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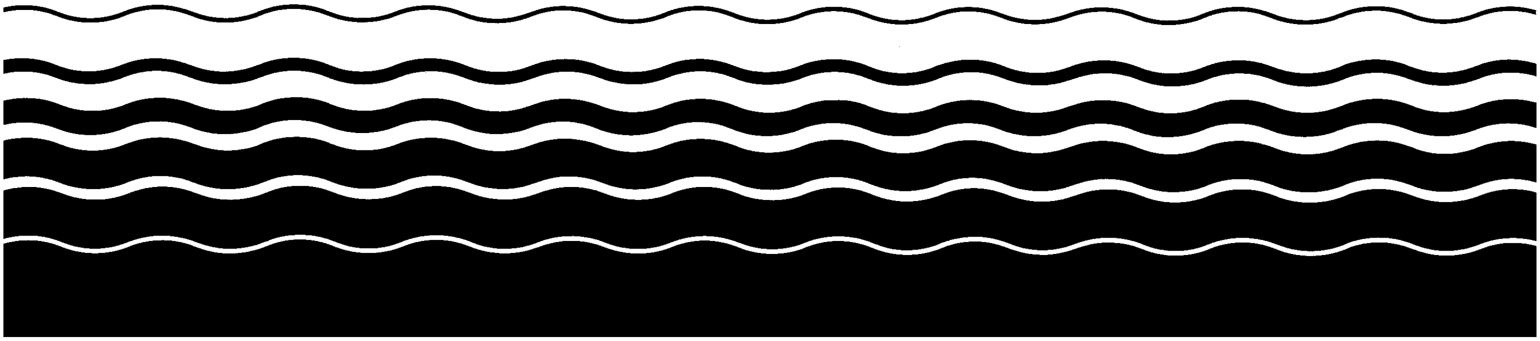

Environmental Assessment of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and Effluent Limitations Guidelines for Concentrated Animal Feeding Operations

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EXECUTIVE SUMMARY

States report that agriculture is the leading source of impairment in the nation's surveyed rivers and lakes. In the states that categorized sources of impacts to rivers in 1998, intensive animal operations accounted for over 15 percent of the total impairment due to agriculture. Manure and other animal wastes from these animal feeding operations (AFOs) can result in human health and potentially significant environmental impacts. Such impacts continue to cause concern despite federal effluent limitation guidelines that address feedlots, which have been in place since 1974. Since the EPA promulgated the original effluent guidelines, there have been persistent reports of discharge and runoff of manure pollutants reaching surface and groundwater and resulting in fish kills and other adverse impacts.

Animal production has undergone significant changes in the past several decades. Between 1987 and 1992, the total number of animal units increased by about 4.5 million (approximately 3 percent). At the same time, the number of facilities has decreased, indicating a consolidation within the livestock industry.

Animal Waste Characteristics

Beef, dairy, swine, and poultry operations generated a total of 291 billion pounds of manure (weight of dry-state or dried manure) in 1997. This figure represents recoverable and non-recoverable manure. Recoverable manure is generally indicative of confined operations, because it is waste that is contained within the production area. The U.S. Environmental Protection Agency (EPA) estimates the amount of manure that is recoverable from each of the four animal sectors addressed by the guidelines to be beef (16 percent), dairy (76 percent), swine (92 percent), and poultry (98 percent).

Animal waste contains a number of pollutants. The presence and concentration of these pollutants may vary depending on the animal species and other factors, such as animal size, maturity, and health, as well as the composition (e.g., protein content) of animal feed.

Nitrogen, an essential nutrient required by all living organisms, exists in fresh manure in organic and ammonium forms. Nitrogen can transform to nitrate, and it is then water soluble and highly mobile in the environment. When farmers apply excess manure as fertilizer to crops, nitrates may run off into surface water and may leach to groundwater. Like nitrogen, phosphorus also exists in animal waste. As animal waste ages, the organic phosphorus mineralizes to inorganic phosphate compounds and becomes available to plants. Organic phosphorus compounds are generally water soluble and may leach through soil to groundwater and run off into surface waters. Inorganic phosphorus attaches to soil particles and may reach surface waters through erosion.

The ammonia content of fresh manure varies among animal species and changes as the manure ages. Ammonia content may increase as organic matter breaks down; it may decrease when volatilization occurs or when nitrate oxidizes to nitrite under aerobic conditions. A major method of transport of ammonia is through atmospheric deposition from airborne emissions.

Livestock manure contains many pathogens, including protozoa, bacteria, and viruses. Multiple species of pathogens may be transmitted directly from a host animal's manure and may increase in number in a waterbody due to loadings of animal manure nutrients. Pathogen contamination from AFOs includes discharges directly to surface waters and discharges from leaching lagoons, and can reach surface waters and groundwater. Soil type, manure application rate, and soil pH are dominating factors in the survivability of bacteria. Type of storage and length of storage also affect bacterial survivability.

Organic compounds in animal manure can enter water directly from feedlots and land application sites. They then undergo decomposition by aquatic bacteria and other microorganisms. In the process, the organisms consume dissolved oxygen, reducing the amount available for aquatic animals. Measures that indicate presence of the organic compounds in manure are the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD). Even after treatment, these measures are much higher for animal waste than for municipal treated waste.

Several other pollutants can reach surface water and groundwater. Dissolved mineral salts and several trace elements (including arsenic, copper, selenium, and zinc) can reach surface waters via discharges directly to the waterbody as well as runoff from land application sites and can leach into groundwater. Although present in small amounts in manure, trace elements may bioconcentrate in plants and animal tissues and persist in the environment. The degradation of animal wastes by microorganisms may produce gases with strong odors. Particulate emissions, pesticides, antibiotics, and hormones also exist in animal waste and may impact the environment.

Human Health Hazards Associated with Animal Wastes

Many constituents of animal waste, including primary nutrients, pathogens, salts, and gases, can affect human health. Elevated nitrate levels in drinking water are a major health concern. In particular, infants are at risk from nitrate poisoning (also referred to as methemoglobinemia or "blue baby syndrome"), which results in oxygen starvation. Nitrate poisoning may increase the risk of birth defects and miscarriages, and is potentially fatal.

Pathogens in animal waste cause many human diseases. These include salmonellosis, cryptosporidiosis, giardiasis, cholera, typhoid fever, and polio. Humans may come into contact with the pathogens via the fecal-oral route, inhalation, or consumption of contaminated water. The protozoan *Cryptosporidium parvum* is of particular concern because it is resistant to conventional drinking water treatment. *Cryptosporidium* can produce gastrointestinal illness, with symptoms such as severe diarrhea.

Salts in animal waste are also a human health hazard. At low levels, salts can increase blood pressure in salt-sensitive individuals, increasing the risk of stroke and heart attack. Trace metal elements in manure can also impact human health For example, while zinc (a feed additive) is a requirement for human physiology, it may induce toxicity at elevated concentrations.

The primary gases associated with aerobic decomposition include carbon dioxide and ammonia. Gases associated with anaerobic conditions, which dominate in typical, unaerated animal waste lagoons, include methane, carbon dioxide, ammonia, hydrogen sulfide, and over 150 other compounds. Many of the end products can produce negative impacts, including strong odors.

Ecological Effects Associated with Animal Wastes

Animal waste can also have an effect on the natural ecosystem. Perhaps the most documented impact of nutrient pollution is the increased surface water eutrophication (nutrient enrichment) and its effects on aquatic ecosystems. Eutrophication causes the enhanced growth and subsequent decay of algae, which can lower dissolved oxygen content of a waterbody to levels insufficient to support fish and invertebrates. In some cases, this situation can produce large areas devoid of life because of a lack of sufficient dissolved oxygen. An example of this is the "Dead Zone," a 10,000 km^2 area in the Gulf of Mexico. Researchers believe the Dead Zone is caused by excess chemical fertilizer; however, nutrients from animal waste have also contributed to the problem. Eutrophication may increase the incidence of harmful algal blooms, which release toxins as they die and can severely impact wildlife as well as humans.

Parasites, bacteria, and viruses in animal waste may be harmful to wildlife. Certain bacteria in livestock waste cause avian botulism and avian cholera, which have killed thousands of migratory waterfowl. Shellfish can concentrate a broad range of microorganisms in their tissues, providing a pathway for pathogen transmission to predator organisms.

Ammonia is highly toxic to aquatic life and is a leading cause of fish kills. It is of environmental concern because it exerts a direct oxygen demand on the receiving water as it breaks down. Ammonia loadings can contribute to accelerated eutrophication of surface waters. Also, organic matter in surface waters supports increased microbial population and activity, and as these microorganisms degrade the organic matter, the amount of dissolved oxygen available to other aquatic organisms decreases.

Salts from manure can impact the ecosystem. In fresh water, increasing the salinity can disrupt the balance of the ecosystem. On land, salts can become toxic to plants and deteriorate soil quality by reducing permeability and generally impacting physical condition. Trace elements in manure can impact plants, aquatic organisms, and terrestrial organisms. For example, metals such as zinc (a feed additive) can accumulate at high concentrations in soil and become toxic to plants.

National and Local Impacts from Animal Agriculture

Several analyses have estimated nationwide impacts from animal operations. First, in an analysis of nitrogen sources (including manure, fertilizers, point sources, and atmospheric deposition) in 107 U.S. watersheds, the U.S. Geological Survey (USGS) found that proportions of nitrogen originating from various sources differ according to climate, hydrologic conditions, land use, population, and physical geography (Puckett, 1994). In several watersheds (particularly in the South and Northeast), manure nitrogen accounts for a large portion of the total nitrogen added to the watershed.

In a second analysis, Lander et al. (1998) estimated the quantity of nutrients available from confined livestock manure relative to crop growth requirements, by county, based on data from the 1992 Census of Agriculture (USDC/Census Bureau, 1994). Recoverable manure nitrogen exceeded crop system needs in 266 counties, and recoverable phosphorus exceeded crop system needs in 485 counties.

A third analysis, by Smith et al. (1997), modeled transport of manure nutrients to surface water. The authors found that animal waste is a significant source (relative to other local sources) of in-stream nutrient concentrations in many watershed outlets, particularly in the central and eastern United States. They also conclude that livestock waste contributes more than commercial fertilizer application to total phosphorus exported from local sources (independent of upstream sources).

The EPA has also documented local impacts. In Oklahoma, Lake Eucha has very high nutrient loads associated with poultry production operations. In Florida, Lake Okeechobee has experienced significant effects of phosphorus loadings from AFOs. In southeastern Delaware and the Eastern Shore of Maryland, where poultry production is widespread, over 20 percent of wells have nitrate levels exceeding the Maximum Contaminant Level (MCL) set by the EPA's Office of Ground Water and Drinking Water. Furthermore, localities have reported various ecological impacts associated with releases from AFOs, including eutrophication and fish kills. Over a 10-year period, localities have also reported nearly 100 individual fish kill events associated with spills and discharges from AFOs.

This Report

Unlike environmental assessments prepared to support other effluent guidelines, this report focuses on the qualitative impacts on human health and the environment associated with releases of wastes to surface water from concentrated animal feeding operations (CAFOs). The EPA is not currently able to quantitatively evaluate all human health and ecosystem benefits associated with water quality improvements from reduced releases of CAFO wastes. The EPA is even more limited in its ability to assign monetary values to those benefits. The economic benefit analysis is available in the benefit report, titled "Environmental and Economic Benefits of the NPDES/ELG CAFO Rules" and located in section 9.5 of the public record.

To present a sense of the scope of the problem, this report relies on state and federal information, as well as news articles and data collected by environmental advocacy groups. While data from government agencies are more reliable, the resources are not available to thoroughly track CAFO-related releases of pollutants to the environment and the resulting environmental and human health impacts. The intention of this more inclusive approach is to provide a sense of the possible scope of the impacts until state and federal agencies can fully document them.

1. INTRODUCTION

1.1 BACKGROUND

Animal waste can have a negative impact on surface water, ground water, soil, and air. While there are many sources of water pollution, states report that agriculture is the leading source of impairment in the nation's surveyed rivers and lakes. Furthermore, nutrients and pathogens account for a large percentage of contaminants found in the nation's impaired waters (USEPA, 2000a).

Animal feeding operations (AFOs or feedlots) can pose a number of risks to human health and the environment, mainly because of the significant amount of animal manure they generate. In 1997, farm animals generated an estimated 291 billion pounds (132 million metric tons) of manure (dry-state basis) (USDA/NRCS, 2000).[1] This figure far exceeds the estimated 49 billion pounds (22 million metric tons) of human sanitary waste produced. Since the calculations handle human and animal wastes differently, this comparison does not provide an indication of relative environmental impact; however, it does indicate the significance of animal waste as a potential source of pollution.

AFOs contribute manure pollutants to the environment via discharges directly into surface water, surface runoff, leaching into soil and ground water, and volatilization/deposition. Sources of these pollutants include animal confinement areas, pastures, treatment and storage lagoons, manure stockpiles, and land application fields. Organic matter, ammonia, nutrients (particularly nitrogen and phosphorus), solids, pathogens, and odorous compounds are the pollutants most commonly associated with animal waste. Animal waste is also a source of salts and trace elements, and to a lesser extent, pesticides, antibiotics, and hormones.

Manure can be a valuable fertilizer and soil conditioner, but in many cases it is applied in excess of crop nutrient requirements due to manure nutrient ratios that differ from crop needs, and/or lack of available nearby land on which to spread the manure. This problem has been of increasing concern as more concentrated feeding operations maintain greater numbers of animals.

In surface water, the waste's oxygen demand and ammonia content can directly result in fish kills and reduced biodiversity. Solids can increase turbidity and suffocate benthic organisms. Nitrogen and phosphorus can contribute to eutrophication and associated algae blooms. These blooms can produce negative aesthetic impacts and increase the costs of drinking water treatment. Turbidity from the blooms can reduce penetration of sunlight in the water column and thereby limit growth of seagrass beds and other submerged aquatic vegetation, which serve as critical habitat for fish, crabs, and other aquatic organisms. Decay of algae blooms (as well as nighttime algal respiration) can depress oxygen levels, leading to fish kills and reduced biodiversity. Eutrophication is also a factor in blooms of toxic algae and other toxic microorganisms, such as *Pfiesteria piscicida*, which can affect human health as well as animal health. Pathogens and nitrogen in animal waste can also affect human and animal health.

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[1] USDA's National Resources Conservation Service calculated animal waste figures using the 1997 Census of Agriculture (USDA/NASS, 1999) and the procedures in Lander et al. (1998).

Nitrogen in manure is easily transformed into its nitrate form, which can be transported to drinking water sources and result in potentially fatal health risks to infants. Trace elements in manure may also present human health and ecological risks. Salts can contribute to salinization and disruption of ecosystems. Antibiotics, pesticides, and hormones may have low-level, long-term human health and ecological effects.

Ground water sources of drinking water can have impacts from nitrates, pathogens, salts, and other contaminants from manure. Ground water is typically more prone than surface water to contamination by nitrates, in particular. In fact, the EPA found that nitrate is the most widespread agricultural contaminant in drinking water wells and estimates that 4.5 million people are exposed to elevated nitrate levels from wells (USEPA, 1990).

In soils, salts and trace elements from land-applied manure can accumulate and become toxic to plants. Salts can deteriorate soil quality by leading to reduced permeability and poor tilth. Crops may provide a human and animal exposure pathway for trace elements and pathogens.

Air emissions from volatilization occurring at AFOs also produce environmental impacts. Odors from anaerobic waste decomposition are particularly offensive. Odors can produce mood disorders such as tension, depression, and fatigue (Schiffman et al., 1995; Thu, 1995). Many odor-causing substances (e.g., ammonia, hydrogen sulfide, and organic dusts) can also cause physical effects. Furthermore, volatilized ammonia can be redeposited on the earth and contribute to eutrophication of surface waters. Methane emissions from anaerobic waste lagoons are a concern because they increase greenhouse gas concentrations.

Such impacts continue to cause concern despite federal effluent limitation guidelines (ELGs, “effluent guidelines,” or “guidelines”) that have been in place for feedlots since 1974. Essentially, these guidelines apply to large operations and prohibit discharges to surface waters except when chronic or catastrophic rainfall events cause an overflow from a containment system. The current regulations do not specifically address discharges that may occur when wastes are applied to soil.

To help address the various concerns outlined above, the EPA is currently revising the feedlots effluent limitation guidelines. This report presents the environmental assessment of the proposed regulations for the pork, poultry, beef, and dairy sectors of concentrated animal feeding operations (CAFOs). Briefly, each animal sector is composed of:

- pork: facilities that produce mature or immature swine;
- poultry: facilities that produce laying hens, broilers, and turkeys;
- beef: facilities that produce all cattle—this includes veal and replacement heifers and excludes mature dairy cattle; and
- dairy: facilities that produce mature dairy cattle, whether milked or dry.

1.2 OVERVIEW OF ANIMAL FEEDING OPERATIONS

Animal production industries have undergone significant changes in the past several decades. Domestic and export market forces, technological changes, and industry adaptations have promoted expansion in the number of confined production units. This includes:

- growth in both existing and new areas;
- integration and concentration of some industries;
- geographic separation of animal production and feed production operations; and
- the concentration of large quantities of manure and wastewater on farms and in some watersheds (USDA/USEPA, 1999).

In terms of production, the total number of animal units produced in the U.S. increased by about 4.5 million (approximately three percent) between 1987 and 1992. During the same period, however, the number of AFOs decreased, indicating a consolidation within the industry overall and greater production from fewer, larger AFOs (USGAO, 1995b). These changes are not uniform across animal type or across the country.

Exhibits 1-1 and 1-2 illustrate the consolidation of animal production between 1978 and 1992. The number of operations decreased significantly for most major animal types during this period (Exhibit 1-1). At the same time, the average number of animals per operation increased significantly (Exhibit 1-2).

EXHIBIT 1-1
Industry Consolidation of Animal Feeding Operations
1978 - 1992

Compiled from data in USGAO (1995b).

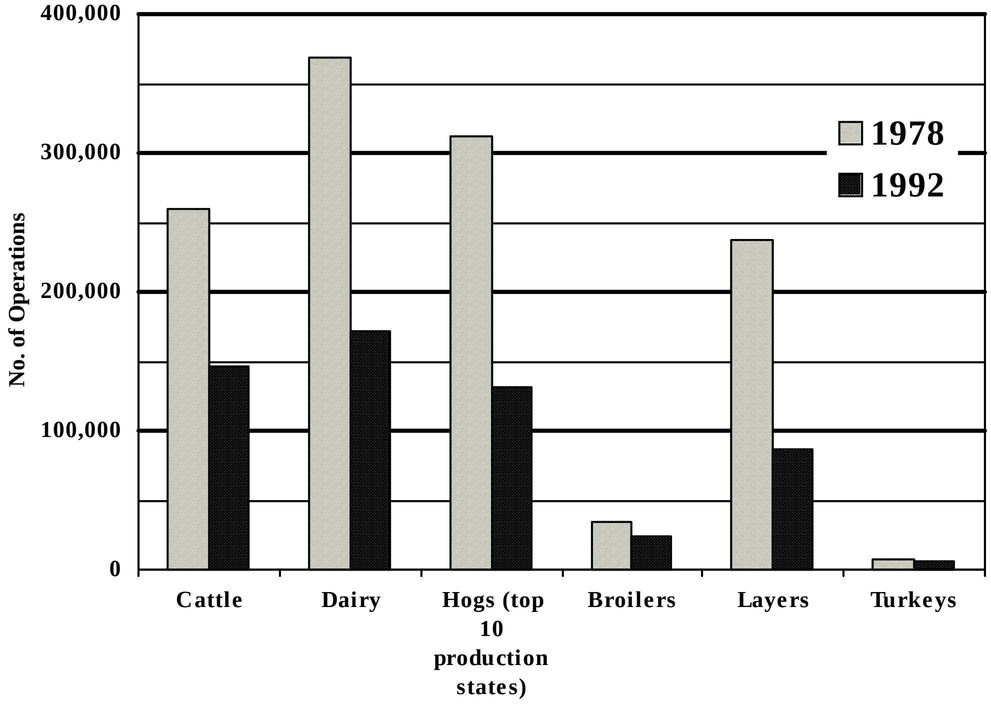

EXHIBIT 1-2
Increase in the Average Number of Animal Units per Operation, 1978-1992

Animal Type	Increase in Animal Units/Operation
Swine	134%
Layers	176%
Broilers	148%
Turkeys	129%
Beef Cattle	56%
Dairy Cattle	93%

Derived from data in USGAO (1995b).

Confined AFOs range in size from small-scale operations with few animals to large, intensive production facilities. Letson and Gollehon (1996) analyzed 1992 Census of Agriculture data (USDC/Census Bureau, 1994) to estimate the distribution of confined animals among various farm sizes (Exhibit 1-3). Their analysis shows that for all animal types, small facilities accounted for a large share of farms, but a small percentage of animals. Larger farms were less numerous, but maintained a disproportionately greater percentage of animals. The greatest proportion of layers and beef cattle were raised on large farms, whereas medium-sized farms accounted for the greatest proportion of swine, broilers, turkeys, and dairy cattle.

EXHIBIT 1-3
Farms, Number of Head, and Cropland, by Confined Animal Facility Size, 1992

Animal Type	Small (< 50 AUs)		Medium (50 to 999 AUs)		Large (> 1,000 AUs)	
	Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Swine						
Number of farms	115,830	56%	88,042	43%	2,578	1%
Total Head (1,000s)	3,089	5%	38,984	68%	15,270	27%
Total Cropland (1,000 acres)	17,029	30%	37,121	66%	1,795	3%
Layers						
Number of farms	81,903	93%	5,733	6%	599	1%
Total Head (1,000s)	4,033	1%	137,366	39%	209,911	60%
Cropland (1,000 acres)	8,848	90%	881	9%	149	2%
Broilers						
Number of farms	17,657	49%	16,704	47%	1,398	4%
Total Head (1,000s)	2,193	<1%	684,507	73%	246,667	26%
Total Cropland (1,000 acres)	2,207	58%	1,371	36%	211	6%
Turkeys						
Number of farms	7,379	70%	2,911	28%	276	3%
Total Head (1,000s)	892	1%	64,019	74%	21,703	25%
Total Cropland (1,000 acres)	848	60%	535	38%	33	2%
Beef						
Number of farms	134,847	92%	11,411	8%	943	1%
Total Head (1,000s)	995	10%	1,941	19%	7,098	71%
Total Cropland (1,000 acres)	34,199	75%	10,160	22%	1,117	2%
Dairy						
Number of farms	43,700	28%	110,700	71%	939	1%
Total Head (1,000s)	238	3%	8,002	84%	1,252	13%
Total Cropland (1,000 acres)	6,097	16%	32,524	83%	515	1%

Source: Letson and Gollehon (1996).

The Letson and Gollehon (1996) analysis also provides useful insight regarding the cropland held by various sizes of AFOs. As shown in Exhibit 1-3, medium and large poultry operations (particularly layer facilities and beef operations) account for a large percentage of animals, but a small percentage of cropland on which to apply manure. Pork and dairy operations exhibit a similar characteristic for large farms. The amount of cropland ultimately influences animal waste disposal options. Historically, farm enterprises integrated crop and animal production by using the manure generated to fertilize crops, constituting a crucial element of manure management. Such integrated pork and dairy operations are still common, particularly in the eastern Corn Belt. However, the breeding and raising phases of livestock production increasingly occurs in large-scale, specialized operations. This trend toward high-volume commercial enterprises separates the locations of manure generation and cropland available for its application (Letson and Gollehon, 1996).

1.3 ORGANIZATION OF REPORT

This report presents a water-quality-based environmental impact assessment of the proposed regulations for swine, poultry, beef, and dairy CAFOs. Chapter 2 quantifies the amount of manure and total solids generated by swine, poultry, beef, and dairy operations as well as by other livestock and humans. Chapter 2 also provides information on animal manure constituents. Chapter 3 describes the potential human health and ecological hazards from manure pollutants. Chapter 4 discusses studies that estimate the potential environmental impact of animal waste at the national level and describes other reported impacts. Finally, Chapter 5 describes potential and reported benefits from the implementation of proposed management practices to control wastes from animal feeding operations.

To present a sense of the scope of the problem, this report relies on state and federal information, as well as news articles and data collected by environmental advocacy groups. While data from government agencies are considered more reliable, the resources are not available to thoroughly track CAFO-related releases of pollutants to the environment and the resulting environmental and human health impacts. This more inclusive approach is intended to provide a sense of the possible scope of the impacts until state and federal agencies can fully document them.

2. ANIMAL WASTE CHARACTERISTICS AND TRANSPORT TO SURFACE WATERS

Animal feeding operations generate large volumes of waste of the following types:

- animal manure and urine;
- hair, feathers, and corpses;
- bedding and spilled feed;
- wash-flush water; and
- other processing wastes.

Many of these wastes are convertible to useful resources, such as fertilizer, soil conditioner, and feed (Shih, 1993; Edwards and Daniel, 1992a; USDA, 1992). However, these wastes can be a source of environmental degradation when improperly managed. In many cases, manure is applied in excess of crop nutrient requirements, due to manure nutrient ratios that differ from crop needs and/or lack of available nearby land. For example, the U.S. Fish and Wildlife Service estimates that the amount of phosphorus currently excreted by livestock in Nebraska exceeds what can currently be applied to farm fields at agronomic rates statewide (USFWS, 2000). This problem has received increasing attention as livestock operations have become more concentrated, with a trend toward more animals on fewer farms and less land. Incidents of discharges from waste storage lagoons, excessive runoff, leaking lagoons, and offensive odors have heightened public awareness and concerns about environmental impacts from AFOs.

Although many of the above-mentioned wastes can pose environmental risks, this chapter focuses on the characteristics of manure, which is often cited as a significant contributor to water quality degradation (USEPA, 1997a). In general, pollutant production figures reported here are based on 1997 data, the most readily available Census of Agriculture data (USDA/NRCS, 2000; USDA/NASS, 1999). USDA's Natural Resources Conservation Service (NRCS) estimated the quantities of manure and primary nutrients generated by livestock. NRCS based its approach on Lander et al. (1998), which provides a more detailed description of the methods and data sources used.

2.1 QUANTITY OF MANURE GENERATED

2.1.1 Total Manure

The large quantity of animal waste helps demonstrate why proper handling and disposal are essential in limiting environmental risks from manure. Animal manure is significantly more abundant than human waste. USDA's National Resources Conservation Service estimated that 291 billion pounds of manure measured on a wet basis (132 million metric tons when dried) was generated in 1997 from swine, poultry, and beef and dairy cattle (USDA/NRCS 2000) (see

Exhibit 2-1).[2] By comparison, the human sanitary waste production for that year was only 49 billion pounds (22 million metric tons total solids, dry-weight basis) (USDA/NRCS, 1996). This comparison, however, cannot be used as a surrogate for the relative extent of environmental impacts, since human and animal wastes are handled differently. For example, human sanitary waste is typically treated at a wastewater treatment plant, with the liquid effluent being discharged after treatment to surface water and the residual solids (sludge, or biosolids) being land applied, landfilled, or incinerated. Animal waste is typically land applied in its entirety, without an associated point source discharge (if properly applied). Nevertheless, the figures provide a sense of the significance of the total animal waste problem, especially in light of industry trends toward increased concentration of animals on farms. The figures are also relevant when considering that disposal of human waste is highly regulated, but disposal of animal waste has been largely unregulated.

EXHIBIT 2-1
Manure Production by Both Livestock and Humans

Species	Average Mass of Species (pounds)	Pounds Per 1,000 Pounds Live Unit Weight Per Day	
		Wet-Weight Manure [a]	Dry-Weight Manure [b]
Swine	135	84	8.2
Layer	4.0	64	16
Broiler	2.0	85	21
Turkey	15	47	12
Beef	800	58	6.9
Dairy	1,400	86	10
Human	150	30	3.3

Sources: Livestock data are "as excreted" and are from ASAE (1999); human waste data are "as excreted" and are from USDA/NRCS (1996).
Values rounded to two significant figures.
[a] Includes feces and urine as voided.
[b] Calculated using average solids content for each category, based on data from USDA/NRCS (1996).

2.1.2 Recoverable Manure

Although the above figures give a good indication of the magnitude of the total animal waste problem, they are not the best indicators of the problem that the proposed regulations address, because much of the total manure is generated by grazing or pastured animals, which are not the subject of the proposed regulations. Instead, the regulations address the manure generated by confined animal facilities, which is considered recoverable manure because waste is contained within the production area. Recoverable manure may include scraped manure, stored slurry

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[2] These quantities reflect the most recent estimates by USDA of manure generation from livestock operations, using data from the 1997 Census of Agriculture (USDA/NASS, 1999) and an approach developed by Lander et al. (1998). USDA's estimates are calculated on a wet manure basis, but expressed on a "dry-state" basis (to adjust for water content). Previous studies have reported a wide range of manure generation estimates for livestock and poultry operations that vary depending on the approach used and on whether the load is estimated on a wet or dry basis.

manure, lagoon effluent, and poultry litters, and may be applied later to croplands as fertilizer (Westerman et al., 1985).

It is important to estimate the amount of recoverable manure produced, not only to provide a good representation of the amount produced by confined animal operations, but also because recoverable manure may be a usable resource. For each state, Exhibit 2-2 lists the fraction of manure produced by major animal sectors that is recoverable. Lander et al. (1998) prepared these estimates using state survey responses from a study by Van Dyne and Gilbertson (1978).

As presented in Exhibit 2-2, nearly all manure (90 to 100 percent) from layers and broilers in the major producing states was recoverable. Turkey manure recovery ratios varied more widely in the top producing states. For example, recovery ratios ranged from 70 to 100 percent in North Carolina, South Carolina, Texas, Virginia, and Wisconsin, whereas they were only 20 to 45 percent in California, Michigan, and Minnesota. Approximately 90 percent of all swine manure in North Carolina was recoverable. In other major pork producing states, manure recovery ratios ranged from 65 to 85 percent. In top producing beef states, only five to ten percent of the manure from grazing cattle was recoverable, whereas 60 to 90 percent of the manure from fattened cattle was recoverable. Recovery ratios for milk cows in top producing states ranged from 75 to 90 percent.

EXHIBIT 2-2

Fraction of Recoverable Manure, by Animal and by State (Top Ten Producing States Indicated by Bold Font)

State	Beef (Grazing)	Beef (Fattened)	Milk	Swine (Breeding)	Swine (Other)	Laying Hen/Pullet	Pullets (<3 mos.)	Broilers	Turkeys (slaughter)	Turkeys (breeding)
AL	0.10	0.70	0.40	0.75	0.75	**0.95**	**0.95**	**0.98**	0.85	0.85
AZ	0.05	0.85	0.80	0.85	0.85	0.90	0.90	0.90	0.65	0.65
AR	0.10	0.50	0.50	0.50	0.50	**0.80**	**0.80**	**0.95**	**0.70**	0.70
CA	**0.05**	**0.85**	**0.80**	0.85	0.85	**1.00**	**1.00**	**1.00**	**0.20**	**0.20**
CO	**0.05**	**0.85**	0.80	0.85	0.85	0.95	0.95	0.95	0.65	0.50
CT	0.10	0.85	0.90	0.80	0.80	1.00	1.00	0.95	0.95	0.95
DE	0.10	0.85	0.80	0.80	0.80	0.90	0.90	**0.95**	0.95	0.95
FL	0.00	0.00	0.50	0.40	0.40	0.95	0.95	0.95	0.85	0.85
GA	0.00	0.75	0.70	0.50	0.50	**0.90**	**0.90**	**0.95**	0.85	0.85
ID	0.00	0.85	0.95	0.70	0.70	0.90	0.90	0.90	0.65	0.65
IL	0.10	0.60	0.80	**0.70**	**0.70**	1.00	1.00	1.00	0.95	**0.95**
IN	0.10	0.75	0.60	**0.80**	**0.80**	**0.95**	**0.95**	0.95	**0.95**	**0.95**
IA	**0.10**	**0.63**	**0.87**	**0.80**	**0.80**	0.99	0.99	0.99	**0.69**	0.69
KS	**0.05**	**0.75**	0.85	**0.80**	**0.80**	0.95	0.95	0.95	0.75	0.75
KY	0.08	0.70	0.70	0.60	0.60	0.80	0.80	0.80	0.80	0.80
LA	0.00	0.80	0.50	0.80	0.80	1.00	1.00	1.00	0.80	0.80
ME	0.10	0.85	0.80	0.80	0.80	0.90	0.90	0.95	0.95	0.95
MD	0.10	0.85	0.80	0.80	0.80	0.90	0.90	**0.95**	0.95	0.95
MA	0.10	0.85	0.80	0.80	0.80	0.90	0.90	0.95	0.95	0.95
MI	0.08	0.75	**0.90**	0.66	0.66	1.00	1.00	1.00	0.45	0.45
MN	0.15	0.90	**0.90**	**0.85**	**0.85**	**1.00**	**1.00**	1.00	**0.40**	**0.40**
MS	0.10	0.75	0.60	0.65	0.65	0.90	0.90	**0.95**	0.85	0.85
MO	**0.10**	**0.60**	0.65	**0.65**	**0.65**	0.85	0.85	0.90	**0.75**	**0.75**
MT	0.01	0.85	0.75	0.80	0.80	1.00	1.00	1.00	0.90	0.90
NE	**0.08**	**0.90**	0.80	**0.66**	**0.66**	1.00	1.00	1.00	0.64	**0.64**

EXHIBIT 2-2

Fraction of Recoverable Manure, by Animal and by State (Top Ten Producing States Indicated by Bold Font)

State	Beef (Grazing)	Beef (Fattened)	Milk	Swine (Breeding)	Swine (Other)	Laying Hen/Pullet	Pullets (<3 mos.)	Broilers	Turkeys (slaughter)	Turkeys (breeding)
NV	0.05	0.85	0.80	0.85	0.85	0.90	0.90	0.90	0.65	0.65
NH	0.10	0.85	0.80	0.80	0.80	1.00	1.00	1.00	0.95	0.95
NJ	0.10	0.85	0.80	0.80	0.80	0.90	0.90	0.95	0.95	0.95
NM	0.00	0.80	0.85	0.85	0.90	0.90	0.90	0.90	0.65	0.65
NY	0.10	0.85	**0.80**	0.80	0.80	0.90	0.90	0.95	0.95	0.95
NC	0.00	0.75	0.59	**0.90**	**0.90**	**1.00**	**1.00**	**1.00**	**0.99**	**0.99**
ND	0.00	0.85	0.80	0.50	0.50	1.00	1.00	1.00	0.85	0.85
OH	0.10	0.70	**0.90**	**0.75**	**0.75**	**1.00**	**1.00**	1.00	0.70	**0.70**
OK	**0.10**	**0.80**	0.65	0.75	0.75	1.00	1.00	1.00	0.80	0.80
OR	0.05	0.85	0.60	0.85	0.85	0.90	0.90	0.90	0.65	0.65
PA	0.05	0.85	**0.80**	0.80	0.80	**0.95**	**0.95**	0.95	**0.95**	0.95
RI	0.10	0.85	0.80	0.80	0.80	0.90	0.90	0.95	0.95	0.95
SC	0.00	0.80	0.59	0.49	0.49	1.00	1.00	1.00	0.85	**0.85**
SD	**0.10**	**0.75**	0.80	**0.70**	**0.70**	0.95	0.95	0.95	0.80	0.80
TN	0.10	0.75	0.60	0.65	0.65	0.90	0.90	0.95	0.85	0.85
TX	**0.05**	**0.85**	**0.75**	1.00	1.00	**1.00**	**1.00**	**1.00**	**1.00**	0.80
UT	0.05	0.85	0.80	0.85	0.85	0.90	0.90	0.90	0.65	0.65
VT	0.20	0.90	0.90	0.80	0.80	0.90	0.90	0.95	0.95	0.95
VA	0.10	0.85	0.60	0.80	0.80	1.00	1.00	**1.00**	**1.00**	**1.00**
WA	0.05	0.85	**0.80**	0.85	0.85	0.80	0.80	0.80	0.65	0.65
WV	0.00	1.00	0.80	0.75	0.75	1.00	1.00	1.00	1.00	1.00
WI	**0.08**	**0.70**	**0.90**	0.66	0.66	1.00	1.00	1.00	0.70	0.70
WY	0.05	0.80	0.80	0.75	0.75	0.95	0.95	0.95	0.75	0.75

Source: Recoverable fractions are from Lander et al. (1998). Top producing states were identified through the 1992 Census of Agriculture (USDC/Census Bureau, 1994).

Exhibit 2-3 lists the amount of recoverable manure and recoverable nutrients (nitrogen and phosphorus) generated by individual animal sectors (beef, dairy, swine, and poultry operations) throughout the U.S. in 1997. Nationwide, approximately 16 percent of beef manure was recoverable, accounting for 22 percent of total recoverable livestock manure (dry-state). Approximately 76 percent of dairy manure was recoverable, translating to 37 percent of recoverable livestock manure. About 92 percent of swine manure was recoverable, accounting for 13 percent of total recoverable livestock manure. Nationwide, 98 percent of poultry manure was recoverable, representing approximately 27 percent of recoverable livestock manure. These quantities reflect the most recent estimates by USDA of manure generation from livestock and poultry operations, using an approach developed by Lander et al. (1998). The benefits analysis contains additional information on manure production.

EXHIBIT 2-3
Estimated Recoverable Manure and Manure Nutrients Generated by Sector

	1997 Manure Production			
Animal Group	**Recoverable Manure (million lbs)**	**Percent of Total Manure Production That Is Recoverable**	**Recoverable Nitrogen (1,000 lbs)**	**Recoverable Phosphorus (1,000 lbs)**
Beef	28,637	16%	484	340
Dairy	47,476	76%	672	266
Swine	17,120	92%	274	277
Poultry - Total	34,979	98%	1,153	554
Layers	7,101	98%	231	123
Broilers	19,199	98%	616	255
Turkeys	8,679	98%	306	175
Total, all livestock	**128,212**	**44%**	**2,583**	**1,437**

Calculated by USDA/NRCS based on 1997 Census of Agriculture (USDA/NASS, 1999) using procedures in Lander et al. 1998. Numbers are "dry state" (wet basis, adjusted for water content).

Recoverable Nitrogen

Poultry manure has the highest amount of recoverable nitrogen (58 percent), making up 45 percent of all recoverable nitrogen for the sectors under consideration. Dairy manure has the next highest amount of recoverable nitrogen (30 percent), accounting for 26 percent of all recoverable nitrogen for the sectors under consideration. Manure from pork operations had the third highest amount of recoverable nitrogen (23 percent), accounting for 11 percent of the total for these sectors. Beef manure had the lowest ratio of recoverable nitrogen (6 percent), but due to volume this source accounted for 19 percent of the total for all sectors (Lander et al., 1998).

Recoverable Phosphorus

Poultry manure also had the highest amount of recoverable phosphorus (83 percent), making up 39 percent of all recoverable phosphorus. Swine manure had the second highest amount of recoverable phosphorus (78 percent), accounting for 19 percent of the recoverable phosphorus from the sectors considered. Manure from dairy operations ranked third for recoverable phosphorus (66 percent) and generated 19 percent of the recoverable phosphorus from all four sectors. As with nitrogen, beef manure also had the lowest ratio of recoverable phosphorus (14 percent), but due to volume this source ranked second for all sectors with 24 percent (Lander et al., 1998).

2.2 POLLUTANTS OF CONCERN

The primary pollutants associated with animal waste are nutrients (particularly nitrogen and phosphorus), ammonia,[3] pathogens, and organic matter. Animal waste is also a source of salts and trace elements, and to a lesser extent, antibiotics, pesticides, and hormones. The actual composition of manure depends on the animal species, size, maturity, and health, as well as on the composition (e.g., protein content) of animal feed (Phillips et al., 1992). After waste has been excreted, it may be altered further by the bedding and waste feed, and may be diluted with water (Loehr, 1972; USDA, 1992).

The following sections describe the characteristics of each main group of AFO pollutants. The estimates of manure pollutant production are based on average values reported in the scientific literature and compiled by the American Society of Agricultural Engineers (ASAE, 1999), USDA/NRCS (1996), and USDA/ARS (1998).

2.2.1 Nutrients

The three primary nutrients in manure are nitrogen, phosphorus, and potassium. Much of the past research on animal manure has focused on these constituents, given their importance as cropland fertilizers. The following discussions provide more detail on nitrogen and phosphorus characteristics and concentrations in manure. Scientific literature and policy statements commonly cite these two nutrients as key sources of water quality impairments. In the central United States, a 1995 estimate notes that 37 percent of all nitrogen and 65 percent of all phosphorus inputs to watersheds come from manure (USFWS, 2000). Actual or anticipated levels of potassium in ground water and surface water are unlikely to pose hazards to human health or aquatic life (Wetzel, 1983). Potassium does contribute to salinity, however, and applications of high salinity manure are likely to decrease the fertility of the soil.

Exhibit 2-4 presents the amounts of total Kjeldahl nitrogen,[4] total phosphorus, orthophosphorus, and potassium generated per 1,000 pounds live animal weight per day (ASAE, 1999). For comparison, Exhibit 2-4 presents similar information for humans. The figures illustrate that per-pound nutrient output varies among animal types and is much higher for animals than humans.

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[3] Ammonia is also a nutrient but is listed separately here because it exhibits additional environmental effects, such as aquatic toxicity and direct dissolved oxygen demand.

[4] Total Kjeldahl nitrogen is the sum of organic nitrogen in the trinegative oxidation state and ammonia.

EXHIBIT 2-4
Primary Nutrients in Both Livestock and Human Manures

Nutrient	Animal Group						Human
	Swine	Layer	Broiler	Turkey	Beef	Dairy	
Mass of animal (lbs.)	135	4.0	2.0	15	800	1,400	150
Pounds per 1,000 pounds live animal weight per day							
Nitrogen (Total Kjeldahl)	0.52	0.84	1.1	0.62	0.34	0.45	0.20
Phosphorus (Total)	0.18	0.30	0.30	0.23	0.092	0.094	0.02
Orthophosphorus	0.12	0.09	n/a	n/a	0.03	0.061	n/a
Potassium	0.29	0.30	0.40	0.24	0.21	0.29	0.07

Sources: Livestock data are "as excreted" and are from ASAE (1999); human waste data are "as excreted" and are from USDA/NRCS (1996).
Values rounded to two significant figures.
n/a = not available

Nitrogen Compounds

Nitrogen (N) is an essential nutrient required by all living organisms. Nitrogen occurs in the environment in gaseous forms (elemental nitrogen, N_2; nitrogen oxide compounds, N_2O and NO_x; and ammonia, NH_3); water soluble forms (ammonia, NH_3; ammonium, NH_4^+; nitrite, NO_2^-; and nitrate, NO_3^-); and as organic nitrogen, bound up in the proteins of living organisms and decaying organic matter (Brady, 1990). The transformation of the different forms of nitrogen among land, water, air, and living organisms is known as the nitrogen cycle (Exhibit 2-5).

Nitrogen in fresh manure exists primarily in the organic and ammonium forms (NCAES, 1982). Sixty to 90 percent of total nitrogen in fresh manure is in the organic form.[5] 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 ($(NH_2)_2CO$) (USDA, 1992). In organic form, nitrogen is unavailable to plants. However, via microbial processes, organic nitrogen is transformed to ammonium (NH_4^+) and nitrate (NO_3^-) forms, which are bioavailable and therefore have fertilizer value.

Under aerobic conditions, ammonia can oxidize to nitrites and nitrates. Subsequent anaerobic conditions can result in denitrification (transformation of nitrates/nitrites to gaseous nitrogen forms). Overall, depending on the animal type and specific waste management practices, between 30 and 90 percent of nitrogen excreted in manure can be lost before use as a fertilizer (Vanderholm, 1975).

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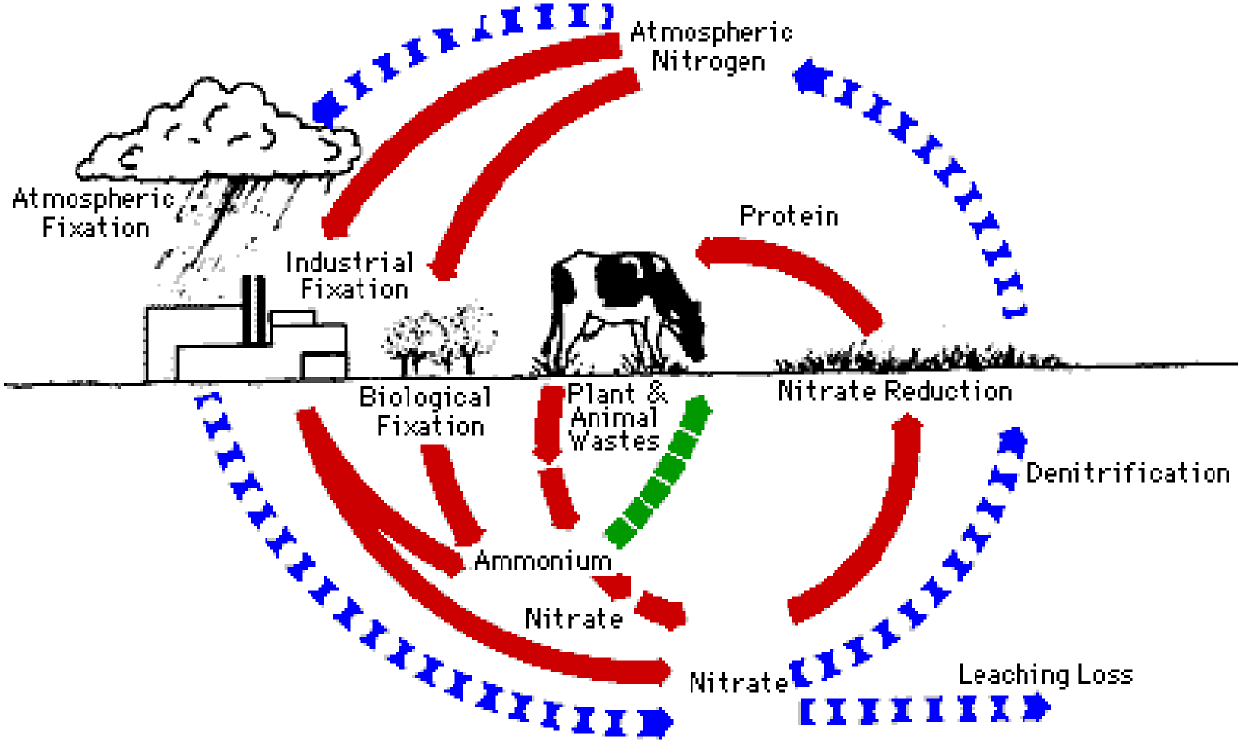
[5] In an anaerobic lagoon, the organic fraction is about 20 to 30 percent of total nitrogen (USDA, 1992).

EXHIBIT 2-5
The Nitrogen Cycle



Source: O'Leary et al., 1997.

Phosphorus Compounds

Phosphorus exists in solid and dissolved phases, in both organic and inorganic forms. Like nitrogen, the various forms of phosphorus are subject to transformation (Exhibit 2-6). Dissolved phosphorus in the soil environment consists of orthophosphates (PO_4^{-3}, HPO_4^{-2}, or $H_2PO_4^{-}$), inorganic polyphosphates, and organic phosphorus (Poultry Water Quality Consortium, 1998). Solid phosphorus exists as organic phosphorus in dead and living materials; mineral phosphorus in soil components; adsorbed phosphorus on soil particles; and precipitate phosphorus, which forms upon reaction with soil cations such as iron, aluminum, and calcium (Poultry Water Quality Consortium, 1998). Orthophosphate species, both soluble and attached, are the predominant forms of phosphorus in the natural environment (Bodek et al., 1988). Soluble (available or dissolved) phosphorus generally accounts for a small percentage of total soil phosphorus. However, soils saturated with phosphorus can have significant occurrences of phosphorus leaching. Soluble phosphorus is the form used by plants and is subject to leaching. About 73 percent of the phosphorus in most types of fresh livestock waste is in the organic form (USDA, 1992). As animal waste ages, the organic phosphorus mineralizes to inorganic phosphate compounds and becomes available to plants.

2.2.2 Ammonia

Ammonium (NH_4^+) is produced when microorganisms break down organic nitrogen products (e.g., urea and proteins in manure). This decomposition can occur in either aerobic or anaerobic environments. In solution, ammonium enters into an equilibrium reaction with ammonia (NH_3), as shown in the following equation:

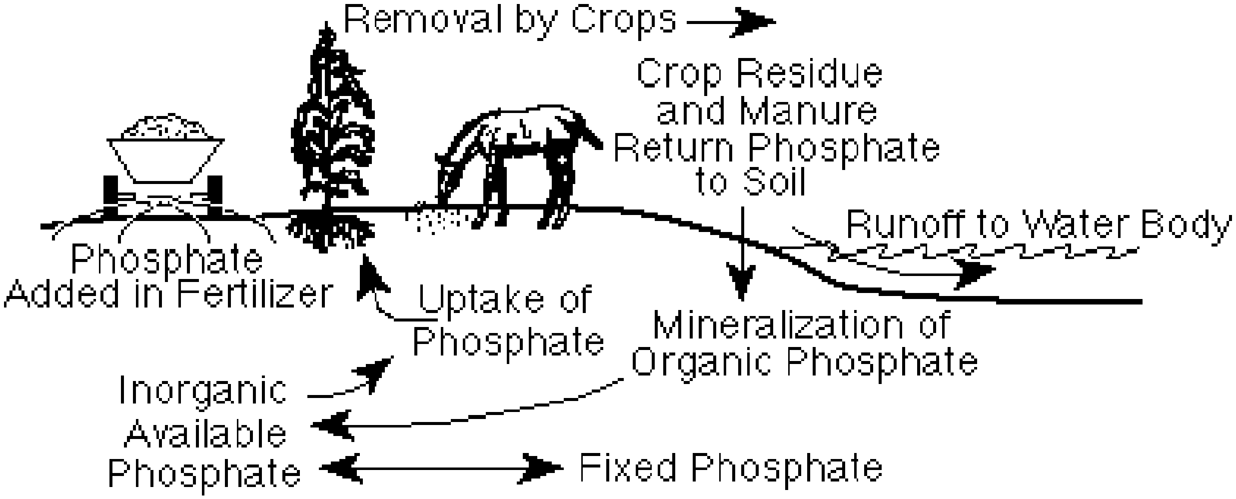
$$NH_4^+ \rightleftarrows NH_3 + H^+$$

Up to 50 percent or more of the nitrogen in fresh manure may be in the ammonia form or converted to ammonia relatively quickly once manure is excreted (Vanderholm, 1975). Ammonia is very volatile, and much of it is emitted as a gas, although it may also be absorbed by or react with other substances.

Higher pH levels (lower H^+ concentrations) favor the formation of ammonia, while lower pH levels (higher H^+ concentrations) favor the formation of ammonium. The ammonia form is subject to volatilization.

The ammonia content of fresh manure varies among animal species and changes as the manure ages. Ammonia content may increase as organic matter breaks down; it may decrease when volatilization occurs or when nitrate oxidizes to nitrite under aerobic conditions.

EXHIBIT 2-6
The Phosphorus Cycle



Source: Busman et al., 1997.

2.2.3 Pathogens

Both manure and animal carcasses can be sources of pathogens (disease-causing organisms) in the environment (Juranek, 1995). Livestock manure may contain bacteria, viruses, fungi, helminths, protozoa, and parasites, many of which are pathogenic (USDA, 1998; Jackson et al., 1987). For example, researchers have isolated pathogenic bacteria and viruses from feedlot wastes (Derbyshire et al., 1966; Hrubant, 1973; Derbyshire and Brown, 1978). In addition, USFWS (2000) has shown fields receiving animal waste applications to have elevated levels of fecal coliforms and fecal streptococci. Specifically, bacteria such as *Escherichia coli* O157:H7, *Salmonella* species, *Campylobacter jejuni, Listeria monocytogenes,* and *Leptospira* species are often found in livestock manure and have also been associated with waterborne disease. A recent study by the USDA revealed that about half the beef cattle presented for slaughter during July and August 1999 carried *Escherichia coli* O157:H7 (Elder et al., 2000). Also, protozoa, including *Cryptosporidium parvum* and *Giardia* species (such as *Giardia lamblia*), may occur in animal waste. *Cryptosporidium parvum* is associated with cows in particular; newborn dairy calves are especially vulnerable to infection and excrete large numbers of the infectious oocysts (USDA, 1998). Most pathogens are shed from host animals with active infections.

Presence of bacteria (and other pathogens) is often measured by the level of fecal coliforms, *Escherichia coli*, or enterococci in manure (Bouzaher et al., 1993). Use of indicator organisms such as these has limitations; specifically, that there are no established relationships between fecal coliform and pathogen contamination. However, indicators are still used because specific pathogen testing protocols are too time consuming, expensive, and/or insensitive to be used for monitoring purposes (Shelton, 2000). Exhibit 2-7 lists the number of total coliform bacteria, fecal coliform bacteria, and fecal streptococcus bacteria per cubic foot of manure for swine, poultry, beef, and dairy animals (ASAE, 1999).

EXHIBIT 2-7
Coliform Bacteria in Manure (colonies per cubic foot of manure, as excreted)

Animal Group	Total Coliform Bacteria	Fecal Coliform Bacteria	Fecal Streptococcus Bacteria
Swine	1.6×10^{11}	5.9×10^{10}	18×10^{11}
Poultry (layers)	4.7×10^{11}	3.2×10^{10}	0.69×10^{11}
Beef	3.2×10^{11}	14×10^{10}	1.5×10^{11}
Dairy	36×10^{11}	5.2×10^{10}	3.0×10^{11}

Source: ASAE (1999).
Values rounded to two significant figures.

2.2.4 Organic Matter

Livestock manures contain many carbon-based, biodegradable compounds. These compounds are of concern in surface water because dissolved oxygen is consumed as aquatic bacteria and other microorganisms decompose these compounds. This process reduces the amount of oxygen available for aquatic animals.

The greater the manure's concentration of materials that can be readily decomposed, the greater the manure's oxygen demand. Two measures are often used to estimate oxygen demand. *Biochemical oxygen demand (BOD)* is an indirect measure of the concentration of biodegradable substances present in an aqueous solution. The ultimate BOD is the amount of oxygen required to completely degrade the waste biologically under aerobic conditions. BOD is often expressed as BOD_5. This measure refers to the amount of oxygen required by bacteria while decomposing organic matter under aerobic conditions over a five-day period at 20°C in a laboratory test. BOD_5 is expressed as the number of milligrams of oxygen required to support oxidation of the compounds in one liter of liquid waste. Alternatively, the *chemical oxygen demand (COD)* test uses a chemical oxidant. This test provides an approximation of the ultimate BOD and can be estimated more quickly than the five days required for the BOD_5 test. If the waste contains only readily available organic bacterial food and no toxic matter, the COD values correlate with BOD values obtained from the same wastes (Dunne and Leopold, 1978).

Exhibit 2-8 lists BOD_5 and COD estimates for manure generated by swine, poultry, beef, and dairy animals and, for comparison, provides values for domestic sewage. Reported BOD_5 values for various untreated animal manures range from 24,000 mg/L to 33,000 mg/L. COD values range from 25,000 mg/L to 260,000 mg/L. Dairy and beef cattle manure have BOD_5 and COD values of similar magnitude. By comparison, the BOD_5 value for raw domestic sewage ranges from 100 mg/L to 300 mg/L. Even after biological treatment in anaerobic lagoons, animal waste BOD_5 concentrations (200 mg/L to 3,800 mg/L) are much higher than those of municipal wastewater treated to the secondary level (about 20 mg/L) (USDA, 1992).

EXHIBIT 2-8
Reported BOD_5 and COD Concentrations for Manures and Domestic Sewage

Waste	BOD_5 (mg/L)	COD (mg/L)
Swine manure		
Untreated	27,000 to 33,000	25,000 to 180,000
Anaerobic lagoon influent	13,000	n/a
Anaerobic lagoon effluent	300 to 3,600	n/a
Poultry manure		
Untreated (chicken)	24,000	100,000 to 260,000
Anaerobic lagoon influent (poultry)	9,800	n/a
Anaerobic lagoon effluent (poultry)	600 to 3,800	n/a
Dairy cattle manure		
Untreated	26,000	68,000 to 170,000
Anaerobic lagoon influent	6,000	n/a
Anaerobic lagoon effluent	200 to 1,200	n/a
Beef cattle manure		
Untreated	28,000	73,000 to 260,000
Anaerobic lagoon influent	6,700	n/a
Anaerobic lagoon effluent	200 to 2,500	n/a
Domestic sewage		
Untreated	100 to 300	400 to 600
After secondary treatment	20	n/a

Sources: Untreated values, except for beef manure BOD_5, are from NCAES (1982). The BOD_5 value for beef manure is from ASAE (1997). Lagoon influent and effluent concentrations are from USDA/NRCS (1996).
Values rounded to two significant figures.
n/a = not available

2.2.5 Salts and Trace Elements

The salinity of animal manure is directly related to the presence of the nutrient potassium and dissolved mineral salts that pass through the animal. In particular, significant concentrations of soluble salts containing the cations sodium and potassium remain from undigested feed that passes unabsorbed through animals (NCAES, 1982). Other major cations contributing to salinity are calcium and magnesium; the major anions are chloride, sulfate, bicarbonate, carbonate, and nitrate (National Research Council, 1993). Salinity tends to increase as the volume of manure decreases during decomposition and evaporation (Gresham et al., 1990).

Trace elements in manure that are of environmental concern include arsenic, copper, selenium, zinc, cadmium, molybdenum, nickel, lead, iron, manganese, aluminum, and boron. Arsenic, copper, selenium, and zinc are often added to animal feed as growth stimulants or biocides (Sims, 1995). Trace elements may also end up in manure through use of pesticides, which farmers apply to livestock to suppress houseflies and other pests (USDA/ARS, 1998).

It is useful to compare trace element concentrations in manure to those in municipal sewage sludge, which is regulated by the EPA's Standards for the Use or Disposal of Sewage Sludge promulgated under the Clean Water Act and published in 40 CFR Part 503 (USEPA, 1993c). Regulated trace elements in sewage sludge include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. Sims (1995) has reported total concentrations of trace elements in animal manures as comparable to those in some municipal sludges, with typical values well below the maximum concentrations allowed by Part 503 for land-applied sewage sludge.

2.2.6 Antibiotics

A number of pharmacological agents, including antibiotics, are used in animal feeding operations and can appear in animal wastes. Some of these agents are used only therapeutically (e.g., to treat illness). Others are used both therapeutically and as feed additives to promote growth or to improve feed conversion efficiency. In 1991, farmers used an estimated 19 million pounds of antibiotics for disease prevention and growth promotion in animals. From 60 to 80 percent of animals receive antibiotics during their productive life span (Tetra Tech, 2000a). Use as feed additives accounts for most of the mass of antibiotics used in both the swine and poultry industries and accounts for the presence of antibiotics in the resulting manure. Although antibiotic residues in beef and dairy manure are also a concern, the EPA could not locate any literature on levels of antibiotics in manure. Estimated concentrations of the antibiotic chlortetracycline in the lagoon systems of a pork producer in Nebraska range from 150 to 300 mg/L; that producer currently uses 16 different antibiotics as feed and drinking water additives (USFWS, 2000).

2.2.7 Hormones

Hormones are the chemical messengers that carry instructions to target cells throughout the body and are normally produced by the body's endocrine glands. The target cells read and follow the hormones' instructions, sometimes building a protein or releasing another hormone. These actions lead to many bodily responses such as a faster heart beat or bone growth. Hormones include steroids (estrogen, progesterone, testosterone), peptides (antidiuretic hormone), polypeptides (insulin), amino acid derivatives (melatonin), and proteins (prolactin, growth hormone). Natural hormones are potent; only very small amounts are needed to cause an effect.

Specific hormones are administered to cattle to increase productivity in the beef and dairy industries, and several studies have shown that hormones are present in animal manures (Mulla, 1999). For example, poultry manure has been shown to contain about 30 ng/g of estrogen, and about the same levels of testosterone (Shore et al., 1995). Also, estrogen was found in concentrations up to 20 ng/L in runoff from fields fertilized with chicken manure (Shore et al., 1995).

2.2.8 Other Pollutants of Concern

AFOs can also be a source of gas emissions, particulates, and pesticides. A general overview of each group of pollutants follows:

- ***Gas emissions.*** The degradation of animal wastes by microorganisms produces a variety of gases. Sources of odor include animal confinement buildings, waste lagoons, and land application sites. In addition to ammonia, which was discussed earlier, three main gases generated from manure are carbon dioxide, methane, and hydrogen sulfide. Aerobic conditions yield mainly carbon dioxide, while anaerobic conditions generate both methane and carbon dioxide. Anaerobic conditions, which dominate in typical, unaerated animal waste lagoons, also generate hydrogen sulfide and over 150 other odorous compounds, including volatile fatty acids, phenols, mercaptans, aromatics, sulfides, and various esters, carbonyls, and amines (O'Neill and Phillips, 1992; USDA, 1992; Bouzaher et al., 1993).

- ***Particulates.*** Sources of particulate emissions from AFOs may include dried manure, feed, epithelial cells, hair, and feathers. The airborne particles make up an organic dust, which includes endotoxin (the toxic protoplasm liberated when a microorganism dies and disintegrates), adsorbed gases, and possibly steroids. At least 50 percent of dust emissions from swine operations may be respirable (Thu, 1995).

- ***Pesticides.*** Pesticides are used in animal feeding operations and can appear in animal wastes. Farmers may use pesticides on crops grown for animal consumption or directly in animal housing areas to control parasites (among other reasons). However, little information is available regarding the concentrations of pesticides in animal wastes or on their bioavailability in waste-amended soils.

2.3 TRANSPORT OF MANURE POLLUTANTS TO SURFACE WATER

Pollutants found in animal manures can reach surface water by several mechanisms. These can be categorized as either surface discharges or other discharges. Surface discharges can result from runoff, erosion, spills, and dry-weather discharges. In surface discharges, the pollutant travels overland or through drain tiles with surface inlets to a nearby stream, river, or lake. Direct contact between confined animals and surface waters is another means of surface discharge. For other types of discharges, the pollutant travels via another environmental medium (ground water or air) to surface water.

2.3.1 Surface Discharges

Runoff

Feedlot runoff contains extremely large loads of nutrients and oxygen-demanding substances, which can severely degrade surface water quality (Mulla, 1999). Water that falls on man-made surfaces or soil and fails to be absorbed will flow across the surface. This process is called runoff. Surface discharges of manure pollutants can originate from feedlots and from overland runoff at land application sites. Runoff is especially likely at open-air feedlots, when rainfall occurs soon after application, and when farmers over-apply or misapply manure. For example, experiments show that for all animal wastes, the application rate has a significant effect on the runoff concentration (Daniel et al., 1995). Other factors that promote runoff to surface waters are steep land slope, high rainfall, low soil porosity or permeability, and close proximity to surface waters. In addition, manure applied to saturated or frozen soils is more likely to run off the soil surface (Mulla, 1999). Runoff of pollutants dissolved into rainwater is a significant transport mechanism for water soluble pollutants, including nitrate, nitrite, and organic forms of phosphorus.

Runoff of manure pollutants has been identified as a factor in a number of documented impacts from AFOs. For example, in 1994, an environmental advocacy group noted multiple runoff problems for a swine operation in Minnesota (Clean Water Action Alliance, 1998), and in 1996, the State of Ohio identified runoff from manure spread on land at several Ohio operations that were feeding swine and chicken (Ohio Department of Natural Resources, 1997). More discussion of runoff and its impacts on the environment and human health appears later in this document.

Erosion

In addition to runoff, surface discharges can occur by erosion, in which the soil surface is worn away by the action of water or wind. Erosion is a significant transport mechanism for land-applied pollutants, such as phosphorus, that are strongly sorbed to soils (Gerritse, 1977).

The USDA Natural Resources Conservation Service (NRCS) reviewed the manure production in a watershed in South Carolina. Agricultural activities in the project area are a major influence on the streams and ponds in the watershed and contribute to nutrient-related water quality problems in the headwaters of Lake Murray. NRCS found that bacteria, nutrients, and sediment from soil erosion are the primary contaminants affecting the waters in this watershed. The NRCS has calculated that soil erosion, occurring on over 13,000 acres of cropland in the watershed, ranges from 9.6 to 41.5 tons per acre per year (USEPA, 1997b).

Spills and Dry-Weather Discharges

Surface discharges can occur through spills or other discharges from lagoons. Catastrophic spills from large manure storage facilities can occur primarily through overflow following large storms or by intentional releases (Mulla et al., 1999). Other causes of spills include pump failures, malfunctions of manure irrigation guns, and breakage of pipes or retaining walls. Manure entering tile drains has a direct route to surface water. (Tile drains are a network of pipes buried in fields below the root zone of plants to remove subsurface drainage water from the root zone to a stream, drainage ditch, or evaporation pond.) In addition, spills can occur as a result of washouts from floodwaters when lagoons are sited on floodplains. There are also indications that discharges from siphoning lagoons occur deliberately as a means to reduce the volume in overfull lagoons (Clean Water Action Alliance, 1998). An independent review of Indiana Department of Environmental Management records indicated that two common causes of waste releases in that state were intentional discharges and accidental discharges resulting from lack of operator knowledge (Hoosier Environmental Council, 1997).

Localities have identified numerous such discharges. The Ohio Department of Natural Resources (ODNR) documented chicken manure traveling through tile drains into a nearby stream in several instances occurring in 1994, 1995, and 1996 (ODNR, 1997). In 1995, a discharge of 25 million gallons of manure from swine farms in North Carolina was documented (Meadows, 1995; NRDC, 1995; Warrick, 1995b). Subsequent discharges of hundreds of thousands of gallons of manure were documented from swine operations in Iowa (1996), Illinois (1997), and Minnesota (1997) (IDNR, 1998; Illinois Stewardship Alliance, 1997; Macomb Journal, 1999; Clean Water Action Alliance, 1998). Between 1994 and 1996, half a dozen discharges from poultry operations in Ohio resulted when manure entered drain tiles (ODNR, 1997). In 1996, more than 40 animal waste spills occurred in Iowa, Minnesota, and Missouri alone (U.S. Senate, 1997). In 1998, a dairy feedlot in Minnesota discharged 125,000 gallons of manure (Clean Water Action Alliance, 1998). Acute discharges of this kind frequently result in dramatic fish kills. For example, fish kills were reported as a result of the North Carolina, Iowa, Minnesota, and Missouri discharges mentioned above.

Direct Contact between Confined Animals and Surface Water

Finally, surface discharges can occur as a result of direct contact between confined animals and the rivers or ponds that are located within their reach. Historically, people located their farms near waterways for both water access by animals and discharge of wastes. Certain animals, particularly cattle, wade into the waterbody, linger to drink, and often urinate and defecate in the water. This practice is now restricted for CAFOs; however, enforcement actions are the primary means for reducing direct access, as described below (McFall, 2000).

In traditional farm production regions of the Midwest and Northeast, dairy barns and feedlots are often in close proximity to streams or other water sources. This close proximity to streams was formerly necessary in order to provide drinking water for the dairy cattle, to cool the animals in hot weather via direct access, and to cool the milk prior to the widespread use of refrigeration. For CAFO-size facilities, this practice is now replaced with more efficient means of providing drinking water for the dairy herd. In addition, the use of freestall barns and modern milking centers minimizes the exposure of dairy cattle to the environment. For example, in New York direct access of animals to surface water is more of a problem for the smaller, traditional dairy farms that use older methods of housing animals. However, at these smaller facilities, direct access to surface water has relatively lower impact on surface water compared with impacts associated with silage leachate and milkhouse waste (Dimura, 2000).

In the arid West, feedlots are typically located near waterbodies to allow for cheap and easy stock watering. Many existing lots were configured to allow the animals direct access to the water. The direct deposition of manure and urine contributes greatly to water quality problems. Environmental problems associated with allowing farm animals access to waters that are adjacent to the production area are well documented in the literature. EPA Region X staff have documented dramatically elevated levels of *Escherichia coli* in rivers downstream of AFOs with direct access to surface water. Recent enforcement actions against direct access facilities have resulted in the assessment of tens of thousands of dollars in civil penalties (McFall, 2000).

2.3.2 Other Discharges to Surface Waters

Leaching to Ground Water

Leaching of land-applied pollutants is a significant transport mechanism for water soluble pollutants. In addition, leaking lagoons are a source of manure pollutants in ground water.

Although manure solids purportedly “self-seal” lagoons to prevent ground water contamination, some studies have shown otherwise. A study for the Iowa legislature published in 1999 indicates that leaking is part of lagoon design standards and that all lagoons should be expected to leak (Iowa State University, 1999). A survey of swine and poultry lagoons in the Carolinas found that nearly two-thirds of the 36 lagoons sampled had leaked into the ground water (Meadows, 1995). Even clay-lined lagoons have the potential to leak, since they can crack or break as they age, and can be susceptible to burrowing worms. In a three-year study of clay-lined swine lagoons on the Delmarva Peninsula, researchers found that leachate from lagoons located in well-drained loamy sand had a severe impact on ground water quality (Ritter and Chirnside, 1990).

Pollutant transport to ground water is also greater in areas with high soil permeability and shallow water tables. Percolating water can transport pollutants to ground water, as well as to surface waters via interflow. Contaminated ground water can deliver pollutants to surface waters through hydrologic connections. Nationally, about 40 percent of the average annual stream flow is from ground water (USEPA, 1993b). In the Chesapeake Bay watershed, the USGS estimates that about half of the nitrogen loads from all sources to nontidal streams and rivers originate from ground water (ASCE, 1998).

Understanding the connection between ground water and surface water is important when developing surface water protection strategies, because ground water moves much more slowly than surface water. For example, ground water in the Chesapeake Bay region takes an average of 10 to 20 years to reach the Bay; thus, it may take several decades to realize the full effect of pollutant additions or reductions (ASCE, 1998).

Discharge to the Air and Subsequent Deposition

Atmospheric deposition can be a significant mechanism of transport to surface waters, as nitrogen emissions to air can return to terrestrial or aquatic environments in dry form or dissolved in precipitation (Agricultural Animal Waste Task Force, 1996). Discharges to air can occur as a result of volatilization of pollutants already present in the manure, and of pollutants generated as the manure decomposes. Ammonia is very volatile and can have significant impacts on water quality through atmospheric deposition (Aneja et al., 1998). Ammonia losses from animal feeding operations can be considerable, arising from manure piles, storage lagoons, and land application fields. Other ways that manure pollutants can enter the air are from spray application methods for land applying manure and from particulates wind-borne in dust.

The degree of volatilization of manure pollutants is dependent on the manure management system. For example, losses are greater when manure remains on the land surface rather than being incorporated into the soil and are particularly high when farmers perform spray application. Environmental conditions such as soil acidity and moisture content also affect the extent of volatilization. Losses are reduced by the presence of growing plants (Follett, 1995).

Once airborne, pollutants can find their way into nearby streams, rivers, and lakes. The 1998 *National Water Quality Inventory* indicates that atmospheric deposition is the third largest cause of water quality impairment for estuaries and the fifth largest cause of water quality impairment for lakes, ponds, and reservoirs (USEPA, 2000a).

2.3.3 Pollutant-specific Transport

Nitrogen Compounds

Livestock waste can contribute up to 37 percent of total nitrogen loads to surface water (Mulla, 1999). Nitrogen compounds and nitrates in manure can reach surface water through several pathways. As suggested by Follett (1995), agricultural nitrate contributions to surface water are primarily from ground water connections and other subsurface flows. Although potentially less significant, overland runoff can also carry nitrate to surface waters. A recent Iowa investigation of chemical and microbial contamination near large-scale swine operations demonstrated the presence of nitrate and nitrite not only in manure lagoons used to store swine waste before it is land applied, but also in drainage ditches, agricultural drainage wells, tile line inlets and outlets, and an adjacent river (CDCP, 1998).

Studies of small geographical areas have revealed evidence of nitrate contamination in ground water. As of 1988, 40 percent of wells in the Chino Basin, California, had nitrate levels in excess of the MCL; USEPA (1993b) identified dairy operations as the major source of contamination. This presents potentially widespread impacts, since water from the Chino Basin is used to recharge the primary source of drinking water for residents of heavily populated Orange County. On the Delmarva peninsula, in Maryland, where poultry production is dominant, over 15 percent of wells were found to have nitrate levels exceeding the MCL. Wells located close to chicken houses contained the highest median nitrate concentrations (Ritter et al., 1989). Measured nitrate levels in ground water beneath Delaware poultry houses are as high as 100 mg/L (Ritter et al., 1989).

Elevated nitrate levels can also exist in surface waters, although these impacts are typically less severe than ground water impacts. In a historical assessment, USGS (1997) found that nitrate levels in streams in agricultural areas were elevated compared to undeveloped areas. Nevertheless, the in-stream nitrate concentrations were generally less than those for ground water in similar locations, and the drinking water MCL was rarely exceeded. The primary exception to this pattern was in the Midwest, where poorly drained soils restrict water percolation and artificial drainage provides a quick path for nutrient-rich runoff to reach streams (USGS, 1997).

When farmers apply manure to land as fertilizer, risk of nitrate pollution generally increases at higher rates of nitrogen application. Even when farmers land apply manure at agronomic rates, nitrogen transport to surface water 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 the manure application method (e.g., drip irrigation, spray irrigation, knifing, etc.); and (7) transport is affected by uncontrollable environmental factors such as rainfall and other local conditions (Follett, 1995).

Phosphorus Compounds

Phosphorus can reach surface waters via discharges directly into surface water and runoff of manure to surface water from feedlots, and via runoff and erosion from land application sites. The organic phosphorus compounds in manure are generally water soluble and subject to leaching and dissolution in runoff (Gerritse, 1977). Once in receiving waters, these compounds can undergo transformation and become available to aquatic plants. Overall, land-applied phosphorus is less mobile than nitrogen, since the mineralized (inorganic phosphate) form is easily adsorbed to soil particles. A report by the Agricultural Research Service noted that phosphorus bound to eroded sediment particles makes up 60 to 90 percent of phosphorus transported in surface runoff from cultivated land (USDA/ARS, 1999). For this reason, most agricultural phosphorus control measures have focused on soil erosion control to limit transport of particulate phosphorus. However, soils do not have infinite phosphate adsorption capacity, and dissolved inorganic phosphates can still enter waterways via runoff even if soil erosion is controlled (National Research Council, 1993).

Livestock waste can contribute up to 65 percent of total phosphorus loads in surface waters (Mulla, 1999). Animal wastes typically have lower N:P ratios than crop N:P requirements, such that application of manure at a nitrogen-based agronomic rate can result in application of phosphorus at several times the agronomic rate (Sims, 1995). Summaries of soil test data in the United States confirm that many soils in areas dominated by animal-based agriculture have excessive levels of phosphorus (Sims, 1995). Research also indicates that there is a potential for phosphorus to leach into ground water through sandy soils with already high phosphorus content (Citizens *Pfiesteria* Action Commission, 1997).

Ammonia

Ammonia can reach surface waters in a number of ways, including discharge directly to surface waters, leaching, dissolution in surface runoff, erosion, and atmospheric deposition. Leaching and runoff are generally not significant transport mechanisms for ammonia compounds in land-applied manure, because ammonium can be sorbed to soils (particularly those with high cation exchange capacity), incorporated (fixed) into clay or other soil complexes, or transformed into organic form by soil microbes (Follett, 1995). However, in these forms, erosion can transport nitrogen to surface waters. A recent Iowa investigation of chemical and microbial contamination near large-scale swine operations demonstrated the presence of ammonia not only in manure lagoons used to store swine waste before it is land applied, but also in drainage ditches, agricultural drainage wells, tile line inlets and outlets, and an adjacent river (CDCP, 1998).

Ammonia losses from animal feeding operations to the air and subsequent deposition to surface waters can be considerable, arising from sources such as manure piles, storage lagoons, and land application fields. For example, in North Carolina, animal agriculture is responsible for over 90 percent of all ammonia emissions (Aneja et al., 1998). Ammonia composes more than 40 percent of the total estimated nitrogen emissions from all sources (Aneja et al., 1998). Furthermore, data from Sampson County, North Carolina, indicate that ammonia levels in rain have increased with increases in the size of the pork industry. Levels more than doubled between 1985 and 1995 (Aneja et al., 1998). Based on EPA estimates, swine operations in eastern North

Carolina were responsible for emissions of 135 million pounds of nitrogen per year as of 1995. If deposited in a single basin, this would result in nitrogen loadings of almost 2.1 million pounds of nitrogen per year (Nowlin et al., 1997).

Pathogens

Sources of pathogen contamination from AFOs include surface discharges and lagoon leachate. Surface runoff from land application fields can be a source of pathogen contamination, particularly if a rainfall event occurs soon after application or if the land is frozen or snow-covered (Mulla, 1999). Researchers have reported concentrations of bacteria in runoff water from fields treated with poultry litter at several orders of magnitude above contact standards (Giddens and Barnett, 1980; Coyne and Blevins, 1995).

A recent Iowa investigation of chemical and microbial contamination near large-scale swine operations demonstrated the presence of pathogens not only in manure lagoons used to store swine waste before it is land applied, but also in drainage ditches, agricultural drainage wells, tile line inlets and outlets, and an adjacent river (CDCP, 1998). Also, studies have reported that lands receiving fresh manure application can be the source of up to 80 percent of the fecal bacteria in surface waters (Mulla, 1999). Similarly, both *Cryptosporidium parvum* and *Giardia* species have also been found in over 80 percent of 66 surface water sites tested (LeChevallier et al., 1991). Since these protozoa do not multiply outside of the host, livestock animals are one potential source of this contamination. The bacterium *Erysipelothrix* spp., primarily a swine pathogen, has been isolated from many fish and avian species (USFWS, 2000).

High levels of indicator bacteria in surface water near CAFOs have been documented. For instance, Zirbser (1998) documented a report of fecal coliform counts of 3,000/100 ml and fecal streptococci counts over 30,000/100 ml downstream from a swine waste lagoon site. (No sampling was performed upstream of the lagoon site.) Fecal coliform pollution from treated and partially treated sewage and storm water runoff is often cited in beach closures and shellfish restrictions.

The natural filtering and adsorption action of soils typically causes a majority of the microorganisms in land-applied manure to be stranded at the soil surface (Crane et al., 1980). This phenomenon helps protect underlying ground water but increases the likelihood of runoff losses to surface waters. Pathogens discharged to the water column can subsequently adsorb to sediments, presenting a long-term health hazard. Benthic sediments harbor significantly higher concentrations of bacteria than the overlying water column (Mulla, 1999). When the bottom stream is disturbed, as when animals have direct access to a stream, the sediment releases bacteria back into the water column (Sherer et al., 1988, 1992).

While surface waters are typically more prone to pathogen contamination than ground waters, subsurface flows may also be a mechanism for pathogen transport depending on weather, site, and operating conditions. Ground waters in areas of sandy soils, limestone formations, or sinkholes are particularly vulnerable. For example, the bacteria *Clostridium perfringens* was detected in the ground water below plots of land treated with swine manure, and fecal coliform has been detected in ground water beneath soil amended with poultry manure (Mulla, 1999). In

1998, *Campylobacter jejuni* was isolated from ground water, and some of the strains were the same type as those from a dairy farm in the same hydrologic area (Stanley et al., 1998).

There are other accounts of high levels of micoorganisms in ground water near feedlots. In cow pasture areas of Door County, Wisconsin, where a thin topsoil layer is underlain by fractured limestone bedrock, ground water wells have commonly been shut down due to high bacteria levels (Behm, 1989). For example, a well at one rural household produced brown, manure-laden water (Behm, 1989). Private wells are more prone to contamination than public wells, since they tend to be shallower and therefore more susceptible to contaminants leaching from the surface. In a survey of drinking water standard violations in six states over a four-year period, the U.S. General Accounting Office (USGAO, 1997) found that bacterial standard violations occurred in 3 to 6 percent of community water systems each year.[6] By contrast, USGAO reported that some bacterial contamination occurred in 15 to 42 percent of private wells, according to statistically representative assessments performed by others.[7]

Several factors affect the likelihood of disease transmission by pathogens in animal manure, including pathogen survivability in the environment. For example, *Salmonella* can survive in the environment for nine months or more, providing for increased dissemination potential (USFWS, 2000); and *Campylobacter* can remain dormant, making water an important vehicle for campylobacteriosis (Altekruse, 1998). Recent studies are better characterizing the survivability and transport of pathogens in manure once it has been land applied. Several researchers (Dazzo et al., Himathongkham et al., 1999; Kudva et al., 1998; Maule, 1999; Van Donsel et al., 1967) found that soil type, manure application rate, temperature, moisture level, aeration, soil pH, and the amount of time that manure is held before it is applied to pastureland are dominating factors in bacteria survival.

Experiments on land-applied poultry manure (Crane et al., 1980) indicated that the population of fecal organisms decreases rapidly as manure is heated, dried, and exposed to sunlight on the soil surface. However, regrowth of fecal organisms also occurred in these experiments. More recent research indicated that pathogens can survive in manure for 30 days or more (Himathongkham et al., 1999; Kudva et al., 1998; Maule, 1999). Kudva found that *Escherichia coli* survived for 47 days in aerated cattle manure piles that were exposed to outdoor weather; drying the manure reduced the number of viable pathogens. Stehman (2000) also notes that *Escherichia coli* O157:H7, *Cryptosporidium parvum,* and *Giardia* can survive and remain infectious in surface waters for a month or more.

The continued application of waste on a particular area could lead to extended pathogen survival and buildup (Dazzo et al., 1973). Additionally, repeated applications and/or high application rates increase the likelihood of runoff to surface water and transport to ground water.

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[6] GAO reviewed compliance data from 1993 through 1996, from more than 17,000 community water systems, in California, Illinois, Nebraska, New Hampshire, North Carolina, and Wisconsin.

[7] The 15 percent figure is from a 1996 study of Nebraska wells by the Nebraska Department of Health and University of Nebraska; the 42 percent figure is from the EPA National Statistical Assessment of Rural Water Conditions (1984).

Organic Matter

Discharge and runoff of manure from feedlots cause large loadings of organic matter to surface waters. There have been numerous incidents of discharges from AFOs nationwide directly to surface waters (see Chapter 4). Discharges can also originate from land application sites when farmers over-apply or misapply manure. Even if farmers apply manure such that there is not a concentrated discharge, organic matter will be present in runoff from land application sites. As shown by Daniel et al. (1995), runoff of organic matter increases as application rate increases.[8] For example, Daniel et al. (1995) reported that when the swine manure slurry application rate increased from 193 lb N/acre to 387 lb N/acre,[9] COD levels in runoff (generated from a rainfall intensity of 2 inches/hour) increased from 282 mg/L to 504 mg/L. By comparison, runoff from a control plot yielded 78 mg/L COD.

Salts and Trace Elements

Salts can reach surface waters via discharges from feedlots and runoff from land application sites. Salts can also leach into ground water and subsequently reach surface water. Trace elements can also be transported by these mechanisms. A recent Iowa investigation showed that trace elements were present not only in manure lagoons used to store swine waste before land application, but also in drainage ditches, agricultural drainage wells, tile line inlets and outlets, and an adjacent river (CDCP, 1998). Selenium concentrations have been detected in swine manure lagoons at up to 6 µg/L, copper has been detected in liquid swine manure prior to land application at 15 mg/L, and zinc has been detected in soils that receive applications of cattle manure at levels up to 9.5 mg/kg in the upper 60 centimeters of soil (USFWS, 2000).

Antibiotics

Little information is available regarding the fate and transport properties of antibiotics, or the potential releases from animal waste compared to other sources such as municipal and industrial wastewaters, septic tank leachate, runoff from land-applied sewage sludge, crop runoff, and urban runoff. However, it is known that the primary mechanisms of eliminating antibiotics from livestock are through urine and bile. Also, essentially all of an antibiotic administered to an animal is eventually excreted, whether unchanged or in metabolite form (Tetra Tech, 2000a).

Although the presence of excreted antibiotics themselves may be of concern, the development of antibiotic-resistant pathogens due to exposure to environmental levels of antibiotics is generally of greater concern. The risk for development of antibiotic-resistant pathogens from this exposure is unknown.

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[8] In a series of experiments, Edwards and Daniel (1992b, 1993a,b, as reported by Daniel et al., 1995) measured runoff from fescue grass plots treated with poultry litter, poultry manure slurry, and swine manure slurry to determine how runoff quality is impacted by application rate and rain intensity. They found that for all wastes, the application rate had a significant effect on the runoff concentration and mass loss of COD (as well as other constituents).

[9] EPA assumes that 175 lb N/acre is a typical requirement for a fescue crop in Arkansas, based on information from U.S. Department of Agriculture extension agents (Tetra Tech, 2000b).

Hormones

Hormones can reach surface waters through the same routes as other manure pollutants, including runoff and erosion as well as direct contact of animals with the water. Considering specific hormones used, however, estrogen is more likely to be lost by runoff than leaching, while testosterone is lost mainly through leaching (Shore et al., 1995).

Several sites have documented the presence of hormones in runoff and surface waters. For example, runoff from a field receiving poultry litter was found to contain estrogen. Also, an irrigation pond and three streams in the Conestoga River watershed near the Chesapeake Bay had both estrogen and testosterone. Each of these sites were affected by fields receiving poultry litter (Shore et al., 1995). Runoff from fields with land-applied manure has been reported to contain estrogens, estradiol, progesterone, and testosterone, as well as their synthetic counterparts. Estrogens have also been found in runoff from heavily grazed land (Addis et al., 1999).

Other Pollutants

There has been almost no research on losses of pesticides in runoff from manured lands. A 1999 literature review by the University of Minnesota discussed a 1994 study showing that losses of cyromazine (used to control flies in poultry litter) in runoff increased with the rate of poultry manure application and the intensity of rainfall. The 1999 literature review also includes a 1995 study documenting that about 1 percent of all pesticides enter surface water. However, the magnitude of the impacts of these losses on surface water are unknown (Mulla, 1999). In general, little information is available regarding the fate and transport of pesticides or their bioavailability in waste-amended soils. Furthermore, there is little information comparing potential releases of these compounds from animal waste to other sources such as municipal and industrial wastewaters, septic tank leachate, runoff from land-applied sewage sludge, crop runoff, and urban runoff.

3. POTENTIAL HAZARDS FROM AFO POLLUTANTS

As described in Chapter 2, animal feeding operations are associated with a variety of pollutants, including nutrients (specifically nitrogen and phosphorus), ammonia, pathogens, organic matter, salts, trace elements, solids, antibiotics, hormones, gas and particulate emissions, and pesticides. These AFO pollutants can produce multimedia impacts, such as the following:

- ***Surface water.*** Impacts have been associated with surface discharges of waste, as well as leaching to ground water and subsurface flow to surface water. Generally, states with high concentrations of feedlots experience 20 to 30 serious water quality pollution problems per year involving manure lagoon spills and feedlot runoff (Mulla, 1999). The waste's oxygen demand and ammonia content can result in fish kills and reduced biodiversity. Solids can increase turbidity and impact benthic organisms. Nutrients contribute to eutrophication and associated algae blooms. Algal decay and nighttime respiration can depress dissolved oxygen levels, potentially leading to fish kills and reduced biodiversity. Eutrophication is also a factor in blooms of toxic algae and other toxic microorganisms, such as *Pfiesteria piscicida*. Human and animal health impacts are primarily associated with drinking contaminated water (pathogens and nitrates), coming into contact with contaminated water (pathogens such as toxic algae and *Pfiesteria*), and consuming contaminated shellfish (pathogens such as toxic algae). Trace elements (e.g., arsenic, copper, selenium, and zinc) may also present human health and ecological risks. Salts contribute to salinization and disruption of ecosystem balance, as well as degradation of drinking water supplies. Antibiotics, pesticides, and hormones may have low-level, long-term ecosystem effects.

- ***Ground water.*** Impacts have been associated with pollutants leaching to ground water. Human and animal health impacts are associated with pathogens and nitrates in drinking water. Leaching salts can increase health risks to salt-sensitive individuals, and can make the water unpalatable. Trace elements, antibiotics, pesticides, and hormones may also present human health and ecological risks through ground water pathways.

- ***Air.*** Air impacts include human health effects from ammonia, hydrogen sulfide, other odor-causing compounds, particulates, and the contribution to global climate change due to methane emissions. In addition, volatilized ammonia can be redeposited on the earth and contribute to eutrophication.

- ***Soil.*** Trace elements and salts in animal manure can accumulate in soil and become toxic to plants. Salts also deteriorate soil quality by leading to reduced permeability and overall poor physical condition. Crops may provide a human and animal exposure pathway for trace elements and pathogens.

This chapter describes in greater detail the known or potential adverse human health and ecological effects of AFO pollutants.

3.1 PRIMARY NUTRIENTS

This section reviews the hazards posed by primary nutrients in animal manure. It focuses on nitrogen and phosphorus, which have received the greatest attention in the scientific literature. Actual or anticipated levels of potassium in ground water and surface water are unlikely to pose hazards to aquatic life or human health (Wetzel, 1983). Potassium does contribute to salinity, however, and applications of high salinity manure are likely to decrease the fertility of the soil.

3.1.1 Ecology

Eutrophication

Eutrophication is the process in which phosphorus and nitrogen over-enrich a waterbody and disrupt the balance of life in that waterbody. Perhaps the most documented impact of nutrient pollution is the increase in surface water eutrophication (nutrient enrichment) and its effects on aquatic ecosystems (Vallentyne, 1974). Although nutrients are essential for the growth of phytoplankton (free-floating algae), periphyton (attached algae), and aquatic plants, which form the base of the aquatic food web, the overabundance of nutrients can lead to harmful algal blooms and other adverse effects, such as:

- Increased biomass of phytoplankton;
- Shifts in phytoplankton to bloom-forming species that may be toxic or inedible;
- Changes in macrophyte species composition and biomass;
- Death of coral reefs and loss of coral reef communities;
- Decreases in water transparency;
- Taste, odor, and water treatment problems;
- Oxygen depletion;
- Increased incidence of fish kills;
- Loss of desirable fish species;
- Reductions in harvestable fish and shellfish; and
- Decreases in aesthetic value of the waterbody (Carpenter et al., 1998).

The type of waterbody impacted may dictate which nutrient (nitrogen or phosphorus) will have the most impact. In estuaries and coastal marine waters, nitrogen is typically the limiting nutrient (i.e., in these waters, phosphorus levels are sufficiently high compared to nitrogen such that small changes in nitrogen concentrations have a greater effect on plant growth). In fresh waters, phosphorus is typically the limiting nutrient (Wendt and Corey, 1980; Robinson and Sharpley, 1995). There can be exceptions to this generalization, however, especially in waterbodies with heavy pollutant loads. For example, estuarine systems may become phosphorus-limited when nitrogen concentrations are high. In such cases, excess phosphorus will produce algal blooms (North Carolina’s Nicholas School of the Environment's Agricultural Animal Waste Task Force, 1994). Thus, both nitrogen and phosphorus loads can contribute to eutrophication in either water type.

Algae and Other Toxic Microorganisms

Eutrophication causes the enhanced growth and subsequent decay of algae, which can lower dissolved oxygen content of a waterbody to levels insufficient to support fish and invertebrates. In some cases, this situation can produce large areas devoid of life because of a lack of sufficient dissolved oxygen. One extreme example is the "Dead Zone," an area of hypoxic water larger than 10,000 km^2 that spreads off the Louisiana coast in the Gulf of Mexico each summer. The Dead Zone is believed to be caused by excess chemical fertilizer; however, nutrients from animal waste have also contributed to the problem. This condition has been attributed to excess nutrients delivered primarily by the Mississippi and Atchafalaya river systems (Atwood et al., 1994). The problem in the Gulf demonstrates that pollutant discharges can have far-reaching downstream impacts. In fact, the nutrient loadings to the Gulf originate from sources over a large land area covering approximately 41 percent of the conterminous United States (Goolsby et al., 1999).

Eutrophication can also affect phytoplankton and zooplankton population diversity, abundance, and biomass, and increase the mortality rates of aquatic species. For example, floating algal mats can prevent sunlight from reaching submerged aquatic vegetation, which serves as habitat for fish spawning, juvenile fish, and fish prey (e.g., aquatic insects). The resulting decrease in submerged aquatic vegetation adversely affects both fish and shellfish populations (USEPA, 2000a).

Another effect of eutrophication is increased incidence of harmful algal blooms, which release toxins as they die and can severely impact wildlife as well as humans. In marine ecosystems, blooms known as red or brown tides have caused significant mortality in marine mammals (Carpenter et al., 1998). In fresh water, cyanobacterial toxins have caused many incidents of poisoning of wild and domestic animals that have consumed impacted waters (Health Canada Environmental Health Program, 1998). Published reports of wildlife poisoning from these blooms include amphibians, fish, snakes, waterfowl, raptors, and deer (USFWS, 2000).

Eutrophication is also associated with blooms of other toxic organisms, such as the estuarine dinoflagellate *Pfiesteria piscicida*. *Pfiesteria* has been implicated as the primary causative agent of many major fish kills and fish disease events in North Carolina estuaries and coastal areas (NCSU, 2000), as well as in Maryland and Virginia tributaries to the Chesapeake Bay (USEPA, 1997b). *Pfiesteria* often lives as a nontoxic predatory animal, becoming toxic in response to human influences including excessive nutrient enrichment (NCSU, 2000). While nutrient-enriched conditions are not required for toxic outbreaks to occur, excessive nutrient loadings are a concern because they help create an environment rich in microbial prey and organic matter that *Pfiesteria* uses as a food supply. By increasing the concentration of *Pfiesteria*, nutrient loads increase the likelihood of a toxic outbreak when adequate numbers of fish are present (Citizens *Pfiesteria* Action Commission, 1997). Researchers have documented stimulation of *Pfiesteria* growth by human sewage and swine effluent spills and have shown that the organism's growth can be highly stimulated by both inorganic and organic nitrogen and phosphorus enrichments (NCSU, 2000).

Increased algal growth can also raise the pH of waterbodies, as algae consume dissolved carbon dioxide to support photosynthesis. Many biological processes, including reproduction, cannot function in water that is very acidic or alkaline (USEPA, 2000a).

Nitrites

Nitrites can also pose a risk to aquatic life: if sediments are enriched with nutrients, the concentrations of nitrites in the overlying water may be raised enough to cause nitrite poisoning or "brown blood disease"[10] in fish (USDA, 1992). In addition, excess nitrogen can contribute to water quality decline by increasing the acidity of surface waters.

3.1.2 Human Health

Nitrates/Nitrites

The main hazard to human health from primary nutrients is elevated nitrate levels in drinking water. In particular, infants are at risk from nitrate poisoning (also referred to as methemoglobinemia or "blue baby syndrome"), which can be fatal. This poisoning results in oxygen starvation and is due to nitrite (a metabolite of nitrate), which is formed in the environment, foods, and the human digestive system. Compared to adults and older children, infants under six months experience elevated nitrite production because their digestive systems have a higher concentration of nitrate-reducing bacteria. Nitrite oxidizes iron in the hemoglobin of red blood cells to form methemoglobin, which cannot carry sufficient oxygen to the body's cells and tissues. Although methemoglobin is continually produced in humans, an enzyme in the human body reduces methemoglobin back to hemoglobin. In most individuals, this conversion occurs rapidly. Infants, however, have a low concentration of methemoglobin-reducing enzyme, as do individuals with an enzyme deficiency. In these people, methemoglobin is not converted to hemoglobin as readily (Nebraska Cooperative Extension, 1995).

Because infants under six months have a higher concentration of digestive bacteria that reduce nitrates, and a lower concentration of methemoglobin-reducing enzyme, they are at higher risk for methemoglobinemia (Nebraska Cooperative Extension, 1995). To protect infant health, the EPA set drinking water Maximum Contaminant Levels (MCLs) of 10 mg/L for nitrate-nitrogen and 1 mg/L for nitrite-nitrogen. MCLs are the maximum permissible levels of pollutants allowed in water delivered to public drinking water systems. Once a water source is contaminated, the costs of protecting consumers from nitrate exposure can be significant. Nitrate is not removed by conventional drinking water treatment processes. Its removal requires additional, relatively expensive treatment units.

Although reported cases of methemoglobinemia are rare, the incidence of actual cases may be greater than the number reported. Studies in South Dakota and Nebraska have indicated that most cases of methemoglobinemia are not reported (Michel et al., 1996; Meyer, 1994). For example, in South Dakota between 1950 and 1980, only two cases were reported, while at least

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[10] Brown blood disease is named for the color of the blood of dead or dying fish, indicating that the hemoglobin has been converted to methemoglobin.

80 were estimated to have occurred (Meyer, 1994). There are at least two reasons for this underreporting. First, methemoglobinemia can be difficult to detect in infants because its symptoms are similar to other conditions (Michel et al., 1996). In addition, doctors are not always required to report it (Michel et al., 1996).

In addition to blue baby syndrome, low blood oxygen due to methemoglobinemia has also been linked to birth defects, miscarriages, and general poor health in humans and animals. These effects are exacerbated by concurrent exposure to many species of bacteria in water (IRIS, 2000). Studies in Australia found an increased risk of congenital malformations with consumption of high-nitrate ground water (Bruning-Fann and Kaneene, 1993). Multi-generation animal studies have found decreases in birth weight, post-natal growth, and organ weights among mammals prenatally exposed to nitrite (IRIS, 2000). Nitrate- and nitrite-containing compounds may also cause hypotension or circulatory collapse (Bruning-Fann and Kaneene, 1993).

High nitrate levels in drinking water have also been implicated in higher rates of stomach and esophageal cancer, although a 1995 National Research Council report concludes that exposure to nitrate and nitrite concentrations in drinking water are unlikely to contribute to human cancer risks (National Research Council, 1995). However, nitrate metabolites such as N-nitroso compounds (especially nitrosamines) have been linked to severe human health effects such as gastric cancer (Bruning-Fann and Kaneene, 1993). The formation of N-nitroso compounds occurs in the presence of catalytic bacteria (e.g., those found in the stomach) or thiocyanate.

Generally, people drawing water from domestic wells are at greater risk of nitrate poisoning than those drawing from public wells (Nolan and Ruddy, 1996), since domestic wells are typically shallower and not subject to wellhead protection or monitoring requirements. Reported cases of methemoglobinemia are most often associated with wells that were privately dug and that may have been badly positioned in relation to the disposal of human and animal excreta (Addiscott et al., 1991). Furthermore, people served by public systems are better protected even if the water becomes contaminated, due to water quality monitoring and treatment requirements.

Phosphorus

Animal manure also contributes to increased phosphorus concentrations in water supplies. Previous evaluations of phosphorus have not identified significant adverse human health effects, but phosphate levels greater than 1.0 mg/L may interfere with coagulation in drinking water treatment plants and thereby increase treatment costs (North Carolina’s Nicholas School of the Environment's Agricultural Animal Waste Task Force, 1994).

Eutrophication/Algal Blooms

To the extent that nitrogen and phosphorus contribute to algal blooms in surface water through accelerated eutrophication as described in Section 3.1.1, these nutrients can reduce the aesthetic and recreational value of surface water resources. Algae can affect drinking water by clogging treatment plant intakes, producing objectionable tastes and odors. Algae can also increase production of harmful chlorinated byproducts (e.g., trihalomethanes) by reacting with chlorine used to disinfect drinking water. These impacts result in increased costs of drinking water treatment, reduced drinking water quality, and/or increased health risks.

Eutrophication can also affect human health by enhancing growth of harmful algal blooms that release toxins as they die. In marine ecosystems, harmful algal blooms such as red tides can result in human health impacts via shellfish poisoning and recreational contact (Thomann and Mueller, 1987). In fresh water, blooms of cyanobacteria (blue-green algae) may pose a serious health hazard to humans via water consumption. When cyanobacterial blooms die or are ingested, they release water-soluble compounds that are toxic to the nervous system and liver (Carpenter et al., 1998).

In addition, eutrophication is associated with blooms of a variety of other organisms that are toxic to humans, such as the estuarine dinoflagellate *Pfiesteria piscicida.* While *Pfiesteria* is primarily associated with fish kills and fish disease events, the organism has also been linked with human health impacts through dermal or inhalation exposure. Researchers working with dilute toxic cultures of *Pfiesteria* exhibited symptoms such as skin sores, severe headaches, blurred vision, nausea/vomiting, sustained difficulty breathing, kidney and liver dysfunction, acute short-term memory loss, and severe cognitive impairment (NCSU, 2000). People with heavy environmental exposure have exhibited symptoms as well. In a 1998 study, such environmental exposure was definitively linked with cognitive impairment and less consistently linked with physical symptoms (Morris et al., 1998).

3.2 AMMONIA

3.2.1 Ecology

Ammonia exerts a direct biochemical oxygen demand (BOD) on the receiving water. As ammonia is oxidized, dissolved oxygen is consumed. Moderate depressions of dissolved oxygen are associated with reduced species diversity, while more severe depressions can produce fish kills. In fact, ammonia is a leading cause of fish kills (USDA, 1992). Ammonia-induced fish kills are a potential consequence of the discharge of animal wastes directly to surface waters. For example, in a May 1997 incident in Wabasha County, Minnesota, ammonia in a dairy cattle manure discharge killed 16,500 minnows and white suckers (Clean Water Action Alliance, 1998). Additionally, ammonia loadings can contribute to accelerated eutrophication of surface waters, which can significantly impact aquatic ecosystems in a number of ways, as noted above.

3.2.2 Human Health

Ammonia is a nutrient form of nitrogen that can have several impacts. First, volatilized ammonia is of concern because of direct localized impacts on air quality. Ammonia produces an objectionable odor and can cause nasal and respiratory irritation.

In addition, ammonia contributes to eutrophication of surface waters. This phenomenon is primarily a hazard to aquatic life but is also associated with human health impacts (see Section 3.1.2). As previously mentioned, eutrophication reduces the aesthetic and recreational value of water bodies. Additionally, the associated algae blooms can affect drinking water by clogging treatment plant intakes, producing objectionable tastes and odors, and increasing production of harmful chlorinated byproducts. These impacts result in increased drinking water treatment costs, reduced drinking water quality, and/or increased health risks. Eutrophication can also impact human health by enhancing the growth of toxic algae and other toxic organisms.

3.3 PATHOGENS

3.3.1 Ecology

Animal wastes carry parasites, bacteria, and viruses, many of which have the potential to be harmful to wildlife (USDA, 1992; Jackson et al., 1987). Some bacteria in livestock waste cause avian botulism and avian cholera, which have killed thousands of migratory waterfowl in the past (USEPA, 1993b). Avian botulism is a food poisoning caused by ingestion of a neurotoxin produced by the bacterium *Clostridium botulinum* type C., and *Salmonella* spp, both of which naturally occur in the intestinal tract of warm-blooded animals (USFWS, 2000).

Pathogens in surface water can adhere to the skin of fish or be taken up internally when present at high enough concentrations. In a controlled experiment, Fattal et al. (1992) detected significant bacterial concentrations in fish exposed to *Escherichia coli* and other microorganisms for up to 48 hours. The data suggest that harmful pathogens could be taken up by fish-eating carnivores feeding in contaminated surface waters.

Shellfish are filter feeders that pass large volumes of water over their gills. As a result, they can concentrate a broad range of microorganisms in their tissues (Chai et al., 1994). This provides a pathway for pathogen transmission to higher trophic organisms. However, little information is available to assess the health effects of contaminated shellfish on wildlife receptors.

3.3.2 Human Health

Pathogens may be transmitted to humans through contaminated surface water or ground water used for drinking, or by direct contact with contaminated surface water through recreational uses. By the year 2010, about 20 percent of the human population (especially infants, the elderly, and those with compromised immune systems) will be classified as particularly vulnerable to the health effects of pathogens (Mulla, 1999). Over 150 pathogens in livestock manure are associated with risks to humans (CAST, 1992). Exhibit 3-1 presents a list of several of these pathogens and their associated diseases, including salmonellosis, cryptosporidiosis, and giardiasis. Other pathogens that have been associated with livestock waste include those that cause cholera, typhoid fever, and polio (USEPA, 1993b). Many of these pathogens are transmitted to humans via the fecal-oral route. In the water environment, humans may be exposed to pathogens through consumption of contaminated drinking water (although the EPA assumes adequate drinking water treatment of public supplies), or by incidental ingestion during recreational activities in contaminated waters.

EXHIBIT 3-1
Some Diseases and Parasites Transmittable to Humans from Animal Manure [a]

Disease	Responsible Organism	Symptoms
Bacteria		
Anthrax	*Bacillus anthracis*	Skin sores, fever, chills, lethargy, headache, nausea, vomiting, shortness of breath, cough, nose/throat congestion, pneumonia, joint stiffness, joint pain
Brucellosis	*Brucella abortus*, *Brucella melitensis*, *Brucella suis*	Weakness, lethargy, fever, chills, sweating, headache
Colibaciliosis	*Escherichia coli* (some serotypes)	Diarrhea, abdominal gas
Coliform mastitis-metritis	*Escherichia coli* (some serotypes)	Diarrhea, abdominal gas
Erysipelas	*Erysipelothrix rhusiopathiae*	Skin inflammation, rash, facial swelling, fever, chills, sweating, joint stiffness, muscle aches, headache, nausea, vomiting
Leptospirosis	*Leptospira pomona*	Abdominal pain, muscle pain, vomiting, fever
Listeriosis	*Listeria monocytogenes*	Fever, fatigue, nausea, vomiting, diarrhea
Salmonellosis	*Salmonella* species	Abdominal pain, diarrhea, nausea, chills, fever, headache
Tetanus	*Clostridium tetani*	Violent muscle spasms, "lockjaw" spasms of jaw muscles, difficulty breathing
Tuberculosis	*Mycobacterium tuberculosis, Mycobacterium avium*	Cough, fatigue, fever, pain in chest, back, and/or kidneys
Rickettsia		
Q fever	*Coxiella burneti*	Fever, headache, muscle pains, joint pain, dry cough, chest pain, abdominal pain, jaundice
Viruses		
Foot and Mouth	virus	Rash, sore throat, fever
Swine Cholera	virus	
New Castle	virus	
Psittacosis	virus	Pneumonia
Fungi		
Coccidioidomycosis	*Coccidioides immitus*	Cough, chest pain, fever, chills, sweating, headache, muscle stiffness, joint stiffness, rash, wheezing
Histoplasmosis	*Histoplasma capsulatum*	Fever, chills, muscle ache, muscle stiffness, cough, rash, joint pain, joint stiffness
Ringworm	Various *microsporum* and *trichophyton*	Itching, rash
Protozoa		
Balantidiasis	*Balatidium coli*	

EXHIBIT 3-1
Some Diseases and Parasites Transmittable to Humans from Animal Manure [a]

Disease	Responsible Organism	Symptoms
Coccidiosis	*Eimeria* species	Diarrhea, abdominal gas
Cryptosporidiosis	*Cryptosporidium parvum*	Watery diarrhea, dehydration, weakness, abdominal cramping
Giardiasis	*Giardia lamblia*	Diarrhea, abdominal pain, abdominal gas, nausea, vomiting, headache, fever
Toxoplasmosis	*Toxoplasma* species	Headache, lethargy, seizures, reduced cognitive function
Parasites/Metazoa		
Ascariasis	*Ascaris lumbricoides*	Worms in stool or vomit, fever, cough, abdominal pain, bloody sputum, wheezing, skin rash, shortness of breath
Sarcocystiasis	*Sarcosystis* species	Fever, diarrhea, abdominal pain

Sources: Diseases and organisms were compiled from USDA/NRCS (1996) and USEPA (1998). Symptom descriptions were obtained from various medical and public health service Internet sites.

[a] Pathogens in animal manure are a potential source of disease in humans and other animals. This list represents a sampling of diseases that may be transmittable to humans.

Although a wide range of organisms may cause disease in humans, relatively few microbial agents are responsible for the majority of human disease outbreaks from water-based exposure routes. This point is illustrated by Exhibit 3-2, which presents reports of waterborne disease outbreaks and their causes (if known) in the United States for the period 1989-1996. Intestinal infections are the most common type of waterborne infection, and affect the most people.

As presented in Exhibit 3-2, most reported outbreaks were associated with protozoa and bacteria. As noted in Exhibit 3-1, *Cryptosporidium parvum* can produce gastrointestinal illness, with symptoms such as severe diarrhea. Relatively low doses of both *Cryptosporidium parvum* as well as *Giardia* species are needed to cause infection (Stehman, 2000). Although healthy people typically recover relatively quickly (within 2 to 10 days) from this type of illness, these diseases can be fatal in people with weakened immune systems. These individuals typically include children, the elderly, people with human immunovirus (HIV) infection, chemotherapy patients, and those taking medications that suppress the immune system.

EXHIBIT 3-2
Etiology of Waterborne Disease Outbreaks Causing Gastroenteritis 1989-1996

Type of Organism	Etiologic Agent	Total Number of Outbreaks	Outbreaks Associated with Drinking Water		Outbreaks Associated with Recreational Water	
			Surface	Ground	Natural	Pool/ Park
Protozoa	*Giardia spp.*	27	12	6	4	5
	Cryptosporidium parvum	21	4	4	2	11
Bacteria with Potential for Infecting Multiple Species	*Escherichia coli* O157:H7	11	-	3	7	1
	Campylobacter jejuni	3	3	-	-	-
	Salmonella typhimurium	1	-	1	-	-
	Salmonella java	1	-	-	-	1
	Leptospira grippotyphosa	1	-	-	1	-
Bacterial Infections Associated with Humans	*Shigella sonnei*	17	-	7	10	-
	Shigella flexneri	2	-	1	1	-
Human viruses	Hepatitis A	3	-	-	-	3
	Norwalk virus	1	-	1	-	-
	Norwalk-like virus	1	-	-	-	1
	Small round structured virus	1	1	-	-	-
Acute Gastroenteritis	Unidentified etiology-many consistent with viral epidemiology	60	8	44	7	1
Other	Cyanobacteria-like bodies	1	1	-	-	-

Source: Stehman, 2000.

Exhibit 3-2 shows that infections caused by *Giardia* species and *Cryptosporidium parvum* (considered the two most important waterborne protozoa) were the leading causes of infectious waterborne disease outbreaks in which an agent was identified, both for total cases and for number of outbreaks (Mulla, 1999; Stehman, 2000). In 1993 in Milwaukee, Wisconsin, *Cryptosporidium parvum* contamination of a public water supply caused more than 100 deaths and an estimated 403,000 illnesses (Smith, 1994; Casman, 1996). The outbreak cost an estimated $37 million in lost wages and productivity (Smith, 1994). The source of the oocysts was not identified, but speculated sources include runoff from cow manure application sites, wastewater from a slaughterhouse and meat packing plant, and municipal wastewater treatment plant effluent (Casman, 1996). Four documented cases of cryptosporidiosis occurring since 1984 have been linked to non-point source agricultural pollution (Mulla, 1999). Two outbreaks of *Cryptosporidium parvum* were also traced to contamination of drinking water by cow manure in England (Stehman, 2000).

The mandated treatment of public water supplies helps reduce the risk of infection via drinking water, but the first step in providing safe drinking water is source water protection, especially because *Cryptosporidium parvum* is resistant to conventional treatment.

Escherichia coli is an important cause of bacterial waterborne infection in untreated and recreational water (Stehman, 2000). Infection can be life-threatening, especially in the young and in the elderly. It can cause bloody diarrhea and, if not treated promptly, can result in kidney failure and death (Shelton, 2000). In particular, *Escherichia coli* O157:H7 is emerging as the second most important cause of bacterial waterborne disease after *Shigella* species, which is associated with human feces. *Escherichia coli* O157:H7 was unknown until 1982, when it was associated with a multistate outbreak of hemorrhagic colitis (Shelton, 2000). In 1999, an *Escherichia coli* outbreak occurred at the Washington County Fair in New York State. This outbreak was possibly the largest waterborne outbreak of *Escherichia coli* O157:H7 in U.S. history. It took the lives of two fair attendees and sent 71 others to the hospital. An investigation identified 781 persons with confirmed or suspected illness related to this outbreak. The outbreak is thought to have been caused by contamination of the Fair's Well 6 by either a dormitory septic system or manure runoff from the nearby Youth Cattle Barn (NYSDOH, 2000). More recently, in May 2000, an outbreak of *Escherichia coli* O157:H7 in Walkerton, Ontario resulted in at least seven deaths and 1,000 cases of intestinal problems; public health officials theorize that one possible cause was floodwaters washing manure contaminated with *Escherichia coli* into the town's drinking water well; an investigation is currently underway (Brooke, 2000). An outbreak of *Escherichia coli* O157:H7 was reported in Canada from well water potentially contaminated by manure runoff (Stehman, 2000).

Cow manure has specifically been implicated as a causative factor in the high bacteria levels and ensuing swimming restrictions on Tainter Lake, Wisconsin (Behm, 1989). Contact recreation can result in infections of the skin, eye, ear, nose, and throat (Juranek, 1995; Stehman, 2000). The EPA's recommended ambient water quality standard for human health protection in contact-recreational fresh waters is either 120 *Escherichia coli* bacteria/100 ml, or 33 enterococcus bacteria/100 ml. (This standard, finalized in 1986, replaces the previous standard of 200 fecal coliform bacteria/100 ml.) About 8 percent of U.S. outbreaks of *Escherichia coli* O157:H7 between the years 1982 and 1996 occurred as a result of swimming (Griffin, 1998). Certain regions, in particular, may be adversely impacted. For example, pathogen impairment of surface waters is a great problem in most rural areas of southern Minnesota. This causes many rivers and lakes to be unsuitable for swimming (Mulla, 1999).

Most human infections caused by bacteria such as *Escherichia coli* O157:H7, *Salmonella* species, Campylobacter jejuni, and *Leptospira* species are spread by foodborne or direct contact (Stehman, 2000). Many pathogens might be transmitted through shellfish (Stelma and McCabe, 1992), which are filter feeders prone to accumulating bacteria and viruses. Others may be transmitted through inhalation. In particular, there is concern that pathogens may also be introduced to the air directly from animal feeding houses or during spray application of wastes. Flies and other vectors also present potential pathways for disease transmission.

A final concern is exposure to pathogens via consumption of raw foods improperly subjected to manure application. Cieslak et al. (1993) suggest that a 1993 *Escherichia coli* outbreak in Maine was the result of manure applications to a vegetable garden. Additionally, three *Escherichia coli* outbreaks (Montana in 1995, Illinois in 1996, and Connecticut in 1996) were traced to organic lettuce growers. It is suspected that the lettuces were contaminated by infected cattle manure (Nelson, 1997). In another incident in Maine, a few hundred children were sickened by *Cryptosporidium parvum*. The source was fresh-pressed apple cider made from apples gathered from a cattle pasture (Millard et al., 1994). Although this exposure route can cause health problems, the proposed revisions to the EPA regulations do not attempt to address it directly.

3.4 ORGANIC MATTER

3.4.1 Ecology

Increased organic matter loading to surface waters supports increased microbial population and activity; as these organisms aerobically degrade the organic matter, dissolved oxygen is consumed, reducing the amount available for aquatic organisms. This impact is exacerbated in warm waters compared to colder waters, because the dissolved oxygen saturation level is lower and because the higher temperatures support increased microbial metabolism.

As a result of dissolved oxygen depletion, aquatic species may suffocate (USEPA, 1993a) or be driven out of areas that lack sufficient oxygen. This phenomenon can occur rapidly, particularly with loadings of high-strength waste such as those that may result from catastrophic lagoon breaches (Goldman and Horne, 1983). There are many examples nationwide of fish kills resulting from manure discharges from animal feeding operations (see Chapter 4). In Nebraska in 1995, 50 percent of all agriculture-related fish kills investigated were due to livestock waste. In 1996, that percentage rose to 75 percent. In 1997 and 1998, 100 percent of agriculture-related fish kills were traced to livestock waste (USFWS, 2000).

Oxygen-stressed aquatic systems may also experience decreases in species richness or community structure as sensitive species are driven out or die off. Organisms living in borderline hypoxic (low oxygen) water are also likely to experience physiological stress, which may increase the potential for diseases, decrease feeding rates, or increase predation. Livestock has been widely reported to cause significant decreases in wildlife species and numbers (Mulla et al., 1999). For example, reduction in biodiversity due to AFOs has been documented in a study of three Indiana stream systems (Hoosier Environmental Council, 1997). That study shows that waters downstream of animal feedlots (mainly swine and dairy operations) contained fewer fish and a limited number of species of fish in comparison with reference sites. Excessive algal growth; altered oxygen content; and increased levels of ammonia, turbidity, pH, and total dissolved solids were also observed.

High oxygen depletion rates due to microbial activity have been reported in manure-amended agricultural soils as well. In soils, elevated microbial populations can affect crop growth by competing with plant roots for soil oxygen and nutrients (USDA, 1992).

3.4.2 Human Health

The release of organic matter to surface waters is a human health concern insofar as it can impact drinking water sources and recreational waters. As aquatic bacteria and other microorganisms degrade organic matter in manure, they consume dissolved oxygen. This can lead to foul odors and ecological impacts, reducing the water’s value as a source of drinking water and recreation. Additionally, increased organic matter in drinking water sources can lead to excessive production of harmful chlorinated byproducts, resulting in higher drinking water treatment costs and/or higher health risks. Pathogen growth is another concern, as large inflows of nutrient-rich organic matter, under the right environmental conditions, can cause rapid increases in microbial populations.

3.5 SALTS AND TRACE ELEMENTS

3.5.1 Ecology

Salts in manure can impact the water and soil environment. In fresh waters, increasing salinity can disrupt the balance of the ecosystem. Drinking water high in salt content was shown to inhibit growth and cause slowed molting in mallard ducklings (IEC, 1993). On land, salts can accumulate and become toxic to plants, and reduce crop yields. Salts can damage soil quality by reducing permeability and deteriorating soil structure (Bloom, 1999).

Trace elements in manure can impact plants, aquatic organisms, and terrestrial organisms. While many of the trace elements are essential nutrients at low concentrations, they can have significant ecotoxicological effects at elevated concentrations. For example, metals such as zinc (a feed additive) can accumulate in soil and become toxic to plants at high concentrations. Arsenic, copper, and selenium are other feed additives that can produce aquatic and terrestrial toxicity at elevated concentrations. Bottom feeding birds can be quite susceptible to metal toxicity because they are attracted to shallow feedlot wastewater ponds and waters adjacent to feedlots. Metals can remain in aquatic ecosystems for long periods of time because of adsorption to suspended or bed sediments or uptake by aquatic biota.

Several of the trace elements in manure are regulated in treated municipal sewage sludge (but not manure) by the Clean Water Act’s Part 503 Rule. Total concentrations of trace elements in animal manures have been reported as comparable to those in some municipal sludges, with typical values well below the maximum concentrations allowed by Part 503 for land-applied sewage sludge (Sims, 1995). Based on this information, trace elements in agronomically applied manures should pose little risk to human health and the environment. However, repeated application of manures above agronomic rates could result in exceedances of the cumulative metal loading rates established in Part 503, thereby potentially impacting human health and the environment (USFWS, 1991).

In 1991, the U.S. Fish and Wildlife Service (USFWS) reported on suspected impacts from a large number of cattle feedlots on Tierra Blanca Creek, upstream of the Buffalo Lake National Wildlife Refuge in the Texas Panhandle. USFWS found elevated concentrations of the feed additives copper and zinc in the creek sediment (as well as elevated aqueous concentrations of ammonia, chemical oxygen demand, chlorophyll *a,* coliform bacteria, chloride, conductivity, total Kjeldahl nitrogen, and volatile suspended solids). The relative contribution of these contaminants from various sources (e.g., runoff from facilities without containment lagoons, lagoon discharges, and lagoon leachate) was not assessed (USFWS, 1991).

In 1998, USFWS found copper and zinc in wetlands fed by wastewater from a nearby swine production operation in Nebraska. Concentrations of copper exceeded both a proposed aquatic life criterion of 43 µg/L and the current least-protective criterion of 121 µg/L. Zinc concentrations exceeded the concentrations recommended for the protection of aquatic life (USFWS, 2000).

3.5.2 Human Health

Salts from manure can impact surface and ground water drinking water sources. Salt load into the Chino Basin from local dairies is over 1,500 tons per year, and the cost to remove that salt by the drinking water treatment system ranges from $320 to $690 for every ton (USEPA, 1993b). At lower levels, salts can increase blood pressure in salt-sensitive individuals, increasing the risk of stroke and heart attack. Salts can also make drinking water unpalatable and unsuitable for human consumption.

Some of the trace elements in manure are essential nutrients required for human physiology; however, they can induce toxicity at elevated concentrations. These include zinc, arsenic, copper, and selenium, which are feed additives (Sims, 1995). Although these elements are typically present in relatively low concentrations in manure, they are of concern because of their ability to persist in the environment and to bioconcentrate in plant and animal tissues. These elements could pose a hazard if manure is overapplied to land, due to insufficient acreage available to accommodate manure from increasingly concentrated AFOs. Over-applied manure increases the likelihood of pollutants reaching surface water and ultimately being ingested.

Trace elements are associated with a variety of illnesses. For example, arsenic is carcinogenic to humans, based on evidence from human studies; some of these studies have found increased skin cancer and mortality from multiple internal organ cancers in populations who consumed drinking water with high levels of inorganic arsenic. Arsenic is also linked with non-cancer effects, including hyperpigmentation and possible vascular complications. Selenium is associated with liver dysfunction and loss of hair and nails, and zinc can result in changes in copper and iron balances, particularly copper deficiency anemia (IRIS, 2000).

3.6 SOLIDS

Excessive silting and sedimentation are prime agents responsible for the long-term degradation of rivers, streams, and lakes. Major sources of siltation include runoff from agricultural, urban, and forest lands and other non-point sources (USEPA, 1992b).

Solids entering surface water can degrade aquatic ecosystems to the point of non-viability. Suspended particles can reduce the depth to which sunlight can reach, decreasing photosynthetic activity (and the resulting oxygen production) by plants and phytoplankton. The increased turbidity also limits the growth of desirable aquatic plants that serve as critical habitat for fish, crabs, and other aquatic organisms. In addition, suspended particles can clog fish gills, degrade feeding areas, and reduce visibility for sight feeders (Abt Associates, 1993), and can disrupt migration by interfering with fish's ability to detect chemical communication signals in water (Goldman and Horne, 1983). Sediment can smother eggs, interrupt the reproductive process, and alter or destroy habitat for fish and benthic organisms.

Solids can also degrade drinking water sources, thereby increasing treatment costs. Furthermore, solids provide a medium for the accumulation, transport, and storage of other pollutants, including nutrients, pathogens, and trace elements. Sediment-bound pollutants often have a long history of interaction with the water column through cycles of deposition, resuspension, and redeposition.

3.7 ANTIBIOTICS AND ANTIBIOTIC RESISTANCE

Antibiotic-resistant strains of bacteria develop as a result of continual exposure to antibiotics. Use of antibiotics in raising animals, especially broad spectrum antibiotics, is increasing. As a result, more strains of antibiotic-resistant pathogens are emerging, along with strains that are increasingly resistant (Mulla, 1999). Antibiotic-resistant forms of *Salmonella, Campylobacter, Escherichia coli,* and *Listeria* are known or suspected to exist. An antibiotic-resistant strain of the bacterium *Clostridium perfringens* was detected in the ground water below plots of land treated with swine manure, while it was nearly absent beneath unmanured plots.

Antibiotic resistance poses a significant health threat. In April 2000 the New England Journal of Medicine published an article that discussed the case of a 12-year-old boy infected with a strain of *Salmonella* that was resistant to no fewer than 13 antimicrobial agents (Fey et al., 2000). The cause of the child's illness is believed to be exposure to the cattle on his family's Nebraska ranch.

The Centers for Disease Control and Prevention, the Food and Drug Administration, and the National Institutes of Health issued a draft action plan in June 2000 to address the increase in antibiotic resistant diseases (CDCP, 2000). The plan is intended to combat antimicrobial resistance through surveys, prevention and control activities, research, and product development. One of the action items involves conducting pilot studies to assess the impact of environmental contamination by antimicrobial drug residues and drug-resistant organisms that enter the soil or water from human and animal waste.

3.8 HORMONES AND ENDOCRINE DISRUPTION

The presence of estrogen and estrogen-like compounds in surface water has caused much concern. Their ultimate fate in the environment is unknown, although early studies indicate that no common soil or fecal bacteria can metabolize estrogen (Shore et al., 1995). When present in high concentrations, hormones in the environment are linked to reduced fertility, mutations, and the death of fish, and there is evidence that fish in some streams are experiencing endocrine disruption (Shore et al., 1995; Mulla, 1999).

Estradiol, an estrogen hormone, was found in runoff from a field receiving poultry litter at concentrations up to 3.5 µg/L. Fish exposed to 0.25 µg/L of estradiol often have gender changes; exposures at levels above 10 µg/L can be fatal (Mulla, 1999). Estrogen levels of 10 µg/L have been shown to affect trout (Shore et al., 1995).

Endocrine disruptors have also been the subject of increasing concern because they alter hormone pathways that regulate reproductive processes in both human and animal populations. Estrogen hormones have been implicated in the drastic reduction in sperm counts among European and North American men (Sharpe and Skakkebaek, 1993) and widespread reproductive disorders in a variety of wildlife (Colburn et al., 1993). A number of agricultural chemicals have also been demonstrated to cause endocrine disruption as well, including pesticides (Shore et al., 1995). The effects of these chemicals on the environment and their impacts on human health through environmental exposures are not completely understood. They are currently being studied for neurobiological, developmental, reproductive, and carcinogenic effects (Tetra Tech, 2000a). The EPA is not aware of any studies done on the human health impact of hormones from watersheds that have impairment from animal manure.

3.9 OTHER POLLUTANTS OF CONCERN

3.9.1 Gas Emissions

Odor sources include animal confinement buildings, waste lagoons, and land application sites. As animal waste decomposes, various gases are produced. The primary gases associated with aerobic decomposition include carbon dioxide and ammonia. Gases associated with anaerobic conditions, which dominate in typical, unaerated animal waste lagoons, include methane, carbon dioxide, ammonia, hydrogen sulfide, and over 150 other odorous compounds (USDA, 1992; Bouzaher et al., 1993; O’Neill and Phillips, 1992). These include volatile fatty acids, phenols, mercaptans, aromatics, sulfides, and various esters, carbonyls, and amines. The decomposition process is desirable because it reduces the biochemical oxygen demand and pathogen content of the waste. However, many of the end products can produce negative impacts, including strong odors. Heavy odors are the most common complaint from neighbors of swine operations in particular (Agricultural Animal Waste Task Force, 1996).

Odor is itself a significant concern because of its documented effect on moods, such as increased tension, depression, and fatigue (Schiffman et al., 1995). Odor also has the potential for vector attraction and affects property values. Additionally, many of the odor-causing compounds can cause physical health impacts. For example, hydrogen sulfide is toxic, and ammonia gas is a nasal and respiratory irritant.

In 1996, the Minnesota Department of Health found levels of hydrogen sulfide gas at residences near AFOs that were high enough to cause symptoms such as headaches, nausea, vomiting, eye irritation, respiratory problems (including shallow breathing and coughing), achy joints, dizziness, fatigue, sore throats, swollen glands, tightness in the chest, irritability, insomnia, and blackouts (Addis et al., 1999). In an Iowa study, neighbors within two miles of a 4,000-sow swine facility reported more physical and mental health symptoms than a control group (Thu, 1998). These symptoms included chronic bronchitis, hyperactive airways, mucus membrane irritation, headache, nausea, tension, anger, fatigue, and confusion.

Methane and carbon dioxide are greenhouse gases that contribute to global warming. Methane also contributes to the formation of tropospheric ozone (a component of photochemical smog). Based on various EPA estimates (USEPA, 1989 and USEPA, 1992a), methane emissions from U.S. animal wastes are a very small contributor to the global warming effect.

3.9.2 Particulates

Sources of particulate emissions from AFOs may include dried manure, feed, skin, hair, and possibly bedding. The airborne particles make up an organic dust, which includes endotoxin (the toxic protoplasm liberated when a microorganism dies and disintegrates), adsorbed gases, and possibly steroids (Thu, 1995). At least 50 percent of dust emissions from swine production facilities are believed to be respirable. The main impact downwind appears to be respiratory irritation due to the inhalation of organic dusts. Studies indicate that the associated microbes generally are not infectious, but may induce inflammation (Thu, 1995).

3.9.3 Pesticides

Pesticides may pose risks to the environment, such as chronic aquatic toxicity, and human health effects, such as systemic toxicity. In a few studies, common herbicides have been shown to cause endocrine disruption. There is some evidence that fish in some streams are experiencing endocrine disruption and that contaminants including pesticides may be the cause (Mulla, 1999).