



United States Department of Agriculture  
Natural Resources Conservation Service

---

**Part 651**  
**Agricultural Waste Management**  
**Field Handbook**

---

**Chapter 3**

---

**Agricultural Wastes and  
Water, Air, and Animal  
Resources**

---

Issued February 2012

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW., Washington, DC 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

---

# Acknowledgments

---

Chapter 3 was originally prepared and printed in 1992 under the direction of by **James N. Krider** (retired), national environmental engineer, Soil Conservation Service (SCS), now Natural Resources Conservation Service (NRCS). **James D. Rickman** (retired), environmental engineer, NRCS, Fort Worth, Texas, provided day-to-day coordination in the development of the handbook. Authors and those who made major contributions to chapter 3 included **Michael F. Walter**, Cornell University, Ithaca, New York; **Victor W.E. Payne** (retired), environmental engineer, NRCS, Auburn, Alabama; and **Timothy Powers** (retired), environmental engineer, NRCS, Nashville, Tennessee.

This version was prepared under the direction of **Noller Herbert**, director, Conservation Engineering Division (CED), Washington, DC. Revisions to the chapter were provided by **Bill Reck**, environmental engineer, East National Technical Support Center, Greensboro, North Carolina, and **Greg Zwicke**, air quality engineer, West National Technical Support Center, Portland, Oregon. It was finalized under the guidance of **Darren Hickman**, national environmental engineer, CED, Washington, DC.

Editorial and illustrative assistance was provided by **Lynn Owens**, editor; **Wendy Pierce**, illustrator; and **Suzi Self**, editorial assistant, National Geospatial Management Center, Fort Worth, Texas.



## Chapter 3

# Agricultural Wastes and Water, Air, and Animal Resources

<b>Contents</b>	<b>651.0300</b>	<b>Introduction</b>	<b>3-1</b>
	<b>651.0301</b>	<b>Pollution versus contamination</b>	<b>3-1</b>
	<b>651.0302</b>	<b>Effects of animal waste on the water resource</b>	<b>3-2</b>
		(a) Constituents affecting surface water quality .....	3-2
		(b) Constituents affecting groundwater quality .....	3-15
	<b>651.0303</b>	<b>Factors affecting the water pollution process</b>	<b>3-16</b>
		(a) Pathways to pollution .....	3-16
		(b) Transformations on the soil surface .....	3-16
		(c) Filtering in the upper soil layer .....	3-17
		(d) Transformations within the deep soil profile.....	3-17
	<b>651.0304</b>	<b>Controlling the water pollution process</b>	<b>3-18</b>
		(a) Limiting availability.....	3-19
		(b) Preventing detachment .....	3-20
		(c) Interrupting transport .....	3-20
	<b>651.0305</b>	<b>Effects of animal waste on the air resource</b>	<b>3-21</b>
		(a) Odors.....	3-21
		(b) Particulate matter.....	3-21
		(c) Greenhouse gases .....	3-21
		(d) Ozone precursors .....	3-22
		(e) Animal health and asphyxiation .....	3-22
	<b>651.0306</b>	<b>Effects of animal waste on the animal resource</b>	<b>3-24</b>
	<b>651.0307</b>	<b>Conservation practice physical effects</b>	<b>3-25</b>
	<b>651.0308</b>	<b>Summary</b>	<b>3-25</b>
	<b>651.0309</b>	<b>References</b>	<b>3-27</b>

<b>Tables</b>	<b>Table 3-1</b>	A sampling of influent BOD <sub>5</sub> concentrations and range of effluent concentration for various types of anaerobic lagoons	3-4
	<b>Table 3-2</b>	Concentrations of total ammonia (NH <sub>3</sub> + NH <sub>4</sub> ) in mg/L that contain an un-ionized concentration of 0.020 mg/L NH <sub>3</sub>	3-6
	<b>Table 3-3</b>	Estimated concentrations of total dissolved nitrogen in runoff from land with and without livestock and poultry manure surface applied	3-7
	<b>Table 3-4</b>	Estimated dissolved P concentrations in runoff from land with and without animal wastes surface applied	3-10
	<b>Table 3-5</b>	Diseases and organisms spread by animal manure	3-14
	<b>Table 3-6</b>	Typical allowable limits for fecal coliform bacteria based on water use	3-14
	<b>Table 3-7</b>	Typical fecal coliform to fecal streptococcus ratios (as excreted) for several animal species	3-14
	<b>Table 3-8</b>	Soil factors affecting infiltration and movement (leaching) of bacteria in soil	3-17
	<b>Table 3-9</b>	Properties and physiological effects of the most important gases produced from animal wastes in an anaerobic environment	3-23
<b>Figures</b>	<b>Figure 3-1</b>	Aerobic cycle of plant and animal growth and decomposition as related to nitrogen and carbon	3-4
	<b>Figure 3-2</b>	Site analysis diagram	3-5
	<b>Figure 3-3</b>	Phosphorus inputs and losses at a waste application site and P transformation within the profile (abbreviated P cycle)	3-8
	<b>Figure 3-4</b>	Phosphorus retention and solubility as related to soil pH	3-10
	<b>Figure 3-5</b>	Lake trophic states based on model by Vollenweider	3-13
	<b>Figure 3-6</b>	Transformations on or in the soil	3-18
	<b>Figure 3-7</b>	Possible danger points in the environment from uncontrolled animal waste	3-26

---

### 651.0300 Introduction

This chapter focuses on the effects that agricultural wastes can have on water, air, and animal resources. Special emphasis is placed on the reactions of particular contaminants within the aquatic environment (how they change and how they affect aquatic life and human health). The impact of contaminants on designated uses of water is not covered in detail here because it is adequately covered in chapter 1 of this handbook. The pollutant delivery process—the movement of pollutants from the source to a stream or water body—is described in this chapter.

---

### 651.0301 Pollution versus contamination

In addressing the subject of pollution, we must be aware that none of the natural resources, especially water and air resources, is completely pure. Air often contains pollen, dust, volcanic ash, and other particulates. In that sense, the air we breathe would rarely be “pure,” even without the influence of humans.

Likewise, all natural water, including surface water, groundwater, and precipitation, contains foreign substances; it is not simply two parts hydrogen and one part oxygen (H<sub>2</sub>O). Some foreign substances occur naturally, and some are there because of cultural contamination (human activity on the land).

Natural water might contain minerals, salts, algae, bacteria, gases, and chemicals and have an unpleasant taste, yet it still might not be considered polluted. Water generally is considered polluted only if foreign substances in the water result in impairment of a specific, designated use of the water. The determination of use impairment is based on the quality of water not meeting established limits for specific constituents (e.g., 5 mg/L of dissolved oxygen) and not necessarily on an obvious problem, such as an alga bloom or bad taste and odor.

Water may be contaminated by substances, but not be considered polluted with regard to meeting established standards. A farmer, for example, may fertilize the farm pond at recommended rates in the spring to enhance fish production. This purposeful addition of nutrients to the water and the subsequent minor enrichment do not constitute an act of pollution because the intended use of the water (fish production in this case) is not impaired; rather, fish production is enhanced.

On the other hand, if the water from that same farm pond was discharged to a stream having an inlet pipe for a municipal water supply immediately downstream, the discharge could be considered polluted if it contained a concentration of any substance that did not meet State standards for a water supply. The alga that served as a source of feed for aquatic organisms in the pond could become unwanted suspended solids and a potential problem at the water treatment plant.

In this chapter, pollution refers to a resource that has been contaminated beyond legal limits. Such limits are specifically designated by State agencies, but may be limited to only the water and air resources. However, limits can also be applied to soils and plants to prevent unsafe levels of heavy metals where municipal sludge is being applied. Fish and cattle (animal resources) may also be contaminated to unsafe levels with pesticides or other substances, but specific pollution limits for this resource may not be a part of State standards.

Chapter 1 of this handbook provides detailed information on the designated use classifications that most States use to establish pollution limits for water. Information on the ways in which each use can be affected by agricultural pollutants and the characteristics of nonpoint source pollution are also included in that chapter.

## **651.0302 Effects of animal waste on the water resource**

Animal waste contains a number of contaminants that can adversely affect surface and groundwater. In addition, certain of the constituents in animal waste can impact grazing animals, harm terrestrial plants, and impair air quality. However, where animal waste is applied to agricultural land at acceptable rates, crops can receive adequate nutrients without the addition of commercial fertilizer. In addition, soil erosion can be substantially reduced and the water-holding capacity of the soil can be improved if organic matter from animal waste is incorporated into the soil.

### **(a) Constituents affecting surface water quality**

The principal constituents of animal waste that impact surface water are organic matter, nutrients, and fecal bacteria. Animal waste may also increase the amount of suspended material in the water and affect the color either directly by the waste itself or indirectly through the production of algae. Indirect effects on surface water can also occur when sediment enters streams from feedlots or overgrazed pastures and from eroded streambanks at unprotected cattle crossings. The impact that these contaminants have on the aquatic environment is related to the amount and type of each pollutant entering the system and the characteristics of the receiving water.

#### **(1) Organic matter**

All organic matter contains carbon in combination with one or more other elements. All substances of animal or vegetable origin contain carbon compounds and are, therefore, organic.

When plants and animals die, they begin to decay. The decay process is simply the various naturally occurring microorganisms converting the organic matter—the plant and body tissue—to simpler compounds. Some of these simpler compounds may be other forms of organic matter or they may be compounds, such as nitrate and ortho-phosphate, or gases, such as nitrogen gas ( $N_2$ ), ammonia ( $NH_3$ ), and hydrogen sulfide ( $H_2S$ ).



When manure or other organic matter is added to water, the decay process occurs just as it does on land. Microorganisms attack these organic materials and begin to consume and convert them. If the water contains dissolved oxygen, the organisms involved in the decay process are aerobic or facultative. Aerobic organisms require free (dissolved) oxygen to survive, while facultative organisms function in both aerobic (oxygen present) or anaerobic (oxygen absent) environments.

As the organisms consume the organic matter, they also consume free oxygen. The principal by-products of this aerobic digestion process are carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O). Figure 3-1 is a schematic representation of the aerobic digestion cycle as it relates to nitrogenous and carbonaceous matter.

In a natural environment, the breakdown of organic matter is a function of complex, interrelated, and mixed biological populations. However, the organisms principally responsible for the decomposition process are bacteria. The size of the bacterial community depends on its food supply and other environmental factors including temperature and pH.

If a large amount of organic matter, such as manure, is added to a water body, the bacterial population begins to grow, with the rate of growth expanding rapidly. Theoretically, the bacterial population doubles with each simultaneous division of the individual bacteria; thus, one divides to become two, two becomes four, four becomes eight, and so forth. The generation time, or the time required for each division, may vary from a few days to less than 30 minutes. One bacterium with a 30-minute generation time could yield 16,777,216 new bacteria in just 12 hours.

Because each bacterium extracts dissolved oxygen from the water to survive, the addition of waste and the subsequent rapid increase in the bacterial population could result in a drastic reduction in dissolved oxygen in a stream. The point in a stream where the maximum oxygen depletion occurs can be a considerable distance downstream from the point where pollutants enter the stream. The level of oxygen depletion depends primarily on the amount of waste added; the size, velocity, and turbulence of the stream; the initial dissolved oxygen levels in the waste and in the stream; and the temperature of the water.

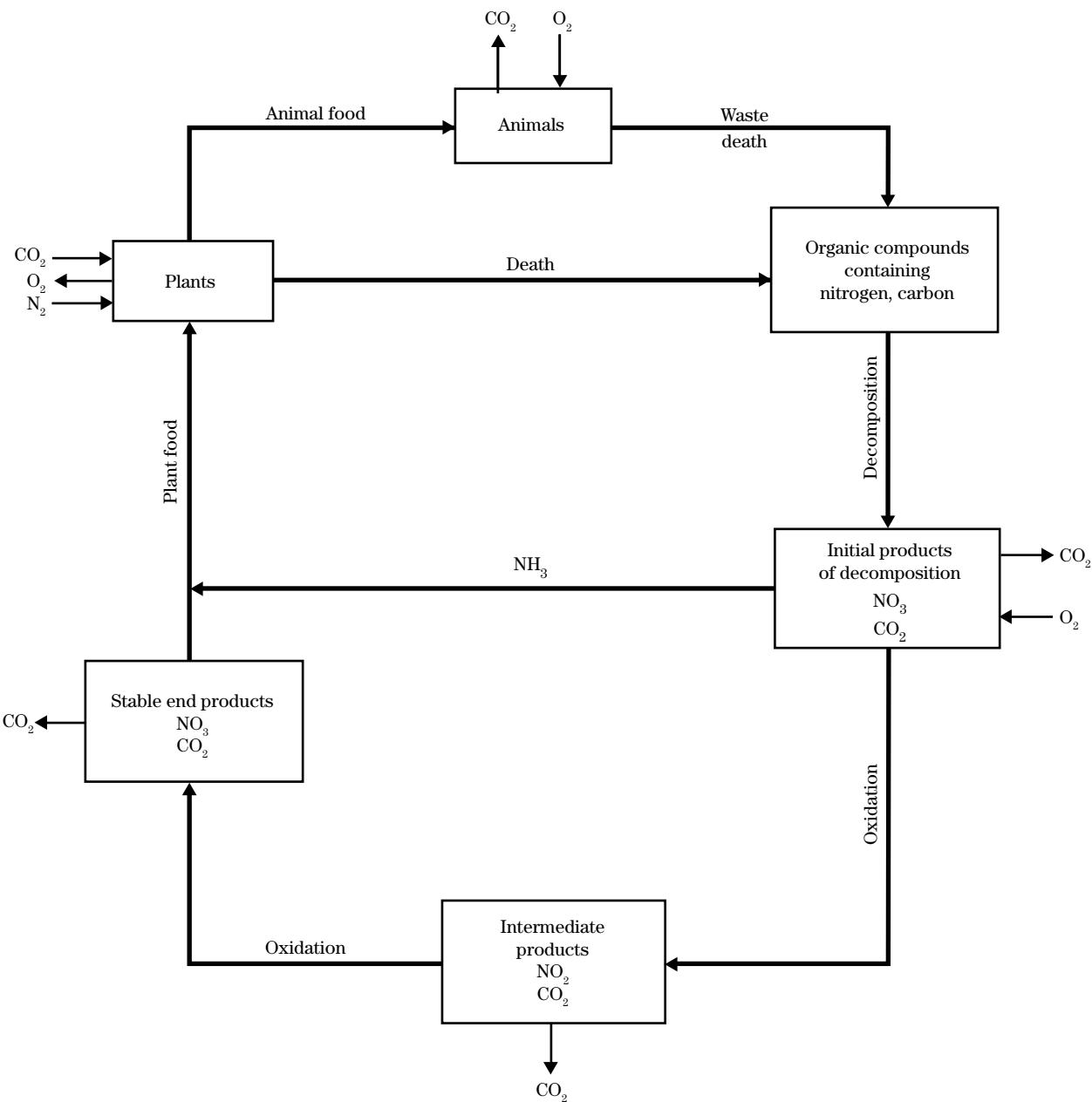
A turbulent stream can assimilate more waste than a slow, placid stream because the turbulence brings air into the water (re-aeration) and helps replenish the dissolved oxygen. In addition, cold water can hold more dissolved oxygen than warm water. For example, pure water at 10 degrees Celsius (50 °F) has 10.92 milligrams per liter of dissolved oxygen when fully saturated, while water at 30 degrees Celsius (86 °F) has 7.5 milligrams per liter at the saturation level.

An adequate supply of dissolved oxygen is essential for good fish production. Adding wastes to a stream can lower oxygen levels to such an extent that fish and other aquatic life are forced to migrate from the polluted area or die for lack of oxygen. The decomposition of wastes can also create undesirable color as well as taste and odor problems in lakes used for public water supplies.

The amount of organic matter in water can be determined with laboratory tests, including those for 5-day biochemical oxygen demand (BOD<sub>5</sub>), chemical oxygen demand (COD), and volatile solids (VS). Table 3-1 illustrates BOD<sub>5</sub> values for a sampling of lagoon influents and effluents for various livestock facilities. The table is used for illustration only and shows how “strong” agricultural wastes can be, even after treatment. Concentrations will vary considerably from these values, depending on such factors as the age and size of the lagoon, characteristics of the waste, geographical location, and the amount of dilution water added.

The BOD<sub>5</sub> value for raw domestic sewage ranges from 200 to 300 milligrams per liter, while that for municipal wastewater treated to the secondary level is about 20 milligrams per liter. Because municipal waste is so much more dilute, the concentrations of BOD<sub>5</sub> are much lower than those in treated animal waste. Nevertheless, animal wastewater released to a stream, though smaller in total volume relative to municipal discharges, can be more concentrated and cause severe damage to the aquatic environment.

**Figure 3-1** Aerobic cycle of plant and animal growth and decomposiion as related to nitrogen and carbon



**Table 3-1** A sampling of influent BOD<sub>5</sub> concentrations and range of effluent concentration for various types of anaerobic lagoons

Source	Lagoon influent	Lagoon effluent
	----- mg/L -----	
Dairy	6,000	200-1,200
Beef	6,700	200-2,500
Swine	12,800	300-3,600
Poultry	9,800	600-3,800

## (2) Nutrients

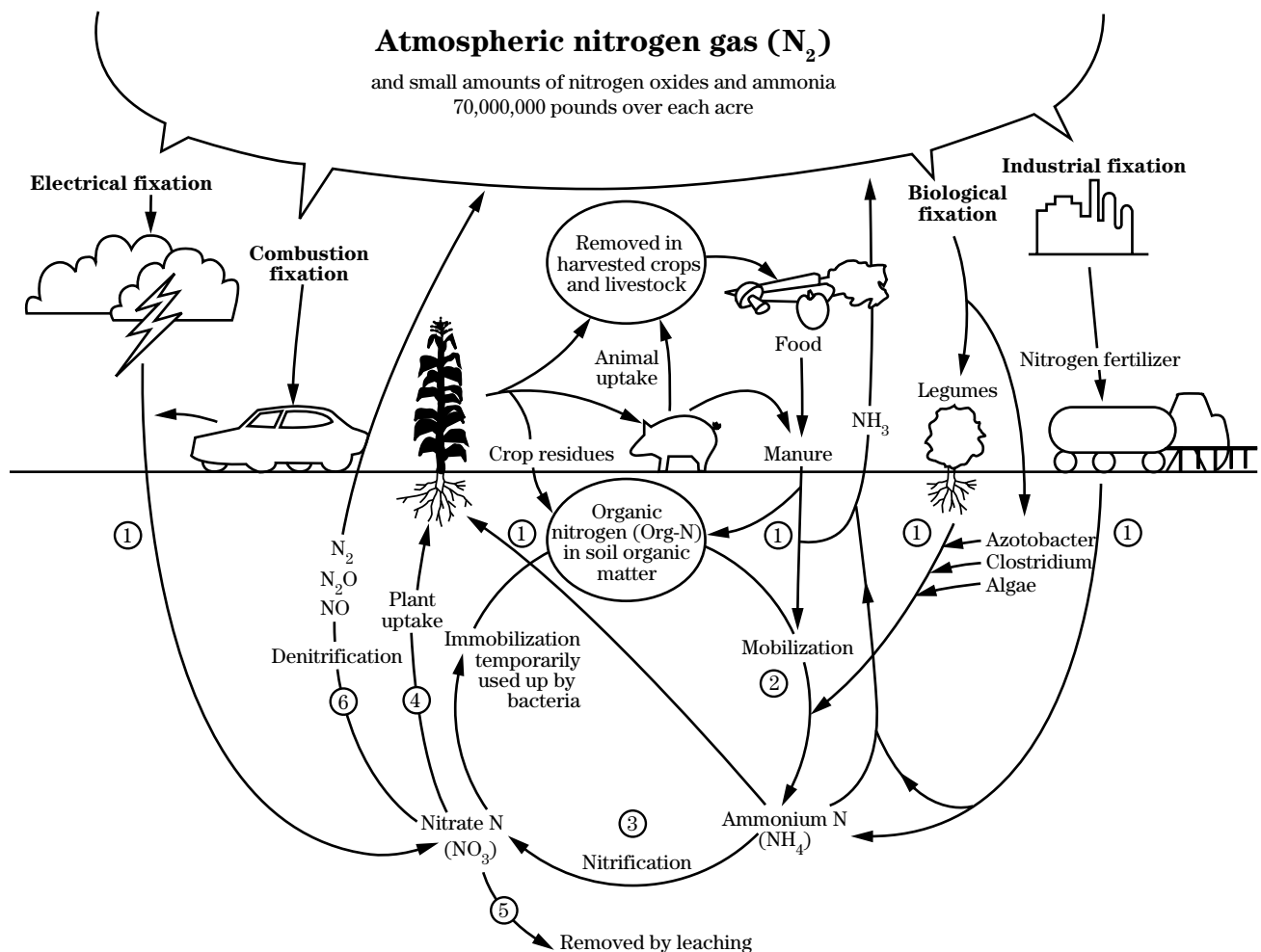
The principal nutrients of concern in the aquatic environment are nitrogen (N) and phosphorus (P). An understanding of how these nutrients react in the environment is important to understanding the control processes described in later sections.

**(i) Nitrogen**—Nitrogen occurs throughout the environment—in the soil, water, and surrounding air. In fact, 78 percent of the air we breathe is N. It is also a

part of all living organisms. When plants and animals die or when waste products are excreted, N returns to the environment and is cycled back to the land, water, and air and eventually back to other plants and animals.

Figure 3–2 depicts the N cycle. It shows the flow from one form of N to another. The various forms of N can have different effects on our natural resources—some good and some bad.

**Figure 3–2** Site analysis diagram



The conversion from one form of N to another is usually the result of bacterial processes. Some conversions require the presence of oxygen (aerobic systems), while others require no oxygen (anaerobic systems). Moisture content of the waste or soil, temperature, and pH speed or impede conversions.

In water quality analyses, total nitrogen (TN) includes the organic (Org-N), total ammonia ( $\text{NH}_3 + \text{NH}_4$  (the ammonium ion)), nitrite ( $\text{NO}_2$ ), and nitrate ( $\text{NO}_3$ ) forms. Total Kjeldahl nitrogen (TKN) includes the total organic and total ammonia nitrogen. The  $\text{NH}_3$ ,  $\text{NO}_2$ , and  $\text{NO}_3$  forms of N may be expressed in terms of the concentration of N ( $\text{NO}_3\text{-N}$  or  $\text{NH}_4\text{-N}$ ) or in terms of the concentration of the particular ion or molecule ( $\text{NO}_3$  or  $\text{NH}_4$ ). Thus, 45 milligrams per liter of  $\text{NO}_3$  is equivalent to 10 milligrams per liter of  $\text{NO}_3\text{-N}$ . (See chapter 4 of this handbook for conversions and expressions.)

**Organic nitrogen**—Nitrogen in fresh manure is mostly in the organic form (60–80% of TN). In an anaerobic lagoon, the organic fraction is typically 20 to 30 percent of TN. Org-N in the solid fraction (feces) of most animal waste is usually in the form of complex molecules associated with digested food, while that in the liquid fraction is in the form of urea.

From 40 to 90 percent of the Org-N is converted to  $\text{NH}_3$  within 4 to 5 months after application to the land. The conversion of Org-N to  $\text{NH}_3$  (called mineralization) is more rapid in warmer climates. Under the right temperature and moisture conditions, mineralization can be essentially complete in 60 days. Conversion to  $\text{NH}_3$  can occur either under aerobic or anaerobic conditions.

Org-N is not used by crops; however, it is not mobile once applied to the land unless runoff carries away the organic matter or soil particles to which it might be attached.

**Ammoniacal nitrogen**—This term is often used in a generic sense to refer to two compounds:  $\text{NH}_4$  (the ammonium ion) and  $\text{NH}_3$  (un-ionized ammonia). These forms of  $\text{NH}_3$  exist in equilibrium, with the concentrations of each depending on pH and temperature.

Un-ionized  $\text{NH}_3$  is toxic to fish and other aquatic life in very small concentrations. In one study, the concentration required to kill 50 percent of a salmonid

(e.g., trout) population after 96 hours of exposure (the 96-hour  $\text{LC}_{50}$ ) ranged from 0.083 to 1.09 milligrams per liter; for nonsalmonids the range was 0.14 to 4.60 milligrams per liter. Invertebrates are more tolerant of un-ionized  $\text{NH}_3$  than fish, and phytoplankton and vascular aquatic plants are more tolerant than either the invertebrates or fish.

To protect aquatic life, the U.S. Environmental Protection Agency (EPA) has established a recommended allowable limit of 0.02 milligrams per liter for un-ionized  $\text{NH}_3$ . Table 3–2 shows, in abbreviated form, the relationship between un-ionized  $\text{NH}_3$  and  $\text{NH}_4$  as related to pH and water temperature. As water temperatures and pH rise, the amount of total  $\text{NH}_3$  required to provide a lethal concentration of un-ionized  $\text{NH}_3$  becomes smaller.

The concentration of un-ionized  $\text{NH}_3$  from an overflowing lagoon or other storage structure with concentrated animal waste can exceed the EPA criterion by as much as 3,000 times. Runoff from a feedlot or overfertilized pasture can also have high levels of total ammonia nitrogen ( $\text{NH}_3 + \text{NH}_4$ ).

Ammonium nitrogen is relatively immobile in the soil. The positively charged ammonium ion tends to attach to the negatively charged clay particles and generally remains in place until converted to other forms.

Ammonia can be lost to the atmosphere in gaseous form (volatilization), a process that is not a function of bacterial activity. As much as 25 percent of the  $\text{NH}_3$  irrigated from an animal waste lagoon can be lost between the sprinkler head and the ground surface. Temperature, wind, and humidity will affect losses.

**Table 3–2** Concentrations of total  $\text{NH}_3$  ( $\text{NH}_3 + \text{NH}_4$ ) in mg/L that contain an un-ionized  $\text{NH}_3$  concentration of 0.020 mg/L  $\text{NH}_3$

Temp (°C)	pH values						
	6.0	6.5	7.0	7.5	8.0	8.5	9.0
5	160	51	16	5.1	1.6	0.53	0.18
10	110	34	11	3.4	1.1	0.36	0.13
15	73	23	7.3	2.3	0.75	0.25	0.09
20	50	16	5.1	1.6	0.52	0.18	0.07
25	35	11	3.5	1.1	0.37	0.13	0.06

Ammonia can be converted to  $\text{NO}_2$  and then to  $\text{NO}_3$  (nitrified) only under aerobic conditions. For this reason, Org-N and ammonia nitrogen generally are the only forms of N in anaerobic lagoons and waste storage ponds. The  $\text{NH}_3$  begins to nitrify when the waste from these structures is applied to the land where aerobic conditions exist.

**Nitrite**—This is normally a transitory phase in the nitrification and denitrification processes. Very little  $\text{NO}_2$  is normally detected in the soil or in most natural waters.

Nitrites occasionally occur in significant concentrations in farm ponds and commercial fish ponds during a fall “overtake” or when the mud on the bottom of the pond is disturbed during commercial harvesting. If the bottom material is enriched with nutrients (from excess commercial feed, fish waste, or other sources of animal waste), the concentrations of nitrites in the overlying water can be raised enough to cause  $\text{NO}_2$  poisoning or brown blood disease in fish when this mud is disturbed. The dead or dying fish have “chocolate” colored blood, which indicates that the hemoglobin has been converted to methemoglobin.

$\text{NO}_2$  concentrations at or below 5 milligrams per liter should be protective of most warm-water fish, and concentrations at or below 0.06 milligrams per liter should suffice for cold-water fish. Concentrations as high as these are unlikely to occur as a result of natural conditions in surface water.

The EPA has not recommended any special limits on nitrates in surface water; however, some States have criteria for  $\text{NO}_2$  concentrations in finished or treated water (see chapter 1 of this handbook).

**Nitrate**—The  $\text{NO}_3$  form of N is the end product of the mineralization process (the conversion of N from the  $\text{NH}_3$  form to  $\text{NO}_2$  and then to  $\text{NO}_3$  under aerobic conditions). The  $\text{NO}_3$  form of N is soluble in water and is readily used by plants.

Under anaerobic conditions, microbial activity can convert  $\text{NO}_3$  to a gaseous form of N, a process called denitrification. N in animal waste that has been converted to  $\text{NO}_3$  after land application can leach into the soil profile, encounter a saturated anaerobic zone, and then be denitrified through microbial activity. The gaseous forms of N created in this process can then

migrate upward through the soil profile and be lost to the atmosphere.

The principal source of agricultural  $\text{NO}_3$  in surface water is runoff from feedlots, cropland, and pastures. Table 3–3 illustrates the possible differences in dissolved N concentrations in runoff from fields that had manure surface applied at agronomic rates and those that had no manure applied.

The values in table 3–3 represent estimates of dissolved N only and do not represent amounts that could also be transported with sediment. Although these values were obtained from published data, they do not reflect the variability that could result from such factors as differences in rainfall in various geographic regions, slope of land, amount and age of manure on the ground surface, or extent of crop cover. Therefore, table 3–3 is presented only to illustrate the extent to which  $\text{NO}_3$  concentrations can be increased in runoff from land that has received applications of manure.

Elevated  $\text{NO}_3$  levels have also been observed in the spring runoff from fields where manure had been applied to snow-covered or frozen ground. In addition, the discharge from underground drainage lines in cropland fields can have elevated concentrations of nitrate.

Nitrates are toxic to fish only at very high concentrations—typically in excess of 1,000 milligrams per liter for most freshwater fish. Such species as largemouth bass and channel catfish, could maintain their normal growth and feeding activities at concentrations up to 400 milligrams per liter without significant side effects.

**Table 3–3** Estimated concentrations of total dissolved nitrogen in runoff from land with and without livestock and poultry manure surface applied

Cropping conditions	Dissolved N concentration in runoff	
	With manure	Without manure
	----- mg/L -----	
Grass	11.9	3.2
Small grain	16.0	3.2
Row crop	7.1	3.0
Rough plow	13.2	3.0

Source: *Animal Waste Utilization on Cropland and Pastureland* (USDA 1979)

These concentrations would not result from natural causes and are not likely to be associated with normal agricultural activities.

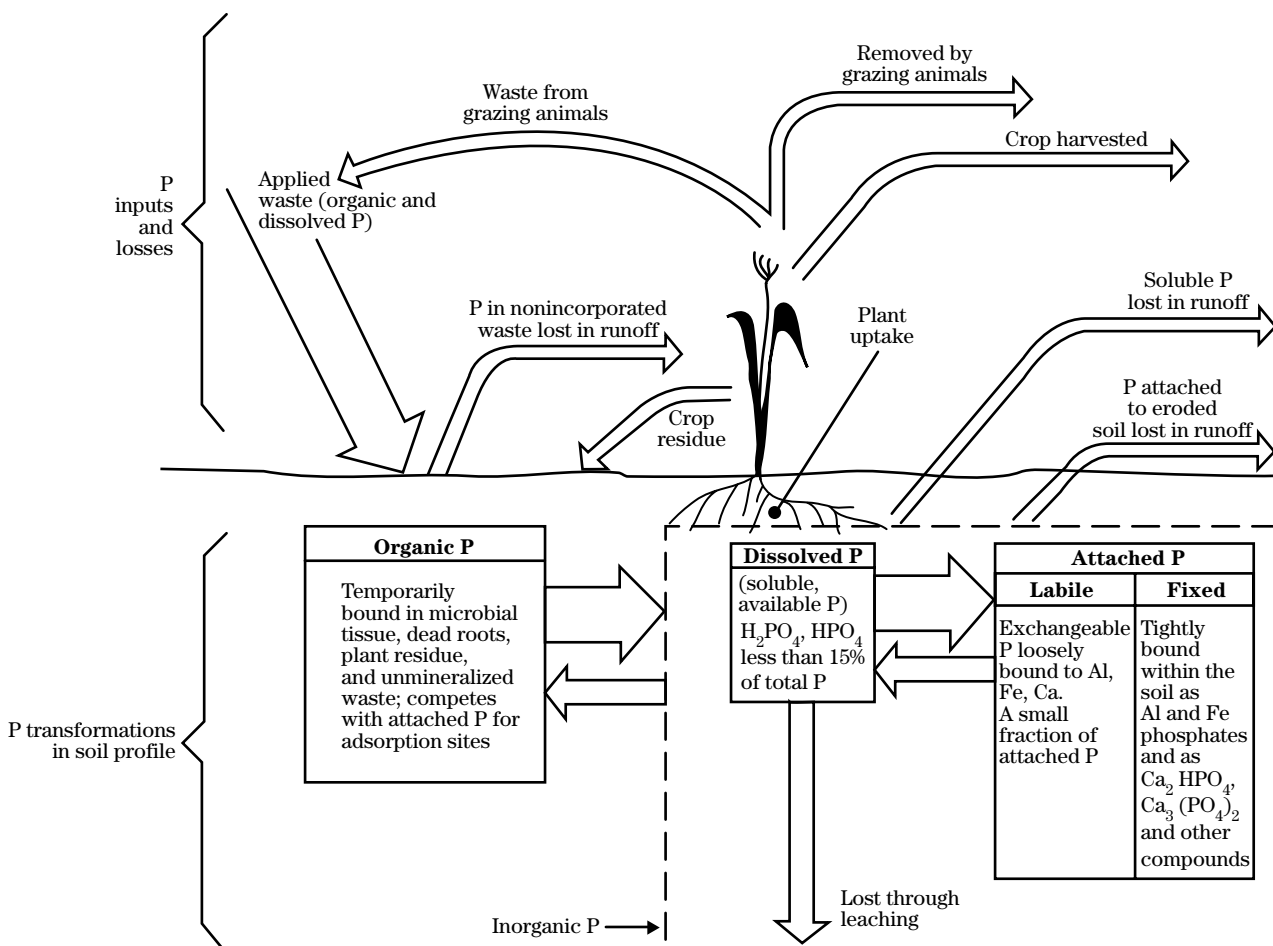
Although nitrates are not normally toxic to aquatic organisms, nitrate is a source of enrichment for aquatic plants. If an adequate supply of other essential nutrients is available (especially P), nitrates can help promote algae blooms and the production of other aquatic vegetation.

The EPA has not recommended any limiting criteria for nitrates as related to surface water. (See chapter 1, section 651.0107(b) for a description of limits related to drinking water as it comes from the tap.)

**(ii) Phosphorus**—Phosphorus is one of the major nutrients needed for plant growth, whether the plant is terrestrial or aquatic. Because P is used extensively in agriculture, the potential for pollution from this source is high.

**Forms of Phosphorus**—Water samples are often analyzed for only total P; however, total P can include organic, soluble, or “bound” forms. An understanding of the relationship among these forms is important to understanding the extent to which P can move within the environment and the methods for its control. Figure 3–3 depicts the relationship between the P forms and illustrates ways that P can be lost from waste application sites.

**Figure 3–3** Phosphorus inputs and losses at a waste application site and P transformation within the profile (abbreviated P cycle)



Organic P is a part of all living organisms, including microbial tissue and plant residue, and it is the principal form of P in the metabolic by-products (wastes) of most animals. About 73 percent of the P in the fresh waste of various types of livestock is in the organic form

Soluble P (also called available or dissolved P) is the form used by all plants. It is also the form that is subject to leaching. The soluble form generally accounts for less than 15 percent of the total P in most soils.

Attached P includes those compounds that are formed when the anionic (negatively charged) forms of dissolved P become attached to cations, such as iron, aluminum, and calcium. Alum has been successfully used as an additive to poultry litter to capture dissolved P in attempts to prevent it from leaving application fields with stormwater runoff. Attached P includes labile, or loosely bound, forms and those that are “fixed,” or tightly adsorbed, on or within individual soil particles.

It should be noted that the P that is loosely bound to the soil particles (labile P) remains in equilibrium with the soluble P. Thus, when the concentration of soluble P is reduced because of the removal by plants, some of the labile P is converted to the soluble form to maintain the equilibrium.

**Factors affecting the translocation of Phosphorus**—A number of factors determine the extent to which P moves to surface or groundwater. Nearly all of these factors relate to the form and chemical nature of the P compounds. Some of the principal factors affecting P movement to surface and groundwaters are noted.

**Degree of contact with the soil**—Manure that is surface applied in solid form generally has a higher potential for loss in surface runoff than wastewater applied through irrigation, especially in areas that have frequent, high-intensity storms. This also assumes the irrigation water infiltrates the soil surface. Because P readily attaches to soil particles, it is important that fields used for manure applications have low erosion potential. For some soils, the potential for loss in surface runoff may be reduced by incorporating land applied solid wastes into the soil profile. Before incorporation is used to reduce runoff potential, the potential damage to soil structure should be considered. Grasslands and soils under no-till commonly devel-

oped improved soil structure that increase infiltration and reduces runoff. Destroying soil structure that has developed through the absence of tillage by incorporation could inadvertently increase runoff potential.

**Soil pH**—After animal waste makes contact with the soil, the P will change from one form to another. Organic P eventually converts to soluble P, which is used by plants or converted to bound P. However, the amount of soluble P is related to the pH of the soil as illustrated in figure 3–4. In acid soils, the soluble P occurs primarily as dihydrogen phosphate ion ( $\text{H}_2\text{PO}_4$ ), and when the pH increases above 7, the principal soluble form is  $\text{HPO}_4$ .

Figure 3–4 illustrates that most inorganic P occurs as insoluble compounds of aluminum, iron, calcium, and other minerals typically associated with clay soils. Therefore, these bound forms of P will generally remain in place only so long as the soil particles remain in place.

**Soil texture**—Phosphorus is more readily retained on soils that have a high clay fraction (fine-textured soils) than on sandier soils. As noted in figure 3–4, those soil particles that contain a large fraction of aluminum, iron, and calcium are very reactive with P. Thus, clay soils have a higher adsorption potential than that of sandy soils. Sand grains that have a coating of aluminum or iron oxides can also retain some amount of P.

Research has shown that soils with even a modest clay fraction have the potential to adsorb large amounts of P. For example, one study revealed that a Norfolk sandy loam soil receiving swine lagoon effluent at P application rates of 72, 144, and 288 pounds per year would require 125, 53, and 24 years to saturate the adsorption sites in the soil profile to a depth of 105 centimeters (41 in). This does not mean that all of the applied P would be adsorbed within the soil profile. Rather, the soil simply has the potential for such adsorption, assuming none is lost through other means.

**Amount of waste applied**—Organic P readily adsorbs to soil particles and tends to depress the adsorption of inorganic P, especially where organic P is applied at high rates. Thus, the concentrations of soluble and labile P increase significantly at high application rates of organic P.

When organic P and commercial superphosphate are applied at the same rates, the superphosphate P will be less effective in raising the concentration of soluble P than the P applied in manure or other organic waste. This occurs because the organic P competes for adsorption sites, resulting in more P staying in soluble form rather than becoming attached as labile P.

Long-term applications of organic P at rates that exceed the uptake rate of plants will result in saturation of the adsorption sites near the soil surface. This, in turn, results in greatly increased concentrations of both soluble and labile P. The excess soluble P can either leach downward to a zone that has more attachment sites and then be converted to labile P or fixed P, or it can be carried off the land in runoff water.

If soils that have high labile P concentrations reach surface water as sediment, they will continuously desorb or release P to the soluble form until equilibrium is attained. Therefore, sediment from land receiving animal waste at high rates or over a long period of time will have a high potential to pollute surface water.

Table 3-4 illustrates typical dissolved P concentrations reported in surface runoff from fields where animal waste was applied at recommended agronomic rates. Although this table is based on research findings, it is provided for illustration only because it does not necessarily represent concentrations that might occur in

different regions of the country where the land slopes, soil types, waste application quantities and rates, or amounts of precipitation could be different than those for which the research was conducted.

Waste that is surface applied can produce total P concentrations in surface runoff higher than those shown in table 3-4, especially if the waste is applied at high rates, not incorporated, applied on snow-covered or frozen ground, or applied on fields with inadequate erosion control practices.

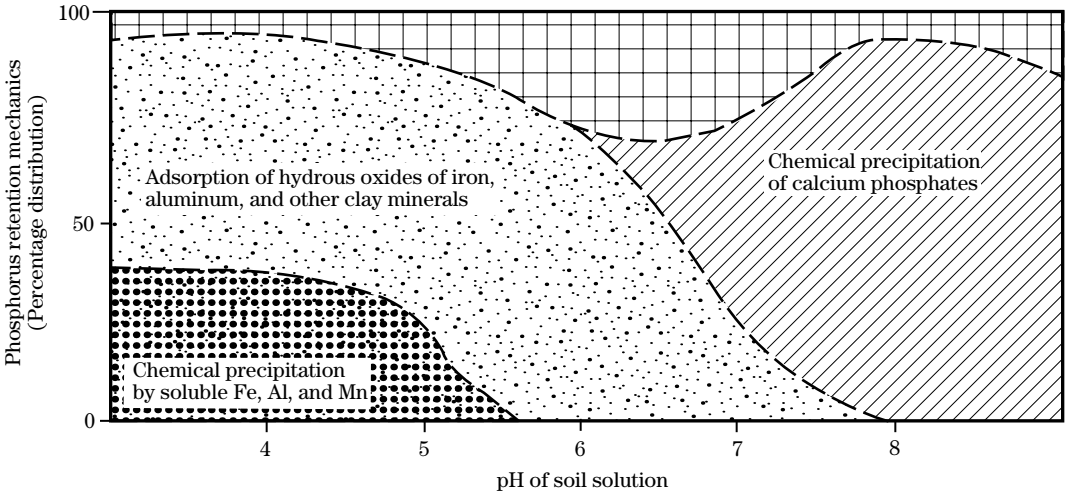
*Erosion control measures*—Although organic matter increases the water-holding capacity of soils and generally helps to reduce the potential for erosion,

**Table 3-4** Estimated dissolved P concentrations in runoff from land with and without animal wastes surface applied

Cropping conditions	Dissolved P in runoff	
	With manure	Without manure
----- mg/L -----		
Grass	3.0	0.44
Small grain	4.0	0.40
Row crop	1.7	0.40
Rough plow	1.7	0.20

Source: *Animal Waste Utilization on Cropland and Pastureland* (USDA 1979).

**Figure 3-4** P retention and solubility as related to soil pH





erosion can still occur on land receiving livestock and poultry wastes. If wastes are applied to satisfy the N requirements of the crops, the P concentrations in the soil may become extremely high. Because such soils generally have a high concentration of labile P, any loss of soil to surface water poses a serious threat to water quality in the receiving water, especially ponds and lakes. For this reason, good erosion control measures are essential on land receiving animal waste.

*Phosphorus entrapment*—Providing an adequate buffer zone between the source of organic contaminants (land spreading areas, cattle feedlots) and stream or impoundment helps provide settling and entrapment of soil particles with attached P. Forested riparian zones adjacent to streams form an effective filter for sediment and sediment related P. In addition, water and sediment control basins serve as sinks for sediment-attached P.

Animal waste lagoons are also very effective for P storage. Typically 70 to 90 percent of the P in waste that enters a waste treatment lagoon will settle and be retained in the sludge on the bottom of the lagoon. It should also be noted that this P accumulation will eventually need to be addressed.

*Phosphorus retention*—Sandy soils do not effectively retain P. If the groundwater table is close to the surface, the application of waste at excessive rates or at N-based rates will most likely contaminate the groundwater beneath those soils. However, groundwater that is below deep, clay soils is not likely to be contaminated by P because of the adsorptive capacity of the clay minerals.

P will change forms rapidly once contact is made with the soil. Equilibria can be established between the bound forms and those in solution within just a few hours. However, as time goes on, more of the P is converted to the fixed or tightly bound forms. The conversion to these unavailable forms may take weeks, months, or even years. Therefore, the soil has the potential to retain large amounts of P (to serve as a P “sink”), especially if given ample time between applications. Caution should be taken in that high P concentrations can inhibit both plant nutrient uptake and soil biological activity. Soil and manure can be treated with substances containing calcium, iron, or aluminum cations, like alum, to improve their ability to retain soluble P.

*Aerobic conditions*—Compounds of P, iron, manganese, and other elements react differently where oxygen is present or absent in the surrounding environment. This is true in the soil environment as well as in impoundments. Under anaerobic conditions, iron changes from the ferric to the ferrous form, thus reducing P retention and increasing P solubility.

Soils receiving frequent applications of wastewater can become saturated and anaerobic. Such soils will not be as effective at removing and retaining P as well-aerated soils.

*Harvesting*—Soluble P will be removed from the soil by plants. The amount removed depends on the amount required by the plant and the reserve of P in the soil. If the plants are removed through mechanical harvesting, all of the P taken up by the plant will be removed except that associated with the roots and unharvestable residue. If the plants are removed by grazing animals, only a part of the plant P will be removed because a large fraction of the P consumed will be returned to the land in the feces. If plants are not harvested and removed, either mechanically or through animal consumption, they will eventually die, decay, and return the P to its source. It then becomes available again as a source of plant food or pollution.

*Effects of phosphorus in the aquatic environment*—When P enters the freshwater environment, it can produce nuisance growths of algae and aquatic weeds and can accelerate the aging process in lakes. Direct toxicity to fish and other aquatic organisms is not a major concern. Some algae species are toxic to animals if ingested with drinking water.

In the marine or estuarine environment, however, P in the elemental form (versus phosphates or other forms of combined P) can be especially toxic and can bioaccumulate in much the same way as mercury. For this reason, the EPA has established a criterion of 0.01 micrograms per liter ( $\mu\text{g/L}$ ) of yellow (elemental) P for marine and estuarine water. This concentration represents a tenth of the level demonstrated to be lethal to important marine organisms. Other forms of P are virtually nontoxic to aquatic organisms.

Although no national criteria exist for other forms of P to enhance or protect fresh water, the EPA recommends that total phosphate concentrations not exceed 50 micrograms per liter (as P) in any stream at the

point where it enters a lake or reservoir (EPA 1986). A desired goal for the prevention of plant nuisances in streams or other flowing water not discharging directly to lakes or impoundments is 100 micrograms per liter of total P.

Relatively uncontaminated lakes have from 10 to 30 micrograms per liter total P in the surface water. However, a phosphate concentration of 25 micrograms per liter at the time of spring turnover in a lake or reservoir may occasionally stimulate excessive or nuisance growths of algae and other aquatic plants.

The EPA reports these findings regarding P in natural water (EPA 1984):

- High P concentrations are associated with accelerated eutrophication of water when other growth-promoting factors are present.
- Aquatic plant problems develop in reservoirs and other standing water at P values lower than those critical in flowing streams.
- Reservoirs and lakes collect phosphates from influent streams and store part of them within consolidated sediment, thus serving as a phosphate sink.
- P concentrations critical to noxious plant growth vary, and nuisance growths may result from a particular concentration of phosphate in one geographic area, but not in another.

Whether or not P will be retained in a lake or become a problem is determined by nutrient loading to the lake, the volume of the photic (light-penetrating) zone, the extent of biological activity, the detention time of the lake, and level at which water is withdrawn from the lake. Thus, a shallow lake in a relatively small watershed and with only a surface water discharge is more likely to have eutrophication problems than a deep lake that has a large drainage area-to-lake volume ratio and bottom water withdrawal. This assumes that the same supply of nutrients enters each lake.

Figure 3–5 depicts average inflowing P concentrations into a lake versus hydraulic residence time, which is the time required for the total volume of water in the lake to be replaced with a “new” volume. The dotted lines represent P concentrations of 10, 25, and 60 micrograms per liter and roughly delineate the boundar-

ies between oligotrophic, mesotrophic, eutrophic, and hyper-eutrophic conditions. Figure 3–5 is presented for purposes of illustration only because the delineations between the different trophic states cannot be precisely defined. The model used to develop figure 3–5 is only one of many models used to predict trophic state. Some are more useful in cool, northern climates, while others are best suited to warm-water lakes or lakes in which N rather than P is limiting.

### (3) Fecal organisms

The excreta from warm-blooded animals have countless microorganisms, including bacteria, viruses, parasites, and fungi. Some of the organisms are pathogenic (disease causing), and many of the diseases carried by animals are transmittable to humans, and vice versa. Table 3–5 lists some of the diseases and parasites transmittable to humans from animal manure.

Many States use fecal coliform (FC) bacteria as an indicator of pollution from warm-blooded animals, including man. The test for FCs is relatively simple and inexpensive compared to testing for specific pathogens. To test water for specific pathogens, such as salmonella, a number of samples of the suspect water must be collected to ensure that any pathogenic organisms in the water are actually captured.

The alternative to this impractical approach is to use an indicator organism that simply indicates when pollution from the waste of warm-blooded animals is present, thus providing a way to estimate the potential for the presence of pathogenic organisms. The indicator organism must have the following characteristics:

- It must exist in large numbers in the source (animals, humans) in far greater numbers than the pathogens associated with the source.
- The die-off or regrowth rate of the indicator organism in the environment should be approximately the same as most pathogens.
- The indicator should be found only in association with the source of waste; its presence, therefore, would be a definite indicator that pollution from that type of source is present.

One indicator organism used widely to check for the presence of pathogens is a family of bacteria known as the coliforms. The total group of coliforms is associated with both the feces of warm-blooded animals and

with soils. However, the FC group represents a part of the total coliforms and is easily differentiated from the total coliforms during testing.

A positive test for FC bacteria is a clear indication that pollution from warm-blooded animals exists. A high count indicates a greater probability that pathogenic organisms will be present.

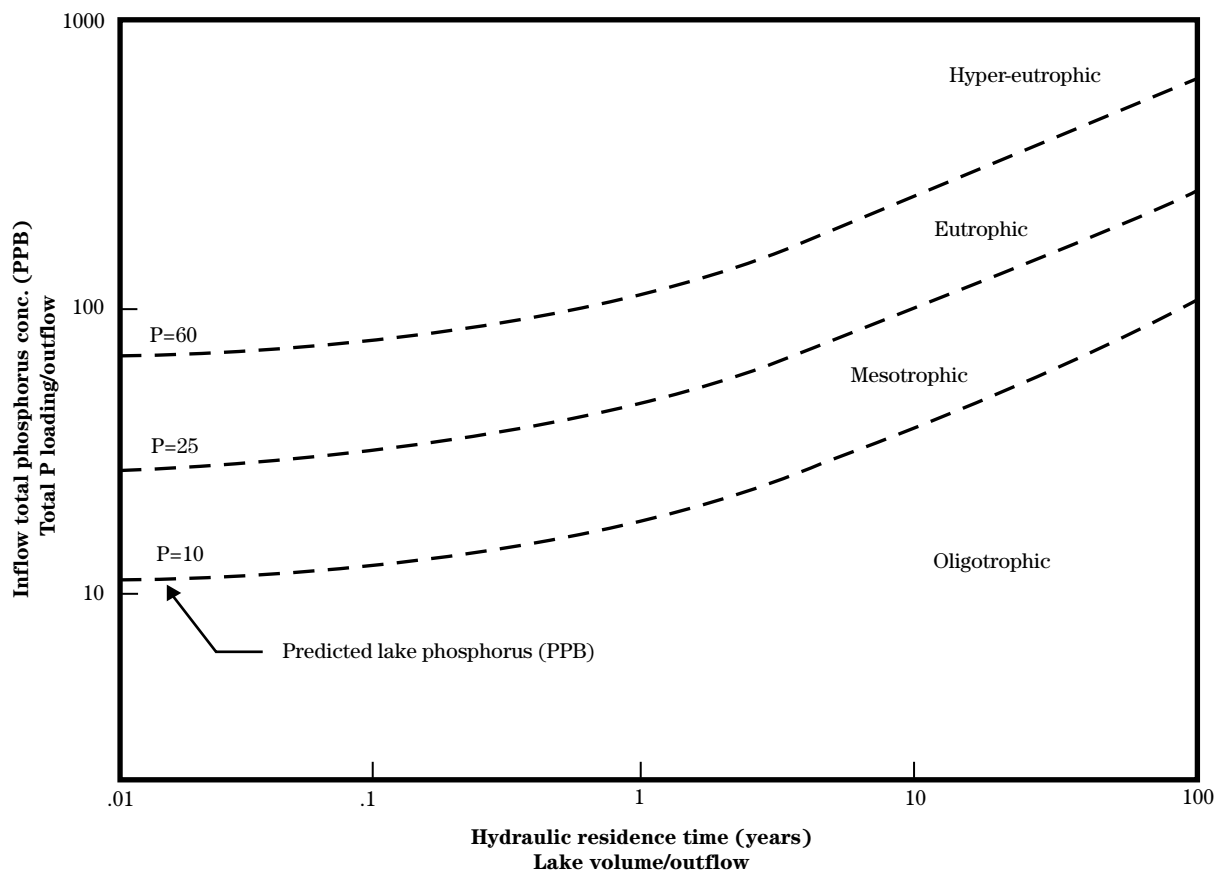
Some FCs generally are in all natural water even without the influence of humans or their domestic animals. Birds, beaver, deer, and other wild animals contribute FCs to the water, either directly or in runoff. It is necessary, therefore, to have acceptable limits for FC bacteria, taking into account the beneficial use of the stream or water body. The EPA established water quality criteria for FC bacteria in its Quality Criteria for Water (1976), which many States have adopted. Typical limits are shown in table 3-6.

Some planners have used the ratio of FC to fecal streptococcus (FS) bacteria to help identify whether a suspected source of water pollution is from humans or other warm-blooded animals. Table 3-7 shows the typical FC/FS ratios (as excreted) for different animal species.

Some questions remain regarding the usefulness of this method of identifying sources because the die-off rates between the two types of bacteria can differ significantly. Consequently, it would only have meaning when the sampling point is close to the source. For this reason, the FC/FS ratio should be used with extreme caution as a tool for determining sources of pollution.

In more recent years, the EPA has established criteria for using *Escherichia coli* (*E. coli*) and enterococci as a measure of harmful levels of bacterial pollution in

**Figure 3-5** Lake trophic states based on model by Vollenweider (adapted from EPA 1990)



**Table 3–5** Diseases and organisms spread by animal manure

Disease	Responsible organism
<b>Bacterial</b>	
Salmonella	Salmonella sp.
Leptospirosis	Leptospiral pomona
Anthrax	Bacillus anthracis
Tuberculosis	Mycobacterium tuberculosis
	Mycobacterium avium
Johnes disease	Mycobacterium aratuberculosis
Brucellosis	Brucella abortus
	Brucella melitensis
	Brucella suis
Listeriosis	Listeria monocytogenes
Tetanus	Clostridium tetani
Tularemia	Pasturella tularensis
Erysipelas	Erysipelothrix rhusiopathiae
Colibacillosis	E. coli (some serotypes)
Coliform mastitis-metritis	E. coli (some serotypes)
<b>Rickettsial</b>	
Q fever	Coxiella burneti
<b>Viral</b>	
New castle	Virus
Hog cholera	Virus
Foot and mouth	Virus
Psittacosis	Virus
<b>Fungal</b>	
Coccidioidomycosis	Coccidioides immitus
Histoplasmosis	Histoplasma capsulatum
Ringworm	Various microsporum and trichophyton
<b>Protozoal</b>	
Coccidiosis	Eimeria sp.
Balantidiasis	Balatidium coli.
Toxoplasmosis	Toxoplasma sp.
<b>Parasitic</b>	
Ascariasis	Ascaris lumbricoides
Sarcocystiasis	Sarcocystis sp.

**Table 3–6** Typical allowable limits for FC bacteria based on water use

Water use	Bacteria/100 ml sample
Public water supply (before treatment)	2,000 * 4,000 max
Swimming	100 coastal * 200 fresh water *
Fish and wildlife	2,000 max

\* Based on a geometric mean of at least five samples collected over 30 days at intervals of no less than 24 hours.

**Table 3–7** Typical FC to FS ratios (as excreted) for several animal species

Species	FC/FS ratio
Human	4.4
Ducks	0.6
Sheep	0.4
Pig	0.4
Chicken	0.2
Turkey	0.1

\* Based on a geometric mean of at least five samples collected over 30 days at intervals of no less than 24 hours.

ambient waters. *E. coli* (a FC type) and enterococci are natural inhabitants of warm-blooded animals, and their presence in water samples is an indication of fecal pollution and the possible presence of pathogens. Some strains of enterococci are found outside warm-blooded animals.

The EPA reports that a direct relationship between the density of enterococci and *E. coli* in water and the occurrence of swimming-associated gastroenteritis has been established through epidemiological studies of marine and freshwater bathing beaches. The resulting criteria can be used to establish recreational water standards. The EPA criteria for freshwater bathing are based on a statistically significant number of samples (generally not less than five samples equally spaced over a 30-day period). The geometric mean of the indicated bacterial densities should not exceed one or the other of the following:

*E. coli* 126 per 100 ml  
Enterococci 33 per 100 ml

These criteria should not be used without also conducting a statistical analysis based on information provided by the EPA.

### **(b) Constituents affecting groundwater quality**

Nitrates and bacteria are the primary constituents of animal waste that affect groundwater quality. Phosphorus and potassium (K) do not constitute a threat to public health through water supplies. In their common forms, P and K are relatively insoluble and are not normally leached below the top several inches of most soils, especially those with a high clay fraction.

Phosphorus readily combines with aluminum and iron in acidic soils and with calcium in basic soils. Because these substances are relatively abundant in most soils, a large fraction of the total P applied to the land will be quickly immobilized. Only a small fraction of the soluble inorganic P will be available for plants (see previous description of the characteristics of P in this chapter).

In addition to animal waste, other agricultural-related wastes and their constituents can impact groundwater quality. Salinity has long been recognized as a con-

taminant of groundwater resulting from percolating irrigation application. Two mechanisms influence the amount of salt reaching the groundwater. The first is concentration of salt in the irrigation supplies. The process of evapotranspiration concentrates the salt in the root zone, making it available for solution and transport. The more salt in the irrigation supply, the more salt in the leachate. In addition, percolating water dissolves salts from marine shales, increasing the salinity of the aquifers in that manner.

Pesticides also have been identified as a contaminant of groundwater. The major source of contamination is associated with filling and washing application equipment in the proximity of the wellhead. However, concentrations of selected pesticides have been noted in the vicinity of application areas.

Oils and greases associated with the agriculture industry are also capable of contaminating groundwater supplies. Of most concern are leaking underground storage tanks for fuel oil, but percolating water is also capable of moving spilled oils from the soil surface into the soil profile.

#### **(1) Nitrate**

As noted in section 651.0302(a)(2),  $\text{NO}_3$  is the soluble form of N and is easily leached beyond the root zone of plants. The principal sources of nitrates in groundwater from agricultural activities are animal waste and commercial fertilizers.

The EPA established a criterion of 10 milligrams per liter of  $\text{NO}_3\text{-N}$  for drinking water because of the health hazard that nitrates present for pregnant women and infants. Unborn babies and infants can contract methemoglobinemia, or blue baby syndrome, from ingesting water contaminated with nitrates. In extreme cases, this can be fatal. Blue baby syndrome generally affects only infants that are less than 6 months old. The disease develops when  $\text{NO}_3$  is converted to  $\text{NO}_2$  in the alkaline environment of the baby's stomach. The  $\text{NO}_2$  then enters the bloodstream and interacts with the hemoglobin, converting it to methemoglobin.

Hemoglobin carries oxygen in the bloodstream, but methemoglobin does not. Therefore, as the amount of vitally needed hemoglobin is reduced in the bloodstream, less oxygen is carried to the body's organs, and symptoms of oxygen starvation begin to occur.

The baby's skin takes on a bluish tint. If the situation is not reversed, the baby could die of oxygen starvation.

Even after the baby discontinues consumption of the contaminated water, the buildup of normal hemoglobin can be slow. After the age of 6 months, the baby's stomach pH reaches adult levels, and the disease is rarely a problem.

## **(2) Fecal bacteria**

Contamination of wells and springs by fecal bacteria or other waste-related microorganisms is a possible problem if wastes are spread on sandy soils. Studies in poultry growing areas of the Northeast and South indicate elevated FC and FS concentrations are possible where poultry litter has been applied at high rates.

A number of diseases can be transported between animals and man as noted in section 651.0302(a)(3); however, the potential for contamination of groundwater by fecal organisms is reduced considerably by the filtering action of the soil. The importance of soil filtering is described in the following section.

Well water should be tested regularly for contamination by fecal bacteria. The acceptable limit is zero for potable water (chapter 1, section 651.0108(b), table 1–5).

## **651.0303 Factors affecting the water pollution process**

Water pollution occurs only when a contaminant finds a pathway from the source to the groundwater or to a stream or water body in such quantities that the designated use of the receiving water can no longer be met. However, the contaminant may not find such a pathway because of chemical or physical transformations affecting it in the environment or because the pathway is blocked by natural phenomena or by control processes imposed by humans.

### **(a) Pathways to pollution**

The pathway that a contaminant follows to reach a stream or to enter groundwater depends on its physical and chemical characteristics as well as the surface and subsurface characteristics of the land. Many constituents of manure move as small organic particles (bacteria, viruses, suspended sediment), while others (i.e., ammonium or P) are adsorbed to organic particles or soil. The attached contaminants move in piggyback fashion only when the host material moves.

Sediment, organic particles, or substances adsorbed to particles can be physically detached at the soil surface by the impact of raindrops or by overland flow and then transported to surface water. Larger substances and attached substances are prevented from moving downward by the filtering action of the soil. However, soluble substances, such as nitrates, can move readily downward until impeded by a restricting layer. A fragipan or sandstone layer may cause soluble contaminants to migrate laterally as subsurface flow until they emerge along a streambank as part of bank flow.

### **(b) Transformations on the soil surface**

Manure that is surface applied and not incorporated is exposed to solar radiation and aerobic drying conditions leading to volatilization and the death of pathogens. On warm and windy summer days, all of the initial ammonium in animal waste can be lost to the atmosphere within 24 to 48 hours. Mineralization and immobilization of N through adsorption can also occur rapidly under such conditions.

### (c) Filtering in the upper soil layer

Many factors, including the soil's physical and chemical characteristics and the environment in the soil (table 3–8) affect the removal of fecal bacteria in the soil and prevent their movement into groundwater. The primary factors are filtration, adsorption, and die-off in the soil.

Bacteria passing through the soil matrix can be filtered as a result of three processes acting independently or in combination. These processes are:

- physical filtration or straining by the soil matrix
- sedimentation of bacteria in the soil pores
- “bridging,” whereby previously filtered bacteria block or reduce the size of pores through which other bacteria would normally pass

Soil texture, structure, and pore size vary considerably among soils and influence the effectiveness of the filtering process. Adsorption of microorganisms onto clay particles and organic material effectively removes bacteria from liquids. Filtration and adsorption can remove over 90 percent of the bacteria applied in effluent in the first half inch of soil. Almost total removal can be accomplished in the first 2 inches of fine-textured soils.

Some soils have a tremendous capacity to remove bacteria and protect the groundwater resource. However, coarse-textured or disturbed soils do not provide the same level of treatment as undisturbed, fine-textured

soils. In addition, overloading or constant saturation of the soil can greatly reduce its ability to remove bacteria.

### (d) Transformations within the deep soil profile

The soil can be divided into saturated and unsaturated zones (fig. 3–6). The boundary between these zones varies seasonally and from year to year. In some locations, the saturated zone extends to the surface of the soil in early spring; at other times and locations, it may be hundreds of feet below the surface.

The unsaturated zone includes the root zone and an unsaturated area below the root zone. The root zone is characterized by an abundance of macropores, created in part by decaying roots and wormholes. The macropores allow rapid downward movement of substances carried by percolating water.

The root zone is also characterized by an abundance of carbon created by the decaying roots. Because microorganisms require carbon, biological transformations occur rapidly within the root zone, especially when the soil temperature is warm and adequate moisture is available.

Microbial activity is drastically reduced below the root zone. As a result,  $\text{NO}_3$ , which is available for a variety of other transformations within the root zone, can remain in the  $\text{NO}_3$  form for years below this zone of microbial activity.

**Table 3–8** Soil factors affecting infiltration and movement (leaching) of bacteria in soil

Physical characteristics	Environmental and chemical factors
Texture	Cation-exchange capacity
Particle size distribution	Chemical makeup of ions
Clay type and content	and their concentrations
Organic matter type and content	Bacterial density and dimensions
Pore size distribution	Nature of organic matter
Temperature	in waste effluent solution
Moisture content	(concentration and size)
Fragipan (hardpan)	pH
Surface compaction	

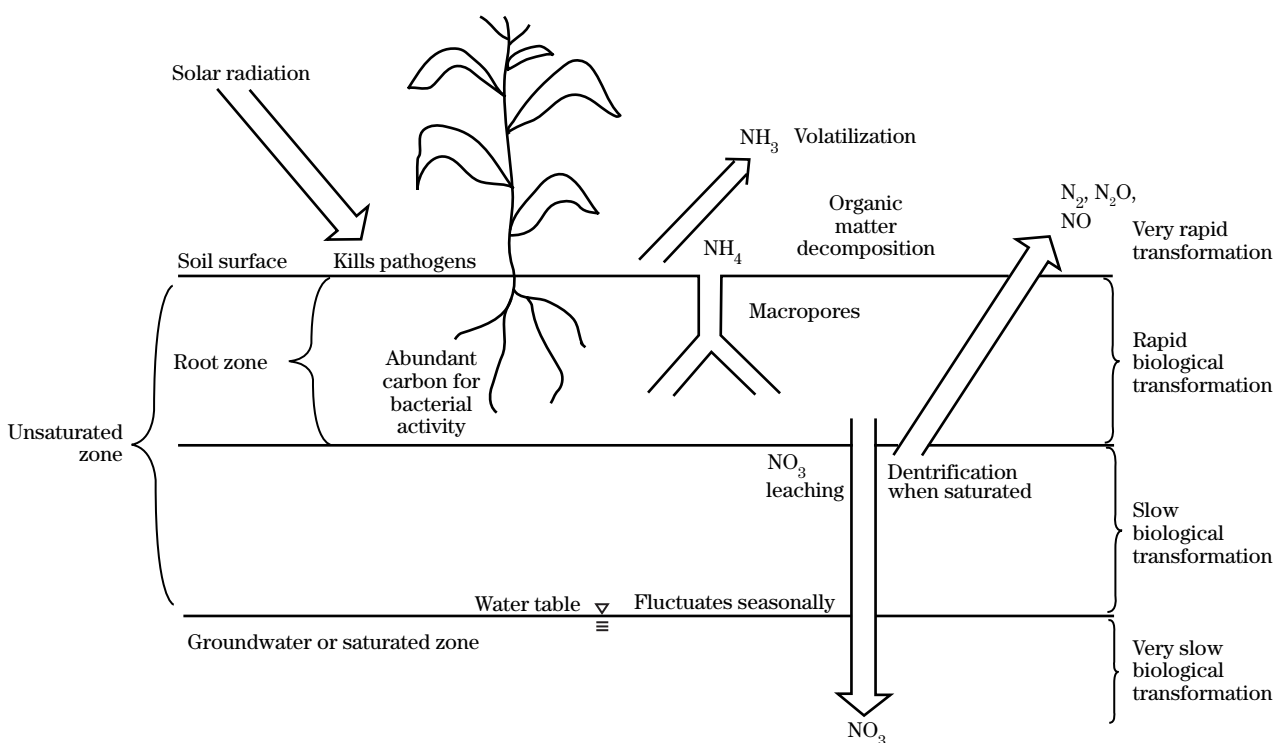
Within the saturated zone or in the groundwater, contaminants can remain unchanged for long periods because of the absence of microorganisms. However, in soils that have a seasonal high water table, the root zone can become saturated and anaerobic. In this environment, anaerobic bacteria can thrive, creating ideal conditions for denitrification (the conversion of nitrates to gaseous forms of N).

## 651.0304 Controlling the water pollution process

Manure is a valuable resource for crop production. It contains not only nutrients but also organic matter. A basic principle is that if manure is utilized to the maximum extent possible, discharge of pollutants to receiving waters will be minimized. The classic pollutant delivery process takes place in three stages: availability, detachment, and transport. Conservation practices that limit availability, prevent detachment, and interrupt transport should be used to prevent manure from contributing to water pollution.

Three elementary factors are required for a contaminant to reach a watercourse or enter the groundwater:

**Figure 3-6** Transformations on or in the soil





- A contaminant must first be available. If pesticides, fertilizers, or animal waste are not used in a watershed, these contaminants are not available.
- If the contaminant is available, it must be detached or removed from its resting place.
- Once detached, the substance must be transported to the point where it is integrated into a stream or water body or leached into the groundwater.

These factors (availability, detachment, transport) must be addressed when attempting to prevent the movement of contaminants from land to water. A brief description of these factors and examples of controls for each factor follow. A variety of management, vegetative, and structural practices can be used to control pollution beyond those illustrated here.

### (a) Limiting availability

Several factors must be known about a contaminant at the time of surface runoff or infiltration through the soil, including:

**Amount of the substance available**—Is the waste applied to the land in one large application or in split applications throughout the growing season? How much manure has been applied to the soil in the application area in previous years?

**Partitioning of the substance between soil and water**—Is the substance in soluble form, such as nitrate, or is it adsorbed to soil particles?

**Position of the substance on or in the soil profile**—Is the manure incorporated immediately after application? Are the soils managed to maximize infiltration?

**Persistence of the substance on or in the soil**—How long will it remain in place before being converted to another form or being lost through volatilization or leaching?

Animal waste can be deposited on pasture or rangeland, in streams where the animals congregate on hot days, or in confinement facilities where the waste must be removed and eventually returned to the land.

In general, the more manure deposited by animals on pasture or feedlots or spread on the land, the greater the concentration of contaminants in runoff or percolating water.

The following examples illustrate how animal waste or the particular constituents within the waste (nutrients, bacteria) can be limited in a watershed or at land spreading sites, assuming a water quality problem has been identified and the source is a livestock operation. Measures that could be used are:

- Remove all animals from the watershed.
- Reduce the number of animals.
- Use cropping systems that require more nutrients throughout the year.
- Improve manure storage capacity to avoid spreading manure during critical runoff periods; for example, when the ground is frozen or covered with snow and ice.
- Apply wastes in split applications throughout the growing season, thereby making smaller amounts of manure available each time.
- Apply wastes over more acres at recommended rates. (Nutrient application rates far exceeding agronomic recommendations can result if, for convenience sake, wastes are applied to only the fields nearest the confinement facility.)
- Use cover crops to prevent erosion and to capture nutrients in the soil system between crops.
- Use reduced tillage systems and manage crop residues to build soil structure that will increase infiltration and decrease surface runoff.
- Incorporate or inject the manure, thus limiting the availability of particular constituents. Phosphorus and  $\text{NH}_4$  will become bound within the soil profile and be less available for detachment.
- Collect and transport wastes to fields in other watersheds or bag the material for sale elsewhere.
- Compost the waste to reduce the availability of N.
- Treat the waste in a lagoon and land apply the waste only from the upper liquid zones of the

lagoon to reduce the amount of N. Some of the N will volatilize, and some will settle.

The Field Office Technical Guide (FOTG), Conservation Practice Physical Effects, lists the most common soil and water control practices used to prevent detachment and interrupt transport of contaminants to surface water.

## (b) Preventing detachment

When the contaminants are on the land (already available), physical detachment generally results from the impact of raindrops or from shear forces in overland sheet flow or concentrated flow. Unprotected soil and surface-applied wastes, fertilizers, and pesticides may be detached in this way. Therefore, the primary control measures to prevent detachment are those that reduce the impact of raindrops, such as vegetative cover or mulch, and those that control the velocity of water moving across the landscape, such as minimum or no tillage.

An understanding of the particular contaminants and how they react on the land or in the environment is helpful in establishing proper methods of control. Preventing detachment can involve control of particular constituents within animal waste (see section 651.0302(a)). If P is an identified water quality problem, then practices must be applied to prevent detachment of P. If the problem is low dissolved oxygen in a stream or lake (possibly from excessive organic matter) or a fish kill from high concentrations of un-ionized  $\text{NH}_3$ , then controls for these constituents should be applied.

Weakly bonded substances, nitrates, and bacteria can be detached and transported by water moving through the soil. Management practices to control detachment include:

- applying less soluble fertilizers
- applying wastes in split applications to prevent too much N from being converted to nitrate at one time
- applying less irrigation water to fields when high levels of soluble substances are available

## (c) Interrupting transport

If detachment of contaminants is inevitable, as with waste flushed from an open lot, then a method is needed to interrupt the transport process. For example, diversions can be designed to channel contaminated runoff into lagoons, waste storage ponds, and settling basins.

In the case of land-applied waste, a number of vegetative and structural practices can be used to intercept contaminants. Sediment basins are useful, especially if sandy soils are involved. Because the trap efficiency for clays can be relatively low, contaminants that are attached to clay particles are best controlled by controlling detachment rather than interrupting transport.

Vegetative and structural practices that slow the movement of water and allow for settling of solids are useful tools for interrupting transport of contaminants. Vegetative conservation buffers that function as filter strips at the edge of fields and infield practices like terraces and contour buffer strips are examples of practices that interrupt the transport process. Vegetative growth, especially a well-established winter cover crop, can take up nutrients that would otherwise be lost and can serve as a filter to trap sediment and adsorbed nutrients. For vegetative areas to be effective, they must slow runoff sufficiently to allow the sediment and organic materials to settle out in the filter and allow increased soil infiltration of runoff water.

## 651.0305 Effects of animal waste on the air resource

Livestock production facilities can be the source of gases, aerosols, vapors, and dust that, individually or in combination, can create such air quality problems as:

- nuisance odors
- particulate matter
- greenhouse gases
- ozone precursors
- animal health and asphyxiation

### (a) Odors

Agricultural odors are a complex mixture of gases that can evoke a wide range of emotional and physiological responses when encountered via the sense of smell. While some odorous compounds can cause health problems, odors from livestock are mainly a community or individual perception issue. Many different compounds can be the potential cause of odors from agricultural operations. These compounds can generally be classified as volatile organic compounds (VOCs), odorous sulfur compounds (including  $\text{H}_2\text{S}$ ) or  $\text{NH}_3$ . Odors may arise from animal operations in a number of ways, including:

- All living organisms (including animals) emit VOCs (including odorous compounds) naturally.
- The breakdown or decomposition of biological materials such as manure or feed can produce odorous compounds, including VOCs, odorous sulfur compounds, and  $\text{NH}_3$ .

### (b) Particulate matter

Particulate matter (PM) is currently a “criteria air pollutant,” which means that the EPA has identified PM as a pollutant that causes significant health (heart and lung) and environmental (deposition, visibility) effects. Particulate matter can be either solid particles or liquid droplets and come in a variety of sizes, shapes, and chemical composition. The EPA has currently

established National Ambient Air Quality Standards (NAAQS) for the two forms of PM:

- Fine PM—currently regulated as  $\text{PM}_{2.5}$  (aerodynamic diameter less than or equal to 2.5 micrometers). **Note:** The diameter of the average human hair is 70 micrometers.
- Coarse PM—currently regulated as  $\text{PM}_{10}$  (aerodynamic diameter less than or equal to 10 micrometers), PM can be emitted directly (primary PM—dust, pollen, soot, etc.) or formed in the atmosphere (secondary PM—formed from the reactions and condensation of sulfates, nitrates, VOCs, and  $\text{NH}_3$ ). Animal operations can influence PM in a variety of ways:
  - Animal activity can produce dust emissions that can be carried by wind or building ventilation.
  - Storage, handling, and the breakdown or decomposition of feed, bedding material, and manure can produce dust emissions as well as the emission of VOCs,  $\text{NH}_3$ , and oxides of nitrogen ( $\text{NO}_x$ ), which includes nitric oxide (NO) and nitrogen dioxide ( $\text{NO}_2$ ).
  - Fuel combustion, or the burning of biological material, can produce fine PM as well as oxides of N and VOCs.
  - Manure decomposition and its application on the land can produce emissions of VOCs,  $\text{NH}_3$ , and oxides of N.

### (c) Greenhouse gases

Greenhouse gases (GHGs) are compounds in the atmosphere that capture and retain energy reflected from the Earth’s surface. They lead to a warming of the atmosphere that is popularly called the “greenhouse effect.” Carbon dioxide, methane ( $\text{CH}_4$ ), and nitrous oxide ( $\text{N}_2\text{O}$ ) are the primary compounds associated with GHGs in agricultural operations. Common processes in animal operations that may produce GHGs are:

- Biological organisms (including animals) emit  $\text{CO}_2$  and  $\text{CH}_4$  naturally. Ruminants, such as cattle and sheep, produce more intestinal  $\text{CH}_4$  than non-ruminants.

- The breakdown or decomposition of biological materials, such as manure, feed, or mortalities, can produce  $\text{CO}_2$  (as a natural by-product of the breakdown/decomposition process),  $\text{CH}_4$  (under anaerobic conditions), and  $\text{N}_2\text{O}$  (mainly from the nitrification/denitrification processes).
- Combustion in on-farm equipment or the burning of biological material also produces  $\text{CO}_2$  as a natural by-product.

#### (d) Ozone precursors

Ozone is a gas composed of three oxygen atoms and is the primary component of smog. Although ozone in the upper atmosphere forms a layer that provides protection from ultraviolet radiation, ozone in the lower atmosphere and at ground level can be harmful. While ozone is not typically emitted directly from agricultural operations, it is formed in the lower atmosphere through the chemical reactions of VOCs and NOx, which are regulated as ozone precursors. Oxides of N and VOCs are known as ozone precursors because they are identified as pollutants that form ozone.

Some ways that animal operations can impact VOC and NOx formation are:

##### VOCs

- All living organisms (including animals) emit VOCs naturally.
- The breakdown or decomposition of biological materials such as manure or feed can produce VOCs.
- Incomplete fuel combustion or the burning of biological material can produce VOCs.

##### NOx

- Fuel combustion or the burning of biological material can produce NOx.
- The breakdown or decomposition (mainly nitrification/denitrification) of biological materials such as manure or feed can lead to NOx formation.

#### (e) Animal health and asphyxiation

A variety of gases can be generated in the operation of a livestock production facility that can cause asphyxiation, poisoning, and explosions. Some of these gases are toxic and can cause illness and even death at relatively low concentrations. Other gases are not toxic, but can displace oxygen and result in asphyxiation.

Different gases are produced as animal waste is degraded by microorganisms. Under aerobic conditions,  $\text{CO}_2$  is the principal gas produced. Under anaerobic conditions, the primary gases are  $\text{CH}_4$  and  $\text{CO}_2$ . About 60 to 70 percent of the gas generated in an anaerobic lagoon is  $\text{CH}_4$ , and about 30 percent is  $\text{CO}_2$ . However, trace amounts of more than 40 other compounds have been identified in the air exposed to degrading animal waste. Some of these include mercaptans (this family of compounds includes the odor generated by skunks), aromatics, sulfides, and various esters, carbonyls, and amines.

The gases of most interest and concern in manure management are  $\text{CH}_4$ ,  $\text{CO}_2$ ,  $\text{NH}_3$ , and  $\text{H}_2\text{S}$ . Table 3–9 provides a summary of the most significant characteristics of  $\text{NH}_3$ ,  $\text{CO}_2$ ,  $\text{H}_2\text{S}$ , and  $\text{CH}_4$ .

Methane is flammable, and in recent years, interest in using it as a source of energy on the farm has increased. Because  $\text{CH}_4$  can be explosive, care is required when attempting to generate and capture this gas for on-farm use.

Carbon dioxide can be an asphyxiant when it displaces normal air in a confined facility. Because  $\text{CO}_2$  is heavier than air, it remains in a tank or other well-sealed structure, gradually displacing the lighter gases.

Ammonia is primarily an irritant and has been known to create health problems in animals in confinement buildings. Irritation of the eyes and respiratory tract are common problems from prolonged exposure to this gas. It is also associated with soil acidification processes (see section 651.0302).

Hydrogen sulfide is deadly. Humans and farm animals have been killed by this gas after falling into or entering a manure tank or being in a building in which a manure tank was being agitated. Although only small amounts of  $\text{H}_2\text{S}$  are produced in a manure tank compared to the other major gases, this gas is heavier than

air and becomes more concentrated in the tank over time.

When tanks are agitated in preparation for pump out,  $H_2S$  can be released to the area overhead. Where a tank is located beneath the animals in a building, forced-air ventilation in the building is imperative before operating the agitation equipment. An exhaust system should also be provided within the tank during agitation and pump out.

Hydrogen sulfide has the distinct odor of rotten eggs. At the first hint of this odor, the area around the tank should be immediately evacuated of all humans. Hydrogen sulfide deadens the olfactory nerves (the sense of smell); therefore, if the smell of rotten eggs appears to have disappeared, this does not indicate that the area is not still contaminated with this highly poisonous gas.

A person should never enter a manure storage tank even to help rescue someone else who has succumbed to the  $H_2S$ . Several lives have been lost attempting such rescues. If a tank must be entered, the air in the tank should first be evacuated using a forced-air ventilation system. Self-contained breathing apparatus, safety lines, and sufficient personnel to man the lines are needed in all cases. A mechanical hoisting device would be preferable (ASABE Standard S607, Ventilating Manure Storage to Reduce Entry Risk).

For more information on how animal waste affects the air resource, see the NRCS National Engineering Handbook, Part 629, Air Quality.

**Table 3–9** Properties and physiological effects of the most important gases produced from animal wastes in an anaerobic environment

Gas	Lighter than air	Odor	Class	Comments
Ammonia ( $NH_3$ )	Yes	Sharp, pungent	Irritant	Irritation of eyes and throat at low concentrations. Asphyxiating, could be fatal at high concentrations with 30- to 40-minute exposure. PM precursor.
Carbon dioxide ( $CO_2$ )	No	None	Asphyxiant	<20,000 ppm=safe level; increased breathing, drowsiness, and headaches as concentration increases; could be fatal at 300,000 ppm for 30 minutes. Greenhouse gas.
Hydrogen sulfide ( $H_2S$ )	No	Rotten eggs	Poison	Headaches, dizziness at 200 ppm for 60 minutes. Nausea, excitement, insomnia at 500 ppm for 30 minutes; unconsciousness, death at 1,000 ppm.
Methane ( $CH_4$ )	Yes	None	Asphyxiant, flammable	Headaches at 500,000 ppm. Greenhouse gas.

## 651.0306 Effects of animal waste on the animal resource

The detrimental effects of the oxygen demand of organic matter and of the ammoniacal N that can come from manure on fish populations have been described previously in this chapter.

Animal mortality is part of all domestic animal feeding operations, and it is important to properly dispose of animal carcasses. Carcasses that are improperly disposed can become a feed source for undesirable predators like coyotes, and in their feeding on carcasses that can contribute to the spread of disease.

Wild turkeys are susceptible to blackhead disease from domestic poultry. Broiler breeder farms are commonly heavily contaminated with the cecal worm (*Heterakis gallinarum*) and their eggs, which can be transported to the field when spreading broiler breeder litter. For this reason, it is advisable to avoid spreading broiler breeder litter in areas where wild turkeys frequent.

Grazing animals can be adversely affected when animal waste is applied to forage crops at an excessive rate. Studies indicate that grass tetany, fescue toxicity, agalactia, and fat necrosis appear to be associated, in part, with high rates of fertilization from poultry litter on cool-season grasses (especially fescue). Highlights of these disease problems are provided. Additional details on the clinical signs of these diseases and methods to reverse or prevent their occurrence should be discussed with a veterinarian.

**Grass tetany**—Although this disease is associated mostly with low blood magnesium, conditions that increase the potential for its occurrence include low calcium, high uptake of N and P, and stress on the animal. Lactating cows grazing new growth of cool-season grasses or winter cereals are especially susceptible. Bulls and nonlactating cows are rarely affected.

**Fescue toxicity**—The precise cause of this disease is not well understood. Climatic conditions, molds and fungi, accumulation of ungrazed forage, and level of fertilization appear to be involved.

**Agalactia**—This term means absence of milk. Cows that have this condition are unable to lactate after giving birth. Not much is known about this disease, but it has often been observed in horses and cattle grazing on heavily fertilized tall fescue.

**Fat necrosis**—This disease is associated with mature cattle grazing tall fescue that has been heavily fertilized for a number of years with poultry litter. It appears to be a herd disease; although, it has occasionally been identified in individual animals. Cattle that have this disease generally have a restricted intestinal tract. In addition, the fat surrounding the birth canal can harden and prevent normal delivery.

Animal waste can be a repository for diseases and serves as a breeding ground for flies and other vectors. The transmission of diseases can be a problem.

Darkling beetles are a common problem in the litter of poultry houses. Left uncontrolled, they can spread disease between flocks and even between houses. Composting the litter in the poultry house between flocks and treatment with an insecticide can be an effective treatment against darkling beetles.

Fly problems are most prevalent where the waste is relatively moist. House flies thrive where the moisture content of the waste is 75 to 80 percent. Female flies generally will not lay eggs in manure in which the moisture content is less than 70 percent, and larvae develop poorly with less than 65 percent moisture. Therefore, fly production is reduced considerably if the waste is kept dry or is flushed regularly from confinement areas to a lagoon. Reducing fly populations will, in turn, reduce the chance for disease transmission within herds and flocks. It will also reduce the potential for nuisance complaints from neighbors.

## 651.0307 Conservation practice physical effects

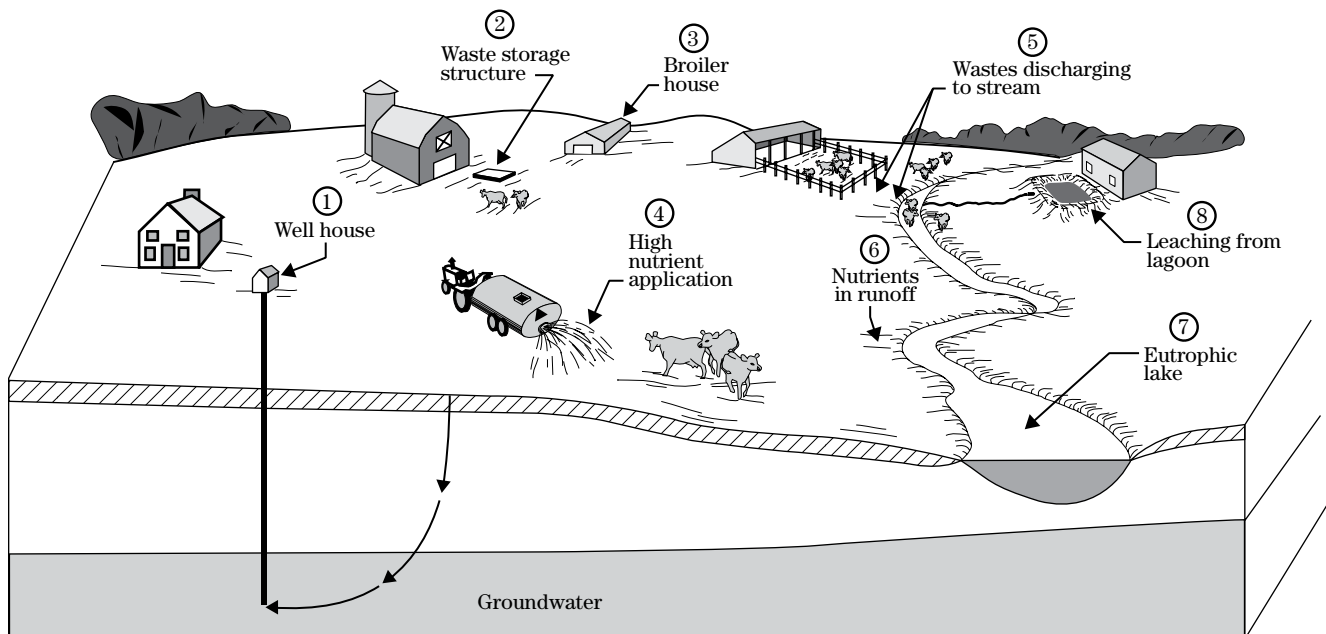
Because of the amount of material available that addresses the role of soil and plant resources in agricultural waste management, these two resources are described in separate chapters in this handbook. The Conservation Practice Physical Effects in the FOTG should be consulted to evaluate the effects on water quality and quantity of conservation practices used in agricultural waste management systems on the soil, water, air, plant, and animal resources.

## 651.0308 Summary

Animal wastes can adversely affect water, air, and animal resources in a variety of ways. Nutrients can kill fish and create algae blooms in surface water. In groundwater, nitrates can make well water unfit for human consumption, particularly for infants. In addition, organic matter can cause dissolved oxygen problems in surface water, while bacteria and other microorganisms can contaminate wells and create health problems in recreational waters.

Certain constituents in animal waste can create health problems in animals grazing cool-season grasses. In addition, the gases that are produced can have a number of adverse effects on the air resource and on animals in confinement.

Figure 3–7 provides an abbreviated graphic summary of the impacts that animal wastes can have on water, air, and animal resources. This graphical depiction does not show all of the possible impacts and does not convey the complexity of the pollution process. Likewise, this chapter as a whole only introduces the pollution process as related to water, air, and animal resources. A more complete understanding of the interaction of animal wastes with the various resources and the methods for pollution control would take intensive study of the volumes already written on this topic in addition to a lot of field experience. Even then, all the answers are not in; more is being learned about the pollution process all the time.

**Figure 3–7** Possible danger points in the environment from uncontrolled animal waste

1. Contaminated well: Well water contaminated by bacteria and nitrates because of leaching through soil. (See item 4.)
2. Waste storage structure: Poisonous and explosive gases in structure.
3. Animals in poorly ventilated building: ammonia, other gases, and particulates create respiratory and eye problems in animals and corrosion of metals in building.
4. Waste applied at high rates: Nitrate toxicity and other N-related diseases in cattle grazing cool-season grasses; leaching of  $\text{NO}_3$  and microorganisms through soil, fractured rock, and sinkholes; loss of excess nitrogen via gaseous emissions.
5. Discharging lagoon, runoff from open feedlot, and cattle in creek: (a) Organic matter creates low dissolved oxygen levels in stream; (b) concentration reaches toxic limits for fish; and (c) Stream is enriched with nutrients, creating eutrophic conditions in downstream lake.
6. Runoff from fields where livestock waste is spread and no conservation practices on land: P and  $\text{NH}_4$  attached to eroded soil particles and soluble nutrients reach stream, creating eutrophic conditions in downstream lake.
7. Eutrophic conditions: Excess algae and aquatic weeds created by contributions from items 5 and 6; nitrite poisoning (brown-blood disease) in fish because of high N levels in bottom muds when spring overturn occurs.
8. Leaching of nutrients and bacteria from poorly sealed lagoon: May contaminate groundwater or enter stream as interflow.



---

## 651.0309 References

- American Society of Agricultural and Biological Engineers (ASABE). 2010. Standard S607, Ventilating manure storages to reduce entry risk.
- Loehr, R.C., W.J. Jewell, J.D. Novak, W.W. Clarkson, and G.S. Friedman. 1979. Land application of wastes, vol. II. Van Norstrand Reinhold Co. New York, NY.
- Olsen, S.R., and S.A. Barker. 1977. Effects of waste application on soil phosphorus and potassium. *In* Soils for management of organic wastes and wastewaters. Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci Soc. Am. Madison, WI.
- Reddy, K.R., R. Khaleel, M.R. Overcash, and P.W. Westernman. 1979. Phosphorus—a potential nonpoint source pollution problem in the land areas receiving long-term applications of wastes. *In* Best management practices for agriculture and silviculture. Ann Arbor Sci. Publ., Inc. Ann Arbor, MI.
- U.S. Department of Agriculture. 2011. National Engineering Handbook, Part 629, Air Quality. Washington, DC.
- U.S. Environmental Protection Agency. 1983. Water quality standards handbook. Washington, DC.
- U.S. Environmental Protection Agency. 1984. Technical support manual: Waterbody surveys and assessments for conducting use attainment. Washington, DC.
- U.S. Environmental Protection Agency. 1986. Quality criteria for water. EPA 440/5-86-001. Washington, DC.
- U.S. Environmental Protection Agency. 1990. The lake and reservoir restoration guidance manual. EPA-440/4-90-006. Washington, DC.