Executive Summary

Proper management of animal manure from agricultural operations is critical to the health of our communities' lakes, rivers, and streams. Runoff from these facilities can carry high levels of nutrients and other pollutants to our waterways, leading to reduced water quality and contributing to human health problems. According to the United States Department of Agriculture, farms and large industrial-style confinement operations currently generate over 500 million tons of manure per year, and most manage or dispose of manure by applying it as fertilizer to row crop, pasture, and other fields. Land application of manure has many benefits, for both farmer and field, but inappropriate applications have created dangerously excessive levels of phosphorus in our soils, high levels of nitrogen in groundwater, streams, lakes, and rivers, and hazardous surges of pathogens to neighboring waterways and wells.

Recently, government and private industry have invested considerable resources into developing alternative manure treatment technologies with the goal of reducing potential pollution stemming from the storage and application of manure. The long-term water quality benefits from these treatment technologies have yet to be evaluated although some companies and organizations assert great environmental improvements. It is important for concerned citizens, community activists, farmers, and local leaders to have accurate information about how and when alternative manure treatment technologies work and their advantages and disadvantages.

This document is intended to provide a detailed introduction to a number of alternative animal manure treatment technologies for swine, dairy, and beef operations, explaining the technical aspects of these manure management practices in lay terms. However, this report does not delve into the other aspects of manure management such as the preparation of nutrient management plans and compliance with environmental laws such as the Clean Water Act and the Resource Conservation Recovery Act. As such, each technology must be independently evaluated within the broader context and objectives necessary to ensure proper use and management of manure.

The technologies discussed in this report are alternative in the sense that they do something more than the traditional application of untreated manure to land, but are similar to technologies used at municipal wastewater treatment facilities. The technologies are summarized briefly below:

Storage covers are not a manure treatment technology *per se*, but provide a barrier between stored manure and the environment. Covers may prevent precipitation-induced overflows and cross-contamination between manure and the environment.

Solids separation is a pre-treatment step that divides the liquid and solid portions of manure. Solids separation makes storage of the solids easier and safer by reducing the potential for pollutants to contaminate groundwater. Separation may allow the use of further treatments that would otherwise be incompatible with the raw manure.

Aerobic digestion uses bacteria to break down manure in an oxygen-rich environment. Aerobic digestion can reduce nutrients, pathogens, and can prepare the manure for other treatment processes, including land application.

Anaerobic digestion uses bacteria to break down manure in an oxygen-free environment. Anaerobic digestion reduces pathogens and manure gases while making the manure more stable for storage and further treatment, but it does not reduce the nutrient content.

Nitrification-denitrification uses different populations of bacteria to convert ammonia, a potential air and water pollutant, to dinitrogen (N_2) gas which can be harmlessly released to the atmosphere.

Constructed wetlands make use of microorganisms and plants to break down dilute manure, absorb nutrients, settle solids, and kill pathogens.

Black soldier flies consume manure, killing pathogens and transferring the nutrients to their bodies, creating a value-added product than can be exported off the farm.

Vermicomposting uses worms to digest manure, creating pathogen-free, nutrient-rich products that can be sold and exported off the farm.

Phytoremediation uses plants to absorb nutrients and other pollutants from contaminated soils, preventing polluted runoff and the migration of contaminants to groundwater.

Ultimately, all of these technologies create end-products that can be applied to land or must be utilized in other fashions. Through the treatment processes the risk of potential pollution has been reduced or eliminated, as summarized in **Table ES.1**. It is very important to note that this table is for guidance purposes only and the pollutant reductions are based on prudent implementation of the basic treatment technologies. Supplementary treatment components or management practices may be added to enhance the overall performance of a single treatment technology. Additionally, it is always better to have a system of treatment technologies rather than relying on a single treatment process. Systems provide a more robust and thorough treatment and are able to meet more treatment objectives.

While some of the technologies discussed in the report may be more practical for large concentrated animal feeding operations (CAFOs) several are scalable to smaller, more traditional farms. The report makes an effort to present these in an objective light, with the goal of providing enough information for concerned citizens to draw accurate conclusions about the effectiveness of these tools in a given situation.

Table ES 1: Alternative treatment technologies and potential benefits.

Chapter Number	Chapter Name	Treatment Process	Reduce Nitrogen	Reduce Phosphorus	Reduce Biochemical Oxygen Demand	Stabilize Manure	Reduce Manure Volume	Reduce Pathogens	Reduce Manure Gases	Reduce Odor	Reduce Ammonia Volatilization	Operate at Low Temperatures	Minimal Footprint	Low Energy Requirement	Create Biogas	Create Value-Added Products
2	Storage Covers	Bank-to-bank							✓	✓	✓	✓	✓	✓		
		Balloon							✓	✓	✓	✓	✓			
		Modular							✓	✓	✓	✓	✓	✓		
3	Solids Separation	Source separation								✓	✓	✓	✓			
		Gravity separation								✓		✓		✓		
		Mechanical separation								✓		✓	✓			
		Chemical separation								✓		✓	✓	✓		
4	Aerobic Digestion	Aerobic digestion	✓	✓	✓	✓		✓	✓	✓	✓	✓				
5	Anaerobic Digestion	Mixed reactor				✓		✓	✓	✓					✓	
		Fixed film				✓		✓	✓	✓					✓	
		Plug flow				✓		✓	✓	✓					✓	
		Ambient lagoon				✓		✓	✓	✓					✓	
		Heated mixed lagoon				✓		✓	✓	✓		✓			✓	
6	Nitrification-Denitrification	Nitrification-denitrification	✓		✓						✓					
7	Composting	Unaerated static pile				✓	✓	✓	✓	✓	✓	✓		✓		✓
		Aerated static pile				✓	✓	✓	✓	✓	✓	✓				✓
		Windrow				✓	✓	✓	✓	✓	✓	✓		✓		✓
		In-vessel				✓	✓	✓	✓	✓	✓	✓	✓			✓
		Pit				✓	✓	✓	✓	✓	✓	✓		✓		✓
		In-barn				✓	✓	✓	✓			✓	✓	✓		✓
8	Constructed Wetlands	Open water	✓		✓			✓	✓					✓		
		Subsurface flow	✓		✓			✓	✓	✓	✓			✓		
		Floating aquatic	✓		✓			✓	✓							
		Reciprocating	✓		✓			✓	✓	✓	✓					
9	Miscellaneous Treatment Technologies	Black soldier fly	✓	✓		✓	✓	✓		✓			✓	✓		✓
		Vermicomposting	✓	✓		✓	✓	✓		✓			✓	✓		✓
		Phytoremediation	✓	✓										✓		✓

Each chapter will discuss advantages and disadvantages, how the technology works, and variations on the technology design.

These technologies are not a cure for the manure management problems plaguing both large concentrated livestock operations and small farms across America. The technologies are not fail-safe; conscientious and diligent operation is needed for any successful manure management program—the capability of the facility owner and operator is a crucial piece of the puzzle. The lesson of our research is that manure treatment technologies must be chosen based on the specific site conditions, current infrastructure, management practices, and treatment objectives of a farm; a technology that is successful on one farm will not necessarily be successful at a neighboring farm. These manure treatment methods may have the potential to reduce water and air pollution from CAFOs and other livestock operations. For citizens concerned about these impacts, reviewing this report will provide a better understanding of how each technology functions, what challenges it poses to an operator, what restrictions site location and size may have on the implementation of the technology, and whether a technology selected by a farmer or project applicant will be able to deliver meaningful environmental protection.

Chapter 1
Background

1.1 Preface

Over the past thirty years Americans have enjoyed growing success in controlling pollution from factory pipes and rediscovering the joys of fishing, boating, and swimming in rivers that were once too contaminated. Yet water quality in the lakes, streams, and rivers of rural America have suffered over the past several decades from increased levels of pollution, primarily excess nutrients, sediment, and pathogens stemming from agricultural processes. As a result, rural water quality is emerging as one of the most prominent environmental issues of our time and one of the most difficult to address.

There is considerable truth in celebrating farmers as some of America's first environmentalists. Many farms provide habitat for wildlife, prevent soil erosion, reduce fertilizer and herbicide losses, and protect neighboring waterbodies. However, there are often tremendous water quality issues associated with modern agriculture. Research and water quality surveys confirm that row crop and livestock production is a significant source of water pollution. Improper or poorly implemented management techniques contaminate streams, rivers, and lakes with excess nutrients, fertilizer residues, and pathogens. Agriculture is the leading contributor to impaired water quality in America's rivers and streams; according to the United States Environmental Protection Agency, animal feeding operations have impaired over 24,616 river and stream miles (United States Environmental Protection Agency, 2000). Over 50 percent of the time, Iowa watersheds draining intensively fertilized row crops or containing dense concentrations of animal feeding operations had nitrate levels that exceeded the EPA's safe drinking water standard (Kalkhoff, 2000). The United States Department of

Agriculture reports that insufficient land exists in 485 counties across the country to land apply manure without exceeding crop nitrogen needs (United States Environmental Protection Agency, 2001). In Nebraska, the amount of phosphorus in manure exceeds the total assimilative capacity of all the agricultural fields statewide (United States Environmental Protection Agency, 2001).

Industrial livestock agriculture has become the standard for creating profit from livestock. In concentrated animal feeding operations (CAFOs) animals are confined in huge housing units. The animals may be crowded together with little room for movement and no access to the outdoors. These animal housing units can be loud and dangerous places. Wherever animals exist, manure exists. Confining large numbers of animals in one location also concentrates large volumes of manure into one location. Typically, the manure is flushed from the housing units into large earthen pits. These pits may be several acres in area and several stories deep. Massive manure spills and overflows of these storage pits have caused catastrophic fish kills. The liquid manure is routinely irrigated onto nearby fields, filling the air and saturating the soil with manure. Nutrient and organic loadings from manure-laden runoff are literally choking aquatic organisms in surface waters downstream from industrial livestock operations. Manure is often treated as a waste, a worthless byproduct of agricultural profits rather than the valuable resource it can be.

Alternatives to industrial livestock agriculture are available. Various organizations have formed to support sustainable agricultural practices, creating a new movement for the future of agriculture. Sustainable agriculture promotes animal welfare, worker welfare, manure management, and the environment while creating a profitable product. Organizations such as Animal Welfare Institute, GRACE, and Center for Rural Affairs address the animal welfare, social, and economic issues associated with livestock agriculture. This report focuses on manure management and the potential positive water quality impacts of responsible manure treatment.

Advances in manure treatment technologies may offer ways to reduce or eliminate pollution from CAFOs. In recent years, government agencies, private corporations, and farmers have investigated and installed alternative treatment technologies. In some cases implementation of the treatment technology has reduced odor and water pollution from individual farms. However, the long-term successes of these treatment technologies have not been extensively evaluated. There are valid concerns about the affordability, effectiveness, and long-term environmental and social impacts associated with some of these technologies.

With this background in mind, Waterkeeper Alliance has prepared this report as a guide for concerned citizens, zoning boards, community activists, and farmers.

Most concerned citizens have little experience with these technologies and lack the information needed to make informed decisions about how they will affect their communities. With the support of a grant awarded by the United States Environmental Protection Agency, Waterkeeper Alliance has prepared this review of currently available alternative manure treatment technologies for cows and pigs. Neither Waterkeeper Alliance nor the Environmental Protection Agency endorse any of these technologies; we do not claim that any single treatment technology will eliminate the manure management, social, or economic problems associated with confined livestock operations.

1.2 INTRODUCTION

Many of the treatment technologies discussed in this report are also used in municipal wastewater treatment plants to treat human waste and to mitigate many of the same pollutants. However, human waste and manure are not entirely analogous in volume or characteristics. Humans produce much less waste than cows and pigs. Compared to livestock manure, human waste contains less of some potential pollutants and more of others. Humans produce almost a third of the total solids that cows and pigs produce, but more biochemical oxygen demand than dry dairy cattle, gestating sows, and piglets. It is for this reason that it is not effective to simply construct municipal wastewater treatment plants at farms to treat manure. Additionally, the volume and content of manure varies greatly between livestock species and breeds and can even vary significantly within a species or breed, depending on the age or gender of the animal, as depicted in **table 1.1**. The values given in table 1.1 are on one thousand pounds of animal basis. This unit allows the potential pollutants to be fairly compared across species and populations within a species. These values are only general guidelines, as many factors affect the amount and characteristics of the manure generated, including breed; quantity, quality, and components of the feed ration; exercise; and many others. Manure treatment technologies must be specifically tailored to volume, characteristics, and variation in manure flow on a particular farm.

This chapter will introduce the reader to the pollutants found in manure, how manure is collected and handled, manure management, treatment approaches, and land application of manure as background information for the chapters on the different treatment technologies.

Table 1.1: Comparison of livestock wastes (United States Department of Agriculture, 1992).

		Dairy			Swine			
Component	Unit	Lactating	Dry	Heifer	Grower	Gestating	Lactating	Nursery
Weight	lb/day/1000lb	80.0	82.0	85.0	63.4	27.2	60.0	106.0
Volume	ft^3/day/1000lb	1.30	1.30	1.30	1.00	0.44	0.96	1.70
Moisture content	percent	87.5	88.4	89.3	90.0	90.8	90.0	90.0
TS*	lb/day/1000lb	12.5	11.6	10.7	10.0	9.2	10.0	10.0
VS†	lb/day/1000lb	8.50	8.10	7.77	5.40	2.13	5.40	8.80
FS‡	lb/day/1000lb	1.50	1.40	1.37	0.94	0.37	0.60	1.80
COD§	lb/day/1000lb	8.90	8.50	8.30	6.06	2.37	5.73	9.80
BOD‖	lb/day/1000lb	1.60	1.20	1.30	2.08	0.83	2.00	3.40
N#	lb/day/1000lb	0.45	0.36	0.31	0.42	0.19	0.47	0.60
P**	lb/day/1000lb	0.07	0.05	0.40	0.16	0.06	0.15	0.25
K††	lb/day/1000lb	0.26	0.23	0.24	0.22	0.12	0.30	0.35

* Total solids, the sum of the volatile solids and the fixed solids. † Volatile solids. ‡ Fixed solids. § Chemical oxygen demand. ‖ Biochemical oxygen demand. # Nitrogen. ** Phosphorus. †† Potassium.

Manure gases: volatile compounds released from animal manure. Many cause problems ranging from offensive odors to adverse human health and environmental impacts.

Eutrophication: A process where a water body becomes nutrient-enriched and eventually unable to sustain plant and animal life.

Anaerobic: An oxygen-free environment or requiring an oxygen-free environment to survive.

Pathogen: A disease-causing organism.

Biodegradable: A material that can be broken down by biological processes.

Stabilization: A microbial process that results in material that cannot be easily decomposed.

Macronutrient: An element required in relatively large amounts for growth and reproduction; nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S).

1.3 Manure Pollutants

Manure contains several different compounds that are potential water pollutants if irresponsibly released to the environment. **Table 1.2** describes some major water pollutants associated with animal manure. **Manure gases**, as discussed in Section 1.3.5, while not direct water pollutants, are a major source of odor and safety problems on farms.

Table 1.2: Principal pollutants in animal manure (adapted from Metcalf and Eddy, 2003).

Constituent	Reason for Importance
Nutrients	Excessive levels in surface water can lead to algal blooms, reductions in dissolved oxygen, and **eutrophication**; can contaminate groundwater and drinking water wells
Suspended solids	Lead to development of solid deposits and **anaerobic** conditions when untreated manure is present in the aquatic environment
Pathogens	Communicable diseases can be transmitted by pathogenic organisms found in manure
Biodegradable organics	Composed principally of proteins, carbohydrates, and fats; if discharged untreated to the environment their biological **stabilization** can lead to the depletion of natural oxygen resources and to the development of septic conditions

1.3.1 Nutrients

Nitrogen and phosphorus are the main pollutants of concern in manure management. **Table 1.3** presents the amounts of nitrogen and phosphorus found in livestock manure. Both of these nutrients are **macronutrients** required for plant growth, but excessive amounts of nitrogen and phosphorus can have devastating effects on water quality.

Table 1.3: Nitrogen (N) and phosphorus (P) in livestock manure (Kellogg et al., 2000).

Livestock	Manure*	Pounds N/ton manure/year†		Pounds P/ton manure/year†	
	(tons/1000lb/year)	As excreted	After losses‡	As excreted	After losses‡
Fattened cattle	10.59	10.98	4.39	3.37	2.86
Milk cows	15.24	10.69	4.30	1.92	1.65
Beef calves§	11.32	8.52	2.56	2.33	1.98
Beef heifers‖	12.05	6.06	1.82	1.30	1.10
Beef breeding#	11.50	10.95	3.30	3.79	3.23
Beef stockers/grass-fed	11.32	8.52	2.56	2.33	1.98
Dairy calves§	12.05	6.06	1.82	1.30	1.10
Dairy heifers‖	12.05	6.06	1.82	1.30	1.10
Dairy stockers/grass-fed	12.05	6.06	1.82	1.30	1.10
Breeding hogs	6.11	13.26	3.32	4.28	3.62
Hogs for slaughter	14.69	11.30	2.82	3.29	2.80

* As excreted, per 1000 pounds of animal. † Includes nitrogen and phosphorus in urine. ‡ Includes nutrient losses from spillage during collection and transfer, minimal treatment, volatilization, rainfall, and runoff from confinement facilities. § From calving to 500 pounds. ‖ For replacement herds. # Includes cows and bulls.

a. Nitrogen

Nitrogen is one of the most abundant elements on Earth. It makes up 78 percent of the air we breathe (Los Alamos National Laboratories, 2003). Nitrogen is required for all life; it is a major component of DNA, RNA, proteins, enzymes, and hormones (Pidwirny, 2004).

The nitrogen cycle, as depicted in **Figure 1.1**, has many components. Atmospheric nitrogen (N_2) is converted by bacteria into a plant-available form, nitrate (NO_3), in a process called nitrogen fixation. The plants take up the nitrate-nitrogen for cellular growth and reproduction. Animals consume the plants, incorporating the nitrogen into their bodies. Nitrogen is released to the environment via manure and decaying plants and animals. When decomposers degrade manure and carcasses, some of the nitrogen is returned to the atmosphere as dinitrogen gas (N_2) and some is mineralized into forms that stay in the soil, including ammonium (NH_4), nitrite (NO_2), and nitrate (NO_3).

Even though nitrogen is an essential part of plant and animal life it is also a potential pollutant and health hazard. The form that nitrogen takes plays a major part in determining if it is a helpful nutrient, a harmful contaminant, or a benign element. **Table 1.4** describes the common forms of nitrogen.

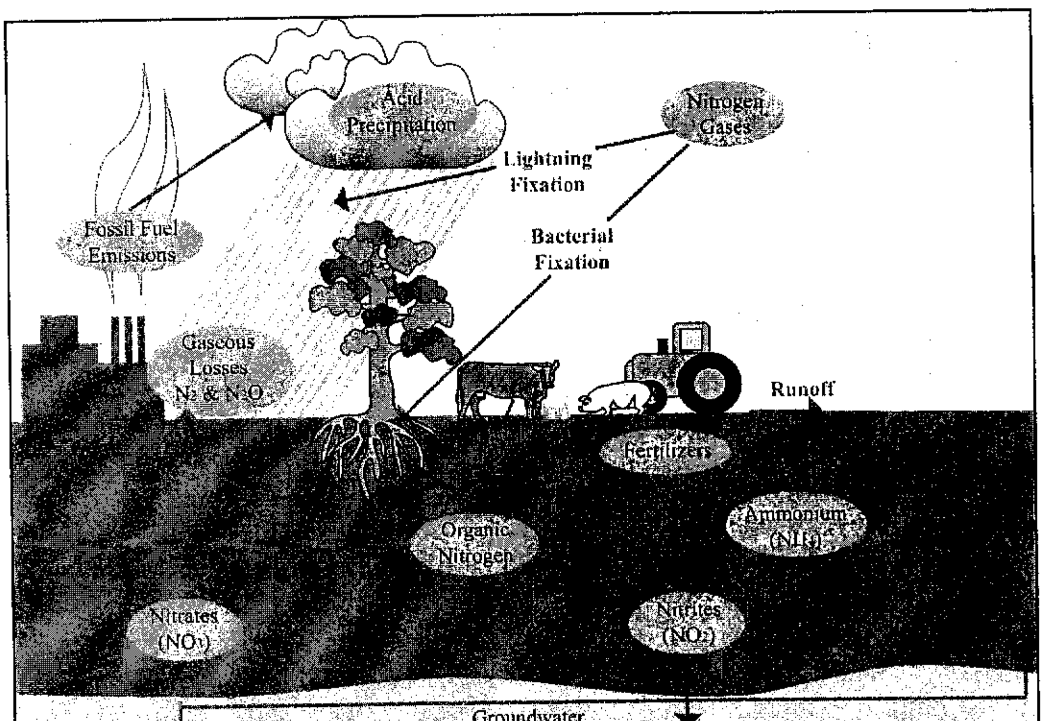

Figure 1.1: Nitrogen cycle (C. White, 2004).