Appendix IV. Environmental Data Summary

Environmental Impacts of Animal Feeding Operations

ENVIRONMENTAL IMPACTS OF ANIMAL FEEDING OPERATIONS

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EXECUTIVE SUMMARY

According to EPA's 1996 *National Water Quality Inventory*, agricultural operations, including animal feeding operations (AFOs), are a significant source of water pollution in the U.S. States estimate that agriculture contributes to the impairment of at least 173,629 river miles, 3,183,159 lake acres, and 2,971 estuary square miles. Twenty-two states reported on the impacts of specific types of agriculture on rivers and streams, attributing 20 percent of the agricultural impairment to intensive animal operations. In addition, NOAA reports that feedlots were a contributing factor in 110 of the 3,404 impaired shellfish areas in 1995. These findings, as well as incidents of waste spills, excessive runoff, leaking storage lagoons, and odor problems, have heightened public awareness of environmental impacts from AFOs.

Manure is the primary source of pollution from AFOs. It is much more abundant than human waste. Estimates indicate that U.S. animal waste production in 1992 was 13 times greater (on a dry-weight basis) than human sanitary waste production. Sources of manure pollution include direct discharges, open feedlots, pastures, treatment and storage lagoons, manure stockpiles, and land application fields. Oxygen-demanding substances, ammonia, nutrients (particularly nitrogen and phosphorus), solids, pathogens, and odorous compounds are the pollutants most commonly associated with manure. Manure is also a source of salts and trace metals, and to a lesser extent, antibiotics, pesticides, and hormones. Animal waste 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. This problem has been magnified as the industry has become more concentrated.

AFO pollutants can impact surface water, groundwater, air, and soil. In surface water, the waste's oxygen demand and ammonia content can result in fish kills and reduced biodiversity. Solids can increase turbidity and smother benthic organisms. Nitrogen and phosphorus can contribute to eutrophication and associated algae blooms. These blooms can produce negative aesthetic impacts and increase drinking water treatment costs. 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 the algae (as well as night-time algal respiration) can lead to depressed oxygen levels, which can result in fish kills and reduced biodiversity. Eutrophication is also a factor in blooms of toxic algae and other toxic estuarine microorganisms, such as *Pfiesteria piscicida*. These organisms can impact human health as well as animal health. Human and animal health can also be impacted by pathogens and nitrogen in animal waste. Nitrogen in manure is easily transformed into nitrate form; transport to drinking water sources can result in potentially fatal health risks to infants. Trace elements in manure may also present human and ecological risks. Salts can contribute to salinization and disruption of the ecosystem. Antibiotics, pesticides, and hormones may have low-level, long-term ecosystem effects.

In groundwater, pathogens and nitrates from manure can impact human health via drinking water. Additionally, leaching salts may cause groundwaters to become unsuitable for human consumption. Nitrate contamination is more prevalent in groundwaters than surface waters.

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 drinking water wells.

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

Air emissions from AFOs also produce environmental impacts. Odors from anaerobic waste decomposition are particularly offensive. Odors can produce mental health impacts, and many odor-causing substances (e.g., ammonia, hydrogen sulfide, and organic dusts) can also cause physical impacts. 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 contribute to global warming.

Nutrients are a major source of impairment of U.S. waters. Several studies have focused on nutrient contribution from animal waste and other sources (e.g., point sources, commercial fertilizers, atmospheric deposition, and urban runoff). In many watersheds, animal waste represents a significant portion of the total nutrients added. In several counties, nutrients from confined animals exceed the uptake potential of non-legume harvested cropland and hayland, according to a USDA analysis of 1992 conditions. USDA found that recoverable manure nitrogen exceeds crop system needs in 266 of 3,141 counties, and that recoverable manure phosphorus exceeds crop system needs in 485 counties. The USDA analysis is not intended to represent actual manure management practices or transport of applied nutrients, and cannot be used to indicate the presence or absence of water quality problems. However, it is useful as a general indicator of excess nutrients on a broad-scale basis.

Transport factors were considered in a national modeling effort by the USGS. Modeling of 1987 conditions indicates that animal manure (from all livestock, not just confined animals) is a significant contributor to in-stream nutrient concentrations in watershed outlets. Per the estimates, manure is a greater contributor than point sources to in-stream total nitrogen in 1,802 (88%) of the 2,056 watershed outlets in the U.S. Additionally, manure is the single largest contributor to total nitrogen in 113 watersheds. USGS also found that manure is a significant contributor to in-stream total phosphorus concentrations, noting that livestock waste is a greater contributor than commercial fertilizer.

1. INTRODUCTION

1.1 Background - A National Perspective

Agricultural operations, including animal feeding operations (AFOs), are a significant source of water pollution in the United States. The latest *National Water Quality Inventory* (EPA, 1997) indicates that agriculture (including crop production, pastures, rangeland, feedlots, animal holding areas, and other animal feeding operations) is the leading contributor to water quality impairments in the Nation's rivers and lakes, and the fifth leading contributor to water quality impairments in the Nation's estuaries. Table 1-1 presents the leading sources of impairment in waters that have been identified as impaired. Table 1-2 presents a summary of the water body quantities that have been surveyed, identified as impaired by any source, and impaired specifically by agriculture. The portion of impairment attributable to animal agriculture nationwide is unknown, though twenty-two states did report on the impacts of specific types of agriculture on rivers and streams. These states reported that 20 percent of the agricultural impairment to rivers and streams is from intensive animal operations (including feedlots, animal holding areas, and other animal operations), and that 23 percent of the agricultural impairment is from rangeland and pastureland. The impairment due to land application of manure was not estimated. These findings indicate that AFOs (as well as grazing and range animals) are a significant environmental concern across the U.S. Many effects of livestock in pasture and range settings are not addressed in this report. Such effects include physical damage to stream channels and riparian vegetation, compaction and reduced infiltration of soils, and imbalance in terrestrial plant communities due to selective grazing.

Table 1-1
Five Leading Sources of Water Quality Impairment in the U.S.
(Percent impairment attributed to each source is shown in parentheses. For example, agriculture is listed as a source of impairment in 70% of impaired river miles.)

Rank	Rivers	Lakes	Estuaries
1	**Agriculture** (70%)	**Agriculture** (49%)	Industrial Point Sources (56%)
2	Municipal Point Sources (14%)	Other/Unspecified Nonpoint Sources (24%)	Urban Runoff/ Storm Sewers (46%)
3	Hydromodification (14%)	Atmospheric Deposition (21%)	Municipal Point Sources (44%)
4	Habitat Modification (14%)	Urban Runoff/ Storm Sewers (21%)	Upstream Sources (30%)
5	Resource Extraction (13%)	Municipal Point Sources (18%)	**Agriculture** (27%)

Reference: *National Water Quality Inventory: 1996 Report to Congress* (EPA, 1997a). Agriculture, including animal feeding operations, is among the leading causes of water quality impairment in U.S. waters. Figure totals exceed 100 percent because water bodies may be impaired by more than one source. The portion of “agricultural” impairment attributable to animal waste (as compared to commercial fertilizers, pesticides, and other pollutant sources) is unknown nationwide.

Table 1-2
Summary of U.S. Water Quality Impairment Survey

Total Quantity in U.S.	Waters Surveyed	Quantity Impaired by All Sources	**Quantity Impaired by Agriculture**
Rivers 3,634,152 miles	19% of total 693,905 miles	36% of surveyed 248,028 miles	**70% of impaired** **173,629 miles**
Lakes, Ponds, and Reservoirs 41,684,902 acres	40% of total 16,819,769 acres	39% of surveyed 6,541,060 acres	**49% of impaired** **3,183,159 acres**
Estuaries 39,839 square miles	72% of total 28,819 square miles	38% of surveyed 11,025 square miles	**27% of impaired** **2,971 square miles**

Reference: *National Water Quality Inventory: 1996 Report to Congress* (EPA, 1997a). AFOs are a subset of the agriculture category. Summaries of impairment by other sources are not presented here.

Table 1-3 lists the leading pollutants impairing surface water quality in the U.S. AFOs are a potential source of all of these. Nutrients, pathogens, oxygen-depleting substances, and solids (which can contribute to siltation) are the pollutants most commonly associated with AFOs (as well as other sources). AFOs are also a potential source of the other leading causes of water quality impairment, such as metals and pesticides, and can contribute to the growth of noxious aquatic plants due to the discharge of excess nutrients. AFOs may also contribute loadings of priority toxic organic chemicals and oil and grease, but probably to a lesser extent than the other leading pollutants.

Table 1-3
Five Leading Pollutants Causing Water Quality Impairment in the U.S.
(Percent impairment attributed to each pollutant is shown in parentheses. For example, siltation is listed as a cause of impairment in 51% of impaired river miles.)

Rank	Rivers	Lakes	Estuaries
1	**Siltation** (51%)	**Nutrients** (51%)	**Nutrients** (57%)
2	**Nutrients** (40%)	Metals (51%)	**Pathogens** (42%)
3	**Pathogens** (32%)	**Siltation** (25%)	Priority Toxic Organic Chemicals (40%)
4	**Oxygen-Depleting Substances** (29%)	**Oxygen-Depleting Substances** (21%)	**Oxygen-Depleting Substances** (33%)
5	Pesticides (21%)	Noxious Aquatic Plants (16%)	Oil and Grease (20%)

Reference: *National Water Quality Inventory: 1996 Report to Congress* (EPA, 1997a). Items in bold print are those most commonly associated with animal feeding operations (as well as other sources). AFOs are also potential contributors of each of the other leading pollutants. Figure totals exceed 100 percent because water bodies may be impaired by more than one source.

Other reports have also indicated that AFOs pose a threat to U.S. marine and estuarine resources. The National Oceanic and Atmospheric Administration (NOAA) estimated that feedlots contributed to the impairment of 110 shellfish beds in 1995 (NOAA, 1995). In the Gulf of Mexico, an oxygen-depleted “dead zone” covering up to 7,000 square miles has been attributed to excess nutrients delivered primarily by the Mississippi River system (Montgomery, 1996). Animal waste is one of several significant sources of nutrients in surface waters (other anthropogenic sources include point sources, commercial fertilizers, atmospheric deposition, urban runoff, and contaminated groundwater). Excess nutrients stimulate algae blooms, which can lead to dissolved oxygen depletion during night-time respiration and during decomposition by other organisms. The problem in the Gulf demonstrates that water quality degradation is not always limited to the pollutant discharge location. The nutrient loadings to the Gulf originate from sources over a large land area, with approximately 41 percent of the U.S. ultimately draining to the Gulf (Montgomery, 1996).

Another significant concern is the potential for AFOs to contribute to nitrate contamination of drinking water, particularly groundwater. Nitrate poisoning is a potentially fatal condition which affects infants by reducing the oxygen-carrying capacity of the blood. According to EPA's *National Survey of Pesticides in Drinking Water Wells* (1990), nitrate (a form of nitrogen) is the most widespread agricultural contaminant in drinking water wells. EPA estimates that 4.5 million people are exposed to elevated nitrate levels (i.e., levels greater than the drinking water Maximum Contaminant Level of 10 mg/l nitrate-nitrogen) in groundwater (EPA, 1990). Animal wastes, commercial fertilizers, septic systems, and leaking sewers can all be significant sources of contamination.

1.2 Pollutant Sources

Pollution from AFOs can arise from several sources, including manure, animal carcasses, process waters (e.g., milkhouse waste), feed, bedding, eroded soil, and emissions from confinement buildings. Manure is the primary origin of AFO pollutants, and is the main focus of this chapter. Sources of manure pollution include direct discharges (from grazing animals or from pipes or other waste conveyances), open feedlots, pastures, treatment and storage lagoons, stockpiles, and land application. Animal manure is much more abundant than human waste. It is estimated that in 1992, approximately 133 million dry tons of animal manure were produced, compared to 10 million dry tons of human sanitary waste (See Appendix A). Yet while the disposal of human waste is highly regulated, the disposal of animal waste has been largely unregulated. Manure can have valuable use as a 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. This problem has been magnified as the industry has become more concentrated, with a trend toward more animals on fewer farms and less land. Incidents of waste spills, excessive runoff, leaking storage lagoons, and odor problems have heightened public awareness and concerns (See Appendix B for a list of documented impacts from animal operations).

1.3 Multi-media Impacts

Animal feeding operations are associated with a variety of pollutants, including oxygen-demanding substances, ammonia, solids, nutrients (specifically nitrogen and phosphorus), pathogens, salts, trace elements, antibiotics, pesticides, hormones, and odor and other airborne emissions. AFO pollutants can produce multimedia impacts. The general categories of impacts are:

1) Surface water impacts. Impacts are associated with waste spills, as well as surface runoff and subsurface flow. 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 night-time respiration can lead to depressed dissolved oxygen levels, which can result in 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 associated with drinking contaminated water (pathogens and

nitrates), contact with contaminated water (pathogens and *Pfiesteria*), and consuming contaminated shellfish (pathogens and 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. Antibiotics, pesticides, and hormones may have low-level, long-term ecosystem effects.

2) Groundwater impacts. Human and animal health impacts are associated with pathogens and nitrates in drinking water. Leaching salts may cause underlying groundwater to become unsuitable for human consumption.

3) Air impacts. Impacts include human health impacts (from ammonia, hydrogen sulfide, other odor-causing compounds, and particulates), and contribution to global warming (due to methane emissions resulting from anaerobic decomposition of manure). Additionally, volatilized ammonia can be redeposited on the earth and contribute to eutrophication.

4) Soil impacts. Trace elements and salts in animal manure can accumulate in the soil and become toxic to plants. Salts deteriorate soil quality by leading to reduced permeability and poor tilth. Crop uptake may provide a human and animal exposure pathway for trace elements and pathogens.

The impacts of specific pollutants are discussed in more detail in the following section.

2. POLLUTANTS OF CONCERN AND ASSOCIATED IMPACTS

2.1 Oxygen-Demanding Substances

Origin and Impacts:
This pollutant category refers to the biodegradable content of manure. When discharged to surface water, the material is decomposed by aquatic bacteria and other microorganisms. During this decay process, dissolved oxygen is consumed, reducing the amount available for aquatic animals. Severe depressions in dissolved oxygen levels can result in fish kills. There are numerous examples nationwide of fish kills resulting from manure discharges and runoff from various types of AFOs (See Appendix B).

More moderate depressions in dissolved oxygen levels are associated with reduced biodiversity (i.e., reduction in desirable species). In a study of three Indiana stream systems, researcher James R. Gammon (1995) found that waters downstream from animal feedlots (mainly hog and dairy operations) contained fewer fish and a limited number of species of fish in comparison with reference sites. Gammon also found excessive algal growth, altered oxygen content, and increased levels of ammonia, turbidity, pH, and total dissolved solids.

Transport:
Grazing animals may deposit manure directly into surface waters. Collected manure may be introduced directly into surface waters either intentionally (via pipe, ditch, or other conveyance)

or unintentionally (via storage structure failure, overflow, operator error, etc.). While severe rainfall conditions have been a causative factor in many waste spills, a review of Indiana Department of Environmental Management records showed that the most common causes of waste releases were intentional discharge and lack of operator knowledge (Hoosier Environmental Council, 1997).

Manure can also be introduced to surface waters via runoff if it is over-applied or misapplied to land. For example, manure application to saturated or frozen soils may result in a discharge to surface waters. Other factors that promote runoff to surface waters are steep land slope, high rainfall, low soil porosity, and proximity to surface waters.

2.2 Solids

Origin and Impacts:
AFOs can be a source of manure solids and soil solids in surface waters. Suspended solids can clog fish gills and increase turbidity. Increased turbidity reduces penetration of light through the water column, thereby limiting the growth of desirable aquatic plants which serve as critical habitat for fish, crabs, and other aquatic organisms. Solids that settle out as bottom deposits can alter or destroy habitat for fish and benthic organisms. Additionally, 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.

Transport:
As described previously, manure solids can be introduced into surface waters either directly or via runoff. Soil solids can be introduced into surface waters due to erosion caused by grazing animals or poor cropland management.

2.3 Nitrogen

Nitrogen (N) is an essential nutrient required by all living organisms. It is ubiquitous in the environment, accounting for 78 percent of the atmosphere as elemental nitrogen (N_2). This form of nitrogen is inert and does not impact environmental quality. It is also not bioavailable to most organisms and therefore has no fertilizer value. Nitrogen also forms other compounds which are bioavailable, mobile, and potentially harmful to the environment. The nitrogen cycle (Figure 2-1) shows the various forms of nitrogen and the processes by which they are transformed and lost to the environment.

Manure nitrogen is primarily in the form of organic nitrogen and ammonia nitrogen compounds. In organic form, nitrogen is unavailable to plants. However, via microbial processes, the organic nitrogen is transformed into ammonium (NH_4^+) and nitrate (NO_3^-) forms, which are bioavailable and therefore have fertilizer value. These forms can also produce negative environmental impacts when they are transported in the environment. The impacts and general transport processes are described in the following subsections.

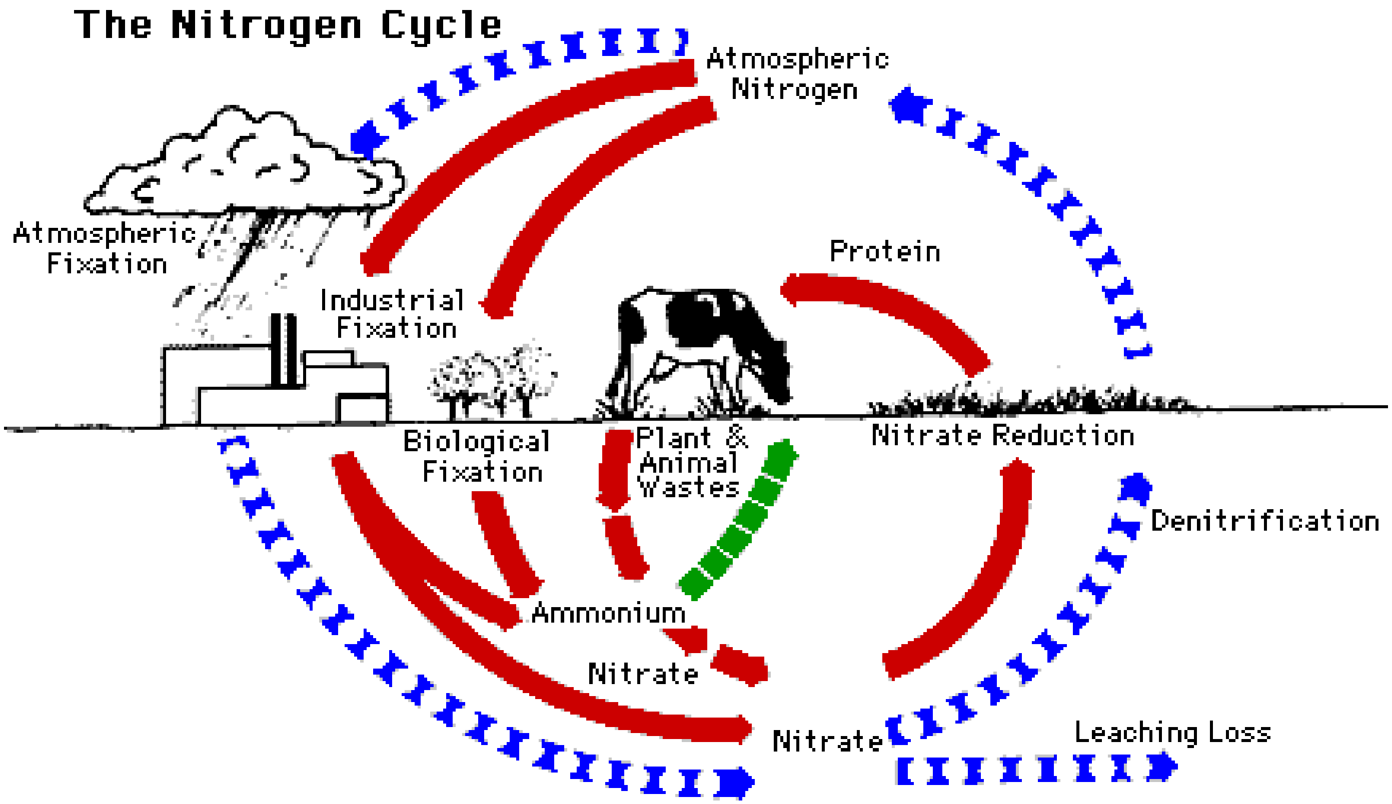

FIGURE 2-1

Source: O'Leary et al., 1997.

2.3.1 Ammonia

Origin and Impacts:

"Ammonia-nitrogen" includes the ionized form (ammonium, NH_4^+) and the un-ionized form (ammonia, NH_3). Ammonium is produced when microorganisms break down organic nitrogen products such as 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, as shown in the following equation:

$$NH_4^+ \text{ W } NH_3 + H^+.$$

As the equation indicates, higher pH levels (lower H^+ concentrations) favor the formation of ammonia, while lower pH levels (higher H^+ concentrations) favor the formation of ammonium. Both forms are toxic to aquatic life, although the un-ionized form (ammonia) is much more toxic. Fish kills due to ammonia toxicity are a potential consequence of the direct discharge of animal wastes to surface waters. This is illustrated by a May 1997 incident in Wabasha County, Minnesota, in which ammonia in a dairy manure release killed 16,500 minnows and white suckers (Clean Water Action Alliance, 1998).

Ammonia is also of environmental concern because it 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.

Additionally, ammonia can lead to eutrophication, or nutrient over-enrichment, of surface waters. Ammonia itself is a nutrient, and it is also easily transformed to nitrate (another nutrient form of nitrogen) in the presence of oxygen. While nutrients are necessary for a healthy ecosystem, the overabundance of nutrients (particularly nitrogen and phosphorus) can lead to nuisance algae blooms. Nitrogen is typically the limiting nutrient in estuaries and coastal marine waters. That is, if all nitrogen is used, plant growth will cease. This is in contrast to freshwaters, where phosphorus is typically the limiting nutrient. There can be exceptions to this generalization, however, particularly in water bodies with heavy pollutant loads. For example, in a typical (nitrogen-limited) estuary, excess nitrogen levels would be expected to produce algal blooms. However, estuarine systems may become phosphorus-limited when nitrogen concentrations are high. In such cases, excess phosphorus will produce algal blooms (Bartenhagen et al., 1994). Thus, both nitrogen and phosphorus loads can contribute to eutrophication in either water type.

In addition to producing negative aesthetic impacts, algal blooms can produce significant ecological and human health impacts. The blooms reduce the penetration of light through the water column (and thereby limit the growth of desirable aquatic plants), and reduce night-time levels of dissolved oxygen via respiration. Decay of dead algae also results in dissolved oxygen depressions. These depressions may reduce biodiversity, or may be severe enough to produce fish kills. Algae can affect drinking water by clogging treatment plant intakes, producing objectionable tastes and odors, and increasing production of carcinogenic chlorinated byproducts such as trihalomethanes. These impacts result in increased drinking water treatment costs.

Blooms of toxic estuarine algae, such as red tides, have been associated with eutrophication in coastal regions, and can result in shellfish poisoning (Mueller and Thomann, 1987).

Blooms of other toxic estuarine organisms, such as the dinoflagellate *Pfiesteria piscicida*, are also associated with nutrient over-enrichment. *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, 1998), as well as in Maryland and Virginia tributaries to the Chesapeake Bay (EPA, 1997b). 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, 1998). People with heavy environmental exposure have exhibited symptoms, as well. In a recent study, such environmental exposure was definitively linked with cognitive impairment, whereas physical symptoms were less consistent (Morris et al., 1998).

Pfiesteria often lives as a nontoxic predatory animal, becoming toxic in response to fish excretions or secretions (NCSU, 1998). 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* by human sewage and swine effluent spills, and have shown that the organism can be highly stimulated by both inorganic and organic nitrogen and phosphorus enrichments (NCSU, 1998).

Transport

Ammonia can reach surface waters in a number of ways, including direct discharge, leaching, dissolution in surface runoff, erosion, and atmospheric deposition. Leaching and runoff are generally not significant transport mechanisms for ammonia compounds, because ammonium can be sorbed to soils (particularly those with high cation exchange capacity, or CEC), incorporated (fixed) into clay or other soil complexes, or transformed into organic form by soil microbes (Follett, 1995). However, in these forms, nitrogen can be transported to surface waters by erosion.

Atmospheric deposition can be a significant mechanism of nitrogen transport to surface waters. Ammonia in solution is subject to gaseous loss to the atmosphere. It can then be redeposited on the earth (or directly into surface waters), either in dry form or dissolved in precipitation (“acid rain”). Losses from animal feeding operations can be significant, arising from sources such as manure piles, storage lagoons, and land application fields. In North Carolina, animal agriculture is responsible for over 90 percent of all ammonia emissions; in turn, ammonia comprises more than 40 percent of the total estimated nitrogen emissions from all sources (Aneja et al., 1998). Data from Sampson County, North Carolina show that “ammonia rain” has increased as the hog industry has grown, with ammonia levels in rain more than doubling between 1985 and 1995 (Aneja et al., 1998).

The degree of ammonia volatilization 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 spray application is performed. Environmental conditions also affect the extent of volatilization. For example, losses are greater at higher pH levels, at higher temperatures and drier conditions, and in soils with low cation exchange capacity, such as sands. Losses are decreased by the presence of growing plants. (Follett, 1995)

Volatilization of ammonia is of concern not only because of atmospheric deposition, but because of direct localized impacts on air quality. Ammonia produces an objectionable odor, and can cause nasal and respiratory irritation.

2.3.2 Nitrate

Origin and Impacts

In the biochemical process of nitrification, aerobic bacteria oxidize ammonium to nitrite (NO_2^-) and then to nitrate (NO_3^-). Nitrite is toxic to most fish and other aquatic species, but it typically does not accumulate in the environment because it is rapidly transformed to nitrate in an aerobic environment. Alternatively, nitrite (and nitrate) can undergo bacterial denitrification in an anoxic environment. In denitrification, nitrate is converted to nitrite, and then further converted to gaseous forms of nitrogen - elemental nitrogen (N_2), nitrous oxide (N_2O), nitric oxide (NO), and/or other nitrogen oxide (NO_x) compounds. Nitrification occurs readily in the typically aerobic conditions of receiving streams and dry soils; denitrification can be significant in anoxic bottom waters and saturated soils.

Nitrate is a useful form of nitrogen because it is biologically available to plants and is therefore a valuable fertilizer. However, excessive levels of nitrate in drinking water can produce negative health impacts on infant humans and animals. Nitrate poisoning affects infants by reducing the oxygen-carrying capacity of the blood. The resulting oxygen starvation can be fatal. Nitrate poisoning, or methemoglobinemia, is commonly referred to as “blue baby syndrome” because the lack of oxygen can cause the skin to appear bluish in color. To protect human health, EPA has set a drinking water Maximum Contaminant Level (MCL) of 10 mg/l for nitrate-nitrogen. 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.

In a national survey by EPA, nitrate was found to be the most widespread agricultural contaminant in drinking water wells (EPA, 1990). In a separate assessment of historical, nationwide water quality data, the U.S. Geological Survey (USGS) found that nitrate levels exceeded the MCL in 12 percent of the domestic-supply wells in agricultural areas (Mueller and Helsel, 1997). Studies of smaller geographical areas have also revealed evidence of nitrate contamination in groundwater. As of 1988, 40 percent of wells in the Chino Basin, California, had nitrate levels in excess of the MCL; dairy operations were identified as the major source of contamination (Anton et al., 1988). 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. In southeastern Delaware and the Eastern Shore of Maryland, where poultry production is prominent, over twenty percent of wells were found to have nitrate levels exceeding the MCL (Ritter et al., 1989). Measured nitrate levels in groundwater beneath Delaware poultry houses have been as high as 100 mg/l (Ritter et al., 1989). 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 the wells are typically shallower and monitoring is not required. People served by public systems are better protected even if the water becomes contaminated, due to water quality monitoring and treatment requirements.

Elevated nitrate levels can also be been found in surface waters, although the impacts are typically less severe than groundwater impacts. This is because typical flat farmland conditions tend to promote infiltration over runoff, and because surface waters provide for greater mixing and more rapid dilution. Additionally, anoxic bottom waters of lakes and streams provide greater opportunity for nitrate removal via denitrification. In the USGS historical assessment, analysts found that nitrate levels in streams in agricultural areas were elevated compared to undeveloped areas. However, they were generally less than those for groundwater 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 (Mueller and Helsel, 1997).

While nitrate levels in many drinking water sources across the country are excessive, reported cases of methemoglobinemia are rare. This does not necessarily mean that cases are not occurring, however. Methemoglobinemia can be difficult to detect in infants because its symptoms are similar to other conditions (Michel et al., 1996). Also, doctors are not always required to report it (Cohen et al, 1996). Studies in South Dakota and Nebraska have indicated that most cases of methemoglobinemia are not reported (Grant, 1981 and Meyer, 1994). For example, in South Dakota during the time period 1950 - 1980, only two cases were reported while at least 80 were estimated to have occurred.

As discussed in Section 2.3.1, nitrate is also a nutrient which can lead to eutrophication of surface waters. Eutrophication can lead to negative aesthetic impacts, fish kills, reduced biodiversity, objectionable tastes and odors, increased drinking water treatment costs, and growth of toxic organisms.

Transport

Nitrate can reach surface waters via direct discharge of animal wastes. Lagoon leachate and land-applied manure can also be significant contributors of nitrate to both surface and groundwaters. Nitrate is water soluble and moves freely through most soils. Overland runoff can carry dissolved nitrate to surface waters. Percolating water and lagoon leachate can transport nitrate to groundwater, as well as to surface waters via subsurface flows. Nitrate can also be introduced into surface waters from interflow and groundwater via hydrologic connections. It is believed that the nitrate contributions to surface water from agriculture are primarily from groundwater connections and other subsurface flows rather than overland runoff (Follett, 1995). In the Chesapeake Bay watershed, for example, USGS estimates that about half of the nitrogen loads from all sources to nontidal streams and rivers originate from groundwater (ASCE, 1998).

Since the groundwaters there take an average of ten to twenty years to reach the bay, it may take several decades to realize the full effect of pollutant additions or reductions (ASCE, 1998). Nationally, about 40 percent of the average annual stream flow is from groundwater (U.S. EPA, 1993b), so groundwater contamination can have significant impacts on surface water quality.

It has been asserted that manure solids effectively "self-seal" lagoons and prevent groundwater contamination, however some studies have shown otherwise. For example, when researchers analyzed samples from the vadose zone (the unsaturated zone above the water table) downgradient of unlined waste lagoons at five Texas dairies, they found that three of the five sites exhibited nitrate levels in excess of the MCL (Frarey et al., 1994). 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 groundwater quality (Ritter and Chirnside, 1990). Artificial liners are preferable to clay liners because they are less permeable. Puncture risk can be minimized by installing the liner between clay layers. (Agricultural Animal Waste Task Force, 1996) Concrete liners are another alternative; they should be properly designed and constructed to help prevent cracking. Glass-lined steel tanks are also being used by some producers to reduce leaching potential.

Nitrate transport is affected by local conditions. For example, potential transport of nitrate to groundwater is greater in areas of high soil permeability and shallow water tables. Direct transport to surface water is greater in areas with low soil permeability and steep slopes. Other factors affecting nitrate transport include surface depressions, soil roughness, and vegetative cover, which decrease runoff potential by promoting water infiltration. Drainage from tile drains may be directed to surface waters or into groundwater wells. Risk of nitrate pollution generally increases at higher rates of nitrogen application. While application of manure and commercial fertilizers are essentially unregulated by EPA, EPA does regulate application of biosolids (municipal sewage sludge). To reduce the risk of nitrate contamination from biosolids, EPA's Part 503 Rule requires that land application be limited to agronomic rates for nitrogen (i.e., the nitrogen applied may not exceed the cover crop's nitrogen requirements).

Application of manure at agronomic rates should not be expected to completely eliminate nitrogen transport to surface and groundwaters, 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 (from the storage lagoon or the application field) before being taken up; 3) it may be difficult to distribute the waste evenly, 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 associated with 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.

2.4 Phosphorus

Origin and Impacts

Animal wastes contain both organic and inorganic forms of phosphorus (P). As with nitrogen, the organic form must mineralize to inorganic form to become available to plants. This occurs as the manure ages and the organic P hydrolyzes to inorganic phosphate-containing compounds. The phosphorus cycle (Figure 2-2) is much simpler than the nitrogen cycle because phosphorus lacks an atmospheric connection and is less subject to biological transformation.

Phosphorus is of concern in surface waters because it is a nutrient which can lead to eutrophication. As discussed in Section 2.3.1, eutrophication can lead to negative aesthetic impacts, fish kills, reduced biodiversity, objectionable tastes and odors, increased drinking water treatment costs, and growth of toxic organisms. Phosphorus is also a concern because phosphate levels greater than 1.0 mg/l may interfere with coagulation in drinking water treatment plants (Bartenhagen et al., 1994).

Phosphorus is of particular concern in freshwaters, where plant growth is typically limited by phosphorus levels. Under high pollutant loads, however, freshwaters may become nitrogen-limited (Bartenhagen et al., 1994). Thus, both nitrogen and phosphorus loads may contribute to eutrophication.

Lake Okeechobee, Florida is one of the Nation's resources that have been impacted by phosphorus loadings from AFOs. Lake Okeechobee is the second largest lake entirely within U.S boundaries, and serves as a drinking water supply for millions of people. In the summer of 1986, blue-green algae spread across more than 120 square miles of the lake surface. Significant algal blooms also occurred in the fall of 1986 and 1987. These blooms have been associated with steadily increasing phosphorus concentrations and phosphorus-to-nitrogen ratios; dairy and beef operations were identified as the main source of phosphorus loadings (Swift et al., 1987).

Transport

Phosphorus can reach surface waters via direct discharge and runoff from land application of animal wastes. The organic P compounds in manure are generally water soluble and subject to leaching and dissolution in runoff (Gerritse, 1977). Once in receiving waters, these organic compounds can undergo transformation and become available to aquatic plants. Overall, land-applied phosphorus is considered much less mobile than nitrogen, since the mineralized (inorganic phosphate) form is easily adsorbed to soil particles. 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 enter waterways via runoff even if soil erosion is controlled. Animal wastes typically have lower N:P ratios than crop N:P ratios, 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 U.S. confirm that many soils in areas dominated by animal-based agriculture have excessive levels of phosphorus (Sims, 1994). Research also indicates that there is a potential for phosphorus to leach into groundwater through sandy soils with high phosphorus content (Citizens *Pfiesteria* Action Commission, 1997).

THE PHOSPHORUS CYCLE

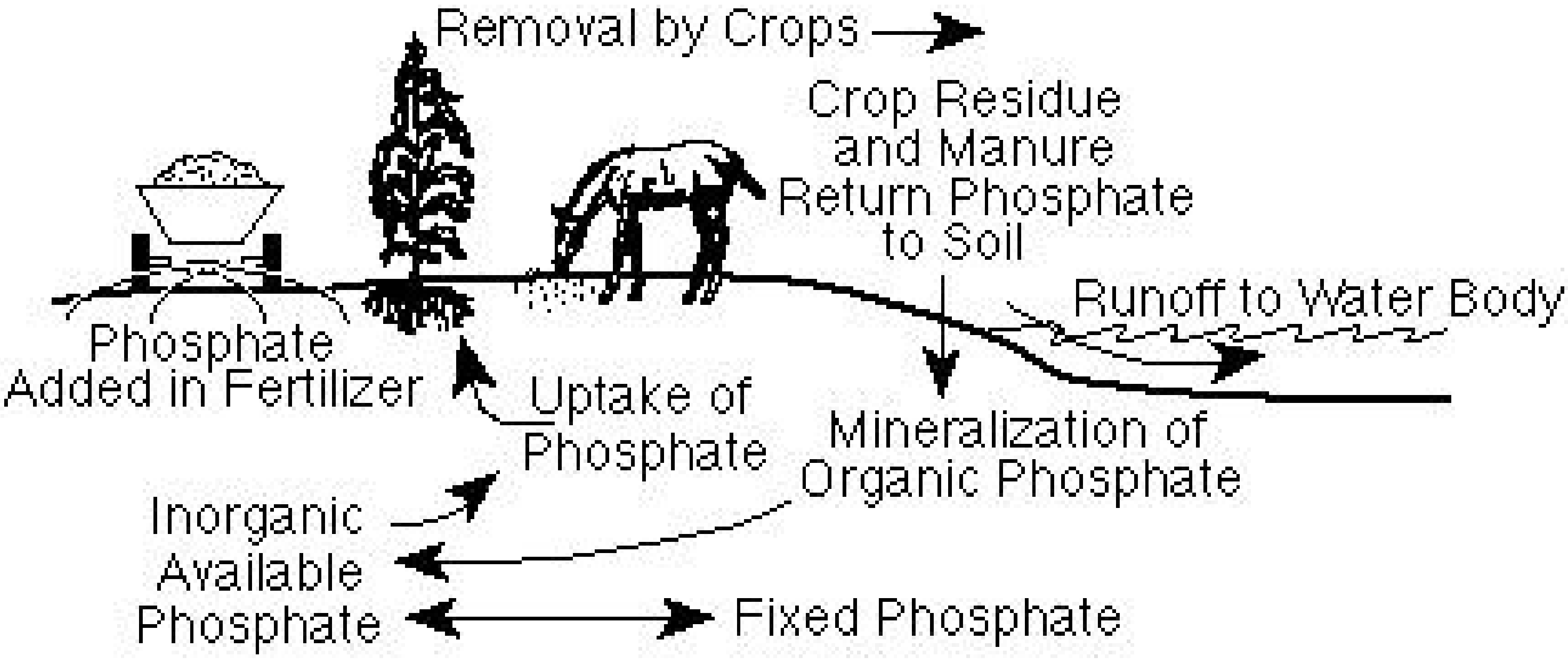

FIGURE 2-2 Source: Busman et al., 1997.

2.5 Pathogens

Origins and Impacts

Both manure and animal carcasses can contain pathogens (disease-causing organisms) which can impact human health, other livestock, aquatic life, and wildlife when introduced into the environment. Many pathogenic organisms found in manure can infect humans. A list of several potential manure-related human diseases and pathogens is presented in Table 2-1.

Table 2-1
Some Diseases and Parasites Transmittable to Humans from Animal Manure

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

DISEASE	RESPONSIBLE ORGANISM	SYMPTOMS
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
Hog 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*	
Coccidiosis	*Eimeria* species	Diarrhea, abdominal gas

DISEASE	RESPONSIBLE ORGANISM	SYMPTOMS
Cryptosporidiosis	*Cryptosporidium* species	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

References: USDA, 1992 (for diseases and responsible organisms). Symptom descriptions were obtained from various medical and public health service Internet websites. 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.

Many of these pathogens are transmitted via the fecal-oral route. Others may be transmitted through inhalation. In the water environment, humans may be exposed to pathogens via consumption of contaminated drinking water, or by incidental ingestion during contact recreation in contaminated waters. Contact recreation can also result in other miscellaneous infections of the skin, eye, ear, nose, and throat. Many of the listed pathogens could conceivably be transmitted through a shellfish vector (Stelma and McCabe, 1992). Shellfish are filter feeders which are prone to accumulating bacteria and viruses. Flies and other vectors also present potential pathways for disease transmission.

Fecal coliform counts are often used as a surrogate measurement for gastroenteric pathogens, since the presence of fecal coliform bacteria is an indication of contamination by human and/or animal wastes. To help protect human health, EPA has recommended an ambient water quality standard of 200 CFU/ml for fecal coliforms in contact-recreational waters. Fecal coliform pollution from various sources is often cited in beach closures and shellfish restrictions. Cow manure has specifically been implicated as a causative factor in the high bacteria levels and ensuing swimming restrictions on Tainter Lake, Wisconsin (Behm (2)). Fecal coliform counts of 3,000 CFU/100 ml and fecal streptococci counts over 30,000 CFU/100 ml have been reported downstream from a hog waste lagoon site (Paul, pers. comm., 1997). Bacteria discharged to the water column can subsequently adsorb to sediments, presenting a long-term health hazard. When the bottom stream is disturbed, the sediment releases bacteria back into the water column (Sherer et al., 1988, 1992).

The mandated treatment of public water supplies helps reduce the risk of infection via drinking water. However, protecting source water is the first step in providing safe drinking water. *Cryptosporidium parvum* is of particular concern, since it is resistant to conventional treatment. *Cryptosporidium* is a protozoan that can produce gastrointestinal illness, with symptoms such as severe diarrhea. Healthy people typically recover relatively quickly (within two to ten days) from gastrointestinal illnesses such as cryptosporidiosis. However, such diseases can be fatal in people with weakened immune systems. This subpopulation includes children, the elderly, people with HIV infection, chemotherapy patients, and those taking medications that suppress the immune system.

In Milwaukee, Wisconsin in 1993, *Cryptosporidium* contamination of a public water supply caused more than 100 deaths and an estimated 403,000 illnesses (Casman, 1996). 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.

There is concern that pathogens may be introduced to the air directly from animal feeding houses (see Section 2.8) or during spray application of wastes. Another concern is exposure to pathogens through the food chain. There is evidence that a 1993 *E. coli* outbreak in Maine was the result of manure applications to a vegetable garden (Cieslak et al., 1993). Additionally, three *E. coli* outbreaks (one in Montana in 1995, one in Illinois in 1996, and one in Connecticut in 1996) were traced to organic lettuce growers. It is suspected that the lettuces were contaminated by infected cow manure (Nelson, 1997). In another incident in Maine, a few hundred children were sickened by *Cryptosporidum*. The source was fresh-pressed apple cider made from apples gathered from a cow pasture (Millard et al., 1994).

Wildlife impacts have also been documented. The U.S. Fish and Wildlife Service estimates that thousands of migratory waterfowl have died each year from avian botulism and avian cholera caused by bacteria in livestock waste (USFWS, 1991).

Transport

Sources of pathogen contamination from livestock operations include direct discharges and leaching lagoons. Surface runoff from land application fields can also be a source of pathogen contamination, particularly if a rainfall event occurs soon after application. 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 helps protect underlying groundwater, but increases the likelihood of runoff losses to surface waters. Depending on weather, site, and operating conditions, subsurface flows may also be a significant mechanism for pathogen transport.

The survivability and transport of land-applied manure pathogens are not well-characterized.

Several researchers (Dazzo et al., 1973; Ellis and McCalla, 1976; Morrison and Martin, 1977; Van Donsel et al., 1967) have found that soil type, manure application rate, and soil pH are dominating factors in bacteria survival. Experiments on land-applied poultry manure (Crane et al., 1980) have indicated that the population of fecal organisms decreases rapidly as the manure is heated, dried, and exposed to sunlight on the soil surface. Regrowth of fecal organisms was also seen in these experiments, however.

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 would be expected to increase the likelihood of runoff to surface water and transport to groundwater. While surface waters are typically expected to be more prone than groundwaters to pathogen contamination, groundwaters in areas of sandy soils, limestone formations, or sinkholes are particularly vulnerable. For example, in cow pasture areas of Door County, Wisconsin, where a thin topsoil layer is underlain by fractured limestone bedrock, groundwater wells have commonly been shut down due to high bacteria levels (Behm (1)). At one rural household, a well produced brown, manure-laden water (Behm (1)). Private wells are more prone than public wells to contamination, 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 (GAO, 1997) found that bacterial standard violations occurred in three to six percent of community water systems each year. By contrast, GAO reported that bacterial contamination occurred in 15 to 42 percent of private wells, according to statistically representative assessments performed by others.

2.6 Salts and Trace Elements

Origin and Impacts

The salinity of animal manure is due to the presence of dissolved mineral salts. The major cations contributing to salinity are sodium, calcium, magnesium, and potassium; the major anions are chloride, sulfate, bicarbonate, carbonate, and nitrate (National Research Council, 1993). In land-applied wastes, salinity is a concern because salts can accumulate in the soil and become toxic to plants, and can deteriorate soil quality by reducing permeability and contributing to poor tilth. Direct discharges and salt runoff to fresh surface waters contribute to salinization and can disrupt the balance of the ecosystem. Leaching salts can deteriorate groundwater quality, making it unsuitable for human consumption.

Trace elements such as arsenic, copper, selenium, and zinc are often added to animal feed as growth stimulants or biocides (Sims, 1995). When land-applied, these elements can accumulate in soils and become toxic to plants. These elements are also of concern because they can impact human and ecological health. Arsenic and selenium, for example, are toxicants. Copper and zinc can cause gastrointestinal irritation.

The trace elements listed herein (as well as cadmium, mercury, molybdenum, nickel, and lead) are regulated in municipal sewage sludge by EPA’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). Metals 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. Documented cases of trace element contamination from animal wastes suggest that control measures may be required to reduce environmental risks. For example, elevated levels of zinc, principally derived from livestock waste, have been found in a Texas Wildlife Refuge (USFWS, 1991).

Transport

More research is needed to better characterize the environmental fate and transport of trace metals in manure. Both salts and trace elements may reach surface waters via direct discharges and runoff from land-application sites. Groundwaters (and subsequently surface waters) may be impacted by leachate from waste lagoons and land application sites. Crop uptake is another potential exposure pathway for humans and wildlife.

2.7 Antibiotics, Pesticides, and Hormones

Origin and Impacts

Antibiotics, pesticides, and hormones are organic compounds which are used in animal feeding operations and can be expected to appear in animal wastes. These compounds may pose risks to the environment. For example, chronic toxicity may result from low-level discharges of antibiotics and pesticides. Estrogen hormones have been implicated in the drastic reduction in sperm counts among Western men (Sharpe and Skakkebaek, 1993) and reproductive disorders in a variety of wildlife (Colburn et al., 1993). Other environmental sources of antibiotics and hormones include municipal wastewaters, septic tank leachate, and runoff from land-applied sewage sludge. Other sources of pesticides include crop runoff and urban runoff.

Transport

Little information is available regarding the concentrations of these compounds in animal wastes, or on their fate/transport behavior and bioavailability in waste-amended soils. These compounds may reach surface waters via direct discharges and runoff from land-application sites. Groundwaters (and subsequently surface waters) may be impacted by leachate from waste lagoons and land application sites.

2.8 Odor and Other Airborne Emissions

Animal waste lagoons are typically not aerated. Under these conditions, the dissolved oxygen in the lagoon is quickly consumed by biological processes, and anaerobic decomposition takes over. In anaerobic decomposition, the wastes are converted biologically to simpler end-products, principally methane and carbon dioxide. Water, ammonia, hydrogen sulfide, phenol, volatile fatty acids, mercaptans, and other compounds are also produced. 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 farms, in particular

(Agricultural Animal Waste Task Force, 1996).

Odor sources include animal confinement buildings, waste lagoons, and land application sites. Odor itself is a significant concern because of its documented effect on mental health (Schiffman et al., 1995), potential for vector attraction, and impact on 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. (Ammonia can also be redeposited on the earth and subsequently contribute to water quality problems. See Section 2.3.1.) In 1996, the Minnesota Department of Health found that levels of hydrogen sulfide gas at residences near CAFOs were high enough to cause symptoms such as headaches, nausea, vomiting, eye irritation, respiratory problems, achy joints, dizziness, fatigue, sore throats, swollen glands, tightness in the chest, irritability, insomnia, and blackouts (Hoosier Environmental Council, 1997). 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” which trap heat in the atmosphere and thus contribute to global warming. With respect to animal wastes, control efforts have focused on methane, since methane is extremely effective at trapping heat in the atmosphere, and is a precursor to the formation of tropospheric ozone (a component of photochemical smog). Additionally, methane is a flammable gas which can be captured and utilized for energy recovery. Less attention has been given to controlling animal waste emissions of carbon dioxide, since it is an otherwise benign compound which would also be produced by many other treatment alternatives (such as aerobic biological treatment and incineration).

It is estimated that methane accounts for about 20 percent of the anticipated global warming from the greenhouse effect (U.S. EPA, 1989). An estimated six to ten percent of total global anthropogenic methane emissions arises from animal waste; approximately 14 percent of the global animal waste emissions is from U.S. animals (EPA, 1992). The amount of methane emitted from manure management systems is projected to increase from about ten percent of total U.S. emissions in 1990 to nearly 15 percent by the end of the century (U.S. EPA, 1993a).

Particulates and airborne pathogens are other contaminants associated with animal operations. 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. 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. NATIONAL ANALYSES OF ANIMAL WASTE

3.1 Nitrogen Production Relative to Other Sources

As discussed in Section 1.1, excess nutrients (specifically nitrogen and phosphorus) are significant contributors to water quality impairment in the U.S. There are many anthropogenic sources of nitrogen and phosphorus, including municipal and industrial point sources, commercial fertilizer, animal manure, and urban runoff. Atmospheric deposition can also be a significant source of nitrogen.

In an analysis of nitrogen sources in 107 U.S. watersheds, USGS found that proportions of nitrogen originating from various sources differ according to climate, hydrologic conditions, land use, population, and physical geography (Puckett, 1994). While the analysis does not provide estimates of the amount of nitrogen that reaches waterways, it does provide insight into the magnitude of various nitrogen sources (including manure, fertilizers, point sources, and atmospheric deposition). The “manure” source estimates include waste from both confined and unconfined animals. CAFOs were included with “manure” sources rather than point sources, since permitted CAFOs are presumably “zero discharge” facilities and it is difficult to obtain representative discharge data from these facilities. Figure 3-1 displays results of the analysis for selected watersheds (1987 base year). As shown, the production of manure nitrogen relative to other sources varies by watershed. In some instances, manure nitrogen is a large portion of the total nitrogen added to the watershed. For example, in the Susquehanna River watershed in Pennsylvania and the White River watershed in Arkansas, animal manure was estimated to contribute 54 and 56 percent, respectively, of the total added nitrogen. Note that this analysis does not include other potentially significant sources of nitrate, such as urban runoff, sewer overflows, septic systems, and contaminated groundwater.

Proportions of Nonpoint and Point Sources of Nitrogen in Selected National Water Quality Assessment Program Watersheds (1987 Base Year)

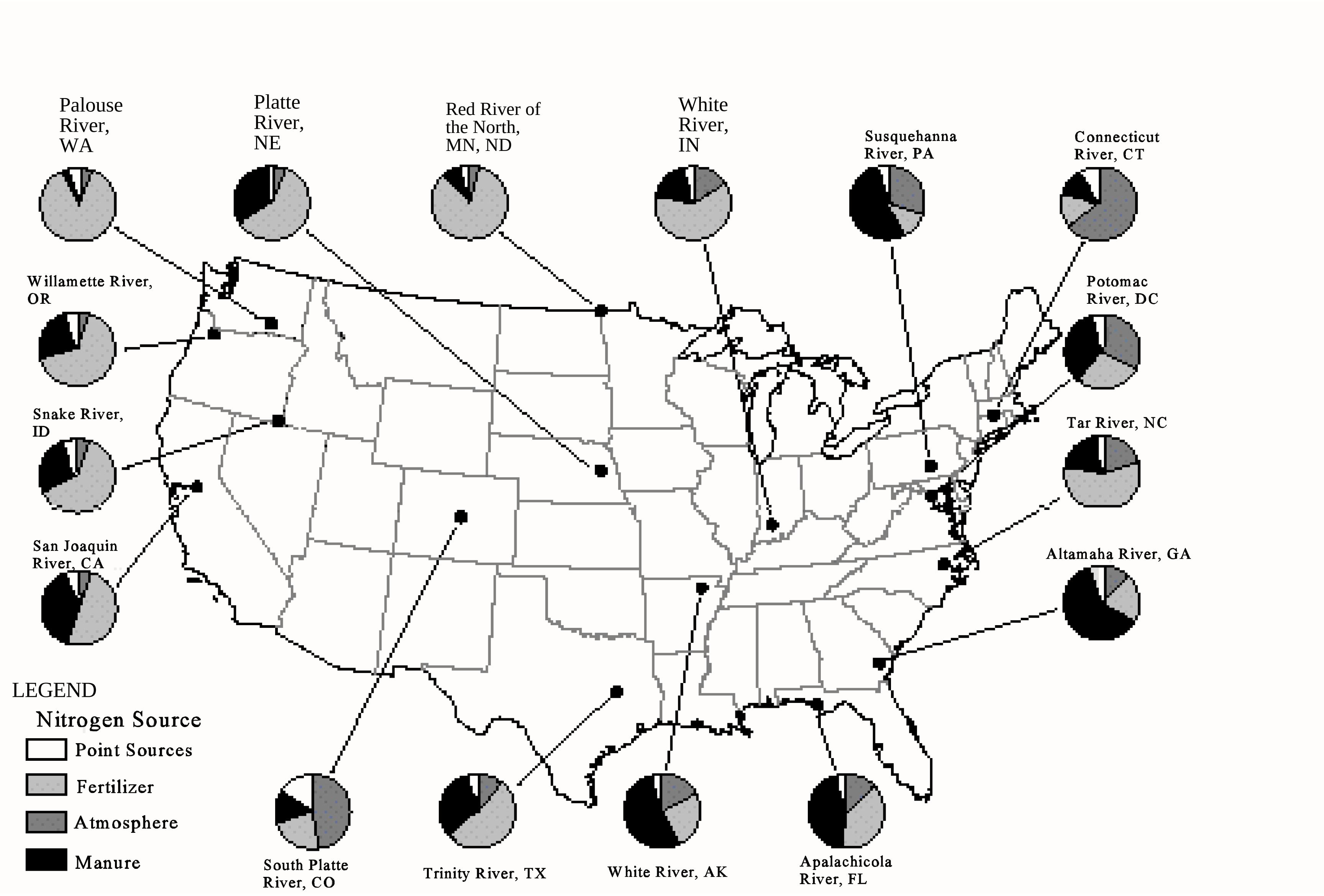

FIGURE 3-1 Source: Puckett, 1994. Note: CAFO point sources are included in the "manure" category.

3.2 Nitrogen and Phosphorus Production Relative to Crop Uptake Potential

One of the main mechanisms for removal of nitrogen and phosphorus from land-applied manure is crop uptake. The U.S. Department of Agriculture (USDA) has performed analyses to determine 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 (Lander et al, 1998). The analyses are intended to reflect the amount of manure that can be recovered and utilized, and therefore do not consider manure from unconfined animals. Figures 3-2 and 3-3 show the estimated manure nitrogen and phosphorus production from confined livestock, including cows, hogs, chickens, and turkeys. The figures account for the inability to completely recover manure, as well as for typical nutrient losses during storage and treatment. These losses can be significant, particularly for nitrogen, due to its high volatilization potential. Considering typical management systems, average manure nitrogen losses range from 31 to 50 percent for poultry, 60 to 70 percent for cattle, and 75 percent for swine. By contrast, the typical phosphorus loss is 15 percent. (Lander, et al., 1998) As discussed in Section 2.3.1, volatilized ammonia can have significant impacts on air quality and water quality (via atmospheric deposition). If ammonia volatilization were reduced, the nitrogen production presented in Figure 3-2 would represent an underestimation.

Figures 3-4 and 3-5 present the potential for manure nitrogen and phosphorus to meet or exceed plant uptake and removal in each of the 3,141 counties, considering non-legume harvested cropland and hayland. Based on this analysis of 1992 conditions, recoverable manure nitrogen exceeds crop system needs in 266 counties, and recoverable manure phosphorus exceeds crop system needs in 485 counties. The relative excess of phosphorus in comparison to nitrogen is not surprising, since manure is typically nitrogen-deficient relative to crop needs. Therefore, when manure is applied to meet a crop’s nitrogen requirement, phosphorus is typically over-applied with respect to the crop requirement (Sims, 1995). County-wide nutrient balances likely understate occurrences of local nutrient excesses, as it appears that most manure remains on the farm where it was generated (Shortle et al., 1993; Meek et al., 1975), and confined animal production farms often do not have enough land to accommodate the manure (Letson and Gollehon, 1998). Large, specialized animal production farms typically have a relatively high animal/acre ratio when compared to smaller, integrated farms. For example, an analysis of beef feedlots (Letson and Gollehon, 1996) indicated that one percent of the operations produce 71 percent of the beef but have only two percent of the cropland. By contrast, 92 percent of the operations produce only ten percent of the beef but have 75 percent of the cropland. Information was not provided on how many operations lease land for manure disposal or give the manure away to others.

The USDA analyses presented here do not account for legume crops (which can “fix” atmospheric nitrogen by helping transform N_2 to ammonia), vegetable/citrus/nut crops, or pastureland, all of which could potentially be used for nutrient uptake. The analyses are not intended to reflect actual manure management practices, but rather the *potential* for manure nutrient usage, without consideration of economic and land ownership limitations, and without consideration of other nutrient sources such as commercial fertilizers. Additionally, the analyses do not account for the transport of applied manure nutrients. Therefore, an excess of nutrients does not necessarily indicate that a water quality problem exists; likewise, a lack of excess nutrients does not imply the absence of water quality problems. Nevertheless, the analyses are useful as a general indicator of excess nutrients on a broad-scale basis. The reader is referred to the original report for a complete list of assumptions and limitations.

3.3 Nitrogen and Phosphorus Loadings to Surface Waters Relative to Other Sources

The abovementioned analyses are useful in comparing manure nutrient production relative to other sources and relative to crop uptake potential. However, they do not account for fate and transport of manure nutrients, and therefore cannot provide an estimate of the quantity of nutrients that reach water bodies. Delivery of nutrients to surface water is affected by many watershed characteristics, such as soil permeability, stream density, and temperature. Variability among watersheds, in addition to sparse water quality sampling data and sampling bias, can make regional water quality assessments difficult. To address these concerns, the USGS developed a model known as SPARROW (SPAtially Referenced Regressions On Watershed attributes). The SPARROW method uses spatially referenced regressions of contaminant transport on watershed attributes. The model equations express in-stream nutrient loads as a function of stream and land-surface characteristics. They incorporate point and nonpoint pollutant sources, as well as factors associated with material transport through the watershed (e.g., soil permeability and stream velocity). The model is used to describe spatial and temporal patterns in water quality and to identify factors and processes that influence those conditions. (Smith, et al., 1997)

USGS (Smith, et al., 1997) has applied the model nationally to the 2,056 hydrologic cataloging units, or watersheds, in the contiguous U.S. to estimate total nitrogen (TN) and total phosphorus (TP) export from various point and nonpoint sources (including commercial fertilizers, livestock waste, atmospheric deposition (for nitrogen), and nonagricultural land). “Livestock waste” estimates include waste from both confined and unconfined animals, based on data from the 1987 Census of Agriculture. CAFOs were assumed to be nonpoint “livestock waste” sources rather than point sources, since permitted CAFOs are presumably “zero discharge” facilities and it is difficult to obtain representative discharge data from these facilities. The estimates represent annual average values for the year 1987 (although point source data were obtained from a 1977 - 1981 inventory).

Nitrogen Modeling:
Figure 3-6 presents the predicted local total nitrogen yield, independent of upstream sources. The presentation is in terms of yield per unit of watershed area. In the analysis, USGS found that commercial fertilizer contributes significantly more than livestock waste to TN yield. This is not surprising, since commercial fertilizers account for the majority of nutrients used in most agricultural production systems (Lander and Moffitt, 1996).

The availability of detailed model results allowed for additional observations with respect to animal waste loadings. To get a sense of the significance of animal waste loadings, EPA compared the predicted nitrogen contribution from manure to that from point sources. Per the

SPARROW estimates, manure is a greater contributor than point sources to in-stream TN throughout the U.S., specifically in 1,802 (88%) of the 2,056 watershed outlets (Figure 3-7). The model also predicts that in 113 watersheds, animal manure is the single largest contributor to nitrogen transport. Many of these watersheds, shown in Figure 3-8, correspond to areas identified by USDA as having county-wide manure nitrogen from confined animals in excess of crop uptake potential. These include areas of Oklahoma, Arkansas, Mississippi, Georgia, Alabama, Delaware, Maryland, Virginia, and North Carolina.

Typically, nutrient loadings originate from a number of sources in a watershed, rather than being dominated by one particular source. SPARROW model results show that animal waste is a significant source of in-stream nitrogen concentrations in many watershed outlets. Figure 3-9 shows the predicted percent contribution of animal waste to in-stream nitrogen. Many of the watersheds with higher values are in areas identified by USDA as having relatively high manure nitrogen production. It is notable that animal waste is estimated to be a significant contributor to TN transport in the Midwest, despite having sufficient crops county-wide to take up confined manure nitrogen. This could be due to additional waste loadings from unconfined animals, inadequate distribution of the waste, and the common use of tile drains on crop fields in the Midwest. Tile drains carry excess water (and dissolved pollutants) from beneath the crops directly to surface waters (although some farmers direct the drainage into groundwater wells).

Phosphorus Modeling:

Figure 3-10 presents the predicted local total phosphorus yield, independent of upstream sources. Interestingly, USGS estimated that livestock waste contributes more than commercial fertilizer application to TP transport. This may be because manure is typically nitrogen-deficient with respect to crop needs, and therefore, applying manure to meet crop nitrogen requirements results in over-application of phosphorus (Sims, 1995).

Similar to the TN analysis, EPA used the model results to make additional observations with respect to phosphorus loadings from animal waste. Per the SPARROW estimates, manure is a greater contributor than point sources to in-stream TP in approximately 1,220 (59%) of the 2,056 watersheds (Figure 3-11), and is the single largest contributor to in-stream TP in 391 watersheds (Figure 3-12). The predicted percent contribution of animal waste to in-stream phosphorus is significant in many watersheds, particularly in the central U.S. and Mid-Atlantic regions (Figure 3-13).

3.4 Contribution to Shellfish Bed Impairment

In August 1997, the National Oceanic and Atmospheric Administration (NOAA) released *The 1995 National Shellfish Register of Classified Growing Waters.* In this report, NOAA characterizes the status of 4,230 shellfish-growing water areas in 21 coastal states, reflecting an assessment of nearly 25 million acres of estuarine and non-estuarine waters. Over 77 million pounds (meat weight) were harvested from these waters in 1995, with a commercial value of $200 million (NOAA, 1997). In the register, NOAA classifies the water areas with respect to harvest limitations. The classifications include "approved" [for harvest], "conditionally approved," "conditionally restricted,""restricted," "prohibited," and "unclassified." NOAA also reports the types of pollution sources contributing to harvest limitations.

NOAA found that 3,404 shellfish areas had some level of impairment (i.e., a classification other than "approved" or "unclassified"). Of these, 110 (3%) were impaired to varying degrees by feedlots, and 280 (8%) were impaired by "other agriculture" (which could include land where manure is applied). Table 3-1 lists the number of shellfish beds impaired by feedlots, distributed according to impairment classifications and estimated level of contribution.

Table 3-1
Number of Shellfish Beds Impaired by Feedlots

Estimated Level of Contribution	Level of Impairment (Harvest Classification)				Total Impaired by Feedlots
	Conditionally Approved	Conditionally Restricted	Restricted	Prohibited	
Actual Contributor (High)	6	0	12	22	40
Actual Contributor (Medium)	3	1	16	23	43
Actual Contributor (Low)	2	1	2	9	14
Potential Contributor	1	0	8	4	13
TOTAL	12	2	38	58	110

Reference: *The 1995 National Shellfish Register of Classified Growing Waters* (NOAA, 1997). Feedlots were estimated to contribute to the impairment of 110 shellfish beds. This does not include other agricultural operations where manure is land-applied.

4. BENEFITS OF MANAGING ANIMAL WASTE

As discussed throughout this chapter, animal waste can have significant impacts on human health and the environment. Treatment and management options can help reduce or prevent these impacts, and also maximize the waste's use as a fertilizer. Table 4-1 presents the major benefits that could arise from treatment/management of animal wastes.

Table 4-1
Potential Benefits of Treating/Managing Animal Waste

Category	Benefit
Human Health Benefits	Reduce incidence of "blue baby syndrome" (associated with high nitrate concentrations in drinking water supplies (surface water and particularly groundwater)).
	Reduce risks associated with pathogens, i.e. consumption of contaminated drinking water (surface water and groundwater), contact recreation in contaminated surface water, consumption of contaminated shellfish, inhalation of airborne pathogens, and consumption of contaminated food.
	Reduce risks associated with odors and odor-causing compounds.
	Reduce risks associated with metals and other compounds present in animal waste.
	Reduce risks associated with toxic organisms (e.g., *Pfiesteria*) whose growth is encouraged by eutrophication.
Ecological/Recreational Benefits	Reduce the number of fish kills and other environmental damage caused by catastrophic waste spills.
	Reduce risks to aquatic and wildlife species associated with non-catastrophic release of animal waste pollutants, including fish kills, fish disease, habitat destruction, reduced biodiversity, and impaired ecosystem function.

Category	Benefit
	Reduce the incidence of impaired use and aesthetic degradation of recreational waterways. Avoid damage to recreational fisheries and tourism industry.
	Reduce contribution to global warming.
Other Benefits	Avoid costs associated with treatment or replacement of nitrate-contaminated drinking water (surface water and groundwater).
	Avoid damage to commercial fishing and shellfishing industry.
	Avoid costs associated with removing algae, odors, and trihalomethanes from drinking water (surface water).
	Stem reduction in property values near animal feeding operations by reducing odors and/or water quality degradation.

In some cases, direct monetary costs have been documented due to impacts from animal wastes. Many of these costs are associated with additional drinking water treatment requirements. For example, in California's Chino Basin, it has been estimated that it would cost over $1 million per year to remove the nitrates from drinking water due to loadings from local dairies (U.S. EPA, 1993c). In Iowa, Des Moines Water Works planned to spend approximately $5 million to install a treatment system to remove nitrates from their main sources of drinking water, the Raccoon and Des Moines Rivers (Hubert, 1991). Agriculture was cited as a major source of the nitrate contamination, although the portion attributable to animal waste is unknown. In Wisconsin, the City of Oshkosh has spent an extra $30,000 per year on copper sulfate to kill the algae in the water it draws from the Lake Winnebago (Behm (2)). The thick mats of algae in the lake have been attributed to excess nutrients from manure, commercial fertilizers, and soil.

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APPENDIX A

ESTIMATED HUMAN AND ANIMAL WASTE GENERATED IN THE U.S. IN 1992

Human Sanitary Waste Production:

References: 1992 population estimate is from:
U.S. Bureau of the Census. April 1998. Historical National Population Estimates, Internet web site, http://www.census.gov/population/estimates/nation/popclockest.txt.

Sanitary waste production rate is from the Center for Agricultural and Rural Development at Iowa State University, as cited in:
U.S. Senate Committee on Agriculture, Nutrition, and Forestry. December 1997. Animal Waste Pollution in America: An Emerging National Problem, Environmental Risks of Livestock and Poultry Production. Report compiled by minority staff for Senator Tom Harkin.

1992 Population:	255 million people
Sanitary Waste Production:	80 dry pounds per person per year

==> HUMAN SANITARY WASTE PRODUCTION (DRY WEIGHT BASIS), 1992 =

20 billion lbs. = **10 million tons**

Animal Waste Production:

Dry weight manure production was estimated using wet weight manure production figures calculated by others, and percent solids values from the literature. Values are on an as-excreted basis.

References: Wet weight manure production was taken from Exhibit 4.2 of:

Abt Associates, Inc. September 30, 1998. Preliminary Study of the Livestock and Poultry Industry, Draft Final Report.

Abt's production calculations are based on 1992 Agricultural Census data and methodology developed by:

Lander, Charles H., David Moffitt, and Klaus Alt (retired). 1998. Nutrients Available from Livestock Manure Relative to Crop Growth Requirements. U.S. Department of Agriculture, Natural Resources Conservation Service.

This methodology accounts for all on-farm animals (both inventory and production) and provides a well-documented stepwise approach to estimate total manure and nutrient loads, using specified Agricultural Census data categories. The approach accounts for waste loading differences by type and maturity level of the animals, and also method of production.

The poultry category excludes miscellaneous poultry such as geese, quail, pheasants, etc.

Percent solids values are average values for each animal category, based on values given in:

USDA Natural Resources Conservation Service, July 1996. Agricultural Waste Management Field Handbook (AWMFH), 210-vi-AWMFH, rev. 1.

Animal Category	1992 Manure Production (Billions of Pounds, Wet Weight Basis)	Percent Solids in Manure	1992 Manure Production (Billions of Pounds, Dry Weight Basis)
Beef	1,201	11.95%	144
Dairy	464	11.60%	54
Pork	185	9.75%	18
Poultry	116	25.00%	29
Sheep	17	25.00%	4
Goats	4	Not available	Neglect
Horses	83	22.00%	18
TOTAL	**2,070**		**267**

ANIMAL WASTE PRODUCTION (DRY WEIGHT BASIS), 1992 =

267 billion lbs. = **133 million tons**

Percent Solid Values for Animal Manure (As-Excreted)

Reference: Agricultural Waste Management Field Handbook (AWMFH),
210-vi-AWMFH, rev. 1, July 1996.

Note: The calcuated averages are simply the arithmetic averages of the percent solids values for each animal type in the category. They do not account for actual distribution of animal types in each category.

Animal Category	% Total Solids	
BEEF		
Feeder, yearling, 750 - 1,100 lb. high forage diet	11.60%	
Feeder, yearling, 750 - 1,100 lb. high energy diet	11.60%	
450 - 750 lb.	13.00%	
Cow	11.60%	
AVERAGE	11.95%	
DAIRY		
Lactating cow	12.50%	
Dry cow	11.60%	
Heifer	10.70%	
AVERAGE	11.60%	
SWINE		
Grower, 40 - 220 lb.	10.00%	
Replacement gilt	10.00%	
Gestation sow	9.20%	
Lactation sow	10.00%	
Boar	9.30%	
Nursing/nursery pig, 0 - 40 lb.	10.00%	
AVERAGE	9.75%	
POULTRY	(does not include bedding)	
Layer	25.00%	
Pullet	25.00%	
Broiler	25.00%	
Turkey	25.00%	
AVERAGE	25.00%	(Assume duck manure has same consistency.)
SHEEP		
Lamb	25.00%	
GOATS	Not available	
HORSES		
Horse	22.00%	

APPENDIX B
DOCUMENTED IMPACTS FROM ANIMAL FEEDING OPERATIONS

Note: The following list represents the results of a non-exhaustive literature search. The large number of direct discharge-related impacts reflects the high public visibility of such events. Other impacts are not documented as extensively, because typical animal waste pollutants (oxygen-demanding substances, nutrients, pathogens, and solids) can also originate from a number of other sources, and it can be difficult to determine the extent of impact attributable to each source. The list includes impacts where AFOs are considered a significant causative factor. Other factors are listed to the extent that they were included in the literature.

SPILLS AND CATASTROPHIC RUNOFF IMPACTS

Date	Location	Source	Description of Event	Monetary Impact	Comments	Source
7/1/97	IL	Hog farm	800,000 gallons discharged		Contaminated drinking water of at least 5 homes with E. coli	27
10/17/97	Clear Creek, IA	Hog farm	28,134 fish killed	$4,000 direct cost + $2,000 fine		46
10/9/97	Brooke Creek, IA	Hog farm	4194 fish killed	$267.50 direct cost + $2,500 fine		46
9/18/97	Prairie Creek, IA	Hog farm	93,403 fish killed	$16,140.84 direct cost; fine was pending		46
8/27/97	South Fork of Iowa River, IA	Hog farm	3,232 fish killed	$264.23 direct cost; fine was pending		46
7/26/97	Crane Creek, IA	3,200 head hog farm	109,172 fish killed	$33,882.73 direct cost; fine was pending	Blocked pipe resulted in discharge	46
9/4/96	North Buffalo Creek, IA	Hog farm	More than 100,000 gallons pumped into Creek; 586,753 fish killed	$30,000 direct cost + $3,000 fine		46
8/26/96	Rock Creek, IA	Hog farm	871 fish killed	$237 direct cost		46
8/19/96	Cedar County, IA	Hog farm	3,676 fish killed	$408.76 direct cost		46
8/19/96	Tipton Creek, IA	Hog farm	46,315 fish killed	$3,908 direct cost + $3,000 fine		46
11/15/95	Indian Creek, IA	Hog farm	4,928 fish killed	$418 direct cost + $3,000 fine		46
9/25/95	Williams Creek, IA	Hog farm	60,650 fish killed	$21,436 direct cost; fine was pending		46

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
9/5/95	East Branch Beaverdam Creek, IA	Poultry farm	9,002 fish killed	$839 direct cost + $500 fine		46
7/23/95	Elk Creek tributary, IA	Hog farm	16,280 fish killed	$1,410 direct cost + $2,500 fine		46
7/20/95	Little Volga River, IA	Hog farm	23,416 fish killed	$8,155 direct cost + $1,500 fine		46
7/16/95	South Fork of Iowa River, IA	Hog farm	8,861 fish killed	$6,000 direct cost + $2,000 fine		46
7/1/95	Fayette, IA		16,000 gallons discharged; 584 smallmouth bass, 22,011 minnows/ shiners killed			20, 12
7/1/95	Hamilton, IA	700 head hog farm	1.5 million gallons discharged; 8,800 fish killed	$8,000 fine		2, 12
7/1/95	Howard, IA		110 black bullheads, 16,000 minnows killed			20, 12
3/28/95	South English River tributary, IA	Hog farm	Fish kill	$4,000 fine		46
9/94	Kossuth County, IA	Hog farm	408 fish killed	$73 direct cost + $2,250 fine		46
9/94	Williams Creek, IA	Hog farm	Fish kill	$2,000 fine		46
8/94	Otter Creek, IA	Hog farm	1,882 fish killed	$968 direct cost		46
5/94	Church Creek, IA	Hog farm	5,750 fish killed	$2,118 direct cost		46
5/94	Hickory Creek tributary, IA	Hog farm	8,397 fish killed	$722 direct cost + $300 fine		46

SPILLS AND CATASTROPHIC RUNOFF IMPACTS

Date	Location	Source	Description of Event	Monetary Impact	Comments	Source
3/94	Eagle Creek, IA	Hog farm	Fish kill	$3,000 fine		46
12/93	Boone River, IA	Hog farm	Fish kill	$5,000 fine		46
11/93	Union County, IA	Hog farm	Fish kill	$1,000 fine		46
10/93	Middle Avery Creek, IA	Hog farm	Fish kill	$9,700 fine	Fine split between farm and waste management design company	46
9/93	South English River tributary, IA	Hog farm	Fish kill	$1,650 fine		46
7/93	Iowa River tributary	Hog farm	Fish kill	$3,000 fine		46
6/93	Keokuk County, IA	Hog farm	Fish kill	$4,500 fine		46
5/93	Brush Creek, IA	Hog farm	265,000 fish killed	$10,000 direct cost + $2,500 fine		46
4/93	Brookside Creek tributary, IA	Hog farm	Fish kill	$2,000 fine		46
4/93	Iowa River tributary, IA	Hog farm	Fish kill	$300 fine		46
8/92	East Nishnabotna River, IA	Hog farm	Fish kill	$1,000 fine		46
8/92	Tipton Creek, IA	Hog farm	34,994 fish killed	$200 fine		46
7/92	Skunk River, IA	Hog farm		$100 fine		46
7/92	South River, IA	Hog farm	6,264 fish killed	$3,448 direct cost + $19,500 fine	From land application of lagoon contents; effects lasted for 2 months	46
7/92	Wright County, IA	Hog farm	Fish kill	$400 fine		46

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
3/92	Cedar River, IA	Hog farm		$250 fine	Retention basin overflow.	46
3/92	Hamilton County, IA	Hog, turkey and dairy farm	Fish kill	$1,000 fine		46
2/92	Beaverdam Creek, IA	Hog farm		$300 fine	Below-building pit overflow.	46
7/11/95	Tuscarora Creek, MD	Manure (animal type unknown)	1,000 fish killed			44
7/26/94	Toms Run, MD	Manure (animal type unknown)	1,500 fish killed			44
10/1/91	Deep Run, MD	Poultry farm	10,000 fish killed			44
6/22/90	Wagram Creek, MD	Manure (animal type unknown)	19,000 fish killed			44
9/24/87	Farm Pond, MD	Manure (animal type unknown)	1,000 fish killed			44
3/30/87	Morgan Creek, MD	Manure (animal type unknown)	2,500 fish killed			44
7/30/86	Liitle Pipe Creek, MD	Manure (animal type unknown)	150 fish killed			44
7/15/86	Cabbage Run, MD	Manure (animal type unknown)	175 fish killed			44
9/30/85	Deep Run, MD	Manure (animal type unknown)	Hundreds of fish killed			44
9/29/85	Jennings Run, MD	Manure (animal type unknown)	3,900 fish killed			44

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
8/10/85	Deer Creek, MD	Manure (animal type unknown)	100,000 fish killed			44
1994	Belle River, MI	Manure (animal type unknown)	Fish kill	$5,150 direct cost + $5,000 fine	Overflow and misapplication of manure	52
1994	Macon Creek, MI	Manure (animal type unknown)	Fish kill	$1,330 direct cost + $5,000 fine	Euipment failure caused manure discharge	52
1994	Salt River, MI	Manure (animal type unknown)	Fish kill	$20,000 direct cost + $2,500 fine	Over-application of manure to field, causing runoff	52
1993	Crockery Creek, MI	Manure (animal type unknown)		$1,650 enforcement costs +$2,500 fine		52
1993	Deer Creek tributary, MI	Manure (animal type unknown)		$4,000 enforcement costs + $20,000 fine		52
3/1/98	Olmsted, MN	Dairy feedlot	125,000 gallons discharged		Contaminated local wells	2
2/98	Lake Wagonga, MN	Manure (animal type unknown)	Manure-contaminated runoff discharged to lake			2
1/98	Nokasippi, MN	Manure (animal type unknown)	Manure-contaminated runoff (from feedlot and stockpile) discharged to river		Failed to notify authorities, made no attempt to abate or recover discharge	2

SPILLS AND CATASTROPHIC RUNOFF IMPACTS

Date	Location	Source	Description of Event	Monetary Impact	Comments	Source
9/97	Blue Earth River, MN	Manure (animal type unknown)	Fish kill of 6,626 catfish, small-mouth bass, rock bass, white bass, and minnows			2
8/97	Hay Creek, MN	Manure (animal type unknown)	Fish kill of 6,000 brown trout and white suckers.			2
8/97	Speltz Creek, MN	Manure (animal type unknown)	300 gallons discharged; 130 minnows killed			2
7/97	Lyon County, MN	250 head cattle farm	Runoff			2
6/19/97	Renville County, MN	9,000 hogs	100,000 gallons discharged; 690,000 fish killed	Fined for failure to notify	Lagoon overflow caused by timer malfunction.	2
6/97	Roseau County, MN	Manure (animal type unknown)	Manure discharge		Discharge from un-permitted tank, caused by improper construction and pump failure.	2
5/97	Wabasha County, MN	Dairy farm	16,500 minnows and white suckers killed		Fish kill caused by ammonia.	2
4/97	Lyon County, MN	800 head cattle farm	Open lot runoff			2
3/97	Grant County, MN	2,000 chicken poultry farm	Pumped waste into wetland			2
3/97	LeSueur County, MN	1,960 head cattle farm	Overapplication and runoff			2
3/97	Lyon County, MN	1,000 head cattle farm	Open lot runoff			2

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
8/96	Meeker County, MN	200 head hog farm	Overflowing lagoon			2
8/96	Nicollet County, MN	1,400 head cattle farm	Overapplication and runoff			2
6/96	Clay County, MN	500 head cattle farm	Multiple runoff culverts to river			2
4/96	Blue Earth County, MN	500 head hog farm	Siphoned basin into a stream and had an un-permitted basin			2
4/96	Blue Earth County, MN	200 head hog farm	Siphoned pit/ un-permitted basin			2
4/96	Crow Wing, MN	100 head dairy farm	Stockpile runoff			2
4/96	Houston County, MN	1,500 head cattle farm	Overflowing basin			2
4/96	Nobles County, MN	Hog farm	Overflowing basin			2
4/96	Watonwan County, MN	700 head hog farm	Overflowing basin			2
2/96 - 4/96	Osborne Township, MN	Hog farm	Overflow from pit onto ground and into Rock River, at rate up to 12 gpm			2
1996	Mankato, MN	Manure (animal type unknown)	Drained manure into Watonwan and Blue Earth Rivers			2
11/95	Morrison County, MN	100 head cattle farm	Runoff to river			2
11/95	Olmsted County, MN	10,000 head cattle farm	Multiple runoff concerns			2

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
10/95	Traverse County, MN	2,500 head hog farm	Overflowing pits			2
9/95	Lincoln County, MN	2,500 head hog farm	Pumped manure basin into a river			2
8/95 - 9/95	Larkin Township, MN	Various animals	3 weeks worth of overflow from lagoon through trench and into Kanaranzi Creek			2
8/1/95	Lincoln, MN	Hog farm	5,000- 10,000 fish killed			2
7/95 - 8/95	Drammen Township, MN	Manure (animal type unknown)	Overflow of pits which drained into a ditch; 19,641 fish killed in Medary Creek			2
5/95	Renville County, MN	700 head hog farm	Manure and contaminated wastewater flowed into a surface tile inlet in a county ditch			2
5/95	Slayton Township, MN	Steer farm	Runoff into a tributary of Beaver Creek			2
3/95	Lyon County, MN	400 head cattle farm	Tile inlet in feedlot			2
3/95	Lyon County, MN	2,000 head cattle farm	Runoff and un-permitted construction			2

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
4/94 - 8/94	Lone Tree Township, MN	Hog farm	Pumped about 5,000 gallons of wastewater containing manure into a ditch every two weeks			2
4/94	LeSueur County, MN	1,000 head cattle farm	Multiple runoff problems			2
4/94	Meeker County, MN	1,500 head hog farm	Multiple runoff problems			2
4/94	Redwood County, MN	750 head cattle farm	Un-permitted basin and discharge			2
1994	Nicollet County, MN	Manure (animal type unknown)	Constant diversion of manure into streams from unknown facilities			2
1985 - 1994	Tyrone Township, MN	950 steer cattle farm	Various problems, including massive runoff			2
1/92	Green Isle Township, MN	Dairy farm	225,000 gallons of manure pumped onto a field in 5 hours, flowed through a drainage tile into Curran Lake			2
9/1/95	Gentry, MO	Hog farm	Unknown			20
8/1/95	Greencastle MO	30,000 head hog farm	Over 20,000 gallons discharged; 173,000 fish killed			20

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
1995	MO	Hog farms	270,000 fish killed			43
8/96	Four-Mile Creek, NE	Hog farm	300-500 bullhead, 100 carp, 100 cyprinids killed		Lagoon discharge	49
6/96	Lost Creek, NE	Unclear if pig or cattle	2,120 fish killed	$1,079.50 direct cost; fine was pending		49
6/95	Scholz Pond, NE	Hog farm	96 fish killed	$13.25 direct cost + $1,000 fine	Land application and pipeline break	48
3/95	Swan Creek, NE	Hog Farm	Fish kill	$971.66 direct cost + $10,000 fine		47
2/1/97	Pamlico, NC	4,000 hogs	1,000 gallon discharge		No noticeable fish kill	17
8/1/95	Brunswick County, NC	6,400 head hog farm	2 million gallons discharged		6th major livestock discharge in 2 weeks	40
8/1/95	Onslow, NC	Hog farm	Under 1 million gallons discharged			40
7/1/95	Bladen, NC	Hog farm	1 million gallons discharged over 2 days			20
7/1/95	Duplin, NC	75,000 chicken farm	8.6 million gallons discharged; fish kill resulted			20
6/21/95	New River, NC	Hog farm	25 million gallons discharged; 3,000-4,000 fish killed	$6,200 direct cost + $92,000 fine		55, 45
6/1/95	Onslow County, NC	10,000 head hog farm	25 million gallons discharged; 3,000-4,000 fish killed	$110,000 fine, including $6,200 for fish kill and $92,000 in civil penalties		37, 20

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
6/1/95	Sampson County, NC	Hog farm	1 million gallons discharged			20
5/1/91	Duplin County, NC	Hog Farm	“Tons of water” discharged			34
05/19/97	Tributary to Chickasaw Creek, OH	Cow manure	Manure from cattle yard to stream via tile			58
03/25/97	Prairie Outlet, OH	Cow manure	Manure leached from holding ponds into creek			58
02/04/97	Tributary to Town Run, OH	Poultry manure	Manure spread on frozen fields, followed by rainfall			58
12/10/96	West Branch Tontagony Creek, OH	Hog manure	Manure leaked into barn and into creek			58
11/19/96	Tributary to Little Scioto River (RM 23.66), OH	Cow manure	Manure spray gun malfunctioned and flooded field			58
11/13/96	Scherman Ditch, OH	Cow manure				58
10/28/96	Apple Ditch, OH	Manure	Manure coming from field tile			58
10/27/96	Little Tymochtee Creek, OH	Cow manure	Manure leaking from pit at dairy farm			58
10/22/96	Dahlinghaus Ditch, OH	Chicken manure	Manure entered field tiles and into stream			58
10/10/96	Dahlinghaus Ditch, OH	Chicken manure	Manure entered field tiles and into stream			58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
10/10/96	Tributary to Beaver Creek, OH	Hog manure				58
09/30/96	Tributary to Coldwater Creek, OH	Cow manure	Manure spread on fields ran into creek			58
09/25/96	Tributary to Chickasaw Creek, OH	Cow manure	Runoff from cattle feedlot into field tile into creek			58
09/18/96	Tributary to Beaver Creek, OH	Manure				58
09/03/96	West Branch Wolf Creek/Aldrich Run, OH	Hog manure	Manure ran off into ditch and into creek			58
08/13/96	Blacklick Creek, OH	Cow manure	Manure sprayed on field ran into tile drain			58
08/04/96	Tributary to Beaver Creek, OH	Hog manure				58
08/03/96	Tributary to Auglaize River (RM 87.75), OH	Hog manure	Liquid manure applied too heavily; runoff into tile			58
07/31/96	Montezuma Creek, OH	Cow and hog manure	Manure entered stream from field tile			58
07/15/96	Tributary to Beaver Creek, OH	Cow manure				58
07/15/96	Tributary to Beaver Creek, OH	Chicken manure	Manure entering stream from field tile			58
07/10/96	Dahlinghaus Ditch, OH	Chicken manure	Runoff from field application of manure			58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
07/09/96	Little Tymochtee Creek, OH	Hog manure	Broken pipe on truck allowed manure to enter creek			58
07/08/96	Cedar Fork, OH	Manure	Hose sprung leak and manure spread onto ground and into tile			58
07/05/96	Wabash River, OH	Manure	Manure runoff from milkhouse into field tile			58
07/04/96	Wabash River, OH	Cow and hog manure	Runoff from field application of manure			58
06/24/96	Little Chippewa Creek and Tributary, OH	Chicken manure	Manure runoff into ditch from farm (retention pond overflow)			58
06/20/96	Threemile Creek, OH	Cow manure	Runoff from field application of manure			58
06/17/96	East Fork Vermilion River, OH	Manure				58
05/23/96	Tributary to Pymatining Creek (RM 23.95), OH	Cow manure	Runoff after spreading manure			58
05/22/96	Little Bear Creek, OH	Cow manure	300,000 gallons of manure spread on fields, washed into creek			58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
05/17/96	Painter Creek, OH	Hog manure	Runoff from manure spreading			58
05/16/96	Tributary to Red Run, OH	Cow manure	Manure spread directly into several ditches			58
03/29/96	Tributary to Little Short Creek, OH	Cow manure	Manure pumped into ravine and into stream			58
02/27/96	Tributary to Pipe Creek, OH	Hog manure	Manure spread on fields, followed by snow melt and rain			58
02/21/96	East Branch Sugar Creek, OH	Cow manure			No fish kill; unsure if pollutants entered stream	58
01/09/96	Tributary to East Fork White Eyes Creek, OH	Cow manure			No fish kill; unsure if pollutants entered stream	58
12/06/95	Tributary to Stillwater River, OH	Hog manure	2,000,000 gallons pumped onto 54 acres			58
12/02/95	Little Tymochtee Creek, OH	Hog manure	Liquid manure pumped onto fields into tiles into creek			58
11/26/95	Leatherwood Creek, OH	Hog manure				58
10/26/95	Tributary to Mile Creek (RM 4.15), OH	Manure	Liquid manure applied too heavily			58
10/25/95	Tributary to Spring Creek (RM 1.25), OH	Hog manure	Manure pumped onto fields, ran into tiles and to stream			58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
10/20/95	Wolf Creek, OH	Hog manure	Unknown amount leaked from storage pit into stream			58
09/03/95	Tributary to Poplar Creek, OH	Manure	Accidental manure spill			58
09/01/95	Indian Creek, OH	Cow manure	600,000 - 800,000 gallons pumped onto 40 acres			58
08/27/95	Indian Creek, OH	Hog manure	Lagoon pumped onto small field; drained into creek			58
08/24/95	Martins Creek, OH	Manure and milk products	Manure and milk washed into drains into creek			58
08/20/95	Montezuma Creek, OH	Cow manure	Sprinkling system to cool animals created excess runoff			58
08/19/95	Tributary to Anderson Fork, OH	Cow manure	Tractor got stuck; manure tank emptied; rain washed to creek			58
08/07/95	Indian Run, OH	Hog manure			Heavy rain after manure application to fields	58
07/10/95	East Fork White Eyes Creek, OH	Cow manure				58
07/05/95	Rock Creek, OH	Manure				58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
07/03/95	Oak Run, OH	Hog manure	Accidental release from drain pipe during application			58
05/03/95	Tributary to Killbuck Creek, OH	Cow manure	Periodic discharges of manure to stream			58
05/03/95	Sugar Creek, OH	Cow manure	Broken pipe at pit, manure flow into tile and then creek			58
04/22/95	Newman Creek, OH	Manure				58
03/27/95	Kiber Run, OH	Cow and hog manure	Runoff from spraying fields ran into field tiles			58
03/20/95	Little Chippewa Creek	Chicken manure	Chicken manure possibly dumped into field tile			58
12/05/94	Big Run, OH	Cow manure	Runoff from pasture and feedlots			58
12/03/94	Kraut Creek, OH	Chicken manure	Manure entered field tile		Accidental removal of plank allowed manure to enter tile	58
10/16/94	Prairie Creek, OH	Manure	Irrigated manure entered tile into creek			58
10/01/94	Second Creek, OH	Hog manure				58
09/24/94	Tributary to Lake Fork Mohican River, OH	Hog manure	Liquid manure entered field tile and creek			58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS

Date	Location	Source	Description of Event	Monetary Impact	Comments	Source
09/21/94	East Branch Salt Creek, OH	Hog manure	Hogs fenced to stream, defecated on land - runoff to stream			58
09/20/94	North Branch Salt Creek, OH	Hog manure	Hogs fenced to stream, defecated on land - runoff to stream			58
09/14/94	Stillwater River, OH	Chicken manure	Manure entered tile, then stream			58
09/11/94	Carter Creek, OH	Hog manure	800,000 gallons of manure applied to 8 acre field; discharged into tile into creek			58
08/29/94	Tributary to Beaver Creek, OH	Cow and hog manure	Crack in holding pit into tile			58
07/18/94	Black Run, OH	Manure				58
06/16/94	Harmon Brook, OH	Cow manure	Crack in lagoon lead to manure leak			58
05/31/94	Grog Run, OH	Hog manure	Lagoon drained via hose to field at edge of creek			58
12/15/93	Tributary to Grand Lake St. Mary's, OH	Cow manure	Manure in ditch and tile leading to stream			58
09/08/93	Little Beaver Creek, OH	Milkhouse wastewater and manure				58
08/20/93	Stony Creek, OH	Cow manure	Runoff from feedlot entered creek			58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS

Date	Location	Source	Description of Event	Monetary Impact	Comments	Source
08/11/93	Middle Fork Sugar Creek, OH	Cow manure				58
07/15/93	Barcer Run, OH	Hog manure	Spray-irrigated manure ran off into stream			58
05/09/93	Henry Ditch, OH	Chicken manure			Approximately 4 miles affected in Indiana	58
04/08/93	Tributary to Wabash River, OH	Hog manure				58
11/18/92	Tributary to Lick Creek, OH	Hog manure	Accidental discharge due to clogged pump			58
09/09/92	Subtributary to Pawpaw Creek, OH	Cow and hog manure	Possible runoff from feedlots			58
08/26/92	Little Sugar Creek, OH	Hog manure				58
08/18/92	Tributary to Coldwater Creek, OH	Manure	Manure applied to field entered creek			58
08/14/92	Mississinewa River, OH	Chicken manure				58
08/12/92	Tributary to Auglaize River, OH	Hog manure	Irrigated manure runoff into tile into creek			58
07/12/92	Tributary to Black Fork Mohican River, OH	Cow manure	Drainage from manure pit through field tile to creek			58
07/08/92	Little Miami River, OH	Manure	Runoff and leachate into stream			58
11/03/91	Sugar Creek, OH	Chicken manure				58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
09/18/91	Salt Creek, OH	Hog manure	Manure washed into stream			58
04/29/91	Tributary to Bear Creek, OH	Manure	Manure entered field tile and into stream			58
04/18/91	Tributary to Little Scioto River, OH	Cow manure	Manure liquids ran off farm into ditch			58
03/02/91	Middle Fork Little Beaver Creek, OH	Manure				58
02/20/91	Mohican River, OH	Cow manure				58
09/13/90	Tributary to Blanchard River, OH	Chicken manure	Runoff from fields into creek			58
08/24/90	Thompson Creek, OH	Hog manure				58
08/20/90	Olentangy River, OH	Cow manure				58
08/18/90	Tributary to Cowan Creek, OH	Cow manure				58
08/16/90	Schenck Creek, OH	Cow manure	Manure pit overflowed into ditch			58
08/08/90	Bear Creek, OH	Hog manure				58
07/30/90	Sycamore Creek, OH	Manure and household wastes				58
06/25/90	Cloverlick Creek, OH	Hog manure				58
06/16/90	Clear Creek, OH	Cow manure				58
06/13/90	Lees Creek, OH	Hog manure				58
05/01/90	Tributary to Caesar Creek, OH	Hog manure				58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
11/09/89	Tributary to Beaver Creek, OH	Manure				58
09/27/89	Jennings Creek, OH	Hog manure				58
08/19/89	Tributary to Jerome Fork, OH	Manure				58
08/12/89	North Fork of Deer Creek, OH	Cow Manure				58
08/07/89	Elkhorn Creek, OH	Manure				58
06/29/89	Painter Run, OH	Cow manure				58
05/31/89	Grassy Fork, OH	Hog manure				58
04/28/89	Kale Creek, OH	Hog manure				58
03/13/89	Wolf Creek, OH	Hog manure				58
10/20/88	Indian Creek, OH	Manure				58
08/02/88	Tributary to Red Run, OH	Cow manure				58
11/15/87	Jennings Creek, OH	Hog manure				58
11/02/87	Powderlick Run, OH	Chicken manure				58
09/28/87	Big Run, OH	Manure				58
09/18/87	Spring Creek, OH	Manure				58
09/02/87	Mill Creek, OH	Hog manure				58
08/04/87	Painter Creek, OH	Hog manure				58
08/03/87	Camp Creek, OH	Hog manure				58
06/27/87	Buck Run, OH	Hog manure				58
05/21/87	Camp Creek, OH	Hog manure				58
05/05/87	Chapman Creek, OH	Hog manure				58

SPILLS AND CATASTROPHIC RUNOFF IMPACTS						
Date	**Location**	**Source**	**Description of Event**	**Monetary Impact**	**Comments**	**Source**
05/02/87	Big Run, OH	Cow manure				58
01/17/87	Unnamed creek, OH	Hog manure				58
8/14/98	Kitchen Creek, WV	Cow Manure	Runoff from cattle manure pond; 13,693 fish killed (rock bass, minnows, suckers, margined madtom, darters, sculpin)		2.1 miles of stream affected	59

HUMAN HEALTH-RELATED IMPACTS

Date	Location	Source	Environmental Impact	Monetary Impact	Comments	Source
6/17/95	Delmarva Peninsula (DE, MD, VA)	Poultry	Possible groundwater contamination from poultry waste		623 million broilers were produced on the peninsula in 1995	7
1990	Delmarva Peninsula (DE, MD, VA)	Hog farm	Ammonium-nitrogen concentrations of 1,000mg/L in shallow monitoring wells around hog waste lagoons		Scientific study	50
1982	Sussex County, DE	Poultry farms	Nitrate levels greater than 10 mg/L in 32% of wells			42
	FL	Poultry farms	Nitrate levels greater than 10 mg/L in one-third of wells			42
6/19/95	LaGrange, IN	CAFOs (unknown what type of animal)	Nitrate contamination in private wells		May be linked to the miscarriages of four women	10
3/1/91	Des Moines, IA	Animal waste, as well as fertilizers	Contamination of drinking water with nitrate	Waterworks will spend $5 million on a nitrate removal system		11

HUMAN HEALTH-RELATED IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
	Hancock, IA	Hog farm	Family complained that for 56 days odor was so bad that it caused nausea and headaches			12
6/15/95	Wichita, KS	Nutrients from farm runoff, including animal manure	Contamination of drinking water supply	Wichita is installing a special filtering mechanism which will cost $1 million per year to operate	Some algal strains growing in the reservoir are thought to produce a liver toxin linked to stomach flu	9
6/18/95	MN	Animal waste	Levels of hydrogen sulfide gas found to be high enough to cause health symptoms		Particularly dangerous for children or people with underlying health problems	10
4/98	Duplin County, NC	2,000,000 head hog farm	Groundwater contamination		Nitrate levels five times state standards	51
12/1/95	Four Oaks, NC	Hog farms	13 private wells contaminated			38

HUMAN HEALTH-RELATED IMPACTS

Date	Location	Source	Environmental Impact	Monetary Impact	Comments	Source
10/1/95	Shannon, NC	1,200 head hog farms	Family complains of overpowering stench and mist of manure when farmer sprays his fields			39
10/1/95	NC	Hog farm	4 private wells were found to have nitrate levels 10 times the health standard		Linked conclusively to the hog farms	39, 36
4/1/95	Browntown, NC	Hog farms	Residents fighting with hog farmers over odor			34
6/13/95	Erath, TX	Dairy farms	Well contamination		Nitrate levels exceeding standards	26
	WI	Varied (including AFOs)	WI DNR estimates that 10% of the states 700,000 wells exceed health standards		Major pollutant sources include CAFOs, development, crop farms, and ski slopes.	1

HUMAN HEALTH-RELATED IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
	WI	Dairy farms	Contamination of surface waters		Ear and skin infections, as well as intestinal illnesses common to swimmers in manure-contaminated waterways	1
	Door County, WI	Dairy farms	Well contamination	State will spend $3 million to protect Door County groundwater	Families have had to drill new wells	1

ECOLOGICAL/RECREATIONAL/OTHER IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
1997	Chesapeake Bay	Poultry farms	30,000 fish killed		*Pfisteria piscicida* outbreak	41
	Appoquinimink River, DE	Poultry, dairy, and beef	Eutrophication		Fish kills and hindered boating	4
	DE	Poultry industry	Eutrophication, fish kills and red tide		Not clear how much to attribute to poultry waste	3
	Taylor Creek, FL	Dairy and beef	Eutrophication in Lake Okeechobee			6
	GA, AL, FL	Animal waste	Excess nutrients in the Apalachicola-Chattahoochee-Flint watershed			31
6/15/95	KS	Feedlots, as well as farms	Eutrophication in Arkansas River		37 species of fish are in danger	9
8/97	Pokomoke River, MD	Poultry farms	20,000-30,000 fish killed		*Pfisteria piscicida* outbreak; 13 humans also affected	53
6/20/95	Kings Creek, MD	Poultry farms	Fish kill		*Pfisteria piscicida* outbreak	54

ECOLOGICAL/RECREATIONAL/OTHER IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
6/19/95	MD	Poultry	Extensive fish kill in the Chesapeake Bay		*Pfiesteria piscicida* outbreak	21
	Double Pipe Creek, MD	Poultry (700,000 chickens)	High fecal coliform counts		Threatens water supply as well as aquatic life and recreation	19
1997	NC rivers	Hog farms	450,000 fish killed		*Pfisteria piscicida* outbreak	41
1985-1995	Sampson County, NC	Mainly hogs (Livestock is responsible for 93% of ammonia emissions across NC. Hogs account for 78% of ammonia emissions from livestock operations in the southern coastal plain of NC, where Sampson County is located.)	100% increase in amount of ammonia in rainwater corresponds with growth of hog industry		Contributes to eutrophication via atmospheric depostion.	13

ECOLOGICAL/RECREATIONAL/OTHER IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
9/1/95	NC	Hogs	Zinc and copper in manure building to potentially harmful levels on fields		Zinc and copper added to feed	35
9/1/95	Neuse River, NC	Hogs	500,000 fish killed		Toxic dinoflagellate outbreak	16
8/1/95	NC	Livestock waste	8-fold increase in ammonia emissions		Contributes to eutrophication via atmospheric depostion.	15
6/13/95	Neuse River, NC	Hogs	1 billion fish killed		Toxic dinoflagellate outbreak	14
1995	Coastal wetlands of NC	Hog farms	Closed shellfish beds			41
	Tar-Pamlico River Basin, NC		Eutrophication resulting in die-off of benthic life and toxic dinoflagellate growth	Shellfish beds have been closed because of fecal coliform	Winter algal blooms occur regularly	22, 8
	NC	Hogs	Low dissolved oxygen, fish kills, loss of submerged vegetation			5

ECOLOGICAL/RECREATIONAL/OTHER IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
1998	Tulsa, OK	Poultry (82.5 million chickens in the watershed)	Excessive algal growth in Lake Eucha; impacts on drinking water taste and odor.	Tulsa spends $100,000 per year to address taste and odor problems in the drinking water.		28, 57
1997	Tulsa, OK	714 Chicken houses, 57 hog houses, and 5 turkey houses in the watershed	Dissolved oxygen problems due to excess algae growth in Lake Eucha. In 1993, dissolved oxygen levels were near zero below five meters in the lake, making 44 percent of it unhabitable.		Nutrient inputs to the watershed tripled in the past 20 years. Fifty percent of the nutrients in Lake Eucha are attributed to nonpoint sources. Lake Eucha provides half of Tulsa's drinking water.	56
	Tillamook Bay, OR	Dairy	High fecal coliform in the waters of the Bay	Affecting tourism and oyster industries	May be causing health hazards as well	23
6/18/95	Waco, TX	Dairies, as well as urban runoff and crop fertilization	An algal bloom of Anabaena, which caused a foul-smelling and tasting chemical in water supplies			32

ECOLOGICAL/RECREATIONAL/OTHER IMPACTS						
Date	**Location**	**Source**	**Environmental Impact**	**Monetary Impact**	**Comments**	**Source**
6/16/95	Erath, TX	Dairy	Total N and P above screening levels in Upper North Bosque River			24
	Nansemond-Chuckatuck watershed, VA	448,000 chickens 24,000 hogs, 2724 beef cows, 125 dairy cows	Eutrophication and contamination with fecal coliform	Shellfish areas closed	Caused by runoff from agricultural areas	29
	WI	Excessive nutrients	90% decline in bass population in one year			1
	Eau Claire, WI	Dairy Farms	Swimming and water skiing are prohibited in Tainter Lake because of bacterial contamination		Sedimentation from development and crop runoff also causing problems	1
	Osh Kosh, WI	Dairy farms, as well as development	Algal blooms in Lake Winnebago	City of Osh Kosh spends $30,000 a year to kill algae	Lake Winnebago represents 17% of the state's surface water	1
	Black Earth Creek Watershed, WI	Dairy	Eutrophication			8

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