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Abstract

Census of agriculture data were used to estimate manure nutrient production and the capacity of cropland and pastureland to assimilate nutrients. Most farms (78 percent for nitrogen and 69 percent for phosphorus) have adequate land on which it is physically feasible to apply the manure produced onfarm at agronomic rates. (The costs of applying manure at these rates have not been assessed). Even so, manure that is produced on operations that cannot fully apply it to their own land at agronomic rates accounts for 60 percent of the Nation's manure nitrogen and 70 percent of the manure phosphorus. In these cases, most counties with farms that produce "excess" nutrients have adequate crop acres not associated with animal operations, but within the county, on which it is feasible to spread the manure at agronomic rates. However, barriers to moving manure to other farms need to be studied. About 20 percent of the Nation's onfarm excess manure nitrogen is produced in counties that have insufficient cropland for its application at agronomic rates (23 percent for phosphorus). For areas without adequate land, alternatives to local land application—such as energy production—will need to be developed.

Keywords: Manure, nutrients, manure nutrients, animal waste, confined livestock, confined animal feeding operation, CAFO, feedlot beef, dairy cows, swine, poultry, animal unit, manure nitrogen, manure phosphorus, water quality.

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Executive Summary

Livestock and poultry manure can provide valuable organic material and nutrients for crop and pasture growth. However, nutrients contained in animal manure can degrade environmental quality if they enter the water. There is growing concern about the large amounts of manure nutrients being generated by large animal feeding operations and the potential for some of the nutrients to enter water resources and impair water quality.

Current manure management practices on the Nation's animal feeding operations are being evaluated in light of the changing structure of the livestock industry and the quantity, location, and sources of manure nutrients. This report—using data collected for the census of agriculture by the National Agricultural Statistics Service—estimates the number of confined animals, the amount of manure nutrients, and the capacity of nearby land to assimilate these nutrients. This analysis provides the basis for later assessment of the economic feasibility of land application as a manure management strategy.

The number of confined livestock farms declined by half from 1982 to 1997, while the number of confined animal units (AU) increased 10 percent. This increase has occurred due to more large farm units (with more than 1,000 AU), rather than large farm units becoming larger. The number of confined animal farms and the number of confined AU **declined** on farms with fewer than 300 AU from 1982 to 1997, and **increased** on farms with more than 300 AU.

Confined livestock and poultry produced over 1.2 million tons of recoverable nitrogen and 0.7 million ton of recoverable phosphorus in 1997. Most farms (78 percent for nitrogen and 69 percent for phosphorus) have adequate land on which it is physically feasible to apply the manure produced onfarm at agronomic rates. Still, manure produced on operations that cannot fully absorb it at agronomic rates accounts for over 60 percent of manure nitrogen and 70 percent of manure phosphorus. Manure nutrient production above potential onfarm assimilative capacity does not imply a water quality problem—it simply means that the manure would need to be transported from the producing farm to be effectively used in growing crops. Incentives may be needed to encourage producers to improve current manure management practices to ensure that applications are made at agronomic rates.

- Some farms in all size classes produce manure nutrients over the farm's potential assimilative capacity. However, the 2 percent of farms in the large size class (more than 1,000 AU) produced almost half of the excess manure nitrogen and more than half the excess manure phosphorus.
- The quantity of excess onfarm manure nutrients increased in all regions over 1982-97, with the greatest quantity increase in the Southern Seaboard region, and the greatest percentage increase in the Heartland.
- Most U.S. counties (about 75 percent) have at least one farm that needs to move manure off the farm to avoid excessive nutrient applications.
- Only about 5 percent of counties have farms that collectively produce manure nitrogen that accounts for over half the total nitrogen needs in the county. However, about 10 percent of counties produce manure phosphorus that exceeds half the county's total phosphorus needs.

As of early 2001, EPA proposals for future National Pollutant Discharge Elimination System (NPDES) permits for concentrated animal feeding operations (CAFOs) would require the development of nutrient management plans (NMP) as part of the permit. These permits would include management strategies for manure collection, storage, and disposal, including the land application of manure nutrients. We estimate that 5 percent of confined livestock farms are potential CAFOs under current regulations. These farms produced over half of the excess onfarm nitrogen and two-thirds of the excess onfarm phosphorus in 1997. If all potential CAFOs followed an NMP, the amount of nutrients available for runoff or leaching to water resources could be significantly reduced.

In areas with high concentrations of animals and high levels of excess onfarm nutrients, there may be insufficient land available for spreading at agronomic rates, particularly where NMPs are phosphorus based. Some producers will need to transport manure offsite, and incentives may be required to encourage local farmers without animals to use manure. Transportation costs will largely determine the economic feasibility of this strategy.

In any case, areas with insufficient land for spreading manure have the greatest need for alternatives to land application. Mechanisms to encourage industrial use of manure as a feedstock for commercial enterprises (fertilizer manufacturing or energy production) or central processing facilities would be especially valuable in these areas. These livestock clusters might also be strong candidates for targeting both policy-driven adjustments and USDA funding and research assistance.

All farms are eligible to apply for technical, educational, and financial assistance in managing manure nutrients under both USDA's Environmental Quality Incentives Program (EQIP) and the Conservation Technical Assistance Program. In addition, EQIP is authorized to assist small and medium-sized confined animal farms (less than 1,000 AU) with investment in storage and treatment facilities. Requests for subsidized manure storage and treatment facilities and nutrient management assistance will likely increase if NMPs are required on more farms.

Successful development of facilities to process manure at a central location may accelerate trends in animal industry concentration, while failure to find viable off-farm alternatives for manure may slow, or even reverse, these trends. Further research is needed to evaluate the impact of manure management policies on the animal industry.

Confined Animal Production and Manure Nutrients

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Introduction

Livestock and poultry manure can provide valuable organic material and nutrients for crop and pasture growth. Careful nutrient management, including the use of manure, can reduce and, in some cases, eliminate the use of commercial fertilizers. The opportunity to jointly manage animal waste and plant nutrients within a single operation has decreased as animal production units grow fewer, larger, and more specialized (Govindasamy *et al*., 1994; Trachtenberg and Ogg, 1994). For farms with livestock and scarce cropland, some producers may apply manure at rates that lower disposal costs rather than optimize the nutrient contribution to the crop. This can cause residual nutrients to be transported to the environment through runoff and leaching, where they degrade water quality and impose costs on water users.

Manure and its associated nutrients are a concern at several stages: from accumulation in open and unpaved feedlots; from storage in holding ponds, lagoons, and uncovered stockpiles; and from excess manure and wastewater applied to land. Reducing runoff and spills from storage and treatment structures often can be accomplished with engineering-based solutions. Depending on farm size, these structures may be regulated as point sources under the Clean Water Act. But reducing the flows of excess nutrients from the application of animal waste to cropland has become a growing challenge. Policymakers are considering mechanisms to link livestock operations with available cropland to increase the nutrient contributions of the manure to crop yield while reducing damages from residual nutrients.

U.S. animal production provided $98.8 billion in sales in 1997, over half (51 percent) of all farm sales (USDA, 1999a). Sales from animals usually produced in confinement (feedlot beef, dairy, swine, and poultry) accounted for over $75.4 billion. Policy changes that affect costs of manure management could have significant economic effects on the livestock sector. Federal policies that directly impact manure management include the Clean Water Act (CWA), Coastal Zone Act Reauthorization Amendments (CZARA), and the Environmental Quality Incentives Program (authorized by the Federal Agriculture Improvement and Reform Act of 1996). We look specifically at those farms that may require permits under the CWA as point-source discharge sites, as well as those farms eligible for assistance under the Environmental Quality Incentives Program (EQIP) of the 1996 Farm Bill.

A growing number of States and local governments are implementing laws directed at specific confined livestock and poultry operations (U.S. EPA, 1999b). These efforts are often less comprehensive and more restrictive for some animal types than are Federal regulations.

This report—using data from the last four censuses of agriculture conducted in 1982, 1987, 1992, and 1997—estimates the amount of manure nutrients produced in the United States and the cropland and pasture available to receive it. The quantity of manure nutrients produced is compared, first, to the amount reasonably applied to land controlled by the confined animal operation, and second, to all crop and pasture land in the county. In short, if a livestock operation applied its manure to the available crop and pasture land under its control at a rate that met the nutrient needs of the plants, how much excess onfarm nutrient production would require disposal?[1]

[1] We assume that manure and commercial fertilizers are optimally managed relative to crop needs on the operator's available land.

This is a narrowly focused but critical question that helps frame part of the policy debate.[2] If the livestock operator has adequate land for manure application, policy efforts can be directed to farm-level solutions. Since manure nutrients can also be applied to land owned by other operators, policies may need to address timing of transfer and applications, liability for improper application, and transportation costs. Finally, if better onfarm management is inadequate to reduce the potential for manure-based water quality problems, we differentiate those areas that need mechanisms to encourage alternatives to land application, such as commercial uses (fertilizer manufacturing or energy production) or central facilities for treatment or processing.

[2] We do not consider potential nutrient losses directly from the animal holding facility.

Nutrient Impacts on Water Quality Gain Public Policy Attention

Animal manure contains nitrogen and phosphorus, nutrients that can harm environmental quality when they enter water systems. Nitrogen is easily soluble and is transported in runoff, in tile drainage, and with leachate. Phosphorus is only moderately soluble, and not as mobile in soils as nitrogen. However, erosion can transport considerable amounts of sediment-adsorbed phosphorus to surface waters. Movement of phosphorus in surface runoff or leaching to shallow ground water or underground drains may occur if manure is applied on lands that have exceeded their soil phosphorus retention levels. This is more likely the case where manure applications have long been based on crop nitrogen needs only, without regard for soil phosphorus levels.

Nitrogen and phosphorus accelerate alga production in receiving surface water and can clog pipelines, kill fish, and reduce recreational opportunities (U.S. EPA, 1998). Nitrogen is primarily a problem in brackish or salt water, while phosphorus is primarily a problem in fresh water. EPA reports that nutrient pollution is the leading cause of water quality impairment in lakes and estuaries, and is the second leading cause in rivers, behind sediment (U.S. EPA, 1998). The National Water-Quality Assessment Program found that the highest concentrations of nitrogen and phosphorus in streams occurred in basins dominated by agricultural uses (see Appendix: Animal Waste and Water Quality). High concentrations of nitrogen and phosphorus in these streams were correlated with inputs from fertilizers and manure used for crops and from livestock wastes (U.S. Department of Interior, 1999).

Current Regulations Focus on Livestock Facilities

The major Federal law affecting manure management on animal operations is the Clean Water Act, under which the National Pollutant Discharge Elimination System (NPDES) program covers animal feeding operations meeting certain criteria. NPDES permits are required by point sources (facilities that discharge directly to water resources through a discrete ditch or pipe) before they can discharge into navigable waters. The permits specify a level of treatment for each effluent source. Federal NPDES permits may be issued by EPA or any State authorized by EPA to implement the NPDES program.

Under 1974 EPA regulations, certain animal feeding operations (AFOs) may be considered a point source in the NPDES program and be designated concentrated animal feeding operations (CAFOs) if they meet the following criteria. First, an AFO is a facility where:

- Animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and
- Crops, vegetation, forage growth, or postharvest residues are not sustained in the normal growing season over any portion of the lot or facility.

A CAFO is defined by EPA regulation as an AFO that:

- Confines more than 1,000 slaughter and feeder cattle, 700 mature dairy cows, 2,500 swine each weighing more than 25 kilograms, 30,000 laying hens or broilers (if a facility uses a liquid manure system), and 100,000 laying hens or broilers (if a facility uses continuous overflow watering), 55,000 turkeys, 500 horses, 10,000 sheep, 5,000 ducks, or combinations of animals totaling 1,000 animal units. The CAFO definition of animals per animal unit is specified only for slaughter and feeder cattle, mature dairy cows, swine, sheep, and horses.
- Confines more than 30 percent of the number of animals specified above **and** discharges pollutants into waters through a manmade ditch, flushing system, or similar manmade device, or directly into waters that pass through the facility.

The CAFO regulation contains an exemption for facilities that discharge pollutants only in the event of a 25-year, 24-hour storm event[3] (i.e., AFOs of any size that have facilities to contain the runoff associated with a local, 24-hour storm of a severity expected only once in 25 years do not need a permit).

The total maximum daily load (TMDL) provisions of the Clean Water Act are intended to be the second line of defense for protecting surface-water quality, and could affect animal feeding operations. When technology-based controls are inadequate for water to meet

[3] The January 12, 2001, draft regulations propose revisions to the NPDES permit manual for CAFOs that remove this exemption (U.S. EPA, 2001).

State water quality standards, Section 303(d) of the Clean Water Act requires States to identify those waters and to develop TMDLs. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. The TMDL for the watershed is the sum of individual wasteload allocations for point sources, load allocations for nonpoint sources and natural background, and a margin of safety. Wasteload allocations for point sources generally become part of their NPDES permit. Load allocations for nonpoint sources can be met through voluntary approaches or regulation.

Section 303(d) of the Clean Water Act requires States to submit to EPA a list of impaired waters and the cause of the impairment. There are more than 20,000 such waters identified nationally, comprising more than 300,000 miles of rivers and streams and more than 5 million acres of lakes (U.S. EPA, 2000). The top impairments from the 1998 303(d) lists are sediment, nutrients, and pathogens. States, territories, and authorized tribes are responsible for establishing and implementing TMDLs. If they fail to establish the TMDLs, EPA must do it. Confined animal operations of any size in a watershed under a TMDL might face animal waste storage, handling, and disposal requirements.

CAFOs in the coastal zones of the 29 States subject to the Coastal Zone Management Act face regulations contained in the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990. EPA requires that discharges from these coastal CAFOs be limited through appropriate storage and an appropriate waste utilization system (U.S. EPA, 1993). The management measures are to be applied to all new facilities regardless of size and to all new or existing facilities with 300 beef, 200 horses, 70 dairy cows, 15,000 layers or broilers, or 200 swine. Exempted are those CAFOs that are required to have an NPDES permit.

Forty-three states are certified by EPA to issue their own NPDES permits (U.S. EPA, 1999b). Of these, 35 have a combination of NPDES and State-level, non-NPDES permitting mechanisms available for addressing the environmental impacts of animal feeding operations. Typically, the non-NPDES mechanism is a construction or operating permit or set-back requirement. State NPDES permit requirements may be more stringent than the EPA requirements (but not less stringent). Of the seven States (AK, AZ, ID, MA, ME, NH, NM) not authorized to administer the NPDES program, three (AZ, ID, NM) impose some form of a State program requirement on AFOs. Of note, 32 States have a requirement covering application rates of manure on the land, and 27 States require at least some of the animal operations to develop and use waste management plans (U.S. EPA, 1999b).

In addition to the regulatory framework, voluntary agricultural programs such as the Environmental Quality Incentives Program (EQIP) and the Conservation Technical Assistance Program are designed to improve water quality by encouraging the use of improved farm nutrient management practices. EQIP, initiated in the 1996 Federal Agriculture Improvement and Reform Act, provides technical, educational, and financial assistance to farmers and ranchers for adopting structural, vegetative, and management practices that protect or enhance environmental quality. Contracts for financial assistance are for 5 to 10 years, and the annual payment limit is $10,000 per person per year, with a maximum of $50,000 per contract. By statute, half of the available funding for the program is targeted at practices related to livestock production on farms with fewer than 1,000 animal units. EQIP funding was $200 million for 1997 and 1998, declining to $174 million in 1999 (USDA, 2000a).

USDA also provides technical assistance for producers wishing to implement conservation practices, including nutrient management. The Conservation Technical Assistance program (CTA) was authorized by the Soil Conservation and Domestic Allotment Act of 1935. The Natural Resources Conservation Service (NRCS) administers the CTA program, which helps land users plan and implement conservation systems for improving soil and water quality (including nutrient management), reducing erosion, improving and conserving wetlands, enhancing fish and wildlife habitat, improving air quality, improving pasture and range conditions, reducing upstream flooding, and improving woodlands. Assistance is provided through conservation districts to land users who voluntarily apply conservation practices, including producers who must comply with local, State, or Federal laws and regulations. As a component of the CTA program, NRCS and State conservation district personnel can help State and regional planning agencies with nonpoint-source pollution control.

Future Regulations To Address Manure Application

In 1999, USDA and EPA announced the Unified National Strategy for Animal Feeding Operations (USDA–EPA, 1999), which sets forth a framework of actions USDA and EPA plan to take—under existing legal and regulatory authority—to minimize impacts to water quality and public health from animal feeding operations and to establish a national performance expectation for animal feeding operations. This coordination of effort was spurred, in part, by:

- The growing concentration and size of animal feeding operations;
- The geographic concentration of feeding operations, which can overwhelm the ability of a watershed to assimilate the nutrients contained in the waste and maintain water quality;
- More and larger animal waste storage lagoons that increase the chance for a leak or a catastrophic break. Over the past several years, major lagoon spills or leaks have occurred in Illinois, North Carolina, Iowa, Kentucky, Minnesota, Missouri, Montana, South Dakota, Utah, Virginia, Washington, and Wisconsin (U.S. EPA, 1999a).

Under the Unified Strategy, all AFO owners and operators will be expected to develop and implement technically sound, economically feasible, and site-specific comprehensive nutrient management plans (CNMP) for properly managing the animal wastes produced at their facilities, including onfarm application and off-farm uses. Nutrient management plans[4] (NMP) will be mandatory for operations that require an NPDES permit, and voluntary for other producers. Inclusion of an NMP as part of the NPDES permit means that for the first time, the application of manure on land will be a part of a required Federal permit (32 States now have alternative versions of this provision— generally for a single animal type—in State regulations).

Proposed nutrient management plans rely on the Natural Resources Conservation Service (NRCS) *Field Office Technical Guide* as the primary technical reference. The NRCS technical guide limits manure application on land to the level determined by the more limiting of the two major nutrients—nitrogen or phosphorus. In the past, manure management has focused on managing manure nitrogen. Shifting to a phosphorus-based standard will require more land on which to spread the same amount of manure; the quantity of phosphorus taken up in the growth of most field crops is much less than nitrogen (only 10 to 20 percent), and application levels depend on existing soil phosphorus levels. Soil phosphorus levels can be rapidly built up in the soil by the application of manure, but may take years to deplete to levels enabling additional manure applications (Sharpley *et al*., 1999). Therefore, basing nutrient management on phosphorus has significant implications for animal operations with excess manure by increasing (1) the acreage needed for spreading, (2) manure application costs, and (3) the number of farms that will need alternative ways to dispose of manure.

Proposed changes in permitting requirements and nutrient management could significantly increase manure management costs for confined animal producers across a range of operation sizes.

The Unified Strategy recommends that EPA review the criteria for determining which operations will require an NPDES permit (see box, "EPA Proposes Revised CAFO Regulations"). Not only will the largest operations still require a permit, NPDES permits may also be issued to smaller operations whose direct discharge through a pipe or ditch contributes to water quality impairments (U.S. EPA, 2001).[5] Knowledge of where animals are highly concentrated could assist resource managers in identifying nutrient-impaired waters and options for remediation.

[4] The Unified Strategy calls for comprehensive nutrient management plans (CNMP), and the draft regulations for the NPDES permits call for permit nutrient plans (PNP). We use "nutrient management plans" as a generic term for plans, inclusive of CNMPs and PNPs, that provide producers with information about manure application levels on farmland to minimize the movement of nutrients to the water resources.

[5] States are required by the Clean Water Act to identify impaired waters, and EPA has recently pushed States to accelerate their efforts to identify such waters and to develop remediation programs (Boyd, 2000). EPA is providing the States guidance for identifying nutrient-impaired waters, the lack of which has hindered States from identifying nutrient-related problems in the past (Gibson *et al*., 2000). These actions could focus attention to watersheds where animals, and animal operations, are concentrated.

Proposed changes in permitting requirements and nutrient management could significantly increase manure management costs for confined animal producers across a range of operation sizes. One of the first steps in evaluating the potential for increased costs from changes in manure management is to examine the extent and magnitude of the problem. The number and location of producers, land available for manure application, and the types and number of animals produced will help indicate the impact of policy change and the resources required to assist livestock and poultry producers. In this report, we apply a documented methodology to a consistent national data set to determine the number and location of operations and animals.

EPA Proposes Revised CAFO Regulations

EPA issued draft regulations for confined animal feeding operations on January 12, 2001 (U.S. EPA, 2001). After a public comment period and rewriting based on the comments received, final regulations are scheduled to be published in December 2001.

The draft regulations propose increases in the number of farms regulated under the National Pollutant Discharge Elimination System (NPDES) permit program. The proposal offers two options for public comment on the number of farms included in the NPDES permit program. One would regulate the largest 26,000 CAFOs in a system that considers only operation size. The second would regulate an estimated 36,000 operations, in a system that considers the largest 12,000 operations and another 24,000 operations based on their potential to allow nutrients to enter waterways considering 6 criteria (distance to streams, adequately sized manure storage facilities, direct contact of animals with surface water, evidence of discharge, presence of adequate nutrient management plan, significant amounts of waste transported offsite).

The draft regulations also require that a component of the NPDES permit include a nutrient management plan covering the land receiving manure. On the CAFO farm, the draft regulations require manure to be applied to crops at the minimum of the phosphorus or nitrogen agronomic level. For farms that export manure to other operators, the proposal also requires either that (1) the regulated farm keep detailed records of manure leaving the operation or (2) the receiving farm certify that manure is applied at agronomic rates.

Data and Methodology

Our analysis estimates the onfarm balance of manure nutrient production relative to the farm's potential to use the nutrients for crop production based on farm-level data collected for the 1982, 1987, 1992, and 1997 Censuses of Agriculture. We then calculate regional assimilative capacity.

Our methodology is direct. First, we estimate manure nutrient production on farms with confined livestock. Second, we use the reported onfarm production of major field crops and pastureland to calculate the potential nutrient assimilative capacity.[6] Third, we examine the balance between manure nutrient production and nutrient need measured by crop uptake and pastureland applications at the farm level, **assuming no supplementary commercial fertilizer use** (see box, "Computation Methods," p. 9). Results based on the farm-level information are then aggregated to geographic units and across animal type.[7] With farm-level data, we evaluate production characteristics of confined-animal producers such as cropland acres, crop production levels, and potential manure nutrient use for crop production. We estimate all parameters at the farm level—to characterize how individual decisions are made—before aggregating.

Livestock operation size categories

Based on 1 AU = 1,000 pounds live weight:

Very small	< 50 AU
Small	50 to 300 AU
Medium	300 to 1,000 AU
Large	>1,000 AU

Based on number of animals from the CWA:

Potential CAFO	CWA specification

Estimates presented here were a joint effort of three USDA agencies: Economic Research Service (ERS), Natural Resources Conservation Service (NRCS), and National Agricultural Statistics Service (NASS).

We used a biologically based definition of an animal unit (AU) of 1,000 pounds of live animal weight[8] to calculate manure production and manure nutrients. We applied this definition to feedlot beef, dairy, swine, and poultry, using average animal weights (table 1). Estimates of annual average AU per farm were obtained using census data on end-of-year inventory and sales. The details of the computation methods may be found in a companion NRCS report (Kellogg *et al*., 2000).

We examined operations of different sizes to observe changes in industry structure and to evaluate the distribution of impacts of potential regulatory changes. Operation size was based on the total number of animals on the farm, not acreage. We report results for a distribution of operation sizes and for those potentially subject to regulation. In order to study farms that may be regulated under current CWA rules, we constructed a category ("Potential CAFO" farms) using the CWA "number-of–head" definitions that includes all of our large category and part of our medium category. It is not possible to precisely identify a livestock operation as a CAFO using the infor-

[6] For crops, this is the amount of nutrients taken up by the plant and removed from the field at harvest, and represents the quantity that can be applied each year without accumulating nutrients in the soil. This assumes that the nutrients in the nonharvestable portion of the plant are returned to the soil and thus available for future plant growth. Per-acre nutrient applications were assumed for cropland used as pasture and permanent pasture based on their relative productivity and the nutrients removed by grazing animals.

[7] Our analysis meets all respondent confidentiality assurances that are required to publish census of agriculture values.

[8] Our definition of an animal unit based on 1,000 pounds of live weight should not be confused with the Clean Water Act (CWA) specification of "1,000 animal units." The CWA specified that a farm producing more than one animal type could be a CAFO if the sum on the animals totaled "1,000 animal units." The act specified an animal per animal unit conversion only for that purpose and only for slaughter and feeder cattle, mature dairy cows, swine, sheep, and horses. No conversions were specified for any type of poultry. These specifications of animals per animal unit have proven to be confusing because they are not complete and are not based on a common specification (such as 1,000 pounds of live weight). Proposed revisions of the regulations drop this terminology and rely only on numbers of animals to specify CAFOs.

mation available in the census of agriculture. Instead, data on “potential CAFOs” were constructed based on current regulations and estimates of the annual average number of livestock on the farm, derived from annual sales data and year-end inventories.[9]

[9] The following rules were used to identify potential CAFOs: (1) farms with fattened cattle sales of 1,000 head or more, (2) farms with milk cow end-of-year inventory of 750 or more, (3) farms with combined sow inventory and hogs on feed (average annual number based on inventory and sales) of 2,500 or more, (4) farms with an average annual number of pullets and layers (based on inventory and sales) of 100,000 or more, (5) farms with an average annual number of broilers (based on inventory and sales) of 100,000 or more, and (6) farms with an average annual number of turkey hens and turkeys for slaughter (based on inventory and sales) of 55,000 or more. No attempt was made to identify CAFOs based on a mixture of these six livestock types.

Table 1—Definitions of animal units (AU) and specification of minimum size for inclusion

Animal type	Number of animals per animal unit[1]	Minimum number of head to be included in the study
Feedlot beef	1.14	15
Dairy cows	0.74	20
Swine for breeding	2.67	10
Swine for slaughter	9.09	50
Laying hens & pullets > 3 mo.	250	50
Broilers & pullets < 3 mo.	455	100
Turkeys for breeding	50	50
Turkeys for slaughter	67	50

[1] Based on 1 AU equaling 1,000 pounds of live animal weight. These values differ from the definition used by EPA to combine animal types in administering the CWA.

Computation Methods

This report examines manure management in the current and the likely future policy context. The data set only included farms with confined animal types operating above a minimum scale (table 1) to reflect commercial operations.* Thus, these estimates are most useful for examining currently regulated CAFO farms, and farms that might be regulated in the future under the CWA, CZARA, or some other authority. This subset of farms does not represent the total production of manure nutrients (see Kellogg *et al.*, (2000) for estimates that include beef cows and bulls, replacement heifers, and calves not in a feedlot), but rather the nutrient production for which policies will most likely be relevant.

Computation of manure nutrients was a three-step process. First, we converted animal numbers to an average annual AU inventory from reported end-of-year inventory and annual sales data. Second, we computed quantities of manure by applying coefficients of manure production by animal type based on the biological definitions of AU. Third, we computed the recoverable portion of the manure nutrients per ton of manure by animal type after adjusting for losses during collection, transfer, and storage. Recoverable manure nutrients represent that portion of manure that can be collected and applied to land net of losses. See Kellogg *et al*. (2000) for details of the estimation process and manure and nutrient production coefficients.

Potential manure nutrient use by the farms on which the nutrients were produced was also estimated. In these calculations, the land area and the per-acre nutrient uptake for the production of 24 major field crops and pastureland applications were computed for each farm in the census based on reported yields and acres. Manure nutrient production on confined livestock farms was compared with crop and pasture assimilative capacity on those same farms to compute a farm-level "excess" of manure nutrients. We recognize this calculation process may overstate excess manure nutrient in some cases because some manure is moved off many production farms. However, total excess nutrients were more likely to be understated because neither commercial fertilizer applications nor atmospheric deposition of nutrients were considered in this analysis. Most crop farms without livestock, and many farms with livestock, use chemical fertilizers because they are less bulky, easier to apply, and have a more predictable nutrient content than manure. The convenience of commercial fertilizers often outweighs the value of manure as a soil amendment that can improve physical and chemical properties of cropland.

Additional analysis shows which geographical areas have sufficient cropland associated with the livestock operation to use all the manure nutrients at an agronomic rate. Manure nutrient production from confined livestock was compared to total county nutrient needs to help identify areas where manure nutrients could provide a major portion of the county's nutrient needs from all farms. The excess values calculated here for a county represent a consistent, national estimate of the manure nutrients that would need to be transported relatively long distances, or transformed into other products, in order to reduce the potential for nutrient flows into the environment. Regional excess is underestimated because small livestock farms are not included and commercial fertilizer use is not accounted for. Partially offsetting the underestimation is the possibility of applying manure to public lands, golf courses, or other nonagricultural land. This option was not considered for several reasons: The census of agriculture data do not include these other land uses; there are few identified areas with animal concentrations and the proximity of accessible public lands; and manure application is often incompatible with multiple uses of land without extensive processing. By using data from several census of agriculture years, we show how the potential excess-nutrient problem has changed over time. See Kellogg *et al.* (2000) for details of the estimation process and crop nutrient needs.

* Confined animal types include feedlot beef, dairy, swine, and poultry. These data do not include estimates of the recoverable portion of manure from cattle, other than fattened cattle and milk cows (bulls, beef cows, dairy and beef replacement heifers, calves less than 500 pounds, and calves greater than 500 pounds not in a feedlot). If cattle other than fattened cattle and milk cows were included in the analysis, farm numbers would double, the number of AU would increase by only 6 percent, and recoverable manure nitrogen would increase by about 5 percent. Restricting the data to commercial operations—$2,000 in sales or at least 3 AU—removed only 2,500 farms (1 percent of operations) with less than 1,000 AU.

Livestock Sector on the Move

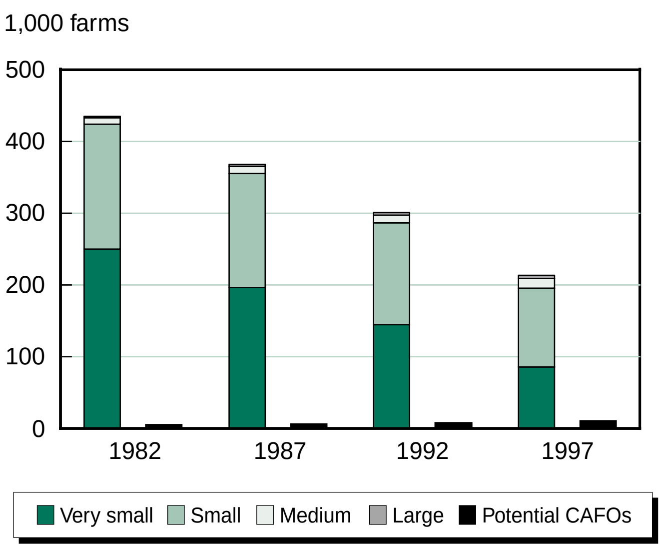
National trends in farm numbers and animal units offer some insight into structural changes of the livestock sector. However, regional and local trends can differ substantially from the national averages and, from a water quality perspective, data on local conditions may be necessary when designing policies to control nutrient flows to the environment.

National Farm Numbers Decline as Animal Units Grow

The number of farms with confined animals declined from 435,000 in 1982 to 213,000 in 1997 (fig. 1). The decline occurred in the very small (less than 50 animal units) and small (50-300 AU) size groupings. During the same period, medium-sized operations (300-1,000 AU) grew by 4,400 farms to account for about 6 percent of all confined livestock farms in 1997. Meanwhile, large farms (more than 1,000 AU) more than doubled to almost 4,000 farms, or 2 percent of all confined livestock operations.

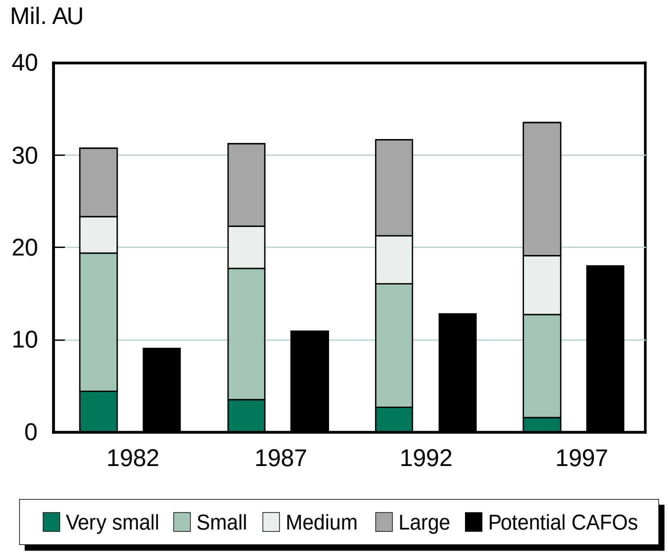
The decrease in the number of farms accompanied a 10-percent increase in the number of confined animal units (fig. 2). A decline in AU on very small farms (from 4.4 million in 1982 to 1.6 million in 1997) and on small farms (from 14.9 million to 11.1 million) was more than offset by growth on medium-sized farms (from 4 to 6.4 million) and, especially, large farms (from 7.4 to 14.5 million). The increase in total AU occurred because there are more large farms, not because the average large farm increased in size. Martinez (1999) and McBride (1997) discuss many of the reasons behind the industrialization of animal production, which leads directly to the growth in large operations.

Figure 1
Confined livestock farms, by size class, 1982-97



Source: Economic Research Service, USDA.

Figure 2
Confined animal units, by size class, 1982-97



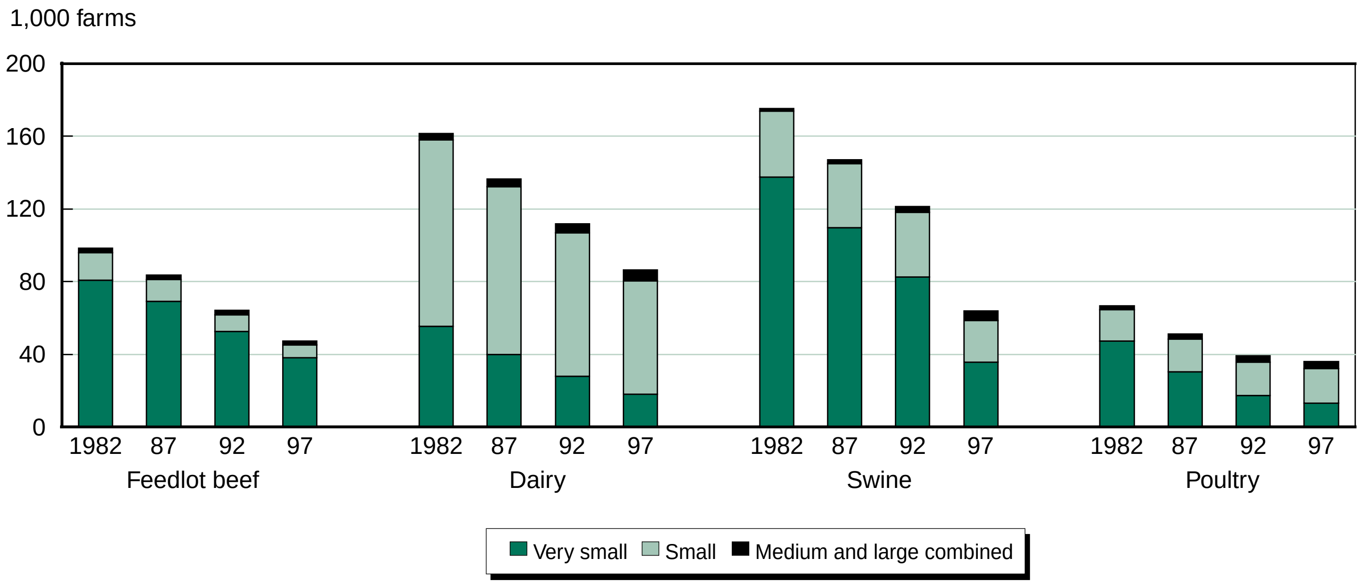
Source: Economic Research Service, USDA.

The dominance in the number of very small and small confined animal farms holds for all animal types over time (fig. 3). In 1997, there were more confined dairy operations (86,350) than any other type, though these were still down 87 percent from 1982. (Prior to 1997, swine farms were most numerous.) Very small and small farms accounted for 93 percent of dairy farms and 92 percent of swine farms in 1997. The number of farms with feedlot beef was less than half its 1982 level in 1997, with 96 percent of these very small or small. The poultry sector experienced the smallest decline in farm numbers over 1982-97, and again, smaller farms dominated: almost 90 percent of confined poultry farms had fewer than 300 AU (fig. 3).

Despite the decline in total numbers, the share of farms with each animal type changed relatively little from 1982 to 1997. The share of farms with dairy increased about 6 percent, mostly since 1992, mirroring the 8-percent decline in relative share for swine.

Figure 3

Confined animal farms by species and size class, 1982-97



Source: Economic Research Service, USDA.

Potential CAFO Farms and Animal Units

Farms with animals over the threshold for an NPDES permit under the Clean Water Act deserve special attention since they may be currently regulated. Our estimation procedure for determining concentrated animal feeding operations (CAFOs) is based on current regulations and the number of animals without considering farms with exemptions. Currently, about 2,500 CAFOs actually have NPDES permits (U.S. EPA, 2001).

The number of potential CAFO operations more than doubled from 1982 to 1997, increasing from about 5,000 to 11,200 (126 percent), or from 1 to 5 percent of all operations (fig. 1). During the same period, the number of AU on these farms almost doubled from 9.1 million (30 percent of total confined AU) to 18.0 million (54 percent) (fig. 2). Nationally, the average number of AU on each potential CAFO did not increase over the period; the gain in AU on potential CAFO farms was due entirely to the increase in the number of potential CAFO operations.

The distribution of potential CAFO farms by animal type underwent substantial change over 1982-97 (fig. 4). There were declines in the share of feedlot beef operations from 47 to 17 percent of potential CAFO farms and growth in swine (21 to 39 percent) and poultry (24 to 33 percent). In 1997, the 4,370 potential CAFO swine operations and 3,760 potential CAFO poultry operations accounted for 72 percent of all potential CAFO operations.

Regionally, Animal Feeding Shifts to Prairie Gateway and Southern Seaboard

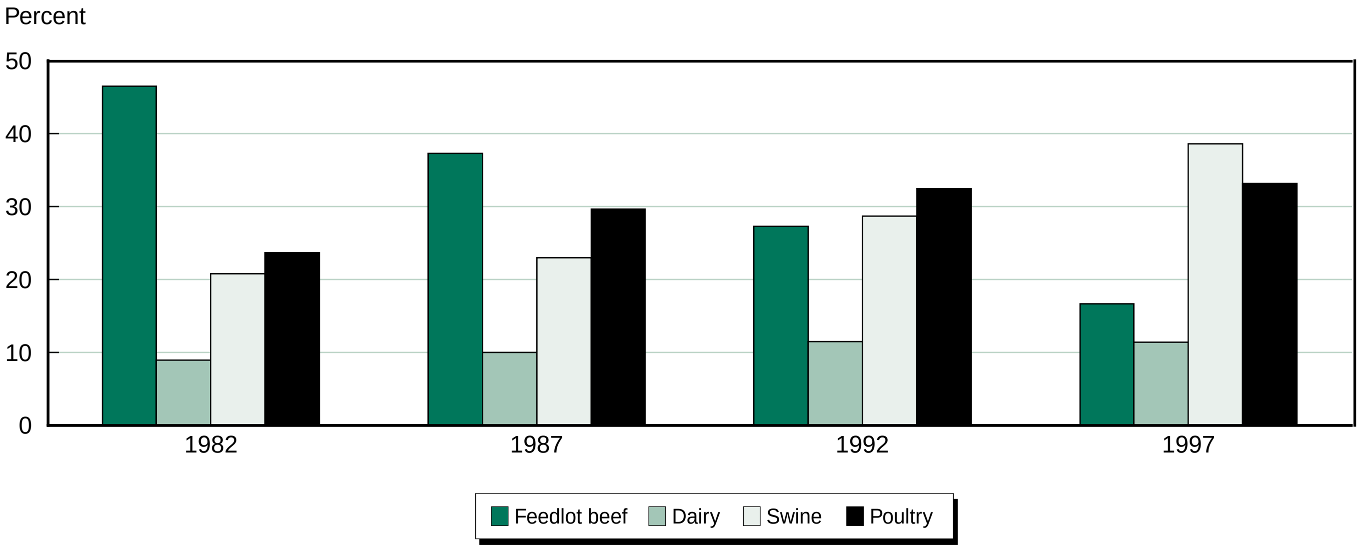
The national figures describe a 50-percent decline in total confined livestock farms and increasing animal numbers, resulting in greater concentration. However, confined livestock operations are not evenly distributed across the Nation. We use a regional assessment of county data to provide more detail and to demonstrate geographic shifts in the industry. The regional presentation is based on ERS Farm Resource Regions, which depict geographic specialization in production of U.S. farm commodities (USDA, 2000b).

The Heartland experienced the greatest decline in the number of confined livestock farms (96,000) over 1982-97. Despite this 56-percent decline, the Heartland contained 74,000 confined animal farms in 1997, 35 percent of the Nation's total (fig. 5). The Northern Crescent, while starting with fewer confined animal farms, lost 50,000 from 1982 to 1997, a 44-percent decline. Still, it contained 63,000 confined livestock farms, 30 percent of the U.S. total in 1997. All other regions experienced declines of 40 to 60 percent.

Animal unit numbers do not follow the farm trend of consistent declines (fig. 6). The Prairie Gateway and Southern Seaboard increased by 2 million (40 percent)

Figure 4

Potential CAFO farms, by animal type, 1982-97



Source: Economic Research Service, USDA.

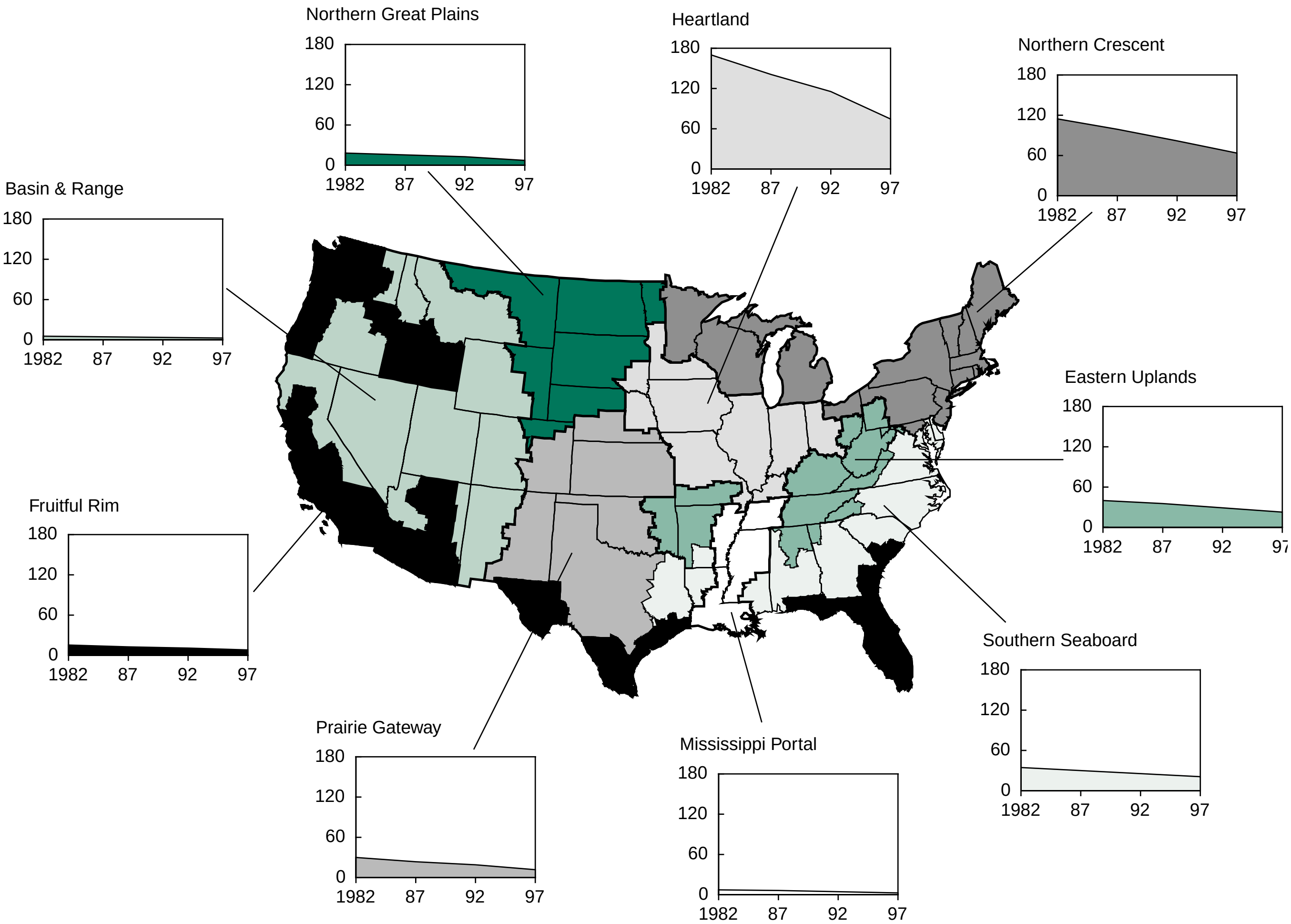
and 1.7 million (70 percent) animal units over 1982-97. These increases were partially offset by declines in the Northern Crescent and Heartland of 17 and 6 percent. All other regions increased their confined AU numbers or showed just slight declines. In 1997, the Heartland had almost 25 percent of the Nation's AU, followed by the Prairie Gateway with 21 percent and the Northern Crescent with 17 percent.

Even regional trends can mask some important local differences, evident by county (fig. 7).[10] The greatest numbers of confined animals are located in a band from southeastern New Mexico through the Plains States to eastern Nebraska and then eastward through Iowa to the Great Lakes. Other areas with large numbers of confined animals include the Northeast, mid-Atlantic, California's southern Central Valley, western Arkansas, and far Northwest areas. Almost every State has at least 1 county with more than 10,000 animal units (fig. 7).

Almost every State has at least 1 county with more than 10,000 animal units.

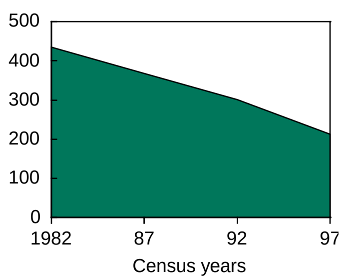
[10] Some counties are shown aggregated to protect confidentiality, but numbers of counties refer to actual counties. The maps used in this report have a visual bias caused by the size variability among counties. Large counties and counties combined to prevent disclosure tend to be placed in higher classes because there are more units in large counties, often concentrated in one part of the county. Maps of units per unit area correct this bias, but do not convey information on magnitudes.

Figure 5
Confined animal farms by ERS region, 1982-97



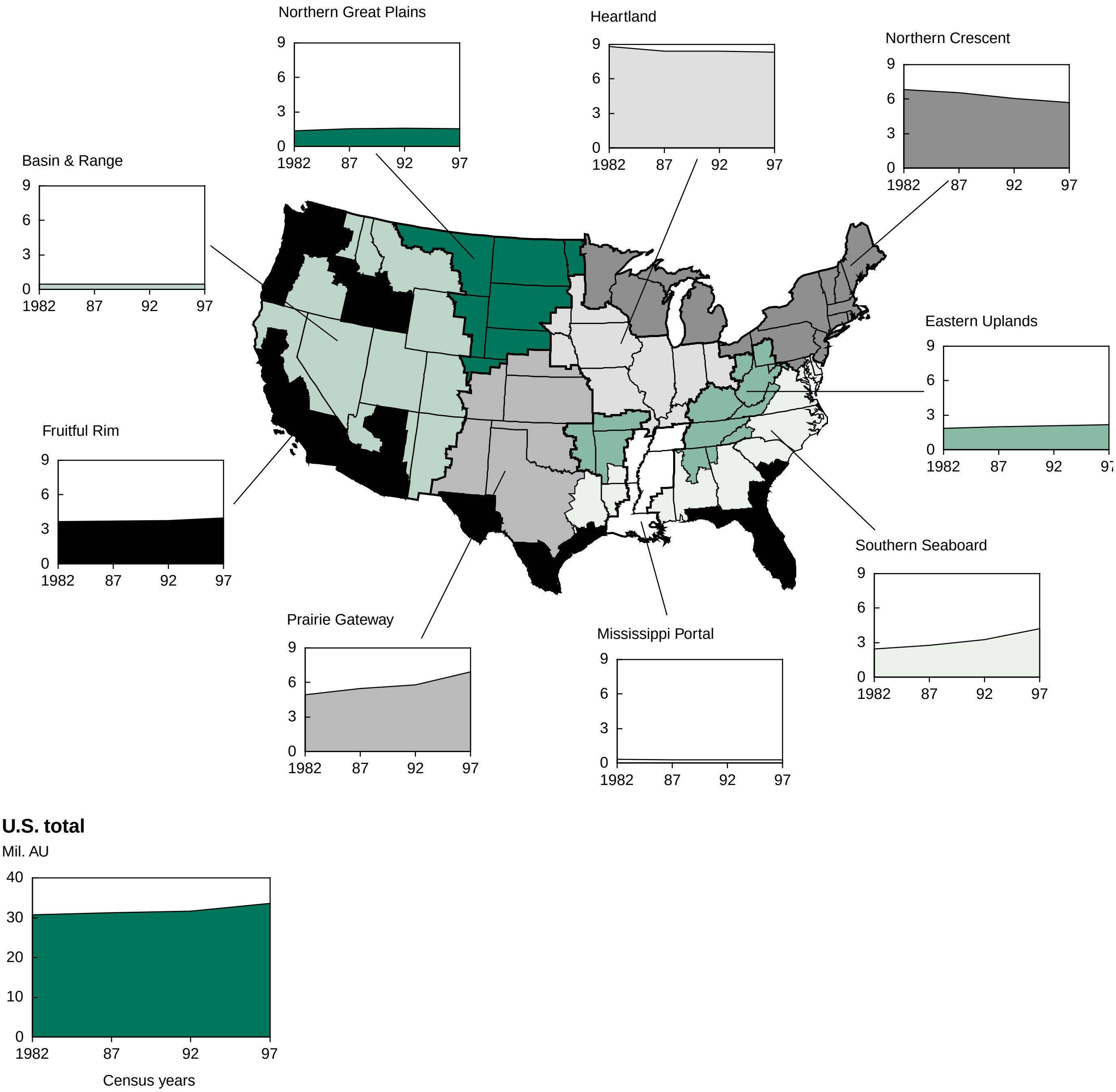
U.S. total

1,000 farms



Source: Economic Research Service, USDA.

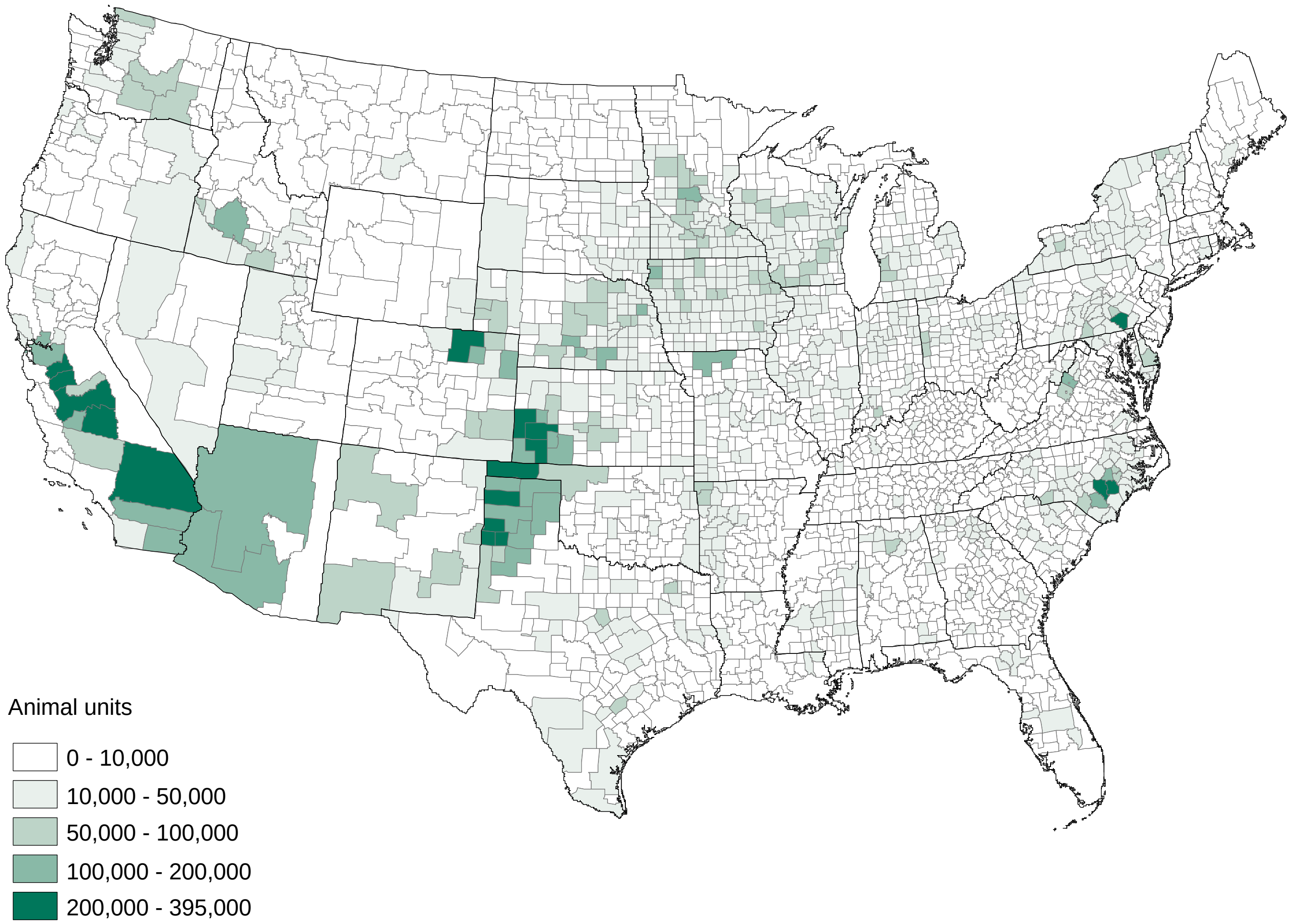
Figure 6
Confined animal units by ERS region, 1982-97



Source: Economic Research Service, USDA.

Figure 7

Location of confined animals, 1997



Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

Land's Capacity To Use Manure Nutrients

The clustering of confined animals does not necessarily mean that manure nutrients will contribute to water quality problems. It is the balance of manure production and crop nutrient use that often determines movement of nutrients to water bodies. A national overview shows how total manure production and potential excess differ by animal type. County-level data show how policies may need to be tailored to local conditions.

Nationally, Poultry Manure a Growing Source of Excess Nutrients

Confined livestock produced an estimated 1.23 million tons of recoverable nitrogen and 0.66 million tons of recoverable phosphorus in 1997.[11] The 73 million acres of cropland and permanent pasture controlled by operators of confined animal operations were estimated to have the capacity to assimilate only 40 percent of the nitrogen and 30 percent of the phosphorus (table 2). Growth in the number of confined AU from 1982 to 1997 increased the quantities of nutrients produced by about 20 percent. Meanwhile, the amount of land on livestock and poultry farms relative to the nutrients produced diminished, resulting in more than a 20-percent increase in potential excess onfarm manure nutrients. The increase in excess nutrients over the 15-year period is one reason for the increased policy attention directed toward confined livestock operations.

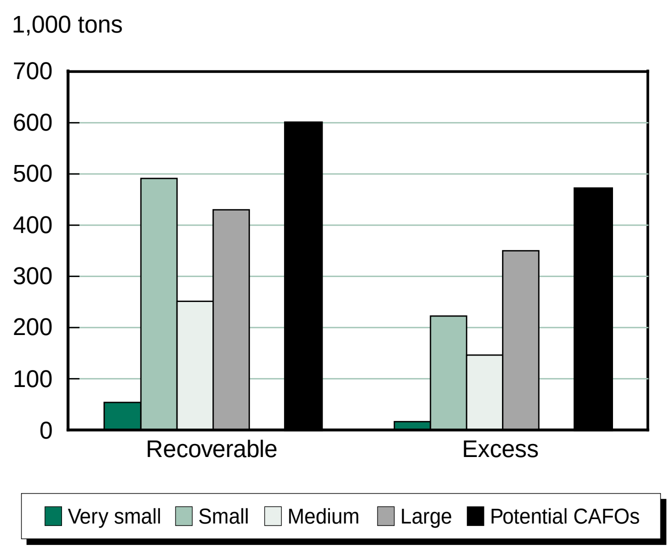
Most farms have the potential to control manure nutrient movement to water sources with proper nutrient management. Across all animal types and size classes, 78 percent of confined animal farms have the assimilative potential to use all the manure nitrogen produced on the farm, 69 percent of farms for phosphorus (table 2). This estimate of the physical feasibility of using manure nutrients at agronomic rates on land does not imply that all producers are doing so, or that it is an economically feasible production option. A farm with the potential assimilative capacity to use all the manure onfarm just means that land application is a viable physical strategy and the producer has control over the entire decision process. The economic viability depends on the costs of adjusting the farm's nutrient plan to include manure, transportation distance and costs, application technology and costs, and savings from fertilizer purchases.

On the 22 percent of farms that produce excess nitrogen and the 31 percent with excess phosphorus, the inability to assimilate all the manure nutrients affects operations of all sizes. In 1997, about 20 percent of the very small farms (<50 AU) did not have the capacity to use all the phosphorus produced on the farm (15 percent for nitrogen). The share of large farms (>1,000 AU) that produce more nutrients than can be used onfarm increases to 72 percent of farms for nitrogen and to over 90 percent of farms for phosphorus.

Small farms (50-299 AU) produce more recoverable nitrogen than any other size class, almost 500,000 tons in 1997 (fig. 8), down from 534,000 tons in 1982. These farms produce about 30 percent of the excess onfarm nitrogen, almost all from poultry farms. Small poultry farms are currently not covered by NPDES permit requirements, except under special circumstances. These farms, along with most others, are eligible for voluntary USDA assistance with manure management through the Environmental Quality Incentives Program and Conservation Technical Assistance Program. Very small farms produce only about 2 percent of the national total of excess onfarm nutrients.

Nutrient production grew significantly from 1982 to 1997 within the medium and large animal operations,

Figure 8
Recoverable and excess manure nitrogen, by size class, 1997



Source: Economic Research Service, USDA.

[11] For comparison, commercial fertilizer use was 12.4 million tons for nitrogen and 4.6 million tons for phosphorus in 1997 (USDA, 2000a).

Table 2—Farms, animal units (AU), land base, and nutrients by confined animal facility size class, 1997

Animal type[1]	Farm size class[2]: Very small (<50 AU)		Small (50-299 AU)		Medium (300-999 AU)		Large (>1,000 AU)		Total	Potential CAFOs[4]	
	Number	*%*[3]	*Number*	*%*	*Number*	*%*	*Number*	*%*	*Number*	*Number*	*%*
Feedlot beef:											
Farms	37,975	81	7,082	15	1,226	3	871	2	47,154	1,897	4
Animal units (1,000)	487	5	734	8	635	7	7,463	80	9,318	8,033	86
Land base (1,000 acres)	16,627	66	6,295	25	1,483	6	938	4	25,343	2,200	9
Nitrogen available (tons)	10,180	5	15,356	8	13,286	7	156,120	80	194,941	168,057	86
Nitrogen excess (tons)	4,741	3	2,091	1	2,411	2	131,082	93	140,325	133,371	95
Phosphorus available (tons)	6,632	5	10,004	8	8,655	7	101,709	80	127,000	109,486	86
Phosphorus excess (tons)	4,392	4	2,501	2	3,062	3	96,008	91	105,963	98,890	93
Dairy:											
Farms	17,981	21	62,536	72	4,534	5	1,303	2	86,354	1,296	2
Animal units (1,000)	583	6	5,344	54	1,836	19	2,135	22	9,899	2,130	22
Land base (1,000 acres)	3,188	12	20,693	75	2,808	10	824	3	27,512	821	3
Nitrogen available (tons)	18,721	6	171,615	54	58,950	19	68,563	22	317,849	68,384	22
Nitrogen excess (tons)	1,799	3	11,352	17	15,291	22	40,041	58	68,483	39,904	58
Phosphorus available (tons)	7,184	6	65,852	54	22,620	19	26,309	22	121,965	26,240	22
Phosphorus excess (tons)	1,236	3	9,262	22	9,600	23	21,918	52	42,016	21,862	52
Swine:											
Farms	35,646	56	22,932	36	4,134	6	1,011	2	63,723	4,374	7
Animal units (1,000)	612	7	2,656	32	2,113	26	2,852	35	8,233	4,670	57
Land base (1,000 acres)	11,696	43	12,118	45	2,525	9	566	2	26,905	2,647	10
Nitrogen available (tons)	10,136	7	44,648	33	35,928	26	46,327	34	137,038	78,375	57
Nitrogen excess (tons)	4,627	7	10,054	14	18,216	26	36,537	53	69,434	53,270	77
Phosphorus available (tons)	10,242	7	45,043	33	36,202	26	46,913	34	138,400	79,083	57
Phosphorus excess (tons)	4,258	5	14,648	17	25,390	29	43,893	50	88,189	67,148	76
Poultry:											
Farms	13,158	37	18,783	52	3,312	9	688	2	35,941	3,763	10
Animal units (1,000)	202	3	2,433	40	1,651	27	1,833	30	6,118	3,019	49
Land base (1,000 acres)	1,692	36	2,113	45	660	14	206	4	4,671	730	16
Nitrogen available (tons)	21,402	4	264,540	46	138,414	24	152,080	26	576,436	278,244	48
Nitrogen excess (tons)	14,261	3	211,014	44	115,761	24	142,611	29	483,646	250,044	52
Phosphorus available (tons)	9,463	3	114,927	42	72,026	26	80,515	29	276,932	136,030	49
Phosphorus excess (tons)	7,157	3	98,090	39	67,719	27	79,527	31	252,493	130,343	52
Total over all types:											
Farms	85,575	40	109,856	52	13,560	6	3,970	2	212,961	11,242	5
Animal units (1,000)	1,612	5	11,105	33	6,387	19	14,463	43	33,568	17,981	54
Land base (1,000 acres)	24,031	33	38,905	53	7,644	10	2,651	4	73,231	6,280	9
Nitrogen available (tons)	53,469	4	491,267	40	251,625	21	429,903	35	1,226,264	599,007	49
Farms with excess nitrogen	13,228	28	24,407	52	6,463	14	2,886	6	46,984	7,483	16
Nitrogen excess (tons)	15,838	2	222,776	30	146,244	20	349,547	48	734,405	470,843	64
Phosphorus available (tons)	29,067	4	233,364	35	141,935	21	259,932	39	664,298	354,331	53
Farms with excess phosphorus	17,133	26	35,514	54	9,566	14	3,718	6	65,931	9,813	15
Phosphorus excess (tons)	8,540	2	112,372	24	100,252	22	241,160	52	462,323	313,243	68

[1] Not additive across animal types, since farms may have more than one type. Excess values summed over farms with an excess. Land base is cropland plus pastureland.
[2] Size classes were based on the total numbers of animals on the farm. Data are for confined operations only.
[3] Percent of total farms, not the percent over all animal types.
[4] Potential CAFOs are all the farms in the large and part of the farms in the medium farm size classes.

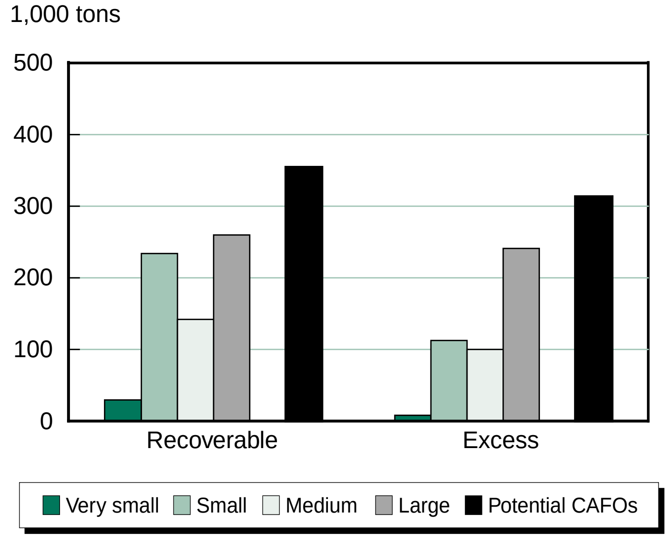
Source: Economic Research Service, USDA.

due to the increase in both farms and AU in these size classes. Recoverable nitrogen production on medium-sized operations increased by 68 percent to 250,000 tons in 1997 and on large farms by over 100 percent to 430,000 tons. Excess onfarm nitrogen increased by 83 percent to 146,000 tons on medium-size farms and by 104 percent to 350,000 tons on large farms in 1997. The 6 percent of livestock farms in the medium size class accounted for 20 percent of the excess nitrogen in 1997, and large farms (2 percent of the total number of farms) accounted for almost half of the excess onfarm nitrogen. Estimated increases in recoverable phosphorus were similar to those for nitrogen. In 1997, medium-size farms accounted for 22 percent and large farms for over half of the excess onfarm phosphorus (fig. 9, table 2).

The production of more excess onfarm nutrients in larger size classes resulted from the shift to more concentrated production units, more specialized management, and the separation of land from livestock.

The production of more excess onfarm nutrients in larger size classes resulted from the shift to more concentrated production units, more specialized management, and the separation of land from livestock. Available cropland and pastureland controlled by confined operations on which to spread manure declined from an average of 3.6 acres per animal unit in 1982 to 2.2 acres per AU in 1997. While very small confined operations had an average of about 15 acres of land on which to spread the manure from each animal unit, large operations were limited to 0.2 acre in 1997 (table 3).[12] These ratios changed little by size group from 1982 to 1997, which implies that nutrient management problems on the average farm of any size group were no worse in 1997 than in 1982. The aggregate problem is much greater, however, because there are now many more large farms with excess nutrient production.

Figure 9
Recoverable and excess manure phosphorus, by size class, 1997



Source: Economic Research Service, USDA.

In 1997, calculated total recoverable manure nitrogen exceeded 1.2 million tons, and 60 percent of that nitrogen exceeded the amount that could be assimilated on the farms that produced it (fig. 10). Crop uptake and pastureland applications on confined livestock farms, with no transfer to other farms, could use only 40 percent of the recoverable manure nitrogen, assuming no commercial fertilizer use. Poultry generated 47 percent of the total recoverable nitrogen and own-farm use could absorb only 8 percent of that amount. The 39 percent of recoverable poultry nitrogen above farm assimilative capacity accounts for 484,000 tons, or 64 percent, of the total excess onfarm nitrogen (fig. 10). Poultry operations produced more excess nitrogen than other animal types because poultry manure contains more nitrogen per AU and poultry operations typically have a much smaller land area over which to spread manure relative to other animal types.

Dairy produced 26 percent of recoverable nitrogen in 1997, and 21 percent could be used on the farm. Thus, dairy operations produced only 5 percent of nitrogen in excess of farm needs, or 9 percent of total excess onfarm nitrogen. Feedlot beef farms produced 18 percent and swine 9 percent of the excess nitrogen (fig. 10).

The share of total recoverable nitrogen in excess of farm needs increased by 17 percentage points from

[12] Based on average nutrient production across all animal types and average uptake over all confined animal farm acres, it required 0.9 acre per AU to apply the nitrogen produced at agronomic rates and 3.7 acres per AU for phosphorus in 1997. This estimate is based on only confined livestock farms and includes the influence of farms with no land on which to spread manure.

1982 to 1997. This increase in excess nutrients implies a growing need to move nutrients off the farm where they are produced. In a species-by-species comparison, 11 points of the 17-percentage-point increase in excess onfarm nutrients occurred in poultry production. A slightly larger share of the beef, dairy, and swine nitrogen was in excess in 1997 compared with 1982.

Poultry operations produced more excess nitrogen than other animal types because poultry manure contains more nitrogen per AU and poultry operations typically have a much smaller land area over which to spread manure relative to other animal types.

Confined livestock operations were even less able to fully use phosphorus on the farm than they were nitrogen. In 1997, 70 percent of the 664,000 tons of recoverable manure phosphorus was in excess of onfarm uptake needs (fig. 11). As with nitrogen, dairy farms were able to use a greater share of the phosphorus produced relative to other animal types, and poultry produced the most recoverable phosphorus. However, the relative share of the poultry contribution was less than for nitrogen, with about half of the excess onfarm phosphorus. Feedlot beef farms generated 22 percent and swine 18 percent of the excess onfarm phosphorus. The largest increases in excess onfarm phosphorus from 1982 to 1997 occurred in poultry, with about 10 percent more of the poultry phosphorus in excess in 1997 than in 1982. The share of swine-produced excess onfarm phosphorus increased by about 7 percent, with little change in dairy and beef.

Potential CAFO Nutrient Production

Farms of sufficient size to need an NPDES permit under the Clean Water Act deserve special attention since they may be currently regulated. Our estimation procedure for determining a concentrated animal feeding operation (CAFO) is based on current regulations, considering only the number of animals without exemptions.

In 1997, the 5 percent of farms identified as potential CAFOs were the source of about half of the recoverable nutrients and two-thirds of the excess onfarm nitrogen and phosphorus from all confined livestock operations (table 2, figs. 8 and 9). CAFOs generated 120 percent more recoverable nitrogen and phosphorus in 1997 than in 1982, with similar increases for excess onfarm nitrogen and phosphorus.

Excess Nutrients Greatest and Growing in Southern Seaboard

National figures show significant quantities of excess manure nutrients. However, as with confined livestock operations, manure nutrients are not evenly distributed across the Nation. A regional assessment of county-level data provides more detail and demonstrates geographical shifts in the livestock industry.

The amount of total recoverable manure nitrogen declined from 1982 to 1997 in the Northern Crescent and slightly in the Basin and Range (fig. 12). The amount increased in all other regions, with the greatest increase in the Southern Seaboard in both absolute (95,000 tons) and relative terms (60 percent).

In 1997, the Southern Seaboard produced the most recoverable manure nitrogen (256,000 tons, over 20 percent of the Nation's total) of any region—despite having about half the animal units of the Heartland (fig. 6). (The Southern Seaboard also had fewer AU

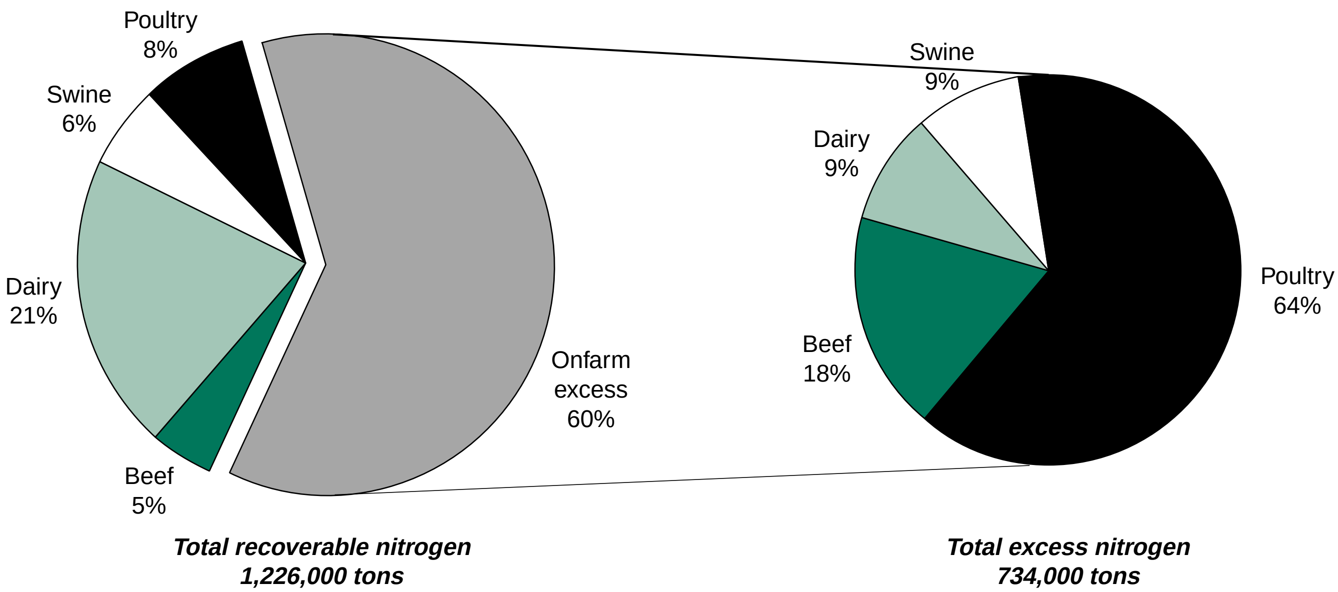
Table 3—Average onfarm acres per animal unit,[1] by size class, 1982 and 1997

Year	Very small < 50 AU	Small 50-300 AU	Medium 300-1,000 AU	Large > 1,000 AU	Potential CAFO[2]
			Onfarm acres per animal unit		
1982	11.27	3.57	1.31	0.19	0.39
1997	14.91	3.50	1.20	0.18	0.35

[1] Based on 1 AU equaling 1,000 pounds of live animal weight.
[2] Potential CAFOs were based on animal numbers specified in the Clean Water Act.

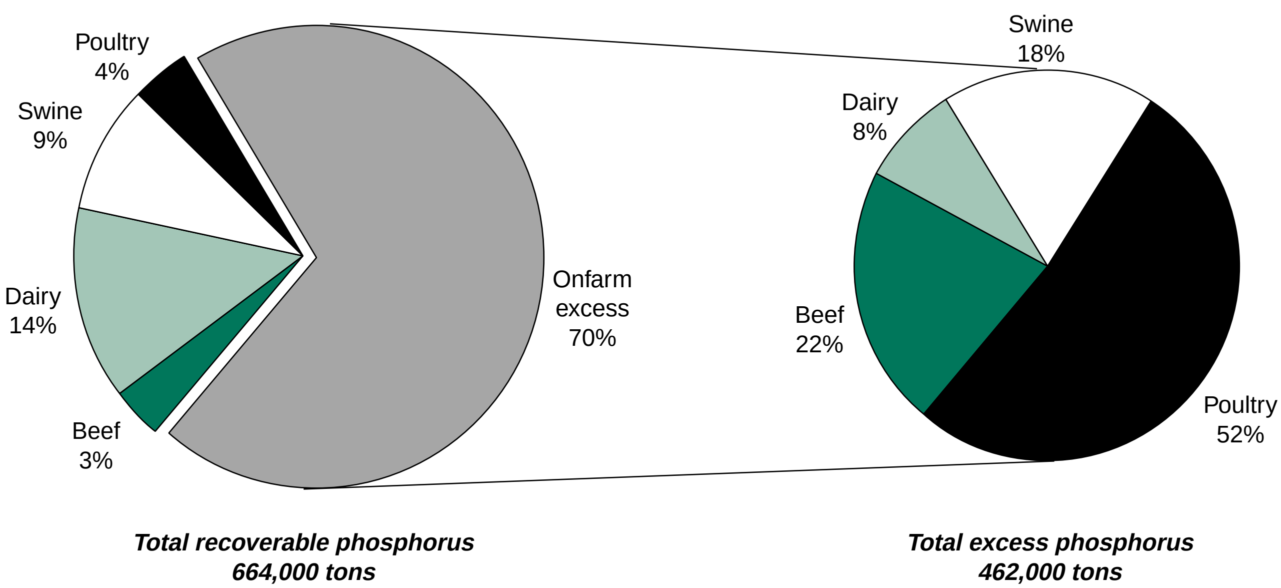
Source: Economic Research Service, USDA.

Figure 10
Onfarm manure nitrogen and excess manure nitrogen, by animal type, 1997



Source: Economic Research Service, USDA.

Figure 11
Onfarm manure phosphorus and excess manure phosphorus, by animal type, 1997



Source: Economic Research Service, USDA.

than the Prairie Gateway and Northern Crescent.) Nutrient production per AU differs by animal type, with some types of poultry producing up to five times as much nitrogen and three times as much phosphorus as feedlot beef per AU. While both the Heartland and Southern Seaboard regions specialize in swine, the Southern Seaboard has more poultry and fewer bovines, resulting in greater recoverable nutrients from fewer AU.

Manure nitrogen in excess of the production farm's ability to assimilate it increased in all regions between 1982 and 1997, with the largest tonnage increases in the Southern Seaboard (almost 90,000 tons) followed by the Heartland, Prairie Gateway, and Eastern Uplands, each with almost 50,000 tons (fig. 12). The Heartland experienced the greatest percentage increase in excess nitrogen (130 percent), indicating significant concentration in the livestock sector and an increasing need to move manure nutrients off the production farm. In the Northern Crescent, excess nitrogen quantities increased over the period despite the decline in recoverable nitrogen production, an indication of increased animals relative to assimilative land. Other major regions (Eastern Uplands, Prairie Gateway, and Southern Seaboard) had 70 to 80 percent increases in excess nitrogen over 1982-97. In 1997, the Southern Seaboard produced the most excess nitrogen (200,000 tons, over 27 percent of the Nation's total excess) of any region; its farms have among the smallest area per AU on which to apply manure.

Manure nitrogen in excess of the production farm's ability to assimilate it increased in all regions between 1982 and 1997, with the largest tonnage increases in the Southern Seaboard.

Recoverable manure phosphorus and excess manure phosphorus follow a temporal pattern similar to nitrogen (fig. 13). In the Heartland, the large number of animals but fewer AU per farm results in large amounts of recoverable manure phosphorus with little tonnage increase. However, the Heartland exhibits increasing concentration in its livestock sector, as it had the greatest percentage increase in onfarm excess nutrients. The Southern Seaboard produced 25 percent of the Nation's excess phosphorus, consistent with the region's poultry and swine concentration.

The recoverable manure nitrogen per county closely follows the location of animal units, though not directly because recoverable nitrogen varies by animal type (fig. 14). For example, the greater recoverable nutrients per animal unit for broiler poultry result in relatively high quantities of manure nitrogen in parts of Georgia, Alabama, and Mississippi.[13]

Figure 15 shows the share of recoverable nitrogen in excess of onfarm crop and pastureland needs in 1997. Shaded counties are those in which there is at least 1 ton of excess manure nitrogen produced on confined livestock and poultry farms somewhere in the county. This does not imply that manure nitrogen is necessarily contributing to water quality and other environmental problems. Figure 15 does indicate that manure movement off confined livestock farms is necessary to avoid excess nitrogen accumulation in 75 percent of the Nation's counties.

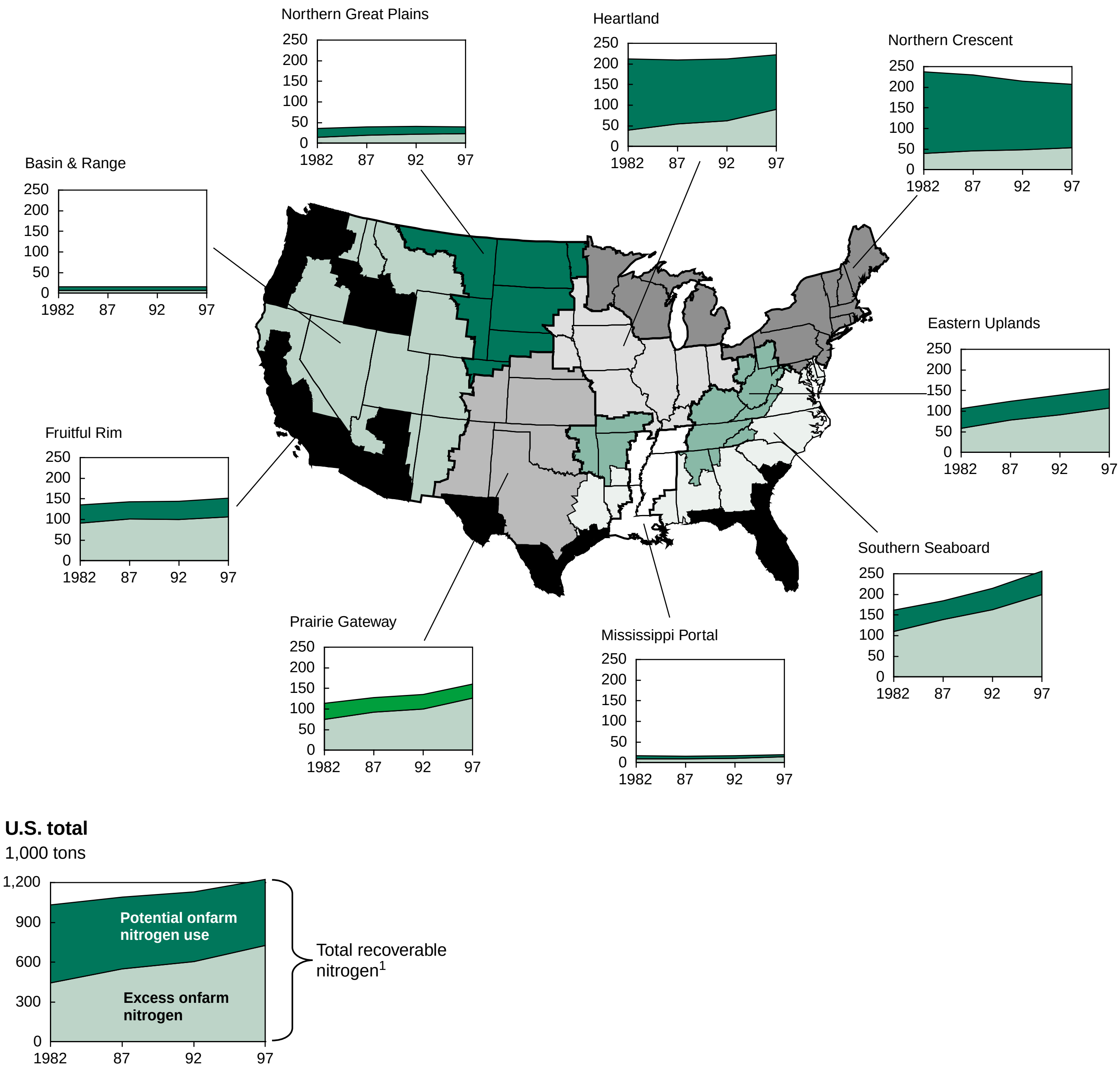
The darker the shading in figure 15, the greater the share of manure nitrogen in excess of onfarm needs, assuming no commercial fertilizer applications. Generally, excess onfarm manure nitrogen is greatest in counties with the most confined animals (fig. 6). As with recoverable nitrogen, northern Alabama and Georgia have levels of excess nitrogen beyond that suggested by AU numbers because poultry manure has a high nitrogen content, poultry is the dominant animal there, and poultry operations do not control as much land for spreading manure. Conversely, northeastern Iowa and southern Wisconsin had among the highest concentration of animals, but have less excess nitrogen than might be expected because of more available land and lower nitrogen production per AU. Again, a large quantity of excess onfarm nitrogen does not indicate an environmental problem; it does indicate where manure must move off-farm to avoid an overapplication of nitrogen.

Manure nitrogen may be used in an agronomic manner if cropland or pastureland on other farms in the "excess" county (or adjacent counties) is available for application. Figure 15 indicates counties where manure would have to move from confined livestock farms to other farms or counties. Not all crop or pastureland in

[13] Ranked the number 1, 3 and 5 States, respectively, in broiler production in the 1997 Census of Agriculture (USDA, 1999b).

Figure 12

Recoverable and excess onfarm manure nitrogen from confined animal by ERS region, 1997

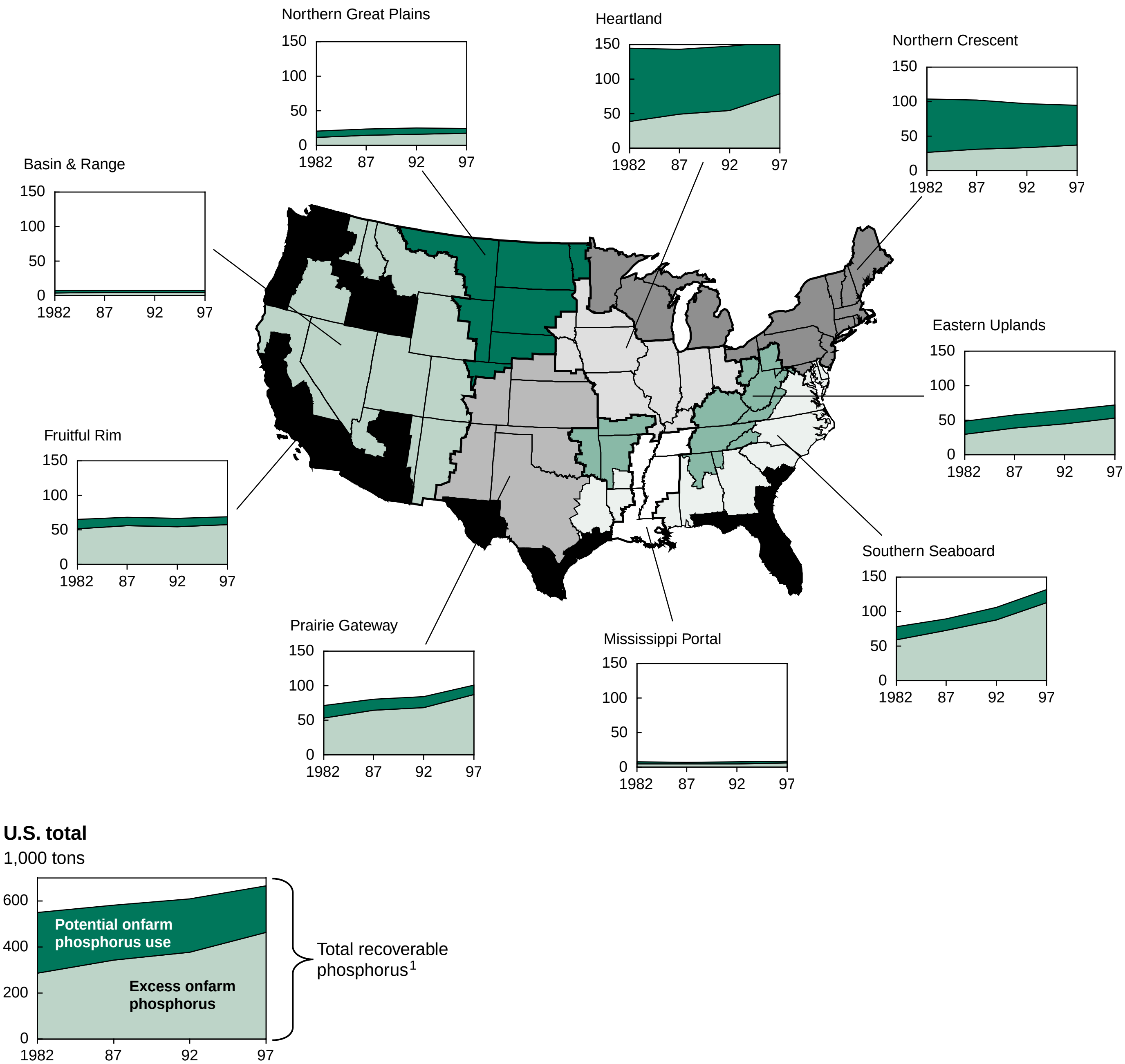


[1] The chart height represents the total recoverable manure nutrient for the 1982, 1987, 1992 and 1997 census years. All regions are drawn on the same scale. The darker area on top represents the onfarm nutrient assimilation potential, and the lighter lower part of each chart presents the nutrient excess of the production farm's assimilation potential.

Source: Economic Research Service, USDA.

Figure 13

Recoverable and excess onfarm manure phosphorus from confined animal by ERS region, 1997



[1] The chart height represents the total recoverable manure nutrient for the 1982, 1987, 1992 and 1997 census years. All regions are drawn on the same scale. The darker area on top represents the onfarm nutrient assimilation potential, and the lighter lower part of each chart presents the nutrient excess of the production farm's assimilation potential.

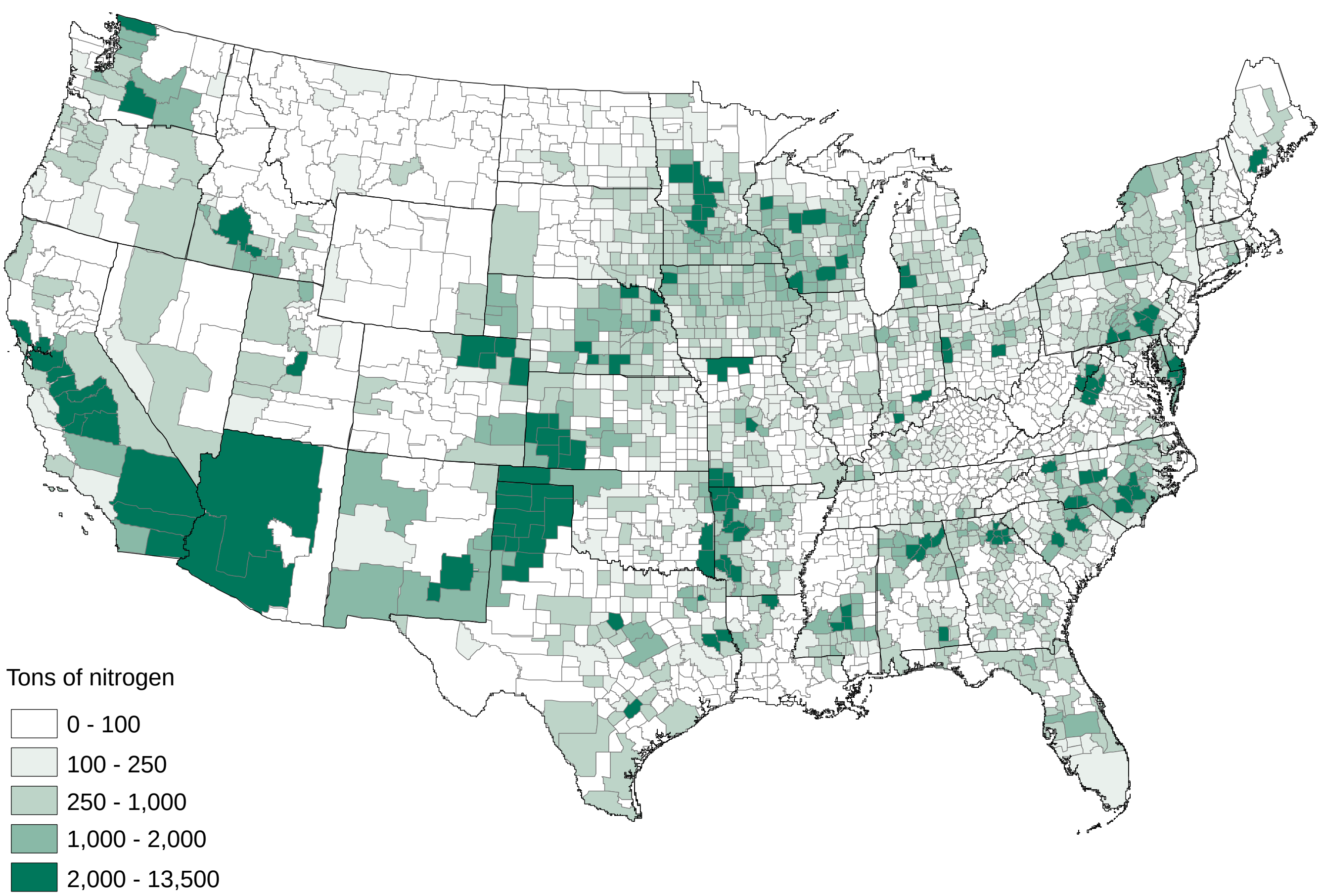
Source: Economic Research Service, USDA.

the county will be available for manure application for many reasons, including transportation costs, timing of applications relative to farming operations, concerns about odors, unclear liability rules for environmental discharges, and producer preference. For example, a 1996 survey showed that 92 percent of corn acres in the Southeast did not receive manure as a nutrient source, possibly indicating a preference of crop producers not to use it (Christensen *et al*., 1998).

Manure movement off confined livestock farms is necessary to avoid excess nitrogen accumulation in 75 percent of the Nation's counties.

We estimate that most U.S. counties (78 percent) need to move manure phosphorus from at least some confined animal farms to avoid phosphorus accumulation (fig. 16). As with nitrogen, excess onfarm manure phosphorus exceeds 75 percent of total manure phosphorus in areas with large numbers of animals (fig. 6).

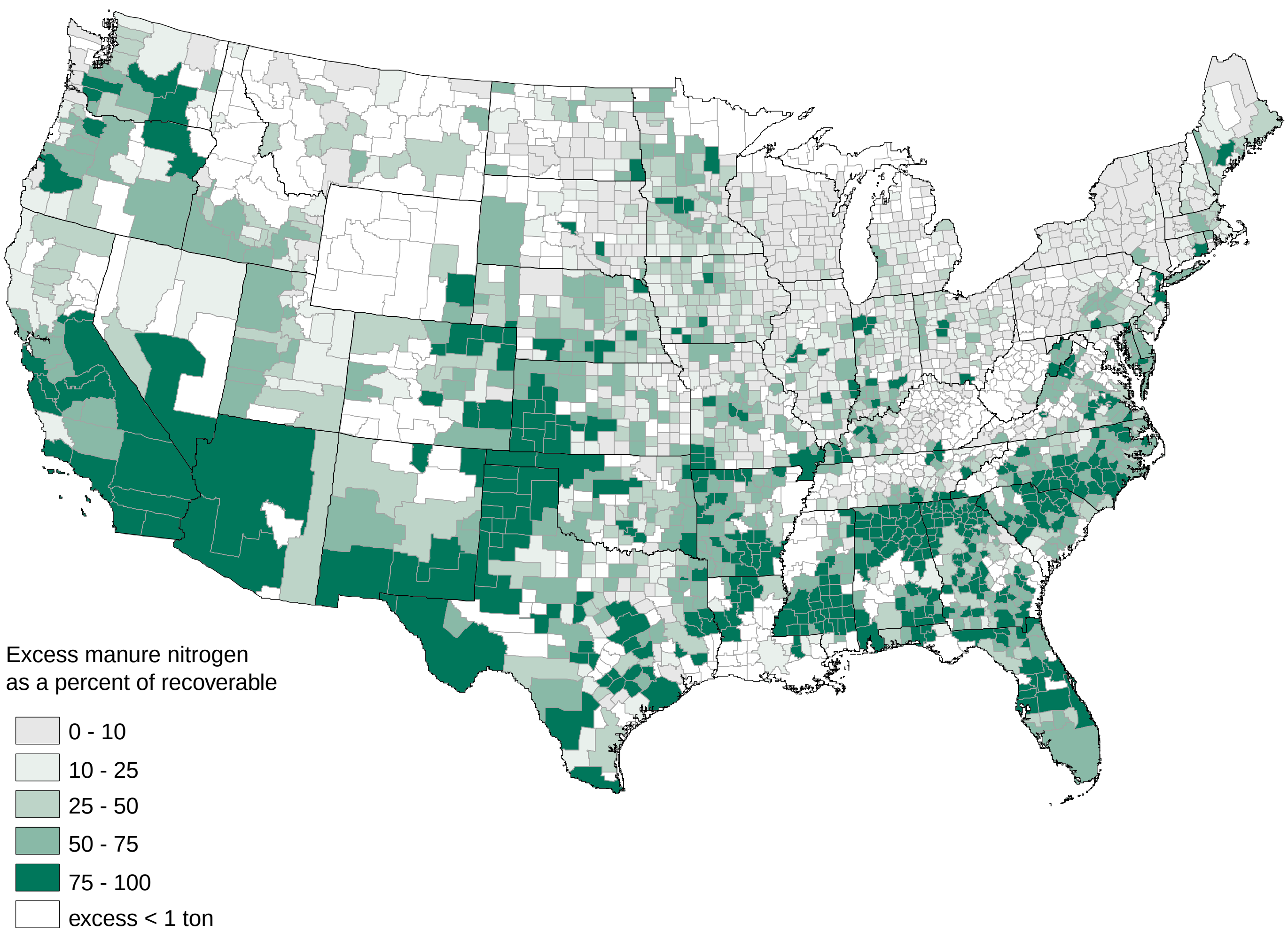
Figure 14
Recoverable manure nitrogen by county, 1997



Some counties are combined to meet disclosure criteria.
Source: Economic Research Service, USDA.

Figure 15

Excess onfarm manure nitrogen as a share of recoverable nitrogen, 1997

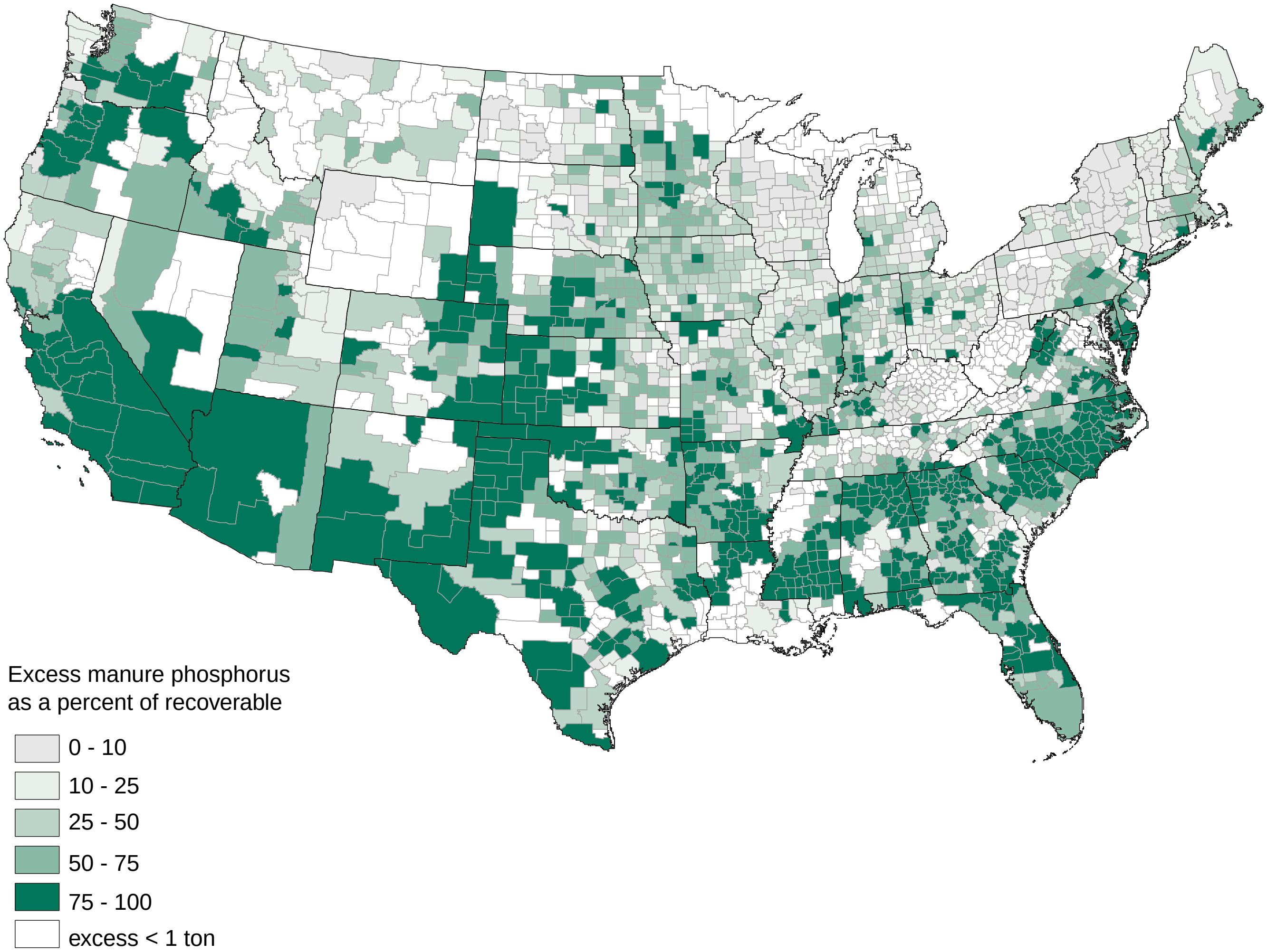


Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

Figure 16

Excess onfarm manure phosphorus as a share of recoverable phosphorus, 1997



Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

Most Counties Can Absorb Excess Nutrients of Individual Farms

We use the county nutrient analysis to illustrate where onfarm nutrient management or nearby cropland may not be sufficient to absorb manure nutrients. These areas may require alternatives to land application and also represent the areas at greatest risk of manure-based, water quality problems. Excess nutrients at the county level were estimated by summing all the onfarm manure nutrient production and comparing it to the potential assimilative capacity of all farms in the county.

In most counties, there is adequate land to physically apply manure nutrients in excess of the production farm's assimilative capacity. Within-county transfers could use as much as 46 percent of excess manure nitrogen and 51 percent of manure phosphorus, without considering producers' willingness to accept the manure or the costs (or benefits) of using manure on many operations where it is not now used.

In 155 counties (5 percent), the estimated manure nitrogen produced on confined livestock and poultry farms could provide at least half the entire county's total nitrogen need. This includes 68 counties where manure nitrogen levels exceed the assimilative capacity of all the county's crop and pasture land (fig. 17). These counties are located primarily in North Carolina, northern Georgia, Alabama, central Mississippi, and western Arkansas, and California.

In 155 counties (5 percent), the estimated manure nitrogen produced on confined livestock and poultry farms could provide at least half the entire county's total nitrogen need. This includes 68 counties where manure nitrogen levels exceed the assimilative capacity of all the county's crop and pasture land.

With such a large share of nitrogen available from confined animal manure, it will be increasingly difficult to find land available for manure spreading in the center of these areas.

Many more counties (152) have surplus phosphorus than have surplus nitrogen (fig. 18). This pattern holds for counties where manure phosphorus is at least half of the county's total need—337 counties for phosphorus relative to 155 for nitrogen. These are areas where it may be difficult to find enough land within the county for spreading manure to avoid phosphorus accumulation in the soil. Areas of particular concern are eastern North Carolina, northern Georgia, northern Alabama, western Arkansas, central California, and western Washington. One implication of the greater

Many more counties have surplus phosphorus than have surplus nitrogen . . .regulations limiting phosphorus applications will be more difficult for producers to meet than those based on nitrogen alone.

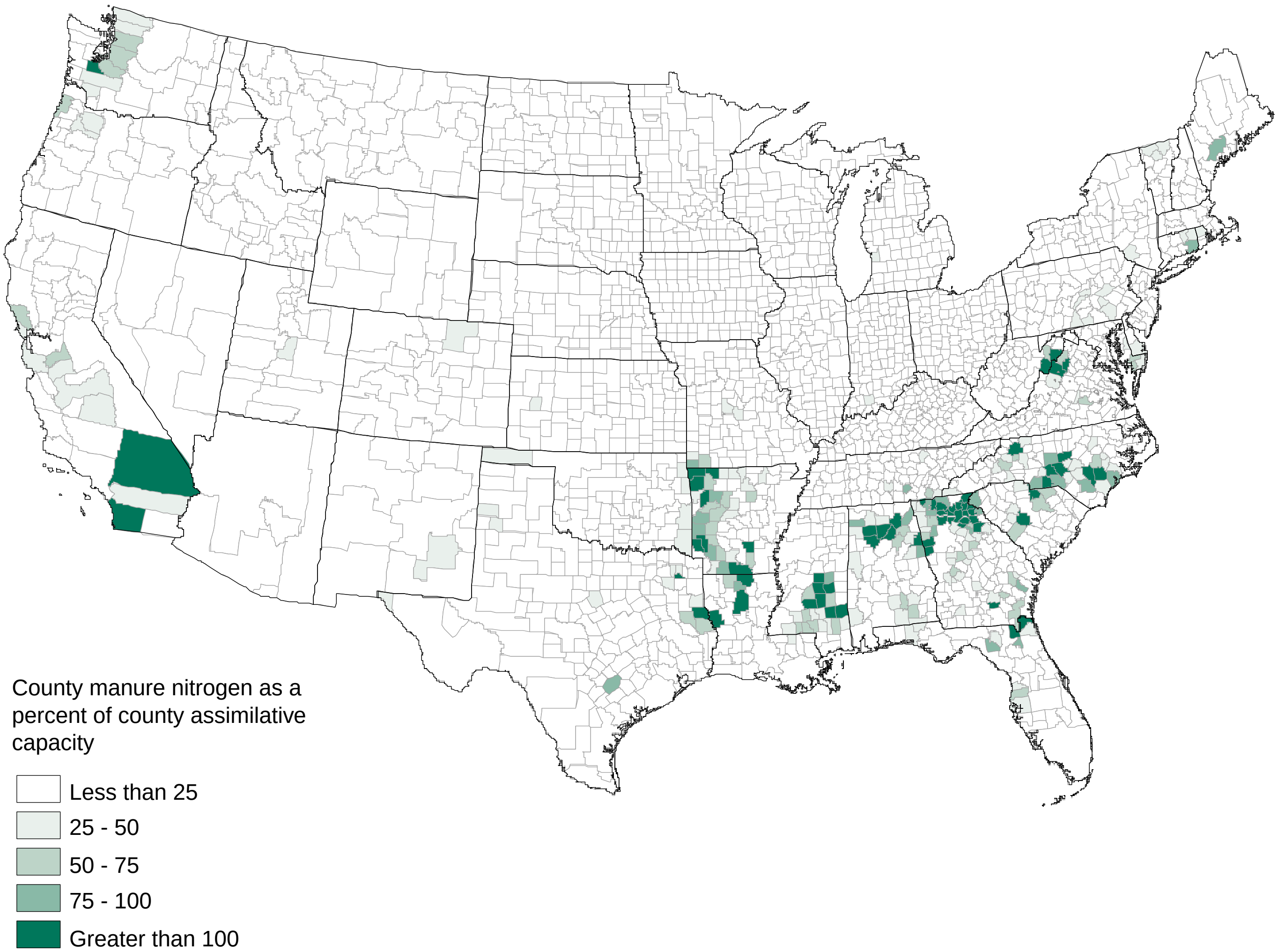
number of counties where manure phosphorus exceeds half the total county's need is that regulations limiting phosphorus applications will be more difficult for producers to meet than those based on nitrogen alone.

Areas with a regional excess of manure nutrients have the greatest need for off-farm alternatives to land application, such as treatment to reduce the volume (composting) or industrial processes that can use manure as a feedstock (fertilizer manufacturing and power generation). The conditions that will define successful technical and viable economic processes to handle manure with centralized treatment facilities need more exploration, as evidenced by the relatively few centralized facilities currently in operation. In addition to the placement of facilities in animal production areas, the location of centralized treatment facilities may influence the size, location, and structure of the animal feeding industry.

Examining counties on the basis of their nutrient-to-assimilative-capacity ratio indicates those counties that produce a disproportionate share of excess nutrients. While only 2 percent of the counties had a nitrogen ratio greater than 1 in 1997, these counties produced 14 percent of the total recoverable manure nitrogen and 20 percent of the excess manure nitrogen (table 4). The 5 percent of counties with a phosphorus ratio greater than 1 produced 19 percent of the recoverable phosphorus and 23 percent of the Nation's total excess phosphorus in 1997. Alternatively, counties with nitrogen ratios of less than 0.25 account for 90 percent of all counties, and while individual farms may need

Figure 17

Excess manure nitrogen as a share of county assimilative capacity, 1997

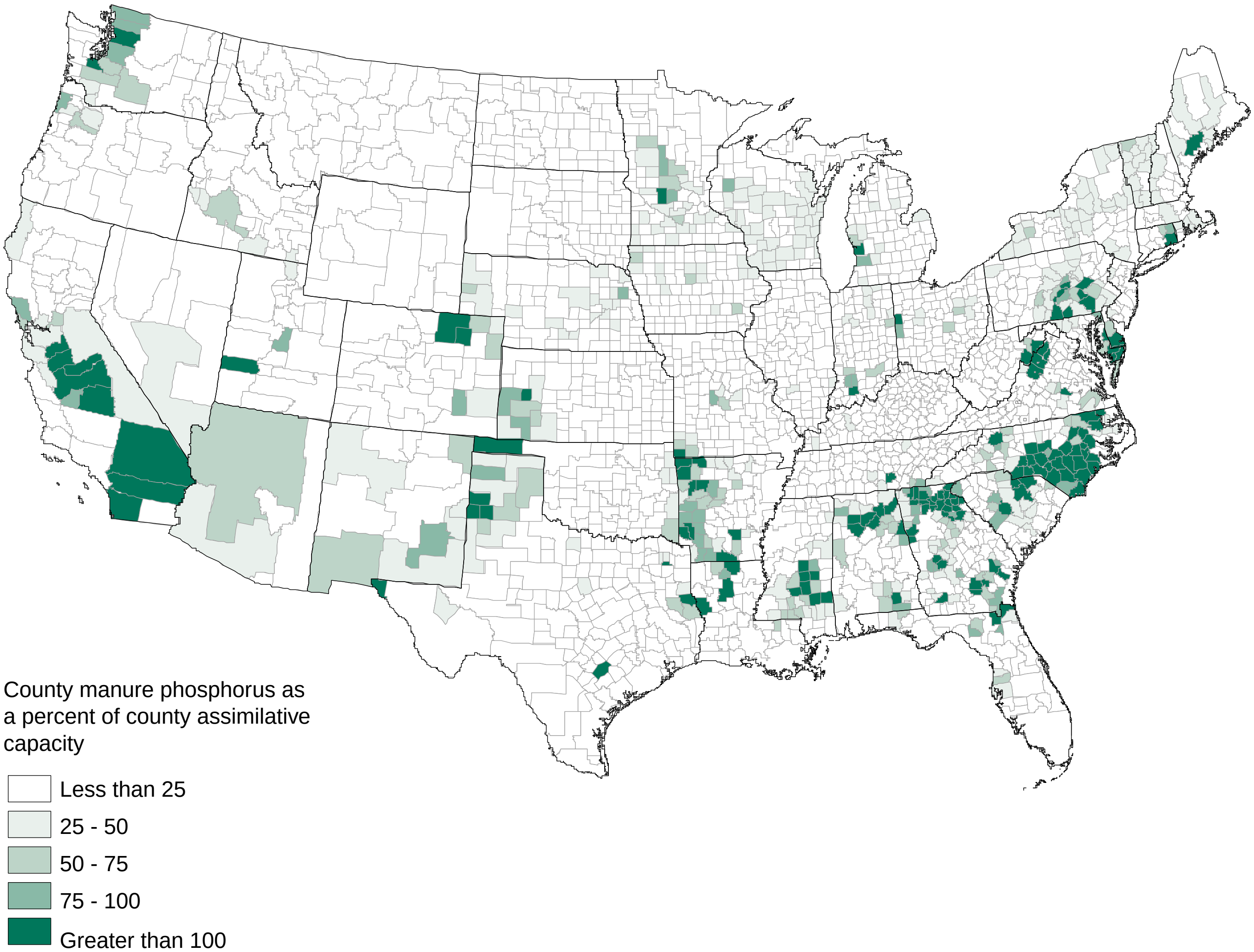


Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

Figure 18

Excess manure phosphorus as a share of county assimilative capacity, 1997



Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.

Table 4—County-level manure nutrients from confined animals relative to the assimilative capacity of crop and pastureland, 1997

County ratio[1]	Counties		Quantity of recoverable nutrient	Quantity of excess nutrient
	Number	*Percent*	*Percent*	*Percent*
Nitrogen:				
Greater than 1.0	68	2	14	20
0.5 to 1.0	87	3	10	14
0.25 to 0.5	140	5	18	21
Less than 0.25	2,775	90	58	45
Total	3,070	100	100	100
Phosphorus:				
Greater than 1.0	152	5	19	23
0.5 to 1.0	185	6	10	12
0.25 to 0.5	382	12	13	10
Less than 0.25	2,351	77	58	55
Total	3,070	100	100	100

[1] A county ratio greater than 1 implies that the recoverable manure nutrients will exceed the nutrient needs of all the county's crop and pastureland.

Source: Economic Research Service, USDA.

improvements in manure management, there should be adequate land to apply manure nitrogen (likely at a higher cost). Phosphorus ratios of less than 0.25 account for most counties, 77 percent, but clearly more areas will have difficulty finding land on which to apply manure phosphorus.

Figures 17 and 18 indicate areas where nutrients in regional excess may trigger manure management requirements for animal operations of any size. The greater the amount of excess nutrients in an area, the greater the risk of water quality impairment. The Unified Strategy and TMDL regulations require nutrient management for any confined feeding operation if excess nutrients are linked to water quality impairments. While water quality problems may occur in any county where manure is improperly managed, figures 17 and 18 indicate areas of greater water quality risk from excess manure nutrient production relative to the potential land on which to apply manure.

Conclusions

In this report, we describe how the size and location of confined livestock farms, and how the manure nutrients produced on those farms, have changed over time. Changes are measured in a variety of ways, including the relationship between manure production and the physical capacity of crop and pastureland to utilize manure nutrients. The physical feasibility of using manure nutrients at an agronomic rate on land controlled by livestock operators or on other crop and pastureland within the same county will determine potential policy options for reducing manure-related environmental problems. The physical capacity defines the universe for economic assessment of any policy options that make use of manure application on crop and pastureland as a waste management approach.

The number of confined animal farms decreased consistently from 1982 to 1997, particularly among smaller farms with fewer than 300 animal units. On the other hand, the total number of animal units increased, with most of the growth occurring in large farms (more than 1,000 animal units). Increasing average size means that more livestock production units will be subject to potential regulation under the Clean Water Act.

Data from the 1997 Census of Agriculture show that 78 percent of animal operations have sufficient crop and pastureland to use all manure nitrogen on the farm (69 percent of farms for phosphorus) at agronomic rates. This finding does not mean that manure is being managed in this manner on all farms with adequate capacity. Nor should it suggest that manure application is necessarily an economically feasible option on these operations. It does, however, indicate the number of livestock operations on which land application can be considered as a sole option. Whether that management option is prohibitively costly or actually profitable has yet to be assessed, and is likely to vary across the operations where land application of manure is physically feasible.

Although most animal operations have adequate land to at least consider manure application as a waste management strategy, the majority of manure nutrients are from the relatively few larger operations that do not control enough land to apply the generated manure at agronomic rates. Manure from these operations accounts for 60 percent of the Nation's manure nitrogen and 70 percent of the manure phosphorus. Thus, even if it is economically feasible to supply crop nutrient needs with manure on all farms where that is physically feasible, a majority of manure nutrients could not be managed so. This excess manure, which is concentrated on larger livestock operations, must be moved off the farm to land not controlled by the producing operation or to an alternative use.

We calculated the potential for manure to be applied at agronomic rates to crop and pastureland that is within the same county, without considering if the land is associated with livestock production. This estimate of the county's potential to use all the manure nutrients produced finds that most counties have sufficient land to apply all the manure produced in that county. However, further research is necessary to assess barriers to the general acceptance of manure as a source of crop nutrients. Transportation costs, application problems (e.g., ease, timing, and odors), and potential liability for nutrient flows to the environment may discourage other farmers from using manure generated by local animal operations. In addition, the costs of including manure as a nutrient source on farms where manure is not currently in use will need to be examined.

We also identified areas in which spreading of all the manure on available land is not viable. About 20 percent of the Nation's **onfarm excess** manure nitrogen is produced in counties that have insufficient cropland for its application (23 percent for phosphorus). Research is necessary to ascertain the costs of alternative uses for manure or spreading manure on lands other than agricultural lands (e.g., public land or recreation areas). In some locations, technologies may be available and cost effective for processing manure into soil supplements or organic fertilizer that can be transported to other areas for application. It may be possible to use manure as a raw material in industrial processes producing energy or other products. The economies of scale associated with these alternative technologies may determine the level of industry concentration (and quantity of manure produced) necessary to solve the problem within an area. The costs of long-haul manure transport relative to technology-based manure processing also need to be assessed.

This analysis of nutrients from confined animal production in 1997 has shown that livestock operations have the potential to use about 40 percent of the manure nitrogen and 30 percent of the manure phosphorus produced if applied at agronomic rates. Successful incentives to encourage more land application off the livestock farm (within the county) might account for another 46 percent of nitrogen and 51 percent of phosphorus. However, in a few counties with high animal concentrations relative to available land, long-distance hauling or further processing will be needed to address the remaining 14 percent of manure nitrogen and 19 percent of manure phosphorus produced.

If the trends in livestock industry concentration that we found between 1982 and 1997 continue, more manure will be produced in areas without the physical capacity to agronomically use all the nutrients. Structural change in animal production may make the land application of manure less feasible as a means of managing livestock waste. Regulations and policies that affect the costs of manure management could affect the economies of scale and regional comparative advantage in animal production, although there is little evidence of environmental regulations affecting the location of livestock production to date. Further research needs to examine the forces driving industry change and how that change could be influenced by policy development.

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Appendix: Animal Waste and Water Quality

A U.S. Geological Survey study of nitrogen loadings in 16 watersheds found that manure was the largest source in 6, located primarily in the Southeast and Mid-Atlantic States (Puckett, 1994). In the Mississippi drainage basin, animal waste is estimated to contribute 15 percent of the nitrogen load entering the Gulf of Mexico (Goolsby *et al*., 1999). Nitrogen (from all sources) transported by the Mississippi River is believed to be largely responsible for the large zone of hypoxic waters in the Gulf of Mexico. A study in the Upper Midwest found that the level of nitrate contamination in surface water is most strongly related to streamflow, acreage in corn and soybean production, the density of cattle, and population density (Mueller *et al*., 1993). The 1996 Water Quality Inventory contains a summary of State water quality assessments, which reports that animal operations (feedlots, confined facilities, and animal holding areas) were contributing sources of pollutants in 20 percent of impaired rivers and streams (U.S. EPA, 1998).[1]

Besides harming aquatic ecosystems, nitrate pollution also has potential human health concerns. The EPA has established a maximum contaminant level (MCL, a legal maximum exposure) of 10 mg/l for nitrate in drinking water. Nitrate can be converted to nitrite in the gastrointestinal tract. In infants, nitrite may cause methemoglobinemia, known as "blue-baby syndrome," which prevents the transport of sufficient oxygen in the bloodstream. Public water systems that violate the MCL must use additional treatment to bring the water into compliance, though exemptions are specified.

The most recent nationwide pollutant loading estimates indicated that in the 1980s, the largest manmade sources of phosphorus to the environment were fertilizer and manure applications (Litke, 1999). The phosphorus content of soils has shown increases in recent years, especially in areas of high manure application rates (Beauchemin *et al*., 1998). High phosphorus concentrations in streams and in soil-drainage water have been linked to areas with high soil phosphorus content (Litke, 1999). Of particular concern is phosphorus from manure, which is more mobile through soil than phosphorus from commercial fertilizer (Eghball *et al*., 1996).

Improved management of manure nutrients will also reduce the likelihood of pathogen contamination of water supplies—an issue attracting increased attention (NRAES, 1996; Olson, 1995). Bacteria are the third leading source of impairment of rivers and the second leading cause in estuaries (U.S. EPA, 1998). Potential sources include inadequately treated human waste, wildlife, and animal operations. Microorganisms in livestock waste can cause several diseases through direct contact with contaminated water, consumption of contaminated drinking water, or consumption of contaminated shellfish. Bacterial, rickettsial, viral, fungal, and parasitic diseases are potentially transmissible from livestock to humans (CAST, 1996). Fortunately, proper animal management practices and water treatment minimize the risk to human health posed by most of these pathogens. However, protozoan parasites, especially *Cryptosporidia* and *Giardia*, are important etiologic agents of waterborne disease outbreaks (CDC, 1996). *Cryptosporidia* and *Giardia* may cause gastrointestinal illness, and *Cryptosporidia* may lead to death in immunocompromised persons. These parasites have been commonly found in beef herds, and *Cryptosporidia* in dairy operations (USDA, 1994; Juranek, 1995).

Outbreaks of waterborne diseases are a growing concern. EPA estimates the cost to drinking water utilities for improved microbial treatment to be about $20 billion over the next 20 years, with about half of that needed immediately (U.S. EPA, 1997a). The health cost of *Giardia* alone is estimated to be $1.2-$1.5 billion per year (U.S. EPA, 1997b). *Cryptosporidia* are a more recently identified threat, with oocysts present in 65-97 percent of surface water sampled in the United States (CDC, 1996). The organism has been implicated in gastroenteritis outbreaks in Milwaukee, Wisconsin (400,000 cases and 100 deaths in 1993), and in Carrollton, Georgia (13,000 cases in 1987). The cost of the Milwaukee outbreak is estimated to have exceeded $54 million (*Health and Environment Digest*, 1994). While the source of the organism in these outbreaks was never determined, its occurrence in livestock herds has brought some attention to this sector, especially given the proximity of cattle and slaughterhouses to Milwaukee (MacKenzie *et al*., 1994).

[1] U.S. EPA's assessment relies on State self-reporting, which is incomplete and inconsistent among States (U.S. GAO, 2000). The Clean Water Act requires that such a report be submitted to Congress every 2 years.