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Water and Land Issues Associated with Animal Agriculture: A U.S. Perspective

The most prominent recent U.S. national policy issue related to livestock, land, and water has been the effect of livestock production on the quality of surface water and groundwater. (Photo from Shutterstock.)

Abstract

Agriculture and society have entered a critical phase as global population grows in number and income while availability of land and freshwater for agriculture diminishes. A major challenge identified by the Food and Agriculture Organization of the United Nations (FAO) in 2006 was how to double the global production of livestock products during the next few decades without increasing the environmental damage caused by livestock production and related activities.

The authors of this Issue Paper use a North American (primarily U.S.) perspective to examine the livestock, land, and water issues raised by the FAO in a global setting. The authors draw heavily on published data and literature to look at current status and trends in physical and biological indicators as well as policy and both regulatory and nonregulatory approaches to addressing the issues.

The authors note that livestock and poultry production account for nearly half the value of U.S. agricultural production, that 45% of U.S. land surface is used for agricultural activities, and that an estimated 70% of global freshwater use by humans is for agriculture, including 38% in the United States. Although historical gains in yields of grain and livestock products have provided consumers with an abundant inexpensive supply of food, food demand is increasing rapidly. For example, global meat consumption is predicted to double and overall food consumption to rise by 70% by 2050.

The authors address major water use and water quality concerns and land use and land degradation concerns that were raised in an FAO publication titled *Livestock's Long Shadow*. Those concerns arise primarily from the large land area used for grazing and producing feed crops and the forecast that another billion tonnes of feed grain will be required annually by 2030. Important concerns also arise from the management of large volumes of manure and from processing wastewater.

Methods of addressing the environmental challenge that were suggested by the authors of *Livestock's Long Shadow* included increased efficiency of livestock production and increased regulation and incentives for pollution reduction. In the United States, the amount of land and feed required to produce a kilogram of animal product has declined substantially during the past several decades. United States research, education, policy, and regulation of livestock production and processing have created technological gains, intensification, increased productivity, and decreased

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CAST Issue Paper 50 Task Force Members

Authors

Kelly D. Zering (Chair), Department of Agricultural and Resource Economics, North Carolina State University, Raleigh

Terence J. Centner, Department of Agricultural and Applied Economics, University of Georgia, Athens

Deanne Meyer, Extension Specialist, Department of Animal Science, University of California–Davis

G. Larry Newton, Department of Animal and Dairy Science, University of Georgia, Tifton

John M. Sweeten, Texas AgriLife Research and Extension Center, Texas A&M University System, Amarillo

Steven Woodruff, Woodruff & Howe Environmental Engineering, Inc., Canton, Georgia

Reviewers

Jane Frankenberger, Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana

John Lory, Department of Plant Sciences, University of Missouri–Columbia

W. F. Owsley, Department of Animal Sciences, Auburn University, Auburn, Alabama

CAST Liaison

A. David Scarfe, American Veterinary Medical Association, Schaumburg, Illinois

pollution rates. Emerging demands and constraints imposed on livestock production systems can have huge influences as the public looks at the quality of air, water, and food.

Despite substantial historical technological and policy achievements reported in this Issue Paper, the authors identify the need for a sustained, integrated research approach to livestock production, manure management, nutrient application, feed crop production, irrigation, and monitoring and management of soil and water quality. The authors cite evidence of declining rates of productivity gains in recent decades. Integrated research, education, and policy will be critical to doubling feed crop and livestock production while protecting the environment, conserving limited resources, and constraining increases in food prices.

The experts who compiled this paper cover production of beef, dairy, pork, and poultry, and they provide a look at trends and new approaches. Some notable examples of emerging regulatory, nonregulatory, management, and research approaches are: (1) a focus on policy transitions to prevent economic damage to producers and consumers; (2) environmental management programs, including goal setting, monitoring, and reporting; (3) the life cycle approach, which provides a comprehensive analysis of effects and a basis for efficient minimization of these effects; and (4) the systems approach, which considers the interdependent effects of livestock production decisions on air emissions, water quality, public health, the economy, and other issues.

The goals of maintaining an abundant supply of food and protecting the environment require sustained research, development, education, and extension programs from universities, government agencies, and the private sector. In this paper, the authors outline current challenges in agriculture and provide factual support for U.S. policymakers and leaders as they invest in continued development of technology, management, markets, and policy for livestock production in the context of rapidly growing global demands on resources.

Introduction

Livestock production, including poultry, is an important part of human activity. A primary function of livestock production is to meet human demand for major dietary components, including high-quality protein, minerals, and vitamins. Livestock constitutes 40% of the value of global agricultural output and more than 50% of that value in developed countries (FAO 2006a). Livestock convert water, plant biomass, and minerals into meat, milk, eggs, and other products. Agriculture is a primary use of land and freshwater by humans. Globally, 30% of the land surface is used for agriculture, including 45% of the land in the United States (FAO 2006a; FAO 2012a; USDA–ERS 2007). An estimated 70% of global freshwater use by humans is for agriculture, including 38% of freshwater withdrawals[1] in the United States (FAO 2006a; USGS 2009).

The 2006 Food and Agriculture Organization of the United Nations (FAO) report titled *Livestock's Long Shadow* (LLS) drew attention to environmental issues arising from anticipated rapid expansion of livestock production. The population of the planet is predicted to grow from 7 billion to 9.1 billion and income per capita is predicted to rise by 150% by 2050 (FAO 2006a). A World Bank study predicted that the number of people in the middle class globally will rise by 167% by 2030 (Bussolo, De Hoyos, and Medvedev 2008). Based on predicted growth in population and income, and based on human propensity to increase meat, milk, and egg consumption as income rises, global consumption of meat, milk, and eggs is predicted to double by 2050 (FAO 2006a). Annual consumption of feed grain is predicted to grow by one billion tonnes between 1999/2001 and 2030, and use of concentrate feeds will increase faster than livestock production in developing countries (FAO 2006a). At current U.S. corn yields, approximately 98 million hectares (ha) or 2.7 times current U.S. corn acreage of additional corn production would be required to produce one billion tonnes.

The FAO estimate apparently does not include the required production of soybeans or other protein sources for animal feed. Consider that a growing human population with an increasing standard of living will convert agricultural land to other uses, will directly consume more freshwater and energy, will emit more pollution, and will demand more environmental protection. In short, how do people double production of meat, milk, and eggs and increase all food

[1] The FAO report (FAO 2006a) defines water use or withdrawals as water removed from a source and used for human needs, some of which may be returned to the source.

production by 70% or more from a diminishing resource base while meeting ever-greater demands for environmental protection and security of public health? The challenge is enormous.

The stated intent of LLS was to draw attention to the need to cut the environmental impact of global livestock production in half "just to avoid increasing" the level of environmental damage as global livestock production doubles by 2050 (FAO 2006a). The report concluded that global livestock production "emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global" (FAO 2006a). Categories of environmental damage include land degradation, climate change and air pollution, water shortage and water pollution, and loss of biodiversity (FAO 2006a). Primary examples of land degradation cited are deforestation in the Amazon and compaction and soil erosion because of overgrazing on pasture and rangeland, particularly in dry areas. Water erosion of soil is a major form of land degradation with particularly large effects in Asia and Africa (FAO 2006a). Air pollution issues associated with livestock production are addressed in a separate CAST Issue Paper (CAST 2011).

The livestock sector accounts for "over 8% of global human water use, mostly for the irrigation of feed crops" (FAO 2006a). According to LLS, in the United States, 55% of sediment and erosion, 37% of pesticide use, 50% of antibiotic use, and a third of the loads of nitrogen (N) and phosphorus (P) into freshwater resources are attributed to livestock production. Those claims are reviewed in this paper. Although important on a global scale, issues of biodiversity are not addressed in this Issue Paper. Previous CAST publications have addressed livestock production in relation to biodiversity (CAST 1999, 2002, 2009a).

A general conclusion of LLS is that "improving the resource use efficiency of livestock production can reduce environmental impacts" (FAO 2006a). A similar conclusion is found for U.S. livestock production by Bull and colleagues (2008). Increased "intensification" of livestock production and increased incentives and regulation of global livestock production and meat processing activities were proposed to achieve resource, environmental, and public health objectives.

The purpose of this CAST Issue Paper is to provide a factual overview of the relationship between livestock production and land and water resources in the United States. This paper provides a summary of scientific inquiry as well as policy and regulatory aspects of livestock production and processing as they relate to land and water issues in the United States. Major points made here include that the relationship between livestock and land and water resources is directly affected by (1) improvements in productivity registered through technological gains and intensification, (2) improvements in waste management systems and understanding of pollution processes, and (3) emerging demands on livestock production systems to address other social goals. Examples of other social goals include protection of air quality, protection of public health, regulation of antibiotic use for livestock, protection of animal welfare, and consumption of locally produced foods.

Contrasts are drawn between the situation in the United States and the global situation described in LLS. Although current status in the United States differs markedly from other parts of the world, growing global demand will affect U.S. citizens directly through the prices of resources and food and through domestic and global environmental effects. This paper emphasizes the need for sustained research, development, and education to dramatically increase the productivity of livestock and related systems while decreasing resource use and negative environmental effects.

Comparison of U.S. and Global Issues, Status, and Trends

Issues related to livestock, land, and water in the United States are compared in the following sections to those identified on a global scale (FAO 2006a). Status and trends are presented to demonstrate fundamental differences between global and U.S. issues.

U.S. Livestock Production in a Global Context

Livestock production in the United States is comparable to the LLS characterization of livestock production in developed countries: intensive, high yielding, and feed efficient in comparison to global livestock production. The largest components of the diverse U.S. livestock sectors are highly efficient producers of milk, meat, and eggs for domestic consumption and export. In contrast to the global situation, livestock is no longer relied on for transportation, draft power, or production of manure for heating fuel (except recent biogas and poultry litter combustion energy recovery) in the United States.

Cash receipts from the U.S. livestock sectors fell from 48 to 42% of total farm receipts between 2007 and 2009 as the price of crops rose sharply (USDA 2011). Feed grains for livestock, including corn used for ethanol and other industrial uses, constituted another 14.4 (2007) to 17.7% (2009) of U.S. farm cash receipts. Cash receipts from soybean meal (used primarily for livestock feed) are not reported separately, but soybeans constituted another 8 (2007) to 10.6% (2009) of U.S. farm cash receipts. United States cash receipts from farming fell from \$288 billion in 2007 to \$283 billion in 2009 and were estimated at \$312 billion in 2010 (USDA 2011).

Livestock production is critical to the employment, income, and subsistence of 1.3 billion people, including one billion of the poorest people on the planet (FAO 2006a). Whereas this statement is less applicable to developed countries, agriculture—including livestock production and processing of meat, milk, and eggs—is an important category of employment in rural areas of the United States. Animal production directly employed 860,800 people in the United States in 2008, representing 41% of total U.S. employment in agriculture, forestry, and fishing (USDL–BLS 2010). Dairy product processing and meat animal slaughter and processing are important categories of rural manufacturing employment in the United States, directly employing 127,900 and 490,200 people, respectively, in 2010 (USDL–BLS 2011). The direct economic effects of livestock production and processing are multiplied when secondary and indirect economic effects are considered. The investment, employment, income, and tax revenue that livestock production and processing provide are critically important to many rural communities and some states across the United States (Promar International 2010). By-products of meat production include tallow and poultry fat. Smaller but significant components of the U.S. livestock sectors provide other goods and services such as wool; honey; specialty meat, milk, and eggs; furs; recreation; and companionship.

The inventory of livestock is the number of animals at any point in time. Production is the number of livestock and/or the weight of livestock, milk, and eggs produced during a specific period of time. United States inventory and annual production of major livestock products are listed in Table 1.

Trends and yield characteristics of U.S. livestock production are evident in Table 1. First, the weight produced and yield (production per animal in inventory per year) of meat, milk, and eggs increased between 1970 and 2008. In some instances the number of animals in inventory fell (e.g., dairy cows), and in other instances inventory rose (e.g., broiler chickens). For each of the species listed, U.S. production increased at a greater rate than inventory, indicating increased yield.

A second characteristic of the U.S. livestock sector is high yield in comparison to the global livestock sector. The right column in Table 1 lists 2008 U.S. inventory and production as a percentage of global inventory or production, respectively, based on FAO data. Evident in that column is that the U.S. share of global production is greater than its share of inventory, indicating a greater yield in the United States than in the global sector. Also evident in the right column is the wide range in U.S. share of global production across species: from approximately 9% of eggs and 10% of pig meat to 15% of milk, 19 to 21% of beef and chicken meat, and 60% of turkey meat.

Table 1. U.S. inventory and annual production of livestock and poultry: 1970, 1990, 2008

Year	1970	1990	2008	% of World 2008
Broilers (young chickens)				
Inventory (billion birds)	0.92	1.33	2.06	11.4%
Production (billion birds)	3.24	6.02	9.07	17.7%
Production (million tonnes)	3.84	8.67	16.68	21.3%
Cattle				
Inventory, total (million head)	112.4	95.8	96.7	7.0%
Production, beef (million head)	39.6	35.3	34.5	11.7%
Production, beef (million tonnes)	10.1	10.5	12.2	19.8%
Swine				
Inventory (million head)	57.05	53.79	65.91	7.0%
Production (million head)	87.05	85.43	112.0	8.5%
Production (million tonnes)	6.09	6.96	10.46	10.1%
Turkeys				
Inventory (million head)	116.1	282.4	271.1	47.6%
Production (million head)	105.5	271.2	260.0	39.2%
Production (million tonnes)	0.78	2.05	3.38	60.3%
Dairy cows				
Inventory, dairy cows and replacement heifers (million head)	12.00	9.99	9.22	3.7%
Production, milk (million tonnes)	53.1	67.0	86.2	14.9%
Chicken eggs				
Inventory, hens kept for egg production (million birds)	312.9	270.9	341.9	5.5%
Production, chicken eggs (billion eggs) (includes table eggs and broiler eggs)	68.5	68.1	90.2	7.8%
Production, chicken eggs (million tonnes)	4.05	4.03	5.34	8.7%

Source: FAO 2012b.

The U.S. livestock and poultry sectors supply domestic consumers and export markets and are among the few sectors that produced a trade surplus for the United States in 2008. The U.S. Department of Agriculture (USDA) reports domestic consumption of meat, milk, and eggs as *per capita disappearance*;[2] this consumption (shown in Table 2) includes pet food consumed by companion animals. United States broiler meat consumption nearly tripled between 1970 and 2008, whereas consumption of beef and, to a lesser extent, pork fell on a per capita basis. The United States is a net exporter of feed grains, forage products, and most livestock products (WAOB 2010). Table 3 lists U.S. net exports and net imports of livestock products. Dramatic increases in net exports of broiler meat and pork are evident between 1990 and 2006.

The focus of the next section shifts to the effects of the livestock sectors on land and water resources in the United States.

U.S. Land Use and Land Degradation Associated with Livestock Production in a Global Context

There are 916.2 million ha of land in the 50 states of the United States. Approximately 178.7 million ha (19.5%) were classified as cropland in 2002 (USDA–ERS 2007). Another 237.3 million ha (25.9%) were classified as grassland, pasture, and range in 2002. The balance of U.S. land area was classified as forest land (28.8%), special uses (rural parks and wildlife areas, roads, etc., 13.1%), urban (2.6%), and other (10%). Direct land use for animal production is very small with the exception of cattle grazing on rangelands that have little alternative commercial use other than wildlife habitat.

The United States occupied 7% of the world's land area, including 8.4% of the global agricultural area, in 2008 (FAO 2012c). Within the category of agricultural land, the United States occupied 12.35% of arable land (suitable for producing crops) and 7.1% of permanent

[2] Italicized terms (except genus/species names, published material titles, and legal case names) are defined in the Glossary.

Table 2. U.S. consumption of meat, milk, and eggs (per capita disappearance)[a,b]

Commodity	1970 (kilograms [kg]/year [yr]/capita)	2008 (kg/yr/capita)
Broiler chicken	16.7	44.1
Beef	51.9	40.7
Pork	33.1	28.9
Turkey	3.7	8.0
Milk	255.8	287.6
Eggs	309 eggs/yr/capita	249 eggs/yr/capita

[a]Source: USDA–Economic Research Service (ERS) Livestock Dairy and Poultry historical data tables (USDA–ERS 2008).

[b]Carcass weight as opposed to retail weight or boneless retail weight.

Table 3. U.S. net exports and net imports of livestock products[a,b]

Product	1990	2006[c]
	Net Exports (tonnes)	
Chicken meat	453,600	1,814,000 (10.9%)[c]
Pork products	18,140	907,200 (8.7%)
Eggs/Egg products	19,050	49,900 (0.9%)
Turkey meat	27,220	63,500 (1.9%)
	Net Imports (tonnes)	
Milk equivalent dairy products	337,500	116,100 (0.1%)
Cattle meat and products[d]	528,900	586,900 (4.8%)

[a]Source: FAO 2012a.

[b]These quantities do not include offals, skins and hides, or fat products (except butter).

[c]Numbers in parentheses in 2006 are percentages of U.S. production.

[d]Boneless beef imports were equivalent to 85 to 110% of this trade deficit (FAO 2012a).

meadows and pastures. The United States includes 7.5% of the global forest area, 4.9% of "other" land, and 15% of the global inland water area, and it is home to less than 5% of the global human population.

More than 70% of U.S. grassland, pasture, and range acreage is located in the mountain states (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming) and southern plains (Oklahoma, Texas) (USDA–ERS 2007). Together those regions have approximately 33% of the U.S. inventory of cattle (both on feed and not on concentrated feed), so it is clear that stocking rates are relatively low on the extensive pasture and rangelands in those states (USDA–NASS 2011a).

A primary use of cropland for animal agriculture is to produce grain for dietary energy, oilseed meal for protein, and hay for ruminants (cattle). The USDA–National Agricultural Statistics Service (USDA–NASS 1960–2010) reported 35.0 million ha were planted with corn in 2009, of which 32.2 million ha were harvested for grain and 2.3 million ha were harvested for silage. Sorghum was harvested from 2.3 million ha, 96% as grain. Oats were planted on 1.4 million ha, with 40% harvested as grain. Approximately 36% of the U.S. corn supply was used for domestic "*feed and residual*" and almost 40% was used for ethanol as well as food, seed, and industrial uses in 2009 (WAOB 2010). Approximately 30% of the mass of corn used for ethanol is returned as distillers grain, a residual fed to livestock.

In 2009, 31.3 million ha were planted with soybeans in the United States, of which 30.9 were harvested. Soybeans are crushed, and the oil is extracted for food use. Almost 50% of U.S. soybeans were crushed domestically and 72% of U.S. soybean meal supply was fed domestically to livestock in 2009 (WAOB 2010). Hay was harvested on 24.2 million ha in 2009.

Land is also used by livestock operations to receive manure. In 2006, manure was applied as a fertilizer to 6.3 million ha, which is equivalent to less than 5% of U.S. planted acres (USDA–ERS 2009). The total included 3.6 million ha of corn and 1.66 million ha of hay and grasses.

The United Nations Environmental Program definition of land degradation describes a loss of resource potential because of processes including soil erosion; deterioration of the physical, chemical, biological, and economic characteristics of the soil; and long-term loss of natural vegetation (FAO 2006a). Specific forms of land degradation include water erosion of soils; desertification including loss of vegetative cover; and yield reduction because of several factors, including soil compaction on cropland. Dregne and Chou (1994) are cited in LLS stating that 74% of dry lands in North America and 70% globally are degraded. Eswaran, Lal, and Reich (2001) identified confusion over definitions of land degradation and lack of a demonstrated link between measures of land degradation and observed soil productivity as being among the obstacles to effective policy. The evolution of U.S. programs for soil conservation and control of land degradation since 1930 was not discussed in LLS. Deforestation is a major issue related to livestock production globally, particularly in South America (FAO 2006a). In contrast, the area of U.S. land in forest increased by 6.88 million ha between 1987 and 2002 (USDA–ERS 2006) despite a dramatic increase in U.S. livestock production during that period.

U.S. Water Use Issues Associated with Livestock Production in a Global Context

An estimated 70% of global freshwater use by humans is for agriculture (FAO 2006a). The livestock sector accounts for "over 8% of global human water use, mostly for the irrigation of feed crops," according to LLS. United States withdrawals of water for all purposes were estimated at 1.552 trillion liters per day in 2005 (USGS 2009). Eighty-five percent of the total was freshwater. Surface water was the source for 80% of all withdrawals. Approximately 49% of U.S. withdrawals was for thermoelectric power generation. Irrigation accounted for 37% of estimated freshwater withdrawals in 2005. An estimated 85% of irrigation withdrawals was in the 17 western *conterminous* states in 2005 (USGS 2009).

Based on U.S. Geological Survey (USGS) estimates made every five years since 1950, total withdrawals declined since peaking in 1975 and 1980. Withdrawals for irrigation have declined steadily since that time, even though irrigated acreage has increased. Irrigation practices have been adopted to improve distribution uniformity and efficiency with a net benefit of less water needed per unit of crop farmed. Withdrawals for domestic and public water supply have increased steadily, reflecting growth in population and in per capita use.

Livestock farms use water for many purposes including

- livestock consumption;
- animal comfort through cooling of animals and barns;
- cooling milk;
- sanitation operations, including animal hygiene and washdown of facilities; and
- collection and transport of wastes.

Intensive cattle feeding facilities may use water for dust control, frost/freeze protection, or feed processing. Estimated U.S. water withdrawal for livestock farm uses in 2005 was 8,101 million liters per day (USGS 2009). Livestock water withdrawals for all categories were estimated at less than 1% (0.61%) of total freshwater withdrawals in 2005. Water withdrawals related to animal agriculture include three categories: the production operation itself; meat, milk, and egg processing facilities; and irrigation of crops used for feed.

Water use data for the southeastern United States presented by Newton and colleagues (2003), for example, reported that animal agriculture in that area, although a significant water user when compared to urban and suburban use, was likely not responsible for recent water shortages. Groundwater was the primary source (60%) of the water used in livestock operations in 2005 (USGS 2009). Surface water and, in some instances, a municipal water provider or irrigation district are other sources for livestock operations. Only minor increases in water withdrawals for livestock uses were reported by U.S. states included in both USGS water use studies conducted in 1995 and 2000 (USGS 2004).

An example of water use in an area of intensive animal production and irrigation was provided by Weinheimer and colleagues (2007). Water use estimated for livestock production on the Texas High Plains was less than 2% of total water use in 2000 and is expected to grow to 2.45% in 2030 and 3.17% in 2060, because of increased confined livestock production (+100%) and shrinking irrigation withdrawals due to improved irrigation water use efficiency or groundwater depletion, even as municipal/industrial water use increases.

In addition to water quantity, water quality is a U.S. and global issue for livestock production. Livestock health problems or below-normal consumption may result from substandard quality water (Weinheimer et al. 2007). Ingestion of mineral or organic contaminants can cause poor performance or nonspecific disease conditions. The most common water quality problems affecting livestock production include excess salinity and high concentration of minerals, measured as total dissolved solids (TDSs); high nitrates or nitrites; bacterial contamination; blue-green algae; or accidental spills of petroleum, pesticides, or fertilizers into the water supply. Although the importance of nitrate, nitrite, sulfate, and TDSs as factors influencing water quality for livestock has been recognized, major livestock health problems associated with water quality are seldom reported except in site-specific instances. Water may serve as a carrier to spread disease and potentially affect acceptability or safety of animal products for human consumption if pathogens are present and *zoonotic* organisms are viable in large enough numbers.

Significant quantities of water are used in meat, table egg, and milk products processing operations. Water is used for washing products; hair and feather removal operations; cleaning and sanitizing equipment and facilities; product cooling; transport of by-products and wastes to by-products recovery systems and/or wastewater treatment units; and cooling of mechanical equipment such as compressors, refrigeration units, and pumps. Adequate water use in meat, egg, and milk products processing operations is required to ensure elimination/reduction of foodborne pathogens and other contaminants.

Water use in meat, table egg, and milk products processing plants is controlled by the USDA Food Safety Inspection Service (USDA–FSIS), the Food and Drug Administration, and/or state food safety/quality inspectors with regulatory jurisdiction over these facilities. Changes in federal and state food safety regulations and/or variations in interpretations by local plant inspectors have resulted in significant increases in water usage in meat, table egg, and milk products processing plants. For example, after implementation of the USDA–FSIS's Hazard Analysis and Critical Control Point rule, water use in the poultry processing industry increased by an estimated 3.8 to 7.6 liters per chicken processed, or an increase of approximately 31% (Russell 2003).

The sources of water used in meat, table egg, and milk products processing facilities include groundwater and surface water withdrawal and treatment systems as well as municipal water providers. The supply water quality for meat, milk, and table egg processing plants must meet applicable standards under the Safe Drinking Water Act, USDA–FSIS sanitation regulations, and/or applicable state regulations and laws.

Table 4 provides information on water usage rates for various meat and table egg processing facilities. Water usage factors and livestock product processing facility production rates for 2000 were used to estimate the annual volume of water used by meat and table egg processing plants. Water usage associated with dairy operations is accounted for in the livestock production water usage information discussed earlier.

Based on this analysis, the estimated annual water usage in the meat and table egg processing industries accounted for less than 0.1% of the total annual freshwater withdrawals in 2005 (USGS 2009). Other ancillary facilities also use water (e.g., broiler hatcheries, feed mills, by-products rendering plants, meat further processing plants, etc.); however, water usage in these operations is typically minor compared to water usage in the slaughter plants. There is minimal loss of water across typical meat and egg processing plants, and a majority of the water used in these operations is treated and returned to the environment. Extension and management efforts have resulted in many meat and egg processing plants using various treatment systems to allow significant reuse of water.

Irrigation of feed crops was identified by LLS as the primary use of water

Table 4. Estimated annual water use at meat and table egg processing plants

Livestock Type	Water Use Range (liters per unit)[a,b]	Average/Mean Value (liters per unit)[a,b]	Annual Production Tonnes LWK or 30 Dozen Cases of Eggs[c]	Estimated Annual Water Used in Processing Operations (Billion liters)[d]
Cattle	3,630–12,518	7,386	20,041,579	148
Calves	3,630–12,518	7,386	162,184	1.2
Hogs	2,028–5,116	3,856	11,643,574	45
Broilers	-	10,757	19,128,085	205.8
Turkeys	-	5,291	3,112,183	16.5
Table eggs	<2–>7	2.8	198,458,333	0.6
			Total	417

LWK—live weight killed

[a]Sources: USEPA 2002. For table eggs: Jones and Northcutt 2005; Northcutt, Musgrove, and Jones 2005. Some values are based on wastewater flows but are similar to water usage, as only minor losses of water occur across typical meat and poultry processing plants.

[b]Units: liters per tonne live weight killed (LWK); for table eggs, liters per 30 dozen case.

[c]Source: USDA–NASS 2008.

[d]Does not include water usage in meat further processing operations.

for livestock production. Irrigated agriculture accounts for 40% of crop production and 60% of cereal production in developing countries (FAO 2006a). Water is essential for the growth of plants. Rainfall and soil moisture are the only sources of water for most agricultural land in the United States. Irrigated acreage has increased from 10.48 million ha in 1949 to 22.78 million ha in 1997 and 22.5 million ha in 2002 (Gollehon and Quinby 2006). Irrigated area was equivalent to 13% of U.S. cropland in 2002. The U.S. average annual application rates of irrigation water declined from 0.63 meters (m) in 1969 to 0.51 m in 2002 (Gollehon and Quinby 2006). Gollehon and Quinby (2006) reported that 3.93 million ha of corn for grain, 2.21 million ha of soybeans, and 2.76 million ha of alfalfa hay were irrigated in 2002. As a percentage of total irrigated ha in the United States in 2002, corn grain was 18%, soybeans 10%, and alfalfa hay 12%. The irrigated acreage represented approximately 12% of total corn acreage, 7% of soybean acreage, and 28% of alfalfa acreage.

A rough estimate of the fraction of U.S. irrigation water used for U.S. livestock production can be obtained by summing across crops, the products of share of irrigated acres and share of crop used for U.S. livestock production. That calculation suggests that approximately 24% of irrigated acreage is used to feed U.S. livestock and poultry. Multiplying 24% of irrigated acres by 37% of U.S. freshwater withdrawals for irrigation produces a rough estimate of approximately 9% of U.S. freshwater withdrawals used to produce feed for U.S. livestock and poultry. This estimate is biased upward to the extent that feed crops use less irrigation water per ha than the average of all irrigated crops.

Gollehon and Quinby (2006) point out that irrigation water use is an economic decision that is affected by costs of water, energy, labor, and irrigation equipment, as well as the price of crops. Restrictions on supply because of factors such as source depletion and weather, as well as regulatory terms and conditions, affect irrigation water use. CAST Issue Paper 44 (CAST 2009b) provides an in-depth exposition of water use and related issues in the United States. A point made in that paper is that growing U.S. population and faster-growing global demand for food, fiber, and other resource-based goods and services will place steadily increasing demands on limited freshwater resources with acute pressure in some regions. Water (both irrigated and rainfall) may become a limiting factor to increased cereal production in major grain-producing and exporting areas such as the U.S. Midwest, central China, and an area of South America (FAO 2006a).

In summary, U.S. freshwater withdrawals for livestock production and processing are less than 1% of total withdrawals. Freshwater withdrawals for irrigation of crops fed to U.S. livestock and poultry are roughly estimated at approximately 9% of total U.S. freshwater withdrawals.

U.S. Water Pollution Issues Associated with Livestock Production in a Global Context

Water pollution issues associated with livestock and poultry production have been prominent in the United States during the past few decades. Importance of the issues is reflected in revisions of state and federal water pollution regulations pertaining to livestock and poultry, in court cases, and in sustained research and extension efforts. Water pollution issues are inextricably linked to air pollution issues related to livestock and poultry (NRC 2003; Rice, Caldwell, and Humenik 2006; USGAO 2008) in that any change to livestock production systems may impact both emissions that affect air and those that affect water. Water pollution issues related to livestock and poultry are also inextricably linked to broader watershed-scale pollution control issues as reflected in total maximum daily load (TMDL) programs in the United States.

United States water quality concerns associated with animal feeding operations include

- nutrient enrichment,
- oxygen depletion from excess organic matter,
- turbidity,
- pathogens, and
- pharmacologically active compounds (PACs) (Sweeten et al. 2007).

Constituents in animal manures that may

be detrimental if allowed to discharge to surface water include

- nutrients,
- organic matter,
- TDSs,
- pathogens, and
- other potential contaminants (trace elements, PACs, pesticides, and endocrine disruptors) (USEPA 2003).

Manure, mortality, wash water, and airborne emissions from animal operations, as well as wastes from processing operations, contain the potential pollutants. The pollutants may reach groundwater or surface water by leaching into the soil or surface runoff from animal feeding areas, waste storage facilities, and fields receiving waste; inflow into faulty wellheads; spills; or deposition from air.

Globally, LLS states that the livestock sector is "probably the largest sectoral source of water pollution." In the United States, LLS estimates livestock is responsible for 55% of sediment and erosion, 37% of pesticide use, 50% of antibiotic use, and a third of the loads of N and P into freshwater resources. The following section reviews these claims in light of details of LLS and other scientific and data sources.

Livestock's Long Shadow attributes 55% of soil erosion from agricultural land in the United States to livestock production by attributing all pastureland to the livestock industry and multiplying by 2 tonnes/ha/yr, attributing 51 million ha of cropland to the livestock industry and multiplying by 12.5 tonnes/ha/yr, and then dividing by an estimate of the total erosion from cropland in the United States plus the calculated erosion from pastureland. The report also attributes 40% of erosion from cropland to the livestock sector and estimates that feed crop production uses 7% of agricultural land in the United States. Approximately 40% of the eroded mass, according to LLS, will end up in water resources without specific reference. The report cites Uri and Lewis (1998) in stating that 90% of U.S. cropland is losing soil at a rate greater than it is regenerating soil and that agriculture is the leading cause of impairment of water resources by sediments. The report cites USDA–NASS (2001), which is *Agricultural Chemical Use*, and the FAO 2006 database as sources (FAO 2006a).

The primary source for soil erosion data in the United States is the National Resources Inventory (NRI) compiled by the USDA–Natural Resources Conservation Service (USDA–NRCS 2010). The 12.5 tonne/ha average used by LLS is close to the 1992 number listed by the USDA. The average soil erosion rate from U.S. cropland declined steadily from 1982 through 1997 and was listed as 10.75 tonnes/ha in 2007. The NRI report emphasizes that soil erosion rates vary widely by region. Two important aspects of the NRI assessment are the distinction between "highly erodible land" and "not highly erodible land" and the distinction between land eroding at "above soil loss tolerable rates" and land eroding at lower rates. Tolerable rates are defined as those at which crop productive capacity of the land is not decreased.

A notable trend in the NRI data is that the amount of U.S. cropland eroding at above soil loss tolerable rates fell by 27.6 million ha between 1982 and 2007 (USDA–NRCS 2010). The NRI report states that 28% of U.S. cropland was eroding at rates above soil loss tolerable rates in 2007, down from 40% in 1982 (USDA–NRCS 2010). The NRI report does not discuss rangeland or grassland other than cropland. Blanco-Canqui and Lal (2008) provide thorough coverage of soil erosion in the United States and around the world. They note that the United States has the least soil erosion problem among regions of the world and that the most serious problems exist in less developed and densely populated regions. They identify overgrazing and deforestation as major causes.

The marginal contribution of livestock production to surface water sediment pollution either from pasture and rangelands or from cropland is not identified by LLS. All erosion from land used in relation to livestock production is simply attributed to livestock and 40% is assumed to be transported to water. No estimate is provided regarding whether or not sediment pollution would be decreased if livestock production was lowered or, if so, by what proportion.

Pollution of surface water with N compounds (nitrate in particular) and P has been and continues to be an important issue in the United States. *Eutrophication* and *hypoxia* caused in part by nutrients from crop production have altered major rivers and coastal waters, including the Chesapeake Bay and Gulf of Mexico (Turner and Rabalais 2003). Citing Carpenter and colleagues (1998) and FAO data for 2001 (FAO 2006b), LLS attributes 51% of N losses and 52% of P losses from U.S. cropland and 100% of N and P losses from U.S. pasture and rangelands to livestock production. The report concludes that 33% of N and P loadings to surface water in the United States is attributable to livestock, based on assumptions that 25% of N applied to fields as fertilizer and 12% of P applied to fields is lost to surface water. The assumed rates of transport to water in LLS are attributed to Galloway and colleagues (2004) and Carpenter and colleagues (1998). Carpenter and colleagues (1998) state that fertilizer N and P losses in runoff are generally less than 5% of the amount applied and slightly higher for manure N and P. They also cite Howarth and colleagues (1996) in assuming that total N and P losses to water, including leaching and atmospheric deposition, are 10 to 40% of the amounts applied on loam and clay soils and 25 to 80% of the amounts applied on sandy soils.

Howarth and colleagues (1996) applied regression analysis to riverine flux estimates for N and P compared to estimates of human-caused N and P loadings in river basins. They state that total estimated N fluxes from rivers are 25% of their estimates of human-caused N loadings in river basins. They also report a correlation coefficient of 0.1 for changes in estimated riverine N flux per change in estimated agricultural and food N loadings in river basins. Additionally, LLS predicted that losses from cropland make up 60% of N losses attributed to livestock. These numbers are presented in the context of rapidly increasing fertilizer use and rapidly increasing production of feed and livestock in Asia and other parts of the world. As stated by LLS, use of mineral fertilizers has decreased substantially since 1991 in developed countries and, in North America, N fertilizer use increased by 2% and P fertilizer use decreased by 20% between 1980 and 2000.

Thirty-seven percent of U.S. pesticide use for agriculture and associated water pollution is attributed to livestock production by LLS. The report cites USDA–NASS (2001) and USDA–ERS (2002), stating that 3 tonnes of pesticides were applied per 1,000 ha of corn plus 1 tonne per 1,000 ha of soybeans in 2001, representing 37% of total agricultural use of herbicides and insecticides, which in turn is 70 to 80% (USDA–NASS 2001) of the United States' use of pesticides. The

37% figure was down from 47% in 1991 (FAO 2006a). The FAO estimate includes all U.S. corn and soybean production, of which less than half is used to support U.S. livestock production.

The nontherapeutic use of antibiotics in livestock production is another issue associated with livestock and water. Public health experts have advocated decreased nontherapeutic use of antibiotics in livestock production to limit antibiotic resistance (Becker 2010). A few studies suggest that water contaminated with animal manure could contribute to antibiotic resistance (Sapkota et al. 2007). Legislators have introduced bills in the U.S. Congress for the phased elimination of nontherapeutic use of some antibiotics used as animal growth promoters (Centner 2008a). Comparative studies in Europe analyzing resistant-bacteria levels after a ban of animal antibiotics show a significant decline in resistance (Emborg et al. 2003). Other studies find increased prevalence of pathogens in herds not treated with antibiotics (Gebreyes et al. 2008). Scientists continue to study whether or not this use of antibiotics may contribute to antibiotic resistance and whether or not it is a net benefit to human health.

Water pollution from livestock manure is an important issue in the United States and globally. Estimations by LLS are that in the United States in 1995, approximately 12% of the N applied to cropland and 100% of the N applied to pastureland came from manure, for a total of 22% of the estimated N applied to agricultural land. The report did not provide a similar analysis for P. The report states that the use of manure as a fertilizer should be encouraged in that mineral fertilizers are replaced and manure N is in an organic form that releases nitrate to the plant through time, potentially decreasing N losses. The report also stresses the need for careful management of manure to limit pollution in the form of N, P, metals such as copper and zinc, pathogens, organic material related to biochemical oxygen demand (BOD), and compounds that affect endocrine systems. The effects of manure on the environment and methods of managing manure to minimize environmental effects have been major focuses of research and education in the United States (LPELC 2011; Rice, Caldwell, and Humenik 2006).

United States water pollution issues related to livestock and poultry include concerns arising from the high concentrations of livestock and poultry production in some regions and the associated concentration of manure to be land applied (USDA–ERS 2001). Livestock production has been concentrating into fewer and larger farms, and the farms have concentrated in regions close to feed mills and processing facilities. Increased specialization of livestock and poultry farms also contributes to fewer farms owning sufficient crop acreage to receive the manure produced, so manure transport is required. United States issues related to manure management also include risk of environmental damage because of spills from manure storage facilities.

Osterberg and Wallinga (2004) are cited by LLS as an example of the frequency of manure spills. Liquid or slurry forms of manure are more prone to spills than dry forms of manure, although flooding can result in stored dry manure entering surface water as well. Storage of manure for up to six months or a year is necessary because best management practices (BMPs) include that manure may only be applied to cropland before crop planting or immediately after harvest or applied to land used for hay only while the crop is growing and when weather and soil conditions present minimum risk of runoff. This is in stark contrast to most large municipal waste treatment plants that discharge treated water continuously into streams and have only a few days of emergency storage capacity. In contrast to general concerns arising from regional concentrations of livestock and poultry and reports of manure spills, actual effects of livestock manure on water quality may vary widely across specific watersheds with differing topography, soils, land use and land cover, and climate. Therefore, an important research focus is pollutant movement through varying terrain such as *karst structures* (Hakk et al. 2009).

United States water pollution issues related to livestock production are components of broader water quality issues defined for various watersheds. Examples include the issue of hypoxia in the Gulf of Mexico (USEPA 2011a) and ongoing efforts to decrease pollution in the Chesapeake Bay. The watershed-wide effort to lower nutrient concentrations in surface water focuses attention on both *point sources* (PSs) and *nonpoint sources* (NPSs) of pollutants. Programs to decrease pollutant loading include TMDL, in which a cap on total loading is established and nutrient trading programs may be established to reallocate discharge rights within a watershed (Stephenson and Shabman 2011).

The comparison or substitution of PS and NPS discharges in affecting water quality is challenging. Sweeping assumptions were made by LLS about what fraction of nutrients in fertilizer applied to cropland or manure deposited on pasture (both NPSs) would reach surface water. True PS discharges are easily measured for nutrient/pollutant content at the outfall into the stream. The substitution of a predicted effect of NPS changes for a known effect of PS changes has been a challenge for basinwide nutrient trading programs. Modeling PS and NPS effects on water quality has been the focus of a major research effort in the United States (Munoz-Carpena et al. 2006). Considerable challenges remain regarding quantification of the contribution of specific NPSs to surface water pollution and, therefore, the benefit of various conservation measures at those sources (SWCS 2006; Tomer and Locke 2011).

U.S. Approaches to Addressing Issues

The preceding sections described status and trends in the poultry and livestock sectors and related land and water issues in the United States with comparisons to the global situation. Issues presented in preceding sections relate to livestock and poultry use of land and water, land degradation, and water pollution. The following sections present U.S. approaches to the issues raised.

Numerous strategies for decreased water use, mitigation and prevention of water pollution, decreased land degradation, and more efficient use of land are suggested in LLS. These strategy suggestions include

- improving irrigation efficiency;
- increasing water productivity;
- improving waste management;
- better diet formulation;
- use of enzymes;
- improved manure collection, storage, treatment, and utilization;
- improved land management;
- adapted grazing systems;
- range improvement;

- improved timing of grazing period;
- improved livestock distribution; and
- use of conservation buffers (FAO 2006a).

Food and Agriculture Organization references for these strategies are primarily U.S. sources, including LPES (2005) and Mosley and colleagues (1997).

The U.S. approach to addressing the land and water issues related to livestock production is an integration of issue-driven research; education and outreach; establishment of BMPs and professional standards; and policy development that includes expert support, financial incentives for change, and performance-based regulation. The outcomes of this approach generally have been steady increases in productivity of the livestock (and feed crops) sectors, corresponding reductions in resource use per unit of livestock and poultry product, and steady reductions in pollutants generated as issues are identified and addressed. Specific aspects of the U.S. approach and resulting outcomes are presented in the following sections.

U.S. Approaches to Land Use and Prevention of Land Degradation

United States approaches to land use and prevention of land degradation have emphasized the aforementioned integration of research, education and outreach, BMPs, policy development, and regulation. A variety of approaches have been applied across the diverse types of agricultural land in the United States. Rangeland in the western United States constitutes more than 40% of U.S. agricultural land (calculated from USDA–ERS 2007). The U.S. government owns approximately 50% of the land area in the 11 western conterminous states (plus 66% of Alaska) (U.S. Census Bureau 2005), including 106 million ha of rangeland in the eleven western conterminous states (CAST 1996; Skaggs 2008). Skaggs (2008) cites estimates that nearly half of U.S. rangeland is owned by either the United States or state or local governments.

In contrast to most U.S. agriculture, governments have a direct role in management of vast areas of rangelands through ownership and the issuance of leases for grazing and other uses (CAST 1996; Skaggs 2008). Management of public lands in western states has drawn considerable attention (Donahue 2005). Congress first regulated these lands under the Taylor Grazing Act of 1934, and subsequent legislation has attempted to balance and reconcile competing interests. Less than 3% of U.S. beef producers (2,000 ranchers) make use of the public lands (Nicoll 2006). Firms desiring to extract minerals and oil and gas pose additional perceived threats to the ecology of these lands (VanAsselt and Layke 2006). Controversy about the management of these lands for recreational, environmental, and commercial uses has challenged policymakers. Ranchers have sought to maintain low grazing fees to allow them to continue commercial grazing on those lands (CAST 1996). Others argue that regulatory provisions often favor grazing at the expense of alternative public benefits from rangeland restoration, water quality improvement, biological diversity, and/or habitat protection (Feller 2004). Environmental and recreational interest groups continue to challenge federal regulatory action as being contrary to statutory mandates (*Blancett v. U.S. BLM* 2006; *Oregon v. BLM* 2005).

Well-managed grazing can serve an important function in sustaining rangelands by controlling invasive species such as musk thistle, cheatgrass, broomweed, juniper, and mesquite (CAST 1996). Ongoing research at state universities and government agencies and establishment of grazing BMPs supported by government-employed extension educators contribute to improved productive use of rangelands, land conservation, and provision of ecological services (CAST 1996, 2002; Mosley et al. 1997; Skaggs 2008).

Use of other agricultural land for livestock production may be less managed directly by the U.S. government, although state governments impose site requirements for larger livestock operations (IDNR n.d.). Use of land for livestock production is also affected by nuisance law and *right-to-farm laws* imposed by state and local governments. Right-to-farm laws, also known as anti-nuisance legislation, have been enacted by all states and nine Canadian provinces to help agricultural producers and in many cases other deserving property owners (Kalmakoff 1999). The laws support the retention of farmland by precluding nuisance lawsuits against those agricultural property uses in existence before new nearby land uses (Centner 2000, 2005). Whereas the laws may adversely affect property rights of nearby property owners, legislatures felt this was needed to support agricultural land uses and business activities important to their economies. A few legislatures have enacted right-to-farm provisions against future nuisances. The denigration of neighboring property rights proffered by one of these provisions may be so great that it operates to effect a *regulatory taking* (*Bormann v. Board of Supervisors* 1998; Centner 2006). Clear allocation of property rights and responsibilities for land use has been an important characteristic of the development of agriculture and environmental protection in the United States.

Past and projected losses of agricultural land in the United States have been addressed by various programs and laws with mixed results. State governments attempted to support continued agricultural production through preferential agricultural assessment laws and other techniques (Kline and Wichelns 1996; Lockeretz 1989). Preferential agricultural assessment relies on governmental direction to value farmland at its (lower) use value rather than fair market value for the purposes of *ad valorem taxation*. Preferential assessment laws may simply slow the rate of farmland loss rather than provide permanent retention of land as undeveloped open space. Other laws use conservation easements, but lack of public access to protected lands may decrease public amenities (Johnston and Duke 2007). Agricultural conservation pensions and rights of first refusal have been proposed as more appropriate techniques to preserve farmland (Duke and Lynch 2007).

Use of cropland is not heavily regulated, but farmers are responsible for effects of some of their actions on neighboring property. Although cropland management is not the focus of this paper, it is important to note that sustained research, education, extension, and policy development have resulted in the dramatic reductions in soil erosion discussed earlier (USDA–NRCS 2010), whereas crop yields have increased dramatically (USDA–NASS 2011b).

U.S. Approaches to Water Use and Protection of Water Quality in Relation to Livestock Production

Water use is regulated to varying

degrees by states and water districts in the United States. Although direct use of water for livestock and poultry production and processing represents less than one percent of U.S. freshwater withdrawals (USGS 2009; calculations described previously), any use of water is contentious in some locations at some points in time (Newton et al. 2003). Water use has long been an issue in the arid western United States and is an ongoing issue for the livestock sector (Weinheimer et al. 2007). Access rights and cost of extraction (well construction and pumping) may limit the use of groundwater from diminishing resources such as the Ogalalla aquifer. Competing demands from a growing human population are likely to further decrease surface water availability for agriculture from resources such as the Colorado River (CAST 2009b). Water supply issues may become acute for irrigated agriculture in some parts of the western states and are emerging in areas of rapidly growing human population in the eastern states. Sustained research and extension programs have contributed to more efficient use of water in livestock and poultry operations and in irrigated agriculture (Gollehon and Quinby 2006).

The United States' approaches to decreasing water pollution associated with livestock and poultry production primarily focus on management of manure and land application. Cropland used to produce livestock feed was the largest source of some pollutants associated with livestock production (N, P, pesticides, sediments), as estimated by LLS. The report stated that U.S. use of N and P fertilizer and the use of pesticides have been declining and that soil erosion has declined dramatically. Improved efficiency of input use and soil conservation have occurred as yields increased dramatically because of a range of successful research and extension programs, both public and private. Among the innovations are genetic improvement of the crops, development of more effective and less toxic pesticides, no-tillage and low-tillage cropping systems, and precision agriculture.

The conservation compliance provisions of the Food Security Act of 1985 were instrumental in decreasing erosion. One way was through the establishment of the Conservation Reserve Program (CRP) (Uri 2001). Under the CRP, farmers can bid to have portions of their land leased for 10 to 15 years to the U.S. government for approved conservation uses in exchange for payments. In 2011, 10.48 million ha were enrolled in the CRP (USDA–FSA 2011). A critical realization underlying the success of the CRP was that a very high proportion of erosion was occurring on a small proportion of land.

The United States' approaches to decreasing water pollution from manure management and pasture management include the previously described integrated approach with a substantial regulatory component. Modifications to the Clean Water Act in 1972 established effluent limitations for numerous industries, including concentrated animal feeding operations (CAFOs), to protect the chemical, physical, and biological integrity of surface waters within the country. United States and state regulatory, research, extension, and educational programs were developed and continue to be improved to minimize discharges of pollutants from livestock operations to surface waters. The United States uses a federal permitting system, with delegation of authority to states, to safeguard water resources. Legal challenges to the Environmental Protection Agency (EPA) and state governments have resulted in orders to take additional action to decrease pollution and have struck down terms of proposed rules in some instances.

The discharge of wastewater and waterborne pollutants from processing and from large CAFOs is governed by regulations promulgated under the Clean Water Act (USC 2008; USCFR 2008; USEPA 2008). The act adopts the basic rule that unpermitted discharges of pollutants into navigable waters are not allowed. A permitting system authorizes discharges of limited amounts of pollutants from PSs under the National Pollutant Discharge Elimination System (NPDES) program. Under this program, most states have the authority to issue NPDES permits. For livestock and poultry farms not defined as CAFOs, PS regulations require adoption of BMPs to qualify for storm water exemptions.

Best management practices are generally based on research and extension program experience and on related standards published by the USDA–NRCS and the American Society of Agricultural and Biological Engineers (ASABE). Research, demonstration, and evaluations of BMPs and similar practices are conducted by the USDA–Agricultural Research Service and the national network of land-grant universities linked through the USDA–National Institute of Food and Agriculture (USDA–NIFA[3]). Examples of research and extension topics include

- design of animal housing facilities to simplify capture and removal of manure;
- design of manure storage and manure treatment facilities to limit pollution and nuisance;
- design and operation of land application systems for manure and treatment effluents to enhance plant production and limit pollution; and
- management of livestock on pastures to limit pollution, conserve pasture plant and soil health, and enhance livestock production (Bull et al. 2008; Mosley et al. 1997; Rice, Caldwell, and Humenik 2006).

Resulting BMPs and professional standards are maintained by the USDA–NRCS (USDA–NRCS 2011), state extension services, and professional organizations such as the ASABE.

Research and extension work on pollution prevention is inextricably linked to research and extension programs on livestock and poultry production. For example, recent work has enabled the addition of the enzyme *phytase* to the feed of monogastric animals (poultry and pigs) to allow them to use the P contained in grain as phytate (Angel et al. 2006). This innovation has decreased the quantity of supplemental P required in the animals' diets, decreased the amount of P excreted by the animals, and increased the proportion of soluble P in the excreta. Complementary work evaluated the effects on P loss from fields of the increased proportion of soluble P (Penn et al. 2004).

A large body of work supports BMPs in land application of manure (Bull et al. 2008; Mosley et al. 1997; Rice, Caldwell, and Humenik 2006). Criteria for land application evolve as pollution concerns change through time. A long-standing criterion limits manure application rates to meet the N needs of the growing crops with plant available N. Concern over P in surface water led to the more recent criterion of limiting P accumulation in soils receiving manure. That criterion

[3] NIFA was previously the Cooperative State Research, Education, and Extension Service (CSREES).

spurred development of indexes of P concentration and P loss assessment tools. Livestock and Poultry Environmental Stewardship programs describe nutrient balance criteria for livestock farms (LPES 2010).

The regulatory dimension of the U.S. approach to limiting water pollution from livestock and poultry production is centered on the national NPDES program. The NPDES permitting provisions governing CAFOs prohibit any discharges from their animal confinement area, manure storage area, raw-materials storage area, and waste containment areas except under extreme storm conditions, usually defined as the 25-year, 24-hour storm event. The remaining potential source of water pollutants from CAFOs arises from the application of manure to land. The federal CAFO regulations require application of manure in accordance with site-specific nutrient management practices to ensure appropriate agricultural use of the nutrients. A nutrient management plan (NMP) is used to meet this requirement. The NMP must include application rates for manure applied to land under the ownership or operational control of the CAFO to minimize P and N transport from the field to surface waters in compliance with the technical standards for nutrient management. The land application of manure by CAFOs with approved NPDES permits may result in allowed discharges that qualify under the agricultural storm water discharge exemption. The federal CAFO regulations define agricultural storm water discharges to include any manure from land areas under the control of a CAFO where the manure has otherwise been applied in accordance with site-specific nutrient management practices that ensure appropriate agricultural use of the nutrients (USCFR 2008).

Controversy has existed as to requirements involving regulatory review of NMPs. Administrative burdens of approving individual permits led the U.S. EPA to adopt regulations that allow for general permits that cover multiple facilities in a geographical area. Many states adopted general permits for CAFOs involving a formal acceptance of permitting terms elaborated in an approved general permit that allows dischargers to be authorized to discharge through a "notice of intent." Interested parties sought the requirement that states' NMPs and notices of intent should be made available to the public (Centner 2008b; *Sierra Club v. Department of Environmental Quality* 2008). Some states adopted permitting requirements considerably more stringent than those specified in the Clean Water Act.

On October 21, 2008, the U.S. EPA issued the revised NPDES permit and *effluent limitations guideline* (ELG) regulations for CAFOs in response to the *Waterkeeper* decision (USEPA 2008). The new CAFO regulations establish various regulatory permitting and reporting requirements for CAFOs, including development and implementation of NMPs and other BMPs. One of the more important findings in the *Waterkeeper* court decision pertained to the requirement to apply for a CAFO NPDES permit; such a requirement could not be based on the potential to discharge and must rather be based on an actual discharge. This ruling was important for dry litter poultry operations, as an actual discharge from these operations is unlikely because both the animal and stored waste materials are not typically exposed to rainfall. The court also confirmed that precipitation-related discharges from agricultural areas where animal wastes are applied in a manner for "appropriate agricultural utilization" qualify as "agricultural storm water" and are excluded from regulation as a PS discharge (i.e., these areas are exempt from regulatory permitting) (USEPA 2007).

Information on the specific animal feeding operations (AFOs) regulated under the new CAFO rule can be found on the U.S. EPA website (USEPA 2011b). More information on the CAFO rule can also be found on the U.S. EPA site (USEPA–NPDES 2011).

Meat, egg, and milk product and by-product processing plants are generally considered manufacturing operations, and wastewater discharge from these facilities is typically regulated under the Clean Water Act and by various federal, state, and local regulatory programs related to water pollution control. Regulatory permits are generally required for facilities that discharge to the following:

- Surface water—regulated under federal and/or state NPDES permitting programs
- Groundwater—regulated under federal and/or state NPDES, Land Application System, Underground Injection Control, and other permitting programs
- Publicly owned treatment works (POTWs)—regulated under federal, state, and/or local indirect discharge programs

In 2002 the U.S. EPA promulgated revised federal ELGs for the meat and poultry products (MPP) PS category, which established minimum federal standards for treatment of wastewater from meat and poultry processing plants, further processing plants, and rendering plants that discharge to surface water. Wastewater discharges from many facilities subject to these regulations are commonly treated to a much higher degree than is required under the new MPP ELGs because of more stringent discharge permit requirements.

Storm water discharges from meat, poultry, egg, and milk products and by-products processing plants (i.e., manufacturing operations) and ancillary facilities (i.e., feed mills, cold storage facilities, further processing plants, etc.) are also generally regulated under federal and state NPDES permitting programs for storm water discharges associated with industrial activities. These programs require development and implementation of site-specific storm water pollution prevention plans, routine sampling of storm water discharges, regulatory reporting and compliance with applicable discharge limitations, and other conditions.

Because of the high levels of pollutants in wastewater from processing plants, pretreatment is commonly required before the wastewater arrives at a municipal treatment facility, called a POTW. Under federal regulations, processing facilities are prohibited from introducing pollutants that "pass through" or "interfere" with the operation of the POTW (USCFR 2008). Pollutants that "pass through" a POTW would cause a violation of the POTW's NPDES permit. Pollutants that "interfere" with a POTW's operations would inhibit or disrupt a process or operation to cause a violation of the POTW's permit. The federal regulations set forth limitations for BOD, total suspended solids, oil and gas, pH, fecal coliform, ammonia (NH_3) as N, total N, total P, and chemical oxygen demand in wastewater discharges from processing facilities. Given these pretreatment regulations, wastewater from meat processing facilities does not impose excessive costs on POTWs. Most PS dischargers pose a risk of spills of untreated or undertreated wastewater during floods or because of failure of equipment, transport systems, or containment facilities. State enforcement agencies typically maintain public records of such spills.

Although significant progress has been made in improving the physical, chemical, and biological integrity of the nation's waters, much more work is needed to restore and protect those waters (USEPA–OW 2002a).

Productivity Growth and "Intensification" of U.S. Livestock and Crop Production

As shown earlier, significant improvements in U.S. yields (product per unit inventory) of animal products are evident in Table 1. Gains in U.S. crop yields are evident in USDA data: average U.S. corn yields exceeded 6.277 tonnes per ha for the first time in 1978 and exceeded 9.415 tonnes per ha for the first time in 2004 (USDA–NASS 2011b) (see Figure 1). The 2009 average U.S. corn yield was estimated at 10.294 tonnes per ha (WAOB 2010), and current genetic developments promise further rapid gains in yield and declines in N and water needed per tonne produced. Technological improvement, increased adoption of existing technology, and improved management and organization of agricultural and food production systems coincided with improved efficiency and decreased costs of animal products (Key and McBride 2007).

Resource requirements per unit of animal product have fallen significantly over time. For example, mass of feed consumed per mass of egg produced fell by 32% between 1960 and 2001 (Arthur and Albers 2003). Fix and colleagues (2010) found a 45% improvement in the ratio of lean gain to feed consumed when comparing 2005 genetic type pigs on a 2005 diet to 1980 type pigs on a 1980 diet. Havenstein, Ferket, and Qureshi (2003a) found that 2001 genetic type broiler chickens on a 2001 diet achieved a 37 to 66% reduction in the mass of feed consumed per mass of broiler produced when compared to 1957 type birds on a 1957 diet. The 37% improvement occurred when the 1957 bird was lighter and older than the 2001 bird, whereas the 66% reduction occurred when the 1957 bird was of equal weight and much older than the 2001 bird. Nitrogen fertilizer applied per ha of corn in the United States rose from 143.5 kg in 1978 to 156.9 kg in 2010 (an increase of 9%) (USDA–ERS 2011), whereas corn yields increased by 51% (USDA–NASS 2011b). These data indicate that the N fertilizer applied per tonne of corn harvested fell by 27.7% over the 32-year period. Similarly, P fertilizer applied per ha of corn fell from 76.2 kg in 1978 to 67.3 kg in 2010: -13% per ha and -41% per tonne harvested (USDA–ERS 2011).

The combined effects of crop yield gains and animal productivity gains are examined in Table 5 and Figure 2. Methods for calculating the estimated changes over time in animal productivity per ha of land (Table 5) are reported in Appendix A. The numbers in Table 5 should be considered index values[4] based on the reported data because some minor types of livestock are excluded from the calculations used to allocate agricultural land area to the various food animal species.

The estimates in Table 5 illustrate reductions of 42 to 66% over 42 years in the agricultural land area needed to produce feed for a unit of meat, milk, or eggs in North America. The U.S. chicken meat industry required about a third of the agricultural land in 2003 that it did in 1961 to produce a unit of product. In 1955 it took 70 days to produce a 1.4-kg

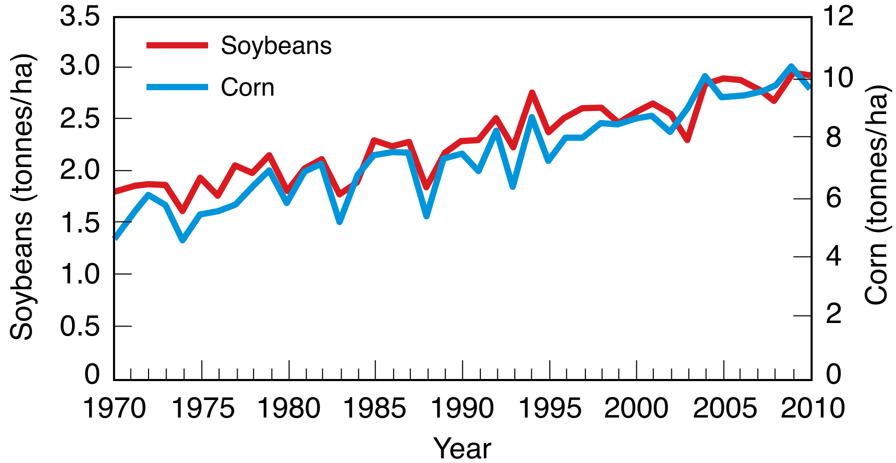

Figure 1. United States yields of corn and soybeans (tonnes/ha) (USDA–NASS 2011b).

[4] One of the factors that has been excluded and that makes the required acreages an index rather than a hard number is that not all animals have been included. Excluded animals include equines, sheep and goats, ducks, fish, and others. Equines may be an especially important factor, as there are limited data on the total grazing land devoted to horses and total grains fed to horses. Horses and mules are important historically as the support of draft animals was one of the largest uses of feed (Jennings 1943) before the almost universal adoption of machine power. The transition to machine power released large areas of land that could then be devoted to the support of food-producing animals. This transition occurred before the period in Table 5. There were four million horses in the United States in 2007 (USDA–NASS 2007).

Table 5. Change in the livestock productivity of North American agricultural land 1961–2003

Kilograms/Hectare Index	1961	1970	1980	1990	2000	2003	% change 1961–2003
Chicken meat, kg/ha	564	751	1,101	1,458	1,817	1,682	198
Pig meat (+lard), kg/ha	307	387	536	636	735	746	143
Turkey meat, kg/ha	400	447	646	905	1,286	1,568	291
Hen eggs (in shell), kg/ha	587	750	1,015	1,269	1,530	1,599	173
Cattle meat, kg/ha	30	39	41	43	50	52	72
Cow milk (whole, fresh), kg/ha	542	669	775	925	1,112	1,228	126

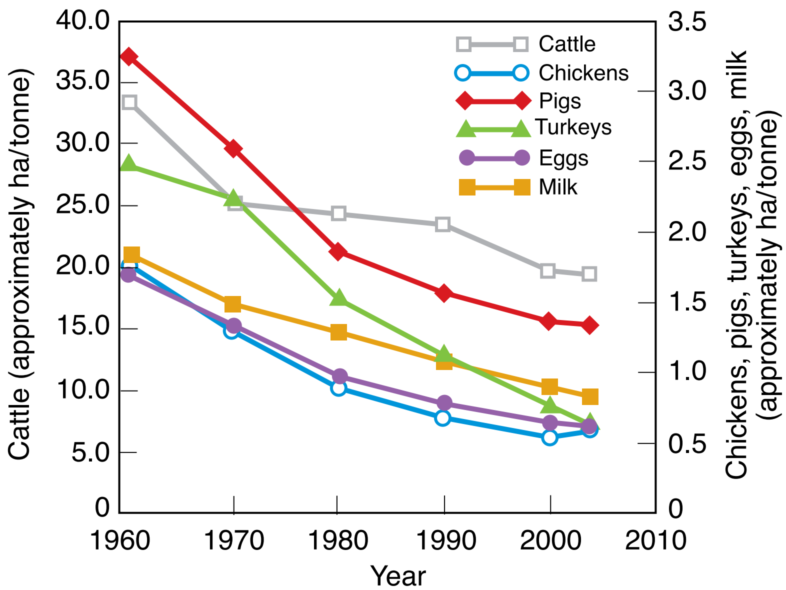

Figure 2. Index of U.S. land required per unit produced (approximately ha/tonne) (Note: Calculated from FAO and USDA data. Cattle land includes range and is plotted on left axis. All others are plotted on right axis.)

chicken that required 2.85 kg of feed per kg of gain, whereas in 2006 it took 49 days to produce a 2.45-kg chicken that required 1.95 kg of feed per kg of gain (MacDonald and McBride 2009). Turkey meat production quadrupled during the period indicated in Table 5, whereas the estimated acreage required to feed all turkeys increased only slightly during this time. Output of eggs has essentially doubled during the past 50 years, but the total land area needed to produce the eggs declined by almost half. The production per ha index for pork is almost 2.5 times greater than 50 years ago, whereas the production of pig meat is approximately 1.75 times greater; so the index of total land required for North American pork production in 2003 was only 70% of that required in the early 1960s.

The production of cattle meat (beef) in North America has also increased more than 175% during the past 50 years, whereas the cattle population (other than for milk) has increased only slightly more than 20%. This production requires only about 5% more land than the earlier land index[5]. In 1983, milk cows consumed 1.01 kg of feed (corn equivalent) for every kg of milk produced (USDA–NASS 1994), whereas in 2009 this number was 0.60 kg (USDA–NASS 2010). The dairy industry supplies approximately 16% of U.S. beef production. The number of milk cows in North America is less than 60% of the number 50 years ago, but milk production is more than 50% greater (Table 5). The total land area index for milk production in the early 2000s was slightly less than 60% of that required in the early 1960s. The increased production coupled with less acreage resulted in more than a 150% increase in the per ha index for milk production.

Total factor productivity (TFP) is an index measure of productivity through which quantity produced is compared to a weighted sum of quantities of various inputs consumed. Relative prices of inputs are used as weights to sum the input quantities. Key, McBride, and Mosheim (2008) found TFP increased at an average rate of 6.3% annually between 1992 and 2004 in the U.S. swine sector. They decomposed the TFP growth and found that the total included 3.0% annual technical progress and 3.4% annual gain in scale efficiency. These growth rates were estimated with data representing a period of rapid transition in the U.S. swine sector. Perrin and Zering (1993) estimated that TFP for the U.S. broiler sector increased by 36.1% between 1967 and 1990. This analysis suggests that 36.1% more broiler meat was produced from the same quantity of inputs in 1990 compared to 1967. Note that if a similar rate of growth in TFP could be maintained from now through 2050, then 68% more broiler meat could be produced without any increase in the quantity of inputs consumed.

Genetic and dietary improvements contributed significantly to the gains in TFP. Feed conversion (FC) is the quantity of feed required to produce one unit of product in which case product can be eggs, meat, wool, or milk. As FC improves, less feed is required per unit output, less farmland is required to grow feed inputs, and fewer nutrients are excreted in manure.

Improvements in animal productivity not only decrease the amount of land required but can directly decrease the quantity of nutrients excreted. Logically, if a certain quantity of nutrients (a) is retained in a unit mass of product and the quantity of nutrients consumed to produce that unit of product falls from (b) to (c, which is < b), then the quantity of nutrients returned to the environment as waste is reduced from (b-a) to (c-a). Furthermore, the proportional reduction in waste is greater than the proportional reduction in feed intake ([c-a]/[b-a]<c/b). Van Heugten (2009) calculated a 23% reduction in nutrient excretion from improved growth performance of 2005 genetic type pigs compared to 1980 genetic type pigs. Van Heugten (2009) also wrote that improved nutrient use by the modern pigs on a modern diet would result in further reductions of excreted nutrients.

Decreased excretion of nutrients implies that less land area is required to receive the manure as a crop fertilizer and, therefore, the loss of nutrients to groundwater and surface water is decreased, all else held constant. A similar analysis can be used to demonstrate that the nutrients lost from mineral fertilizers applied to feed crops fall on a per tonne harvested basis and in some instances on a per ha basis as the application rate per tonne removed falls. Improved efficiency of animal and crop systems is demonstrated to be a very important approach to conserving resources and minimizing environmental effects, particularly as the demand for food increases.

In summary, technological change, increased adoption of existing technology, and improved management and organization of agricultural and food production systems are important methods of lowering resource use and decreasing pollution from animal production. Genetic changes, along with changes in

[5] Although beef production uses more land area than any of the animal commodities, most of this area is grazing land, which is not suitable for production of other foods or for feed use by pigs or poultry.

Textbox 1. Disaggregating Gains in Broiler Productivity.

Quantitative genetics have been used in poultry breeding to develop broiler lines that have increased growth rate and improved feed conversion (FC). Optimized broiler production based on the improved growth traits results in decreased time necessary for animals to reach heavier market weight.

The Athens-Canadian Randombred Control (ACRBC) was established in 1957 by scientists at Agriculture Canada and has been maintained. The production traits of the ACRBC strain were evaluated in 1991 and determined to be unchanged from 1957. This allowed comparison between old genetic lines (1957) and new genetic lines (2001) to evaluate FC and growth rate (Havenstein, Ferket, and Qureshi 2003a), carcass composition and yield (Havenstein, Ferket, and Qureshi 2003b), and immune response (Cheema, Qureshi, and Havenstein 2003). Animals received appropriate feeding regimens, and numerous production traits were studied. The Ross 308 broiler (a current genetic line in 2001) on the 2001 feed was estimated to have reached 1,815 grams BW (body weight) at 32 d (days) of age with an FC of 1.47, whereas the ACRBC on the 1957 feed would not have reached that BW until 101 d of age with an FC of 4.42. The decreased market age and improved FC would require far less feed input (and associated land to grow the feed) to produce a kilogram of meat. The authors attributed 85% of the growth improvement to genetics and 15% to nutrition (Havenstein, Ferket, and Qureshi 2003a). Comparisons of carcass weights of the Ross 308 on the 2001 diet versus the ACRBC on the 1957 diet showed they were 6.0, 5.9, 5.2, and 4.6 times heavier than the ACRBC at 43, 57, 71, and 85 d of age, respectively.

diet, housing, veterinary medical care, and management, resulted in increased efficiency of production of meat, milk, and eggs, requiring less feed per unit of product (Arthur and Albers 2003; Fix et al. 2010; Havenstein, Ferket, and Qureshi 2003a, 2003b). Changes in the structure of several of the animal sectors have accompanied adoption of improved technology and accelerated the pace of improvement in genetic stocks and other aspects of production technology and management (Key and McBride 2007; Key, McBride, and Mosheim 2008). Dramatic productivity gains are attributable to a very successful sustained research, development, and education effort by U.S. land-grant universities and U.S. and state Departments of Agriculture in collaboration with a vigorous and diverse private sector (Alston, Beddow, and Pardey 2009; Bergeron 2010; Fix 2007).

Challenges and Emerging Approaches to Prevention of Pollution from Livestock

A range of research challenges remains for U.S. animal agriculture in relation to use and effects on land and water resources. New approaches are emerging to manage the effects of animal agriculture on land and water resources.

Producer profit is an enduring motive for modifying animal production systems. Impetus for change also arises from those seeking decreased environmental emissions, stronger animal welfare standards, and increased potential profit from conserving and using crop nutrients and energy in manure. Increased profit arises from reductions in the value of inputs used per unit value of product and may include changes to genetics, diet, housing, feeding, watering, ventilation, veterinary medical care, waste management, and the management and organization of animal production systems. A number of research challenges relate to the management of exhaust air from animal housing facilities and feedlots as well as the management of mortality and manure at the farms and the application of manure to land to fertilize crops.

Recent sharp increases in the prices and global demand for N and P fertilizers and energy have increased the potential value of nutrients and energy in manure. Changes in animal diets (e.g., the use of distillers grains) and the use of additives (e.g., phytase) (Angel et al. 2006) occur regularly and affect the quantity and composition of manure; the subsequent chemical and biological transformations of manure; and, therefore, the air emissions, losses to water, pathogen concentrations, and performance as a crop fertilizer. Ongoing research is required to evaluate effects of changes in animal production systems on resource use and profits, environmental emissions, use of manure as fertilizer, and optimal design of facilities and policy.

An emerging approach to manure management is the use of markets for manure. Traditionally in the United States, manure has been applied on land owned by the same farm that owned the livestock. As farms have increased in size and specialization, manure is frequently applied to land on farms other than those housing the livestock. Manure is commonly transported from areas with excess manure nutrients to areas where these nutrients are deficient. Several states have established financial and other assistance programs for the relocation of animal manure to areas deficient in nutrients (Oklahoma State University Extension 2011). Commercial fertilizer is a nascent market for manure. For example, the Perdue AgriRecycle, LLC, plant located in Delaware accepts poultry litter from farms in the Delmarva area and pelletizes this material to produce bulk fertilizer products as well as specialty fertilizer products for use in turf and horticultural industries.

Renewable energy is an emerging market for manure and litter. Fibrominn, a subsidiary of Fibrowatt, LLC, opened a power production facility in Minnesota that uses turkey litter and other agricultural biomass as renewable fuel. Anaerobic digestion of manure has been used to produce biogas for centuries. Microbial digestion of organic carbon under anaerobic conditions yields a mix of gases (referred to as biogas) including 55 to 70% methane with the balance being primarily carbon dioxide and trace amounts of hydrogen sulfide and NH_3. Recent interest in renewable energy and greenhouse gas mitigation has increased interest, incentives, and investment in anaerobic digester systems on U.S. and Canadian livestock farms. The biogas can be burned for heating or burned in a generator set to produce electricity. Biogas also may be scrubbed and pressurized for injection into natural gas lines or for use in vehicles that run on compressed gas. The AgSTAR program (USEPA 2011c) has supported development and installation of biogas technologies for decades. Pathogen concentration and total solids are usually decreased in anaerobic systems (Bull et al. 2008; Rice, Caldwell, and Humenik 2006), whereas other nutrients (P and salts) remain in the digester effluent for use as fertilizer.

Manure as excreted is between 75 and 90% water, depending on the species of animal. The addition of bedding material and evaporation of water during storage may produce a more concentrated form of manure with "as removed" moisture content as low as 30% for turkey litter. The use of anaerobic treatment systems to digest solids, the settling of solids to the bottom of storage facilities, and the accumulation of rainwater in open storage facilities may increase water content to 99.6% of the "as removed" mass in swine lagoon surface liquid (ASABE 2005). The costs of storing, transporting, and land applying manure and manure treatment products are highly conditional on their form. Those costs, as a proportion of the fertilizer or energy value of manure constituents, are highly conditional on the composition of the manure or treatment product. A remaining challenge is to improve efficiency of systems to separate solids and nutrients from water in manure to allow more efficient storage, handling, transport, and use of manure components. Other market approaches to livestock, land, and water issues include basinwide markets for reductions in nutrient discharges associated with TMDL programs.

A remaining research challenge in the United States is the lack of specific information about the effect of land application of manure on water quality. Numerous studies have assessed water quality in the United States, yet many questions remain regarding the specific sources and causes of reported water quality impairment conditions in a number of water bodies across the country. Modifications to the Clean Water Act in 1972 decreased allowable discharges of pollutants to U.S. waters. Public and private investments were made to decrease discharges of pollutants from PSs. By 1987, it was argued that the primary concerns related to pollutants entering waters of the United States from PSs had been addressed, leaving NPS pollution, which originates from many diffuse sources, as a major concern. The U.S. EPA stated that "pollution from urban and agricultural land that is transported by precipitation and runoff (called nonpoint source or NPS pollution) is the leading source of pollution" in the United States (USEPA–OW 2002b).

The lack of information about sources of nutrients found in streams, rivers, and lakes is a persistent problem in efforts to improve water quality in the United States. The National Water Quality Inventory reports rely on state reports of the sources of pollutants that impair water quality. The 2004 report (USEPA–OW 2009) says that state data should not be used for comparisons between states or within states over time because the information in state reports is highly variable from state to state and from one reporting period to the next (USGS 2010). For example, the percentage of assessed lake hectares reported as "not clean enough to support designated uses" jumped from 47% in 2002 to 64% in 2004, based solely on results of new monitoring for mercury in fish and water in Minnesota.

Numerous studies related to land application of manure and surface water effects have measured concentrations and flows at the field edge. Studies have demonstrated the benefits of vegetative buffers in decreasing the flow of contaminants into surface water (Zhang et al. 2010). Much of the watershed-scale information about contaminant movement from livestock operations to surface water, however, is based on predictive models rather than direct measurement. This problem was addressed by a Blue Ribbon Panel of the Soil and Water Conservation Society (SWCS) evaluating the Conservation Effects Assessment Program. Their report to the USDA (SWCS 2006) included the following statement: "The most important and troubling missing piece is the absence of plans for on-the-ground monitoring of change in the environmental indicators and outcomes conservation programs and activities are intended to improve."

Although the USGS and other agencies monitor stream water quality, their ability to monitor effects of sources that do not discharge directly into streams is minimal. The SWCS report recommended that 1% of conservation funding for each program be allocated to monitoring the effects of that program. Ongoing research is needed to monitor changes in water quality through time and across watersheds as land use changes (including land application of manure) within watersheds (see also Tomer and Locke 2011).

The U.S. regulatory and management approaches to controlling effects of livestock on the environment are constantly evolving with livestock production systems. When U.S. livestock sectors consisted of more than a million relatively small operations, the cost of regulatory oversight was daunting, particularly in comparison to the potential environmental damage that any single operation might cause. The rational approach for managing effects from numerous highly dispersed livestock operations is to rely on education and implementation of BMPs and complaint-driven enforcement.

As larger livestock operations have emerged and as social demands for environmental protection have escalated, increased regulation and permitting has been enacted. The Clean Water Act of 1972 introduced permitting requirements for the largest AFOs, which were subject to more stringent regulatory conditions than smaller concerns. Operations using liquid manure handling systems were viewed as a greater risk to water quality and so are subjected to more stringent requirements than dry manure handling operations. The U.S. regulatory approach sought to eliminate direct discharges from livestock operations except under relatively uncommon storm conditions. For example, the 25-year 24-hour storm was used as an engineering design criterion and a BMP threshold.

Incentives to adopt BMPs are important elements of policy. The USDA–NRCS administers several programs to encourage environmentally sound behavior by livestock producers and other farmers. Examples include the following USDA–NRCS programs:

- Conservation Compliance (i.e., "Swampbuster" and "Sodbuster")
- Conservation Reserve Program
- Environmental Quality Incentives Program

As livestock sectors shift to fewer operations that are larger in size, existing CAFO regulations affect a greater proportion of overall manure production. Beginning in the 1990s, rules and regulations governing livestock operations under the Clean Water Act were revised, spurred in part by assessments that NPSs were major sources of pollution. The ongoing shift to large-scale dairy farms and the rapid shift to large-scale pig farms beginning around 1988 also changed expectations for the regulatory system. Revised regulations have resulted in greater safety margins in manure management system design, greater expectations and oversight of the management of manure nutrients applied to land, and integration of multiple environmental and public health concerns into the design of manure handling systems (IDNR n.d.; USDA–NRCS 2011; USEPA 2008). Discourse during the revision of rules under the Clean Water Act and subsequent review of pertinent federal air quality regulations revealed that an integrated approach to managing environmental effects of livestock operations is emerging (NRC 2003).

New approaches to designing and managing livestock operations are emerging in the United States with evolving livestock sector structure and direct communication among environmental and public health advocates, regulators and lawmakers, researchers and educators, and livestock producers. Research and design of livestock production systems in the United States are shifting toward life cycle approaches to analysis of resource use and emissions. Standards for life cycle analysis (LCA) are published by the International Standards Organization (ISO 14040) and by the U.S. LCA database at the National Renewable Energy Laboratory. Livestock organizations in the United States initiated LCAs of their sectors (e.g., dairy, eggs, and swine).

The LCA approach is being accompanied by "process-based modeling" of livestock production activities. Process-based modeling incorporates research-based information on specific biological, chemical, physical, and energy processes that occur in livestock production into a broader model of resource use, outputs produced, and emissions to the environment. Process-based modeling allows checks and balances on observed partial data and allows more credible interpolative and extrapolative predictions of variables of interest. Life cycle analysis and process-based modeling are information-intensive activities enabled by sustained investment in measurement and modeling of specific processes on livestock and poultry farms.

An example of a cooperative research program to inform policy is the U.S. EPA consent agreement with several national livestock and poultry organizations to conduct the National Air Emissions Monitoring Study (NAEMS) at an array of AFOs to measure concentrations of air pollutants of concern and calculate emission rates. Participating entities include representative dairy, swine, and poultry farms. The data and information acquired in the NAEMS program will be used to develop databases that could form the basis for future air permitting and/or emission control programs for applicable AFOs as well as better prediction of air emissions from a wide variety of livestock production operations.

Systems analysis of sustainable livestock production methods is another emerging research and education approach. The USDA–NIFA Research Committee S-1032 is an example of collaboration among land-grant university faculty, USDA researchers, and others to analyze and model the complex systems involved in livestock production. Understanding the interaction of animals, feed, housing, manure management systems, water, energy, and weather as well as pathological, environmental, and other variables in a commercial production setting is the challenge being addressed by the S-1032 group. Another example of systems-oriented research is the work conducted at North Carolina State University under an agreement among the Attorney General of North Carolina, Smithfield Foods, and others (NCSU n.d.). This work included three linked analyses of a number of alternative manure management systems for swine farms in North Carolina: technical performance of the manure management system, environmental emissions from the system, and economic implications of the system.

Innovations are emerging in the management of livestock operations. Various livestock production and processing facilities and associated companies have implemented comprehensive environmental management systems (EMSs). An EMS establishes processes and practices that enable an organization to decrease environmental impacts and increase operating efficiency. International Standards Organization 14000 provides guidelines for third-party auditing and certification of EMS programs. Smithfield Foods, Inc., secured ISO 14000 certification of their EMS program for the company, including its owned AFOs.

The chicken industry implemented a voluntary program for administering nutrient management plans at chicken grower operations. In 2002 the National Chicken Council (NCC) reported to the U.S. EPA that 75% of chicken growers had NMPs in place; a representative with the NCC recently reported that the current grower participation in this program is approaching 100%. Agricultural extension programs across the United States have been assisting livestock producers in developing NMPs (LPELC 2008).

Livestock product processors are adopting advanced management programs to minimize environmental effects. Examples include water reuse under USDA–FSIS regulations that allow reuse of refurbished water in various operations at meat and poultry processing plants. For example, the Smithfield Packing Company's plant in Tar Heel, North Carolina, is currently reusing 25 to 30% of the water it employs. Several meat processing facilities have joined the U.S. EPA's National Environmental Performance Track Program, which drives environmental excellence by encouraging facilities with strong environmental records to go above and beyond their minimum legal requirements.

Some meat, table egg, and milk products production companies have adopted environmental sustainability programs and annual environmental reporting. A number of these companies issue annual reports documenting their efforts related to sustainability, regulatory compliance, resource use, water use, and projects implemented to decrease their environmental and carbon footprints.

Livestock sector environmental awards programs are another example of emerging approaches. For example, the U.S. Poultry and Egg Association established the Clean Water Award to recognize outstanding wastewater treatment facilities operated by poultry companies and the Family Farm Environmental Excellence Award to recognize exemplary environmental stewardship by family farmers engaged in poultry and egg production. The American Meat Institute instituted the MAPS 4-Tier Recognition Awards to recognize member company dedication to continuous environmental improvement through development and implementation of EMSs.

Stakeholder-based approaches to policy development are emerging in animal production and land and water resources policy development in the United States. Two criteria emerge. First, does the new equilibrium or status created by the proposed policy change result in an increased overall welfare of society? In other words, does it make at least one person better off without making someone worse off? Second, does the transition from the current status to the status created by the policy change result in no individual or community being made worse off? This criterion generally implies that those entities bearing the costs of transition are compensated by those entities receiving the benefits of transition. Certainly, these criteria are not adopted in law nor even adhered to uniformly. Nonetheless, the result of political and legal contests along with increased direct communication among stakeholders and integration with issue-oriented research supports more consensus-like policy development (NRC 2003; Zering 2010).

The primary challenge facing U.S. and global animal production systems is to sustain the rate of improvement in plant and animal productivity and in environmental protection observed during the past several decades. Pingali and Heisey (1999) are cited in LLS stating that the productivity of wheat and rice in lowland Asia has been growing at a very slow pace since 1991. Alston, Beddow, and Pardey (2009) highlighted strong positive rates of return on past investments in agricultural research, but they noted declining investment and declining rates of productivity gains in recent years. This Issue Paper illustrates that past investments in an integrated program of research, extension, education, and policy development contributed to significant declines both in the quantity of resources used per unit of production and in pollution per unit of production. How will this effort and the resulting gains be sustained as global demand for animal products doubles during the next few decades?

In summary, new approaches are emerging in research and development, education, management, and regulation and policy pertaining to livestock operations in the United States. Direct communication among interested parties and shared understanding of the issues, data, and uncertainties are shaping a more collaborative, research-based, comprehensive approach to minimizing the effects of livestock production on limited resources, environmental attributes, and public health. Sustaining historical rates of improvement in agricultural productivity, environmental protection, and resource conservation is a major challenge.

Summary

Livestock production provides an abundant, diverse, and relatively inexpensive supply of high-quality protein and other nutrients to the diets of consumers in the United States and other countries. Livestock products generate almost half of the cash receipts of U.S. agriculture and constitute a critical component of the food supply for U.S. consumers and a significant component of net exports. Livestock, primarily cattle, graze the 26% of U.S. land classified as range, pasture, and grassland—land that is generally not suitable for crop production. Livestock, including poultry, also consume feed grains such as corn and oilseed meal such as soybean meal.

Less than 20% of U.S. land area is classified as cropland. Less than 20% of U.S. cropland is planted to corn, and about 36% of corn grain was used for domestic livestock feed in 2009. Similarly, approximately 17.5% of U.S. cropland was planted to soybeans, and soybean meal from about 36% of soybean production was fed to livestock in the United States in 2009. Residuals from corn used for ethanol production (dried distillers grains and solubles) are also fed to livestock. Combined, the area of land required to produce corn, soybean meal, and distillers grain residuals for U.S. animal agriculture is crudely estimated at 16% of U.S. cropland or approximately 7% of total U.S. agricultural land.

Very little land is used to house livestock in the United States. Land near livestock production operations is also used to receive manure as a crop fertilizer and soil amendment. Whereas deforestation is a livestock-related issue in some countries, the area of U.S. land in forests increased by 6.9 million ha between 1987 and 2002, despite dramatic increases in livestock production. Analysis of changes between 1961 and 2003 in the land area required per unit of animal product in North America illustrated sharp declines for beef (40%), pork (59%), milk (61%), eggs (63%), broilers (66%), and turkeys (75%).

Livestock operations, including poultry, accounted for approximately 0.61% of freshwater withdrawals in the United States in 2005. Livestock product processing facilities were estimated to consume about 0.1% of U.S. freshwater withdrawals in 2005. Crop irrigation was the second-largest component of U.S. freshwater withdrawals at 37%, with 85% of irrigation withdrawals occurring in the 17 western conterminous states in 2005. Approximately 13% of U.S. cropland was irrigated in 2002. Corn grain was planted on 18% of irrigated ha, soybeans on 10%, and alfalfa hay on 12%. The irrigated acreage represented about 12% of total corn acreage, 7% of soybean acreage, and 28% of alfalfa acreage. A crude estimate is that 9% of U.S. freshwater withdrawals is used to irrigate feed crops for animal agriculture.

The most prominent recent U.S. national policy issue related to livestock, land, and water has been directed toward the effect of livestock production on the quality of surface water and groundwater. Concerns include the pollution of water with nutrients, pathogens, pharmacologically active compounds, excess organic matter, and turbidity. Potential pollution sources include areas occupied by animals, manure storage and treatment activities, runoff and leaching from land receiving manure as a fertilizer source, mortality storage and disposal facilities, deposition of airborne materials emitted by livestock operations, cropland and pastures, and waste from animal product processing operations.

United States regulation of livestock production to protect water quality was included in the Clean Water Act of 1972. A major revision of EPA rules that regulate livestock operations under the Clean Water Act was initiated in 1993 and is being implemented after a lengthy process of EPA rule making and a series of court challenges. The regulatory approach includes permitting requirements for operations in the largest size categories and less stringent requirements for smaller operations. Discharges to surface water from livestock production operations are generally prohibited except for storm water runoff from cropland receiving manure as a crop fertilizer. Manure from livestock farms is applied to less than 5% of the planted acres in the United States, but the potential harm from manure entering streams has resulted in a sustained effort to limit runoff.

An established, productive research and education program evaluates livestock production and manure management practices and provides critical information, assistance, and BMPs for livestock producers across the country. Water discharges by large livestock product processing operations are strictly regulated under the Clean Water Act and associated regulations pertaining to manufacturing operations.

New approaches are emerging in the United States for managing effects of livestock production on limited natural resources, environmental attributes, and public health. Formal management programs including goal setting, routine monitoring, and regular reporting have been adopted by various operations. Some of these programs, such as EMSs, are audited by third parties and comply with ISO standards. Another emerging concept is the life cycle approach to analysis and management of livestock production. A related emerging approach is the use of systems analysis by researchers to understand the interactions within livestock production systems and optimize complex systems to minimize effects on limited natural resources, environmental attributes, and public health. The systems approach is critical to addressing the interdependent effects of livestock production decisions on air emissions, water quality, the use of land and water, public health, various social issues, the supply of food, and the economic welfare of people and communities.

Progress has been made in improving water quality since passage of the Clean Water Act in 1972. Focus shifted to NPSs of pollution in the 1980s. Agricultural activities, including crop production and land application of manure, are among NPSs of nutrients and other pollutants listed in water quality inventory reports. Notable in several reports is the fact that there has been very little measurement on a watershed scale of the marginal effects of both different NPSs of pollutants and various conservation practices. Vegetative buffers have proved effective in eliminating or decreasing the release rates of pollutants into surface water.

Global and domestic trends will frame policy issues for the next few decades. A major global trend identified by LLS is that a 30% increase in global population by 2050 and a 150% increase in income per capita will result in demand for 70% more food, including 100% more meat and similar increases in milk and egg production. Competing demand for feed grains and oilseeds is expected to rise sharply—for exports, as global population and income rise, and for biofuels, as global biofuel consumption continues to rise. Population, income, and consumption may grow less rapidly in developed countries such as the United States and more rapidly in developing countries. Demand will continue to grow for natural resources including land; water; minerals such as P; and energy, including coal, petroleum, uranium, and renewable energy.

Consumers in developing countries and developed countries such as the United States compete in global markets for resources, goods, and services. The area of land and supply of freshwater available for agriculture are expected to decline in the United States and globally as a growing population uses limited resources for other purposes. An accompanying trend is that people will demand greater protection of the environment, ecosystems, and public health as income rises. Other social trends, such as increased standards of animal welfare and restricted use of antibiotics, will directly constrain animal production systems.

United States policy issues linked to animal production are related to global issues but differ in focus and order of prominence. Social preference for protection of water and air quality, public health, and animal welfare has been a prominent national policy issue in the United States and most developed countries for the past few decades and is expected to continue growing in importance. A modest but significant investment has been made in research to better understand the causes, rates, fate and transport, and effects of emissions from animal production systems. Such information is critical to the design of efficient policy to minimize negative impacts without imposing unnecessary damage on consumers, producers, other individuals, and communities. Sustained research and education efforts are required to further decrease the environmental effects of animal production systems, even as production increases to meet domestic and global demand.

Several issues take on a more regional focus in the United States, although they are common globally. The use of freshwater to irrigate crops and for animal production competes with direct consumption by people and with the use to sustain specific aquatic populations in California, other parts of the western states, and some regions in the eastern United States. The sale or loss of water supply has caused some once agriculturally productive land to be abandoned. Rising human demand for water is increasing the pressure for further abandonment of agriculturally productive hectares in arid regions. Whole communities are affected when agriculture ceases. The potential for the changing climate to decrease rainfall in primary feed-grain growing regions poses additional water resource challenges for agriculture.

Farmland preservation is an established program in the United States, but the pressure to develop agricultural land for other purposes is growing with population and income in many locations. The protection of farmland and the capacity to sustain food production and the provision of ecological and aesthetic services is a policy issue of growing importance.

The high standard of living enjoyed by people in developed countries and the subsistence of people in less developed countries are due in no small part to the steady increase in agricultural productivity during the past several decades. Modest sustained investment in U.S. research and education enabled more food to be produced from declining supplies of natural resources while decreasing the rates of soil erosion and pollution. The awareness that a new commitment is needed to increase agricultural productivity gains over the next forty years and further decrease the environmental effects of agriculture has been created by LLS and other reports. A 70% increase in the quantity of food needed, including a 100% increase in animal products and 907,200,000 tonnes of additional feed grain per year, from a constantly declining resource base while meeting ever higher standards of protection of environmental attributes, public health, and other social preferences requires a tremendous increase in agricultural productivity. Policy to create that productivity growth in both plant and animal systems and in related environmental protection and resource conservation systems is critical. Policy to ensure access to resources and education and timely distribution of food to the poorest people on the planet is needed to prevent disaster.

Appendix A. Methods Used to Calculate Figures in Table 5

This appendix describes the calculation of numbers presented in Table 5, which shows historic changes in the land required for production by selected animal sectors in North America. Data were obtained from the FAOSTAT database (FAO 2012b), crop acreage and yields from ResourceSTAT (FAO 2012c), and feed use of grains (including barley, buckwheat, corn, millet, mixed grains, oats, rapeseed, rye, sorghum, soybeans, and wheat) and animal production (including cattle, pig, sheep, and poultry populations; animal products; meat, milk, and eggs) from the ProdSTAT database

(FAO 2012b). Imported feeds were converted to domestic acres using domestic yields. Reported grain wastage was added proportionally to feed use.

For pigs and poultry, corn feed units (CFUs) (Byerly 1975; Jennings 1943) used per 100 pounds of product (Byerly 1975; Jennings 1943; USDA 1994, 2000, 2008) were plotted with missing values approximated from trend lines. Table egg weight was assumed to be 24 ounces per dozen. United States feed required (CFU) was assumed for all North America. Corn feed unit requirements were calculated per unit of live weight gain and per unit meat production (carcass weight) using U.S. weights (USDA–NASS 1960, 1970, 1980, 1990, 2000 [for red meat]; USDA–NASS 1980, 1990, 2000 [for poultry]). United States lard production was converted to carcass weight using yields presented by Zeigler (1962) and added to carcass weight.

Consumption of various feed grains was converted to corn equivalents and total feed requirement calculated. Arbitrarily, this amount was decreased by 10% to account for the inclusion of fats and other by-products in feed (a crude estimate, especially across time). Total feed required was divided by the overall average per acre yield of the mixed feed grains to create the estimate of the acres required to produce each animal product. Acreage and animal production were used to calculate weight per acre and acres per weight ratios for chicken meat, pig meat, turkey meat, and eggs. Calculated values for amounts in this and the previous paragraph were subsequently converted to metric (International System of Units) units.

The effect of grazing and forage, for which average production and feed value estimates are extremely difficult, complicated the estimation of ruminant land requirements. Calculations were performed in three steps: allocation of feed grains, allocation of grazing, and allocation of harvested forage.

Yearly use of feed grains for milk cows, all beef cattle, and sheep and lambs (USDA 1994, 2000, 2008) and population numbers for dairy cattle and beef cattle were used to allocate the feed grain acreage not assigned to poultry and pigs. The FAOSTAT land use numbers for "permanent meadows and pastures" exceeded USDA (2007) acreage for "cropland used only for pasture or grazing" plus "woodland pastured" plus "pastureland and rangeland other than cropland and woodland pastured" in that the FAO was possibly reflecting allocation of public grazing lands. The FAO does not report acreage used for silage and hay. Acreages for corn and sorghum silages and forages plus all hay (USDA–NASS 1960–2010), relative to "meadows and pastures," were used to calculate North American silage and hay (based on the U.S. percentages).

Byerly (1975) presented data for the utilization of CFUs from grazing for various kinds of animals for the years 1941 through 1973. The percentages of the yearly totals were calculated for milk cows and feedlot cattle plus other cattle (used as the token for beef cattle). These derived data were plotted and extended as trend lines to cover the various years in the data. Resulting percentages were used to allocate grazing land acreage to cattle meat production and cow milk production. Silage acreage was allocated as 100% minus the grazing percentage allocation; that is, if milk production used 25% of the grazing land in a given year, then it was allocated 75% of the silage acreage for that year. Hay acreage was arbitrarily allocated 50% for milk and 50% for cattle meat. The acreage allocations for feed grains, grazing, silage, and hay were summed for each commodity to estimate the total acreage used to produce that commodity. Results in Table 5 reflect the fact that land use for cattle meat and cow milk are changed to include FAO grazing land area plus USDA (and other) reported silage and hay acreage. Thus land use may be overstated. Similarly, inclusion of grain wastage may overstate land requirements in Table 5.

Glossary

Ad valorem taxation. A tax based on the value of real estate or personal property. It is more common than a tax based on the quantity of an item, such as cents per kilogram, regardless of price.

Conterminous. Enclosed within one common boundary.

Effluent limitations guideline. Guidelines and standards established by the EPA for different nonmunicipal (i.e., industrial) categories. These guidelines are developed based on the degree of pollutant reduction attainable by an industrial category through the application of pollutant control technologies (USEPA–NPDES 2007).

Eutrophication. The process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life, usually resulting in the depletion of dissolved oxygen.

Feed and residual. A USDA term that describes the quantity of grain fed to livestock or consumed for some purpose other than the food and industrial use categories specified by the USDA.

Hypoxia. A deficiency of oxygen.

Karst structures. Irregular limestone regions with sinks, underground streams, and caverns.

Nonpoint source. An unidentifiable source of pollution.

Per capita disappearance. A USDA term that describes the quantity of a commodity that was consumed, wasted, or otherwise acquired by consumers divided by the number of people in the country.

Phytase. An enzyme that allows poultry and other monogastric animals to use more phosphorus contained in corn.

Point source. An identifiable confined source from which a pollutant is discharged or emitted.

Regulatory taking. A situation in which a government regulates a property to such a degree that the regulation effectively amounts to an exercise of the government's eminent domain power without actually divesting the property's owner of title to the property.

Right-to-farm laws. Laws that support the retention of farmland by precluding nuisance lawsuits against those agricultural property uses in existence before new nearby land uses.

Total factor productivity. The ratio of an index of aggregate output to an index of aggregate input (Capalbo and Antle 1988).

Zoonotic. Communicable from animals to humans under natural conditions.

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