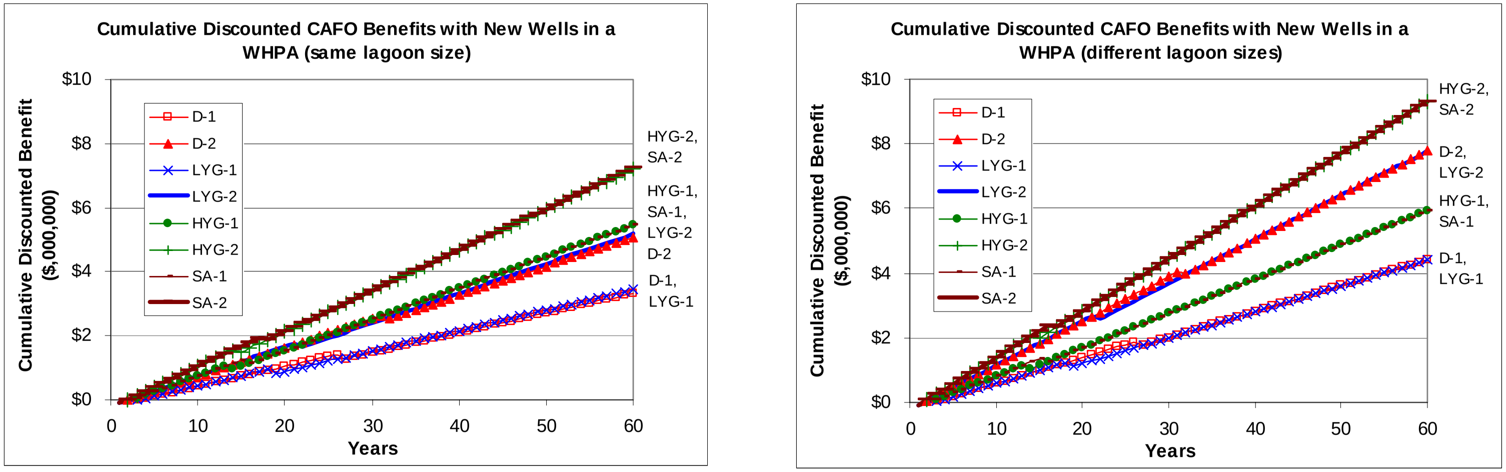

Figure V-10. Cumulative Discounted Benefits of a CAFO with New Wells in a WHPA: same lagoon size (left), smaller lagoon size for D-2, LYG-s, HYG-2, SA-2 (right)

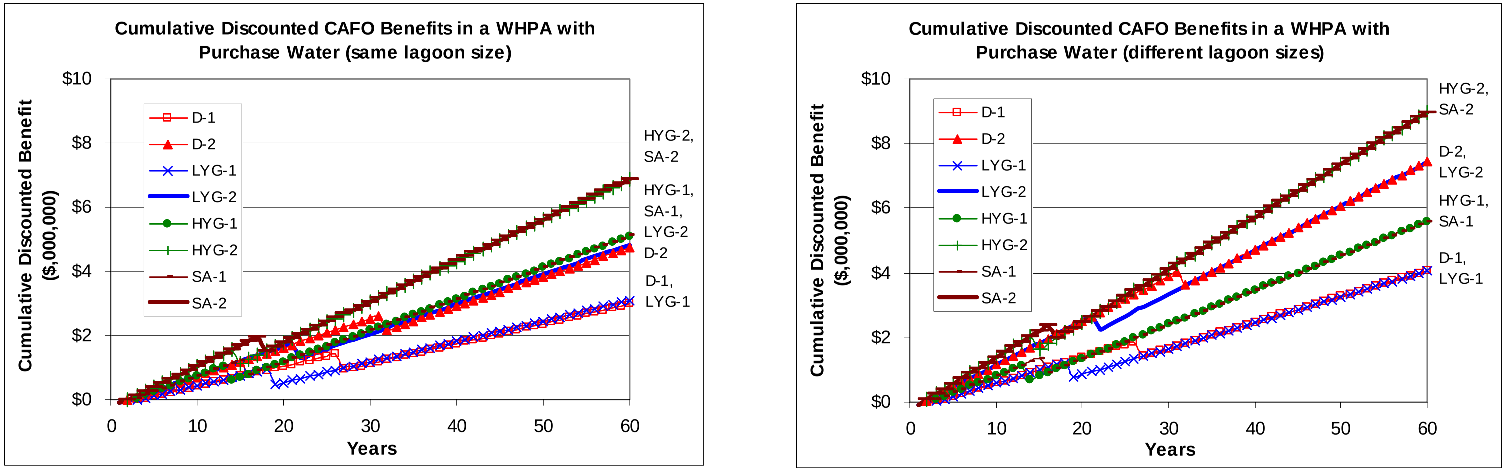

Figure V-11. Cumulative Discounted Benefits of a CAFO in a WHPA with Purchase Water: same lagoon size (left), smaller lagoon size for D-2, LYG-s, HYG-2, SA-2 (right)

To determine whether or not the potential net benefit of a CAFO outweighs the costs of waste management and externality, the annual net present benefit was calculated over 60 years. The results are shown in Table V-10.

Table V-10. Net Present Benefit of a CAFO

				Inside WHPA			Outside WHPA	
	Scenarios	**NPB CAFO**	**Yrs to MCL**	**NPB CAFO - New Well**	**NPB CAFO - Purchase H2O**	**Yrs to MCL**	**NPB CAFO - New Well**	**NPB CAFO - Purchase H2O**
Same Lagoon Size	D-1	$ 7,453,378	27.2	$ 7,202,557	$ 6,632,019	41.2	$ 7,381,019	$ 7,216,426
	D-2	$ 12,105,418	32.4	$ 11,941,026	$ 11,567,088	46.4	$ 12,062,484	$ 11,964,826
	LYG-1	$ 7,707,881	19.3	$ 7,226,809	$ 6,132,527	33.4	$ 7,557,131	$ 7,214,222
	LYG-2	$ 12,359,878	21.8	$ 11,982,062	$ 11,122,655	35.8	$ 12,244,282	$ 11,981,340
	HYG-1	$ 12,718,114	13.8	$ 12,001,985	$ 10,373,025	27.8	$ 12,487,336	$ 11,962,391
	HYG-2	$ 17,435,665	15.0	$ 16,774,046	$ 15,269,080	29.0	$ 17,223,446	$ 16,740,716
	SA-1	$ 12,762,429	15.6	$ 12,151,283	$ 10,761,127	29.6	$ 12,567,394	$ 12,123,752
	SA-2	**$ 17,479,980**	17.3	**$ 16,958,841**	**$ 15,773,420**	31.3	**$ 17,300,856**	**$ 16,893,407**
Different Lagoon Sizes	D-1	$ 7,453,378	27.2	$ 7,202,557	$ 6,632,019	41.2	$ 7,381,019	$ 7,216,426
	D-2	$ 16,409,208	32.4	$ 16,244,816	$ 15,870,879	46.4	$ 16,366,275	$ 16,268,616
	LYG-1	$ 7,707,881	19.3	$ 7,226,809	$ 6,132,527	33.4	$ 7,557,131	$ 7,214,222
	LYG-2	$ 16,663,668	21.8	$ 16,285,852	$ 15,426,445	35.8	$ 16,548,073	$ 16,285,130
	HYG-1	$ 12,718,114	13.8	$ 12,001,985	$ 10,373,025	27.8	$ 12,487,336	$ 11,962,391
	HYG-2	$ 21,739,456	15.0	$ 21,077,837	$ 19,572,871	29.0	$ 21,527,236	$ 21,044,506
	SA-1	$ 12,762,429	15.6	$ 12,151,283	$ 10,761,127	29.6	$ 12,567,394	$ 12,123,752
	SA-2	**$ 21,739,456**	17.3	**$ 21,175,044**	**$ 19,891,192**	31.3	**$ 21,560,331**	**$ 21,152,882**

From the table above it can be seen that the net present benefit (NPB) values are all positive, indicating that the benefit from a CAFO operation outweighs the cost of waste management and externality. This result suggests that the CAFO may be beneficial to the community. The potential benefit of a CAFO is highest under the HYG-2 and SA-2 scenarios (about $17 million) and least under the D-1 scenario (about $7 million). The value is higher for HYG-2 and SA-2 if smaller lagoon size is utilized (about $21 million). After externality is accounted for, the net present benefit for these scenarios are less, but they still present the highest net benefit. Under the new wells approach, the NPB for HYG-2 and SA-2 is about $180,000 less and is $1.5 million less under the purchase water approach. This is consistent with previous discussion signifying that high yield goal scenarios would be more beneficial to CAFO operators. High yield goal practices with least cost waste management approach (smaller lagoon size), propose a higher net present benefit ($ 21million after purchasing water) than if the practice utilizes a bigger lagoon without accounting externality ($17 million).

If the CAFO were located inside the wellhead protection area, the decline in the benefit would occur earlier, thus decreasing the net present benefit of the CAFO. As mentioned previously, the values of the net present benefit (NPB) under all scenarios are positive. This again indicates that CAFO located inside a wellhead protection area would still be beneficial to the community, though with a lower NPB. The NPB of scenarios HYG-2 and SA-2 after incorporating the expenses to purchase water are still the highest ($16 millions if the CAFO uses a bigger lagoon and about $20 millions if CAFO uses smaller lagoon). This high value represents the most preferred option for the CAFO. The least NPB is resulted if scenario D-1 were employed (about $7 million).

CAFOs that overlay a shallow aquifer would contaminate the aquifer at earlier time than if the aquifer were deeper. If the vertical distance from the CAFO to the ground water were 7m(23 ft) or 10 ft from the bottom of the waste lagoon, nitrate would reach the water table within 3 years. Consequently, PWS could also be contaminated in 3 years if the CAFO were located inside the WHPA and 17 years if the CAFO were outside the WHPA. Accordingly, incorporating the cost of externality to the operation decreases the NPB of the operation, shown in Table V-11.

Table V-11. Net Present Benefit of a CAFO Overlying a Shallow Aquifer (10 ft beneath waste lagoon)

			Inside WHPA			Outside WHPA		
	Scenarios	**NPB CAFO**	**Yrs to MCL**	**NPB CAFO - New Well**	**NPB CAFO - Purchase H2O**	**Yrs to MCL**	**NPB CAFO - New Well**	**NPB CAFO - Purchase H2O**
Same Lagoon Size	D-1	$ 7,453,378	27.2	$ 5,757,303	$ 1,899,287	41.2	$ 6,888,967	$ 5,605,115
	D-2	$ 12,105,418	32.4	$ 10,409,342	$ 6,551,326	46.4	$ 11,541,006	$ 10,257,154
	LYG-1	$ 7,707,881	19.3	$ 6,011,805	$ 2,153,790	33.4	$ 7,143,469	$ 5,859,618
	LYG-2	$ 12,359,878	21.8	$ 10,663,802	$ 6,805,786	35.8	$ 11,795,466	$ 10,511,614
	HYG-1	$ 12,718,114	13.8	$ 11,022,039	$ 7,164,023	27.8	$ 12,153,702	$ 10,869,851
	HYG-2	$ 17,435,665	15.0	$ 15,739,589	$ 11,881,574	29.0	$ 16,871,253	$ 15,587,402
	SA-1	$ 12,762,429	15.6	$ 11,066,354	$ 7,208,338	29.6	$ 12,198,018	$ 10,914,166
	SA-2	**$ 17,479,980**	17.3	**$ 15,783,905**	**$ 11,925,889**	31.3	**$ 16,915,569**	**$ 15,631,717**
Different Lagoon Sizes	D-1	$ 7,453,378	27.2	$ 5,757,303	$ 1,899,287	41.2	$ 6,888,967	$ 5,605,115
	D-2	$ 16,409,208	32.4	$ 14,713,132	$ 10,855,116	46.4	$ 15,844,796	$ 14,560,944
	LYG-1	$ 7,707,881	19.3	$ 6,011,805	$ 2,153,790	33.4	$ 7,143,469	$ 5,859,618
	LYG-2	$ 16,663,668	21.8	$ 14,967,592	$ 11,109,577	35.8	$ 16,099,256	$ 14,815,405
	HYG-1	$ 12,718,114	13.8	$ 11,022,039	$ 7,164,023	27.8	$ 12,153,702	$ 10,869,851
	HYG-2	$ 21,739,456	15.0	$ 20,043,380	$ 16,185,364	29.0	$ 21,175,044	$ 19,891,192
	SA-1	$ 12,762,429	15.6	$ 11,066,354	$ 7,208,338	29.6	$ 12,198,018	$ 10,914,166
	SA-2	**$ 21,739,456**	17.3	**$ 20,043,380**	**$ 16,185,364**	31.3	**$ 21,175,044**	**$ 19,891,192**

The table shows similar ranks of highest and lowest NPB as previous analysis, with lower NPB values.

Conclusions

1. The possible net annual benefit from a CAFO operation is highest under the HYG-2 and SA-2 scenarios ($127,303).
2. The possible annual net benefit from a CAFO operation is lowest under the D-1 scenario ($61,947).
3. The possible annual net benefit from a CAFO operation using the least cost of waste system (smaller lagoon size) presents a higher net annual benefit for HYG-2 and SA-2 scenarios ($152,680).
3. The values of the net present benefits of a CAFO under all scenarios are positive, indicating that CAFO operation is still beneficial to the community (profitable even after offsetting the cost of drinking water).

4. After incorporating the cost due to externality, scenarios HYG-2 and SA-2 still offer the highest net present benefit (about $17 million if new wells are installed and $16 million if water is purchased from Hennessey).
5. The net present benefit of HYG-2 and SA-2 is higher if these practices utilize a smaller lagoon size ($21 million).
6. The net present benefit of HYG-2 and SA-2 that incorporated purchasing water and utilized smaller lagoon size a is higher ($20 million) than if the practice utilized bigger lagoon size without any including the cost of externality ($17 million).
7. The values of net present benefit (NPB) after the cost of new wells installation are higher than the NPB after the cost of water purchase.
8. The NPB of CAFOs operating over a shallow aquifer is lower than that of deeper aquifer.
9. The net present benefit of CAFOs located inside a wellhead protection area is lower than if the CAFO were operated outside a wellhead protection area.

CHAPTER VI

EVALUATION OF IMPACT OF A CAFO IN A WELLHEAD PROTECTION AREA

A Wellhead Protection Program is designed to protect a ground water, drinking water source from contamination. The program requires public participation, but it may be difficult for the public to be proactive in communities where a Confined Animal Feeding Operations is found. This is due to the lack of information regarding the program, the importance to protect their source of drinking water, and the potential economic benefit from controlling NPS of pollution. In this chapter, information on the impact of waste management to the aquifer and its effect on the benefits from a CAFO are combined. The objective is to determine and recommend practice(s) that would combine both preservation of water quality and benefits to the producers. This policy recommendation was not discussed with decision makers with regard to their satisfaction with the recommendations.

The conclusion derived from simulation of nitrate leaching from a waste lagoon was not a significant threat to the aquifer. Nitrate leaching from the lagoon does not reach a water table at a depth of 70 ft during the 50 years of simulation. If the geologic setting were different or the distance to the aquifer were closer 10 ft below the bottom of the lagoon), then the additional nitrate leaching into the aquifer would have been significant as the contaminant would reach the water table in 20 years.

Nitrate leaching from effluent application to land, however, was found to be a more severe concern. Different scenarios were simulated to reflect the many options of waste management practices. The results show that nitrate leachate reached the aquifer well within the 60 years of simulation and increased the initial nitrate concentration in the aquifer. The concentration in the aquifer rises and reaches the MCL as early as 13 years under the HYG-1 scenario. In addition, locating the CAFO outside the WHPA is important as it allowed 14 years more before nitrate concentration at the PWS reached the MCL. This means that the further the distance from the CAFO to the public wells, the longer the period of time for the CAFO could operate and employ their current practices.

The most preferred practice would be scenario D-2, however, if the CAFO were located outside the delineated area, scenario HYG-1 could also be considered. On the contrary, if the CAFO were located inside the wellhead delineation area, the type of management employed would be critical. In this case, scenario D-2 would be the most preferred to preserve the quality of groundwater, followed by D-1. Nonetheless, under the Disposal scenarios, nitrate flux concentration to the ground water could be higher and MCL in the groundwater could be reached sooner than estimated. This is due to the lack of supplemental irrigation water to support the growth of Bermudagrass causing less coverage, less nutrient uptake, and hence, producing more nitrate leaching. CAFOs that employ management practice HYG-1, however, need to consider other practices to preserve the quality of ground water. The option would be to apply the effluent over a larger land area to allow a longer time period before the background nitrate concentration in the aquifer is affected. Therefore, LYG-2 would be the most preferred scenario, followed by LYG-1.

Overall, the most preferred management practice with regard to preserving water quality would not only be practice under scenario D-2, but D-2 employed by CAFO located outside a wellhead protection area. This practice is not only beneficial to the environment, but it also allows more time for producers to keep their operation active at the current location. The least favorable practice from a water quality aspect is to have management under the HYG-2 scenario in a wellhead protection area. If this management were employed, the public well could be contaminated within 13 years, and the PWS would be required to look for alternatives to replace their water source. Furthermore, a CAFO may need to look for another location to apply effluent, causing economically inefficiency for both the private and public sectors.

The best option for protecting ground water quality may not be the most preferred management for the CAFO producers. The results from previous discussion suggest that the benefit of a CAFO is higher when the cost of waste management is least. This situation is also related to the higher amount of revenue from Bermudagrass that compensates partial expenses for waste management. Based on these factors, the most beneficial scenario would be HYG-2 and SA-2. Furthermore, operations using a smaller size of lagoon would present an even higher net benefit.

In further analysis, the costs of externalities from CAFO waste management were incorporated. Alternatives considered were installing new wells and purchasing water from the City of Hennessey. Of the two alternatives, installing new wells is preferred over purchasing water because the cost to purchase water is higher. This suggestion is based on the assumption that future location would provide sufficient water of good quality. Even after including the costs of externalities to the costs of waste management, scenarios HYG-2 and SA-2 would still be the most preferred scenarios. Likewise with previous results, operations practicing scenarios HYG-2 and SA-2 with a smaller size of lagoon would offer a higher benefit to those operations using a larger size of lagoons. In addition, the benefit of a CAFO located outside a wellhead protection area would be higher than if a CAFO were located inside the delineated area.

The cumulative benefits for waste management using the same size of lagoon propose the same benefit under scenarios D-2, LYG-2, SA-1 AND HYG-1. However, when the net present benefit is calculated, the D-2 and LYG-2 have a higher value. This is due to the delayed effect of nitrate on the public wells.

The results from nitrate leaching simulations and its effect on the benefit of CAFO operation is shown in Table VI-1. From the table it can be seen that scenario D-2 may be the preferred practice to sustain the quality of groundwater, but may not be the most beneficial to the producers. In addition, the MCL may be reached earlier, due to the possible higher nitrate leachate from less coverage. This description also applies to both the new well and purchase water schemes for scenarios D-2. Using different sizes of lagoon proposes a higher net present benefit. Again, this is because of the lower cost associated with the lagoon costs. On the contrary, scenarios HYG-2 and SA-2 are most favored by producers, based on the highest net present benefit.

Table VI-1. Nitrate Leaching and Its Impact to the Net Present Benefit of CAFO Operation

PARAMETERS	UNITS	SCENARIOS							
		Disposal		Low Yield Goal		High Yield Goal		Split Application	
		D-1	**D-2**	**LYG-1**	**LYG-2**	**HYG-1**	**HYG-2**	**SA-1**	**SA-2**
Concentration	mg/L	300	600	300	600	300	600	300	600
	lbs/ac-in	68	136	68	136	68	136	68	136
Land Area	ac	250	250	250	250	125	125	125	125
	m2	1,018,500	1,018,500	1,018,500	1,018,500	509,250	509,250	509,250	509,250
Total Depth	in	2.5	1.25	2.5	1.25	5	2.5	5	2.5
	mm	62.5	31.3	62.5	31.3	125	62.5	125	62.5
Application Depth	in	1.25	0.63	1.25	0.63	2.5	1.25	1.25	0.63
	mm	31.25	15.63	31.25	15.63	62.5	31.25	31.25	15.63
Number Apply		2	2	2	2	2	2	4	4
Yield Goal	tons/ac	3	3	3	3	6	6	6	6
IN SOIL PROFILE									
NO3-N to Water Table	yrs	18.5	21.2	10.2	12.3	7.6	8.2	8.2	8.6
NO3-N to MCL	yrs	26	31	15	18.2	11.2	13.6	13.6	14.6
Max C(in)	mg/L	23.6	24.8	17.6	15.2	36.2	35.2	28.6	28
NO3-N to Max C(in)	yrs	40	45	20	22	15	20	20	25
IN AQUIFER									
NO3-N increase (lag)	yrs	20.8	22	12.3	14	9.83	11.5	11.8	12.6
Max C(t) at year 60	mg/L	19.8	20.3	16.1	15.1	27.7	26.2	22.5	22
NO3-N to MCL									
Inside WHPA	yrs	27.2	32.4	19.3	21.9	13.3	15	15.6	17.3
NPB	$	$ 7,453,378	$ 12,105,418	$ 7,707,881	$ 12,359,878	$ 12,718,114	$ 17,435,665	$ 12,762,429	**$ 17,479,980**
NPB - NewWells									
Same lagoon size	$	$ 5,757,303	$ 10,409,342	$ 6,011,805	$ 10,663,802	$ 11,022,039	$ 15,739,589	$ 11,066,354	**$ 15,783,905**
Different lagoon sizes	$	$ 5,757,303	$ 14,713,132	$ 6,011,805	$ 14,967,592	$ 11,022,039	$ 20,043,380	$ 11,066,354	**$ 20,043,380**
NPB - Purchase Water									
Same lagoon size	$	$ 1,899,287	$ 6,551,326	$ 2,153,790	$ 6,805,786	$ 7,164,023	$ 11,881,574	$ 7,208,338	**$ 11,925,889**
Different lagoon sizes	$	$ 1,899,287	$ 10,855,116	$ 2,153,790	$ 11,109,577	$ 7,164,023	$ 16,185,364	$ 7,208,338	**$ 16,185,364**
Outside WHPA	yrs	41.2	46.4	33.4	35.9	27.3	29	29.6	31.3
NPB - NewWells									
Same lagoon size	$	$ 6,888,967	$ 11,541,006	$ 7,143,469	$ 11,795,466	$ 12,153,702	$ 16,871,253	$ 12,198,018	**$ 16,915,569**
Different lagoon sizes	$	$ 6,888,967	$ 15,844,796	$ 7,143,469	$ 16,099,256	$ 12,153,702	$ 21,175,044	$ 12,198,018	**$ 21,175,044**
NPB - Purchase Water									
Same lagoon size	$	$ 5,605,115	$ 10,257,154	$ 5,859,618	$ 10,511,614	$ 10,869,851	$ 15,587,402	$ 10,914,166	**$ 15,631,717**
Different lagoon sizes	$	$ 5,605,115	$ 14,560,944	$ 5,859,618	$ 14,815,405	$ 10,869,851	$ 19,891,192	$ 10,914,166	**$ 19,891,192**

Therefore, to preserve the quality of ground water for public benefit and reduced cost for the producer, scenario LYG-2 is the most preferred. This practice will allow producer to employ their current waste management system longer and help control costs. This option also applies to producers either using the same lagoon size or different lagoon sizes.

Conclusions

1. Leaching from lagoon during the 60 years of simulation is insignificant due to the 70 ft distance from the bottom of a lagoon to the aquifer. If the distance to the aquifer were 23 feet (10 ft beneath the waste lagoon as allowed by Oklahoma regulations), the effect of nitrate on the aquifer would be a concern.
2. Waste management using the disposal scenarios (D-1 and D-2) are preferred for delaying water quality effects. This scenario utilizes effluent with higher initial concentration applied over larger land acreage without additional irrigation, reducing the mobilization of nitrate.
3. Of the scenarios examined, the Disposal scenario with higher initial effluent concentration (D-2) generates nitrate leachate that reaches the aquifer last.
4. HYG-1 is the least favored practice, as it affects the public wells earliest.
5. Producers would prefer waste management practices under the HYG-2 or SA-2 scenarios, due to the higher net revenue from Bermudagrass, offsetting the cost of waste management.
6. The least cost of waste management option would be to use a smaller size of lagoon for scenarios D-2, LYG-2, HYG-2, and SA-2. These scenarios do not require larger lagoons, due to the recirculation of water from the lagoon. Under this option, scenarios HYG-2 and SA-2 propose an even lower cost of waste management.
7. To compromise between preservation of groundwater and benefits, scenario LYG-2 is most favored.
8. Based on a 60-year analysis, a CAFO located inside a wellhead protection area was only marginally beneficial than replacing the public well systems for the community.

However, it would not be beneficial if the price of pigs decline from 37 to 32 cents per pound.

9. The NPB is subject to change if the discounted benefit is assessed over a different time period.
10. A CAFO located inside a wellhead protection area may not be beneficial to the community if the price of pigs decreases.

Recommendations for further Research

These analyses are site specific depending on the parameters used. If a different parameter were used, it would present a different outcome. The scenarios used in this framework were simulated for 60 years to determine the maximum nitrate flux concentration produced. Further studies can be conducted to determine the impact to the aquifer under different parameters, such as:

1. simulations of nitrate leaching using different geologic parameters and practices to determine the effect to the aquifer,
2. sensitivity analysis of the net present benefit of CAFO based on the cost of pigs, and
3. evaluation of direct CAFO benefit to the community.

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APPENDICES

Appendix A. Public Well Systems Locations in Kingfisher County

(Obtained from Personal Contact from Oklahoma Department of Environmental Quality, 1999)

NUMBER	TIN WSYS_NAME	TINWSF_NAME	Long	Lat
OK2003701	LOYAL	WELL 1	-98.1074	36.2080
OK2003701	LOYAL	WELL 1	-98.1074	36.2080
OK2003703	OKARCHE	WELL 1	-98.1754	36.2373
OK2003703	OKARCHE	WELL 1	-98.1754	36.2373
OK2003703	OKARCHE	WELL 2	-97.1774	36.2380
OK2003703	OKARCHE	WELL 2	-97.1774	36.2380
OK2003703	OKARCHE	WELL 3	-98.1795	36.2375
OK2003703	OKARCHE	WELL 3	-98.1795	36.2375
OK2003704	HENNESSEY	WELL 1	-97.8985	36.3055
OK2003704	HENNESSEY	WELL 1	-97.8985	36.3055
OK2003704	HENNESSEY	WELL 2	-97.8985	36.2251
OK2003704	HENNESSEY	WELL 2	-97.8985	36.2251
OK2003704	HENNESSEY	WELL 3	-97.8986	36.1393
OK2003704	HENNESSEY	WELL 3	-97.8986	36.1393
OK2003704	HENNESSEY	WELL 4	-97.8900	36.9810
OK2003704	HENNESSEY	WELL 4	-97.8900	36.9810
OK2003704	HENNESSEY	WELL 5	-97.8900	36.8964
OK2003704	HENNESSEY	WELL 5	-97.8900	36.8964
OK2003704	HENNESSEY	WELL 6	-97.8900	36.8128
OK2003704	HENNESSEY	WELL 6	-97.8900	36.8128
OK2003704	HENNESSEY	WELL 7	-97.8846	36.8011
OK2003704	HENNESSEY	WELL 7	-97.8846	36.8011
OK2003704	HENNESSEY	WELL 8	-97.8806	36.8006
OK2003704	HENNESSEY	WELL 8	-97.8806	36.8006
OK2003705	DOVER PUBLIC WORKS TRUST AUTH	WELL 1	-97.9253	36.5668
OK2003705	DOVER PUBLIC WORKS TRUST AUTH	WELL 1	-97.9253	36.5668
OK2003705	DOVER PUBLIC WORKS TRUST AUTH	WELL 2	-97.9124	36.8941
OK2003705	DOVER PUBLIC WORKS TRUST AUTH	WELL 2	-97.9124	36.8941
OK2003705	DOVER PUBLIC WORKS TRUST AUTH	S WELL 1	-97.9120	36.8092
OK2003705	DOVER PUBLIC WORKS TRUST AUTH	S WELL 1	-97.9120	36.8092
OK2003713	TURNER & SONS	WELL 1	-97.7583	36.6033
OK2003713	TURNER & SONS	WELL 1	-97.7583	36.6033
OK2003713	TURNER & SONS	WELL 1	-97.7583	36.6033
OK2003715	OKARCHE RWD	WELL 1	-98.1540	36.3424
OK2003715	OKARCHE RWD	WELL 1	-98.1540	36.3424
OK2003717	LACY STORE	WELL 1	-97.0866	35.1250
OK2003717	LACY STORE	WELL 1	-97.0866	35.1250
OK2003717	LACY STORE	WELL 1	-97.0866	35.1250
OK2003718	WITTROCK TRAILER PARK	WELL 1	-97.9299	36.6649
OK2003718	WITTROCK TRAILER PARK	WELL 1	-97.9299	36.6649
OK2003718	WITTROCK TRAILER PARK	WELL 2	-97.9312	36.6631
OK2003718	WITTROCK TRAILER PARK	WELL 2	-97.9312	36.6631
OK2003721	GPM GAS CORP KINGFISHER	WELL 1	-95.5209	37.3490
OK2003721	GPM GAS CORP KINGFISHER	WELL 1	-95.5209	37.3490
OK2003721	GPM GAS CORP KINGFISHER	WELL 1	-95.5209	37.3490

Appendix B. Swine Facilities Locations in Kingfisher County

(Obtained from Personal Contact from Oklahoma Department of Environmental Quality, 1999)

DESCRIPTION	CAFO 1	CAFO 2	CAFO 3	CAFO 4	CAFO 5	CAFO 6	CAFO 7	CAFO 8	CAFO 9	CAFO 10
LEGALAREA1		SE			NW	NE	SE	NW	NW	NE
LEGALAREA2										
LEGALAREA3										
LEGALAREA4										
LEGALAREA5										
LEGALAREA6										
SECTIONNO	3	12	11	5	18	21	27	2	17	19
TOWNNO	19	19	18	19	19	19	19	18	18	18
TOWNDIR	N	N	N	N	N	N	N	N	N	N
RANGENO	8	9	8	9	8	8	8	8	7	7
RANGEDIR	W	W	W	W	W	W	W	W	W	W
MER	I	I	I	I	I	I	I	I	I	I
COUNTYNAME	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER	KINGFISHER
EPANO	0213									
NUMPARCELS	1	1	1	1	1	1	1	1	1	1
LOCATIONID	AGN025467	AGN027059	AGN031456	WQ0000182	AGN031454	AGN031453	AGN027060	AGN031451	AGN031611	WQ0000090
OWNZIP2										
TYPE	S	S	S	S	S	S	S	S	S	S
SWGT55UNIT	4878.000000	1436.000000	8320.000000	4223.000000	1436.000000	0.000000	2080.000000	2080.000000	2080.000000	2080.000000
WATRSHD_	255	255	255	228	255	255	255	255	275	275
WATRSHD_ID	254	254	254	227	254	254	254	254	274	274
HUC11	11050002050	11050002050	11050002050	11050002040	11050002050	11050002050	11050002050	11050002050	11050002120	11050002120
HUC8	11050002	11050002	11050002	11050002	11050002	11050002	11050002	11050002	11050002	11050002
WSCODE	050	050	050	040	050	050	050	050	120	120

Appendix C. Parameters for WHPA Code

WHPA Version 3.0 RESSQC Module

Run Title:	Kingfisher-Dove	Hennessey	Okeene
Units to use for current problem: (0 = meters and days, 1 = feet and days)	1	1	1
Minimum X-coordinate:			
Maximum X-coordinate:	17500	15840	10512
Minimum Y-coordinate:			
Maximum Y-coordinate:	14500	15840	10583
Perform hydraulic head calculation: (1 = yes, 0 = no)	0	0	0
Maximum spatial length step:	100	100	50
Number of pumping wells in study area:	18	3	2
Number of recharge wells in study area:	0	0	0
Delineate capture zones for pumping wells (1): Contaminant fronts for injection wells (2):	1	1	1
Trasnmissivity (ft**2/d):	1187.5	1200	1140
Aquifer thickness (ft):	25	20	20
Aquifer porosity (dimensionless):	0.3	0.25	0.3
Hydraulic gradient (dimensionless):	0.0027	0.0027	0.001
Angle of ambient flow (degrees):	315	270	135
PUMPING WELL PARAMETERS			
PUMPING WELL 1			
X-coordinate (ft):	3200	8058	5327
Y-coordinate (ft):	10900	8277	3818
Pumping rate (ft**3/d):	15408	17050	12800
Well radius (ft):	0.5	0.5	0.5
Number of pathlines:	20	20	20
Pathline plotting interval:	1	1	1
Time limit for simulation (days):	3650	3650	3650
PUMPING WELL 2			
X-coordinate (ft):	3750	10477	5295
Y-coordinate (ft):	10500	6443	3401
Pumping rate (ft**3/d):	34704	17050	12800
Well radius (ft):	0.5	0.5	0.5
Number of pathlines:	20	20	20
Pathline plotting interval:	1	1	1

Run Title:	Kingfisher-Dove	Hennessey	Okeene
PUMPING WELL 3			
X-coordinate (ft):	3995	13207	-
Y-coordinate (ft):	9995	5368	-
Pumping rate (ft**3/d):	34704	17050	-
Well radius (ft):	0.5	0.5	-
Number of pathlines:	20	20	-
Pathline plotting interval:	1	1	-
PUMPING WELL 4			
X-coordinate (ft):	3985	-	-
Y-coordinate (ft):	9250	-	-
Pumping rate (ft**3/d):	34704	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 5			
X-coordinate (ft):	3800	-	-
Y-coordinate (ft):	8500	-	-
Pumping rate (ft**3/d):	26928	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 6			
X-coordinate (ft):	3350	-	-
Y-coordinate (ft):	8250	-	-
Pumping rate (ft**3/d):	26928	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 7			
X-coordinate (ft):	6200	-	-
Y-coordinate (ft):	7850	-	-
Pumping rate (ft**3/d):	34704	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 8			
X-coordinate (ft):	6900	-	-
Y-coordinate (ft):	8850	-	-
Pumping rate (ft**3/d):	34704	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-

Run Title:	Kingfisher-Dove	Hennessey	Okeene
PUMPING WELL 9			
X-coordinate (ft):	7000	-	-
Y-coordinate (ft):	7250	-	-
Pumping rate (ft**3/d):	26928	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 10			
X-coordinate (ft):	7800	-	-
Y-coordinate (ft):	6000	-	-
Pumping rate (ft**3/d):	34704	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 11			
X-coordinate (ft):	9450	-	-
Y-coordinate (ft):	5750	-	-
Pumping rate (ft**3/d):	15408	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 12			
X-coordinate (ft):	12600	-	-
Y-coordinate (ft):	4300	-	-
Pumping rate (ft**3/d):	34704	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 13			
X-coordinate (ft):	12600	-	-
Y-coordinate (ft):	3950	-	-
Pumping rate (ft**3/d):	34704	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 14			
X-coordinate (ft):	13500	-	-
Y-coordinate (ft):	1750	-	-
Pumping rate (ft**3/d):	38448	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-

Run Title:	Kingfisher-Dove	Hennessey	Okeene
PUMPING WELL 15			
X-coordinate (ft):	13600	-	-
Y-coordinate (ft):	1950	-	-
Pumping rate (ft**3/d):	38448	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 16			
X-coordinate (ft):	16500	-	-
Y-coordinate (ft):	1490	-	-
Pumping rate (ft**3/d):	38448	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 17			
X-coordinate (ft):	13350	-	-
Y-coordinate (ft):	1100	-	-
Pumping rate (ft**3/d):	38448	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
PUMPING WELL 18			
X-coordinate (ft):	13500	-	-
Y-coordinate (ft):	1100	-	-
Pumping rate (ft**3/d):	38448	-	-
Well radius (ft):	0.5	-	-
Number of pathlines:	20	-	-
Pathline plotting interval:	1	-	-
TEMPORAL PARAMETERS			
Time limit for simulation (days):	3650	3650	3650
Number of capture zones with different time values:	2	2	2
Capture zone times:			
Time value #1:	365	365	365
Time value #2:	3650	3650	3650
COORDINATES OF STARTING PARTICLE LOCATIONS			
Number of reverse pathlines:	0	0	0

Appendix D. Monthly Precipitation and Evapotranspiration Calculations

Year	Month	P monthly (in)	Q (monthly) (in)	Flux (in)	Temp (F)	pan coefficient	PET (in) = u = k.f	AET (in)= PET*w
1990	Jan	1.71	0.0188975	1.6911	44.58	6.98	0.6972	0.5318
1990	Feb	4.48	0.2163723	4.26363	44.54	6.85	0.7938	0.7614
1990	Mar	5.94	0.9109078	5.02909	51.52	8.35	1.8126	1.8028
1990	Apr	3.99	0.1508349	3.83917	59.50	8.85	3.2018	2.9993
1990	May	5.66	0.5020983	5.1579	67.61	9.8	5.1030	5.1030
1990	Jun	0.8	0	0.8	82.37	9.82	8.2669	5.0227
1990	Jul	2.08	0.026281	2.05372	80.58	9.99	7.9988	6.4285
1990	Aug	1.29	0	1.29	82.06	9.41	7.7702	5.4861
1990	Sept	2.58	0.0202843	2.55972	76.87	8.36	5.6790	4.8291
1990	Oct	0.81	0	0.81	61.03	7.85	2.8079	1.7131
1990	Nov	1.71	0.0162614	1.69374	54.23	6.93	1.5719	1.1994
1990	Dec	0.53	0	0.53	35.55	6.81	0.4008	0.2104
Total		31.58	1.8619375		740.44		46.1037	36.0874
Average		2.631667	0.1551615		61.70		3.8420	3.0073
1991	Jan	0.61	0	0.61	33.35	6.98	0.3001	0.1623
1991	Feb	0.1	0	0.1	48.21	6.85	0.9791	0.2204
1991	Mar	1.33	0	1.33	54.45	8.35	2.0844	1.4591
1991	Apr	1.76	0.0138109	1.74619	62.83	8.85	3.6538	2.7656
1991	May	5.18	0.4693607	4.71064	72.48	9.8	6.0093	5.8156
1991	Jun	3.16	0.2640069	2.89599	78.83	9.82	7.4769	6.4594
1991	Jul	3.09	0.0977299	2.99227	82.68	9.99	8.4826	7.3872
1991	Aug	2.42	0.0663878	2.35361	81.23	9.41	7.5898	6.2229
1991	Sept	5.71	0.2350504	5.47495	71.03	8.36	4.7266	4.7266
1991	Oct	2.56	0.0987673	2.46123	62.97	7.85	3.0277	2.5111
1991	Nov	2.35	0	2.35	43.90	6.93	0.9080	0.7442
1991	Dec	4.34	0.3057723	4.03423	42.55	6.81	0.6727	0.6287
Total		32.61					45.9110	39.1031
Average		2.7175					3.8259	3.2586

Year	Month	P monthly (in)	Q (monthly) (in)	Flux (in)	Temp (F)	pan coefficient	PET (in) = u = k.f	AET (in)= PET*w
1992	Jan	0.69	0	0.69	42.06	6.98	0.5952	0.2722
1992	Feb	0.65	0	0.65	48.93	6.85	1.0174	0.4537
1992	Mar	1.76	0.0175564	1.74244	53.87	8.35	2.0292	1.3019
1992	Apr	5.38	0.6048297	4.77517	60.63	8.85	3.3522	2.8588
1992	May	2.92	0	2.92	66.03	9.8	4.8244	3.6129
1992	Jun	9.83	0.3176343	9.51237	73.97	9.82	6.4527	6.4527
1992	Jul	3.34	0.1201756	3.21982	81.13	9.99	8.1240	6.2509
1992	Aug	4.41	0.0795701	4.33043	75.35	9.41	6.3859	5.3133
1992	Sept	0.86	0	0.86	73.40	8.36	5.1027	2.5503
1992	Oct	2.01	0.1936314	1.81637	62.32	7.85	2.9535	1.9202
1992	Nov	6.73	0.7351257	5.99487	46.53	6.93	1.0609	0.9561
1992	Dec	2.66	0.0712668	2.58873	40.23	6.81	0.5754	0.4164
Total		41.24	2.1397899				42.4735	32.3595
Average		3.436667	0.1783158				3.5395	2.6966
1993	Jan	2.15	0.00115	2.14885	42.06	6.98	0.5952	0.4071
1993	Feb	1.82	0.065	1.755	48.93	6.85	1.0174	0.6618
1993	Mar	1.93	0.06225	1.86775	53.87	8.35	2.0292	1.3447
1993	Apr	3.95	0.1316667	3.81833	60.63	8.85	3.3522	2.6891
1993	May	9.87	2.6799407	7.19006	66.77	9.8	4.9542	4.9542
1993	Jun	4.72	0.5608221	4.15918	77.50	9.82	7.1890	6.3475
1993	Jul	1.61	0	1.61	84.61	9.99	8.9416	6.1076
1993	Aug	1.12	0	1.12	83.52	9.41	8.0872	4.9206
1993	Sept	5.37	0.260168	5.10983	70.07	8.36	4.5771	4.2423
1993	Oct	0.62	0	0.62	58.03	7.85	2.4831	1.2182
1993	Nov	2.18	0.0403612	2.13964	45.07	6.93	0.9744	0.7234
1993	Dec	1.73	0.0003918	1.72961	42.39	6.81	0.6657	0.4646
Total		37.07	3.8017505				44.8661	34.08098
Average		3.089167	0.3168125				3.7388	2.840082
1994	Jan	0.14	0	0.14	35.48	6.98	0.3639	0.0848
1994	Feb	0.67	0	0.67	37.39	6.85	0.4860	0.2451
1994	Mar	3.15	0.1020207	3.04798	52.48	8.35	1.9002	1.5493
1994	Apr	9.69	2.4443576	7.24564	59.77	8.85	3.2369	3.2369
1994	May	4.63	0.3997598	4.23024	68.29	9.8	5.2247	4.6234
1994	Jun	1.04	0	1.04	81.00	9.82	7.9567	4.7090
1994	Jul	1.7	0.0423104	1.65769	81.52	9.99	8.2129	5.6465
1994	Aug	3.31	0.269134	3.04087	81.71	9.41	7.6936	6.2689
1994	Sept	2.03	0.0570843	1.97292	71.67	8.36	4.8259	3.4929
1994	Oct	1.69	0	1.69	62.65	7.85	2.9905	2.0680
1994	Nov	6.32	2.4442783	3.87572	50.40	6.93	1.3056	1.1310
1994	Dec	0.37	0	0.37	41.58	6.81	0.6313	0.2475
Total		34.74	5.7589453				44.8282	33.3032
Average		2.895	0.4799121				3.7357	2.7753

VITA

Maifan R. Silitonga

Candidate for the Degree of

Doctor of Philosophy

Thesis: FRAMEWORK FOR EVALUATING IMPACT OF A CONFINED ANIMAL FEEDING OPERATION INSIDE A WELLHEAD PROTECTION AREA

Major Field: Environmental Science

Biographical:

Personal Data: Born in Bogor, West Java, Indonesia, On June 10, 1969, the daughter of Toga and Sorta Silitonga.

Education: Bachelor of Science in Biology, graduated from Universitas Nasional, Jakarta, Indonesia in October, 1994. Master of Science in Environmental Science, graduated from Oklahoma State University in December, 1998. Completed the requirements for the Doctor of Philosophy degree at Oklahoma State University in (May, 2004).

Experience: Employed as an administrative assistant by Societe Generale de Surveillance Regional Representative Office. Employed by Oklahoma State University, Department of Biosystems and Agricultural Engineering as a graduate research assistant to Dr. Mike D. Smolen, from January 1998 to 2003.

Professional memberships: American Society of Agricultural Engineers, Society of Environmental Scientists at Oklahoma State University, Oklahoma National Academy of Science, American Water Resource Association, Groundwater Foundation, and Oklahoma Clean Lakes and Watershed Association.

Name: Maifan R. Silitonga Date of Degree: May, 2004

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: FRAMEWORK FOR EVALUATING IMPACT OF A CONFINED ANIMAL FEEDING OPERATION INSIDE A WELLHEAD PROTECTION AREA

Pages in Study: 160 Candidate for the Degree of Doctor of Philosophy

Major Field: Environmental Science

Scope and Method of Study: The purpose of the study is to develop a means of assessing the risk of nitrate contamination of a public well from a CAFO operation inside or near a wellhead protection area. The study focuses on the effect of nitrate contamination of groundwater from the waste lagoon and effluent application to cropland. The waste lagoon liner was 0.5 m thick with K of 10-^{9} m/s; depth 3 m; 27 m of loamy sand between the lagoon and the aquifer. Application scenarios were: Disposal (D), Low Crop Yield Goal (LYG), High Crop Yield Goal (HYG), and Split Application (SA). Each scenario was examined at two concentrations (300 and 600 mg/L), applied twice annually. Soil profile consisted of sandy clay loam (2 m) and loamy sand (28.5 m). Scenario D had no supplemental irrigation water; LYG and HYG had supplemental irrigation to meet crop needs; HYG used one-half the land area of LYG to achieve a higher nutrient application rate; SA was the same as HYG with two additional applications per year. Economic impact and cost were assessed considering crop yield and two alternatives for water replacement. Water replacement costs were accrued at the time $NO3^-$-N in the public well reaches the MCL of 10 mg/L at the PWS.

Findings and Conclusions: Nitrate plume from the lagoon reached a depth of 7 m in 50 years, well short of the aquifer. The aquifer, with an initial $NO3^-$-N concentration of 6 mg/L, reached the MCL latest (32.4 yr) under the D scenario at 600mg/L and earliest under the HYG scenario at 300mg/L. A CAFO located 0.8 km (0.5 miles) outside a wellhead protection area would affect the PWS 14 years later than one inside the wellhead protection area. Scenarios with lower effluent concentration (300mg/L) reached the aquifer earlier than effluent of higher concentration (600mg/L). In the long term, low yield crop production produced lower NO_3 final concentration in the aquifer. Split application of effluent reduced nitrate flux concentration. Scenario HYG had a higher Net Present Benefit (NPB) than scenario D, because Bermudagrass production offsets some of the cost of waste management. In the event the $NO3^-$-N concentration at the PWS reaches the MCL, replacement by drilling new wells would be cheaper than purchasing water from a nearby city.

ADVISER’S APPROVAL: Dr. Michael D. Smolen