Nitrogen and Phosphorus Imports to the Cape Fear and Neuse River Basins To Support Intensive Livestock Production

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Feeds imported to support rapidly expanding intensive livestock operations (ILOs) in North Carolina represent significant quantities and proportions of “new” nutrients in local watersheds. The Cape Fear and Neuse River basins include large fractions of total state inventories of hogs, turkeys, chickens, and cattle. Production of hogs, turkeys, and broiler chickens increased substantially in North Carolina during 1985−1995. Due to growth in the demand for feed and declines in feed crop production in North Carolina, ILOs must import large fractions of feed grains and soybeans they require from out of state. The corresponding quantities of new nitrogen and phosphorus, including inorganic phosphorus used as a diet supplement, imported in animal feeds are more than an order of magnitude greater than current annual loads of these nutrients in each river. The eutrophication threat to these river basins and other areas with expanding animal populations from the potential large nutrient loadings, especially phosphorus, associated with ILOs is substantial.

Introduction

Adoption of carefully managed animal production techniques and the rapid proliferation of intensive livestock operations (ILOs), notably in eastern North Carolina, have driven rising concerns about possible impacts on water quality from nutrient loadings. We estimate here the quantities of nitrogen and phosphorus, the primary nutrients of concern in water quality management, imported to two major river basins in eastern North Carolina (the Cape Fear and Neuse Rivers) in animal feeds and excreted as animal wastes. Accumulation of these “new” nutrients represents an added dimension to the nutrient management challenge posed by the proliferation of ILOs.

The Cape Fear River basin is the largest in North Carolina (area = 23 700 km^2) and includes portions of 27 counties. The river rises in the north central Piedmont and flows directly to the sea near Cape Fear. Biological oxygen demand (BOD), primarily from organic loadings, has been identified as a primary water quality concern in the Cape Fear River (*1*).

The Neuse River forms in the Piedmont and empties into Pamlico Sound through the Neuse River Estuary. The Neuse River basin (area = 16 040 km^2) includes portions of 19 counties. The Neuse River has been designated as Nutrient Sensitive Waters (*2*), since its clarity and shallow depth generally prevent light limitation of algal production.

Calculations

Overview. We calculated net feed imports to support intensive livestock production by comparing data for feed consumption with feed crop production estimates for the state as a whole and for the two river basins. We assumed that all feed crops grown within the state or the respective basins were used as animal feeds within those areas so that import estimates derived from comparisons of consumption and production are conservative. We calculated nutrient contents of feeds from published descriptions of feed mixes and their N and P contents. We used the major feed components with the lowest N and P contents for these calculations as a conservative measure. We calculated manure contents of N and P from published data. We then compared manure N and P values in the river basins to N and P loads in the rivers themselves, to P fertilizer use in the river basins, and to P loading reductions in the rivers driven by North Carolina’s 1989 detergent phosphate ban.

Animal Production. Production of several kinds of animals increased dramatically in North Carolina during 1985−1995 (Table 1). Swine populations increased most rapidly in the 1990−1995 period, rising from an inventory of 2.8 million to 8.2 million (*3, 4*). Turkey production nearly doubled in 1985−1995, with the most rapid growth in 1985−1990 (*3*−*5*). Broiler chicken production also increased about 50% in the 10-year period, with more or less steady annual growth (*3, 4*). Populations of other chickens, mostly used in egg production, have declined slightly in the 10-year period. Total cattle populations have increased only slightly, but this small increase in total cattle masks a 14% decline in dairy cattle populations and a concurrent 25% increase in beef cattle populations (*3, 4*).

The major populations of animals produced by ILOs in North Carolina (hogs, turkeys, broiler chickens, other chickens, and cattle), calculated using county animal census data (*4*) and the estimated fraction of each county lying within the respective river basins, were heavily concentrated in the Cape Fear and Neuse River basins by 1995. Together the two river basins accounted for 71% of the hogs, 66% of the turkeys, 34% of the broiler chickens, 24% of the other chickens, and 24% of the total cattle grown in North Carolina. The Cape Fear River basin is approximately 50% larger than the Neuse River basin but supported a much larger fraction of each kind of animal production, including over half the hog population in the state.

Feed Consumption. Data on animal feed consumption provided by Dr. Kelly Zering (Department of Agricultural and Resource Economics, North Carolina State University) show dramatic increases during 1985−1995 that parallel growth in animal production (Table 2). Changes in animal production patterns during 1985−1995 also led to changes in feed consumption patterns. Swine consumed about 33% of all feed grain (corn + wheat + sorghum) consumed in 1985 and 51% in 1995. Grain consumption by swine surpassed consumption by broiler chickens in 1991 and consumption by all other animals combined in 1995. Grain consumption

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TABLE 1. Changes in North Carolina Animal Populations, 1985−1995[a]

date	hogs	turkeys	broiler chickens	other chickens	total cattle
Jan 1, 1986					1 100 000
Dec 1, 1985	2 350 000			21 250 000	
1985		31 850 000	447 300 000		
Jan 1, 1996				18 835 000	1 200 000
Dec 1, 1995	8 200 000				
1995		61 200 000	670 100 000		
% change	+248	+92	+50	−11	+9

[a] Dates are census report dates; annual values are yearly production estimates (*3*, *4*).

TABLE 2. Feed Consumption (1000 t/yr) To Support Animal Production in North Carolina, 1985−1995[a]

year	hogs	turkeys	broiler chickens	other chickens	total cattle	total
			Grain Consumption			
1985	989	371	1125	279	268	3032
1995	3444	885	1953	254	231	6767
% change	+248	+138	+74	−9	−14	+123
			Soybean Meal Consumption			
1985	239	297	562	138	143	1379
1995	831	708	977	132	128	2776
	+248	+138	+74	−4	−10	+101

[a] Source: K. Zering.

TABLE 3. Feed Grain and Soybean Production (1000 t/yr) in North Carolina, 1985−1995[a]

year	corn	wheat	sorghum	total grains	soybeans
1985	3261	560	81.9	3903	993
1995	1902	714	16.5	2633	679
% change	−42	+28	−80	−32	−32

[a] Source: K. Zering.

by turkeys and broiler chickens also increased substantially in 1985−1995 and at a rate faster than the overall rate of production of these animals. Grain consumption by other chickens (primarily for egg production) and total cattle did not change appreciably. Patterns of soybean meal consumption also paralleled changes in animal production during 1985−1995. Consumption of soybean meal by swine increased in almost exact proportion to the increase in swine populations, with the greatest increase in consumption during 1990−1995. Swine accounted for a smaller fraction of total soybean meal consumption than of feed grain consumption, but their share of total soybean meal consumption rose from 17% in 1985 to 30% in 1995. Broiler chickens accounted for the largest portion of soybean meal consumption throughout the1985−1995 period.

Feed Crop Production. Production of corn, wheat, sorghum, and soybeans in North Carolina showed significant interannual variation during 1985−1995, but there was an overall decline in production of these animal feed materials (Table 3) (*3, 4*). These declines in feed crop production contrast with the rapid increases in feed consumption described above and have created increasing demand to import feed materials to North Carolina.

North Carolina produced a surplus of feed grains (corn + wheat + sorghum) of 870 000 t relative to total feed grain consumption to support animal production in 1985, but soybean production fell approximately 400 000 t short of animal consumption that year. By 1995, the large increases in feed consumption by North Carolina's animal industries and the general decline in feed crop production produced a much greater imbalance between in-state production and consumption. Annual feed grain consumption then exceeded in-state production by over 4.3 million t and soybean consumption exceeded in-state production by over 2 million t. If all corn, wheat, sorghum, and soybeans produced in North Carolina are assumed to be used in-state for animal feed, then animal producers must have imported at least 64% of all feed grains and 75% of the soybeans they used.

Feed Imports. Estimates of feed grain and soybean import to the Cape Fear and Neuse River basins in 1995 were calculated by comparing the consumption of these feeds by the animal populations in each basin with the production of these feed crops in each basin. Feed consumption was assumed to be equal to each basin's fraction of the statewide animal population multiplied by the statewide consumption figures (Table 2). Feed crop production in each basin was calculated using county production data (*4*) and the percentage of each county lying within each basin. Feed crop production in the two river basins generally parallels the temporal patterns for the whole state, with large declines in corn, sorghum, and soybean production during 1985−1995, except for a strong increase in wheat production in the Neuse River basin during that period (*3*, *4*). Comparison of feed crop production with consumption for 1995 shows that 87.2% of grains and 94.5% of soybeans used as animal feed must be imported to the Cape Fear basin, with import estimates of 60.6% of grains and 73.6% of soybeans for the Neuse basin (Table 4). These estimates conservatively assume that all feed crops produced within the basins are used as animal feeds.

N and P Imports. Nitrogen and phosphorus imported to the Cape Fear and Neuse River basins in animal feed were calculated using estimates of the proportion of each animal type in each basin (Table 4), grain and soybean consumption data for each animal type (Table 4), the import estimates for feed grains and soybeans (Table 4), published nitrogen and phosphorus contents for both types of feeds, and estimates of supplemental phosphorus contents of diets. The nitrogen and phosphorus contents of feed grains (corn + wheat + sorghum) were assumed to be 1.19 and 0.25 wt %, respectively. These values are those of yellow corn, which is typically the bulk of the diet fed to most animals (*6*). The grain consumption data available do not break down the percentages of each grain type used, so the relatively low values for corn were used to provide a conservative estimate. Similarly, the lower reported values for nitrogen and phosphorus contents of soybean meal types in animal feeds, 6.16% nitrogen and 0.60% phosphorus, were used (*6*). Due to the poor digestibility of natural phosphate compounds, principally phytate, in corn-based feeds by swine and poultry (*6*−*8*), inorganic phosphate is added to their feeds. Average values for this supplemental phosphorus are derived from data for swine (0.58% of total feed; *6*), chickens (0.40%; *9*), and turkeys (0.48%; *9*). All supplemental phosphorus is assumed to be imported, as the source for this material is the mining of fossil phosphate.

TABLE 4. Calculation of Net Imports of Animal Feeds in the Cape Fear River and Neuse River Basins in 1995[a]

	hogs	turkeys	broiler chickens	other chickens	total cattle	total
			Cape Fear River			
population %	51	46	29	17	18	
grain consumption	1756	407	566	43.2	41.6	2814
soy consumption	424	326	283	22.4	23.0	1078

grain production: corn, 287; wheat, 72.1; sorghum, 1.72; total, 361
production/consumption = 361/2814 = 12.8%: 87.2% imports
soy production: 59.8
production/consumption = 59.8/1078 = 5.5%: 94.5% imports

	hogs	turkeys	broiler chickens	other chickens	total cattle	total
			Neuse River			
population %	20	20	5.5	7	6	
grain consumption	689	177	107	17.8	13.9	1005
soy consumption	166	142	53.7	9.24	7.68	379

grain production: corn, 259; wheat, 136; sorghum, 0.99; total, 396
production/consumption = 396/1005 = 39.4%: 60.6% imports
soy production: 99.8
production/consumption = 99.8/379 = 26.4%: 73.6% imports

[a] All units are 1000 t.

TABLE 5. Nitrogen (N) and Phosphorus (P) Imports (t, Based on 1995 Consumption, Table 4) to the Cape Fear River Basin as Animal Feeds in 1995[a]

	animal industry					
	hogs	turkeys	broiler chickens	other chickens	total cattle	totals
			Consumption			
grain N	20 900	4 840	6 740	510	494	33 500
grain P	4 390	1 020	1 420	108	104	7 040
soybean N	26 100	20 100	17 500	1 380	1 420	66 500
soybean P	2 540	1 950	1 700	135	138	6 460
suppl. P	12 650	3 520	3 400	247		19 800
total N	47 000	24 900	24 200	1 860	1 910	99 900
total P	19 600	6 490	6 520	490	242	33 300
			Imports			
imported N	42 900	23 200	22 400	1 750	1 770	92 000
imported P	18 900	6 250	6 240	469	220	32 100
% imported N	91	93	93	94	93	92.1
% imported P	96	96	96	96	91	96.3

[a] Imports calculated as 87.2% of grain and 94.5% of soybeans.

Animal feed used in the Cape Fear River basin in 1995 incorporated almost 100 000 t of nitrogen and 33 000 t of phosphorus, of which over 90% was imported from outside the basin, or approximately 92 000 and 32 000 t of nitrogen and phosphorus, respectively (Table 5). Approximately 46% of the nitrogen imported to the basin could be attributed to the swine industry, with 50% attributable to the turkey and broiler chicken industries together. The swine industry accounted for 59% of the phosphorus imported to the Cape Fear River basin in 1995, and the turkey and broiler chicken industries together accounted for 39%.

Animal industries in the Neuse River basin consumed approximately 35 300 t of nitrogen and 12 000 ton of phosphorus in 1995 (Table 6). The overall percentages of imported nitrogen and phosphorus are estimated to be lower than in the Cape Fear basin but represent imports of about 24 400 and 10 400 t of nitrogen and phosphorus, respectively. Due to the relatively greater importance of the hog industry in the Neuse basin, hog production accounts for about 51% of the imported nitrogen and 65% of the imported phosphorus.

Manure N and P. Animal manures represent the major product of ILOs likely to remain in-basin as a result of the production process. Comparisons of animal manure nutrient contents with nutrient import values permit an assessment of the amount of imported nutrients potentially contributing to in-basin loadings. Manure and nutrient production in 1995 were calculated and compared to total 1995 nitrogen and phosphorus consumption in animal feeds in the Cape Fear River and Neuse River basins by extrapolation from estimates of the nutrient contents of manure produced by North Carolina animal industries during 1993 (*10*) (Table 7). Comparisons of nutrients consumed, imported, and output as manures show that imported nitrogen and phosphorus exceed manure nitrogen and phosphorus production in the Cape Fear basin and manure phosphorus production in the Neuse basin, meaning that essentially all manure nutrients in these cases represent imported nutrients, while 95% of the manure nitrogen produced in the Neuse basin is imported (Table 7). Nutrient output in cattle manure is much higher than nutrient consumption by cattle in grain- and soybean-based feeds, reflecting very large nutrient inputs through their grazing on natural forages. Among the other animals, which are supported almost entirely by grain- and soybean-based feeds, swine accounted for approximately 58% of the manure nitrogen and 59% of the manure phosphorus produced in the Cape Fear River basin in 1995. Similarly, swine accounted for approximately 64% of the nitrogen and 63% of the phosphorus in animal wastes (excluding cattle) in the Neuse River basin in 1995. These disproportionate inputs by swine populations reflect the comparatively low feed conversion efficiency of hogs as compared with other

TABLE 6. Nitrogen (N) and Phosphorus (P) Imports (t Based on 1995 Consumption, Table 4) to the Neuse River Basin in Animal Feeds in 1995[a]

	animal industry					
	hogs	turkeys	broiler chickens	other chickens	total cattle	totals
			Consumption			
grain N	8 200	2 110	1 280	212	165	12 000
grain P	1 720	443	269	44	35	2 510
soybean N	10 200	8 720	3 310	569	473	23 300
soybean P	997	850	322	55	46	2 270
suppl. P	4 960	1 530	645	108		7 240
total N	18 400	10 800	4 590	781	638	35 300
total P	7 680	2 820	1 240	207	81	12 000
			Imports			
imported N	12 500	7 700	3 210	547	448	24 400
imported P	6 740	2 420	1 045	175	57	10 400
% imported N	68	71	70	70	70	69
% imported P	88	86	84	85	68	87

[a] Imports calculated as 60.6% of grain and 73.6% of soybeans.

TABLE 7. Fresh Manure , Nitrogen (N), and Phosphorus (P) Production (t/yr) in the Cape Fear River and Neuse River Basins for 1995 Animal Populations, Projected from 1993 Production Data (*10*), and as % of N and P Consumed in Grain and Soybean Feed

	hogs	turkeys	broiler chickens	other chickens	total cattle
		1993 NC totals			
fresh manure	9 040 000	2 200 000	3 480 000	411 000	10 200 000
manure N	53 400	31 400	45 800	5 460	56 200
manure P	17 600	11 400	12 400	1 900	14 000
population ratio, 1995:1993	1.519	1.003	1.089	0.975	1.132
		1995 production			
Cape Fear basin (% NC)	51	46	29	16.7	18
fresh manure	7 003 000	1 014 000	1 100 000	68 100	2 081 000
manure N	41 400	14 500	14 500	905	11 400
manure P	13 630	5 240	3 920	310	2 850
% consumed N	88	58	60	49	597
% consumed P	69	81	60	63	11 800
Neuse basin (% NC)	20	20	5.5	7.3	6
fresh manure	2 750 000	441 000	209 000	28 000	694 000
manure N	16 200	6 300	2 740	373	3 810
manure P	5 350	2 280	746	130	950
% consumed N	88	58	60	48	566[a]
% consumed P	70	81	60	63	11 800[a]

[a] Reflects inputs from feeding on pasture.

animals. Data provided by Dr. K. Zering (personal communication) show that the feed consumption:meat production ratio is 1.89 for broiler chickens, is 2.475 for turkeys, and is 3.06 for swine.

Nitrogen and phosphorus imports to the Cape Fear River and Neuse River basins as animal feeds may be put into perspective by comparison to other nutrient loadings. By 1995, animal manure phosphorus production approximately equaled commercial fertilizer phosphorus usage in the Cape Fear basin and accounted for about 25% of total phosphorus loading from these two sources in the Neuse basin (Table 8). Comparisons of commercial fertilizer use between 1985 and 1995 do not show much evidence that animal manures have displaced inorganic fertilizers in either basin.

Water Quality Issues

Nutrients imported to the Cape Fear basin in animal feeds are considerably greater than current nutrient loads in the Cape Fear River (Table 9). Estimates of annual nitrogen and phosphorus loadings to the Cape Fear River were derived from mean flow (J. Bales, U.S. Geological Service, personal communication) and total nitrogen and phosphorus concentration data (*11*) and yield annual loads of 6420 t of nitrogen and 650 t of phosphorus. These estimates are an order of magnitude lower than estimates of the nutrients imported to support the animal industries (Table 5) or the nutrients excreted in animal wastes in the Cape Fear basin (Table 7). This means not only that current animal waste management practices have kept a large proportion of waste nutrients from entering the river itself but also that even relatively effective waste management techniques may potentially allow significant amounts of new nutrients to enter the river.

TABLE 8. Comparisons of Total Fertilizer (tons) Shipped in the Cape Fear River and Neuse River Basins, 1985 vs 1995 (*3, 4*), vs Fertilizer Equivalent of Manure P (from Table 7)

	1985	1995	% change
commercial fertilizer use			
NC total	1 667 000	1 671 000	+0.2
Neuse River basin	300 000	284 000	−5.3
Cape Fear basin	266 000	272 000	+2.2
manure P as 10% P fertilizer			
Cape Fear basin		259 500	
Neuse River basin		94 600	

Nutrients imported to the Neuse basin in animal feeds are also considerably higher than current nutrient loads in

TABLE 9. Comparisons of Annual Nitrogen (N) and Phosphorus (P) Loads in Southeast NC Rivers with Total Manure Nitrogen and Phosphorus Production in the Cape Fear River and Neuse River Basins[a]

	total annual N	total annual P	sources
Cape Fear River (1996)			
mainstem CFR	6 310	746	USGS (*11*)
animal manure production (1995)	82 700	25 950	Table 2
estd P reduction by 1989 detergent ban		434	(*13*)
Neuse River(1990−1994)			
at New Bern	3 950	410	(*2*)
animal manure production (1995)	29 400	9 460	Table 2
estd P reduction by 1989 detergent ban		240	(*13*)

[a] All units are t.

the Neuse River (Table 9). Animal wastes were responsible for the largest fraction of phosphorus loading to the Neuse River as early as 1990 when swine, turkey, and chicken inventories were substantially lower than at the present (*12*). The major source of nitrogen to the Neuse River during this period was fertilizer runoff, with animal wastes the second most important (*12*). Again, it is likely that a large fraction of animal waste nutrients produced in the Neuse River basin, imported and locally derived, have not entered the Neuse River and also that waste management practices must continue to be effective and improve as imports rise in order to prevent very significant nutrient loading in the future.

Efforts to control phosphorus-driven eutrophication during the 1970s and 1980s in North Carolina's rivers and coastal waters led to legislation in 1989 that banned high-phosphate detergents for household use. Studies of phosphate loading after the detergent ban showed reductions of annual phosphorus loads in the Cape Fear and Neuse Rivers of 434 and 240 t of phosphorus, respectively (*13*). However, these reductions are very much smaller than the quantities of animal manure phosphorus now produced annually in these river basins (Table 9). This comparison places the magnitude of the management challenge posed by imports of very large quantities of nutrients into perspective.

It is difficult to determine the actual fraction and quantities of animal waste nutrients entering the Cape Fear and Neuse Rivers themselves, even though we calculate a conservative estimate of nutrient imports to each river basin. Clearly, existing policy and waste management practices have succeeded in preventing direct discharge of most waste nutrients to surface waters. Indirect discharges, such as atmospheric deposition of volatilized ammonia, percolation of dissolved nutrients through groundwater, and runoff of nutrients from land application areas, have proven extremely difficult to quantify. However, various studies have documented that such indirect discharges are occurring and that they are having an effect on water quality in the Neuse and Cape Fear Rivers. For example, stable nitrogen isotope studies have documented loadings of animal waste-derived nitrate in the Cape Fear River drainage (W. Showers, North Carolina State University, personal communication).

An important water quality problem in North Carolina deriving from animal waste inputs is nitrogen loading to surface and groundwaters (*14*−*17*). Nitrogen frequently limits phytoplankton production in North Carolina's coastal waters (*18*), so increased nitrogen loads have stimulated noxious and toxic algal blooms and helped cause fish kills (*19, 20*). The solubility of nitrogen compounds allows them to move rapidly in surface and groundwater flows (*21*−*24*). Nitrogen can also be transported as volatile forms, particularly ammonia, or lost via denitrification from soils (*25*) and wetlands, swamps, and estuarine sediments (*26*−*29*). Aerial deposition of nitrogen, principally ammonia-nitrogen, is recognized as a contributing threat to coastal water quality, particularly in the Neuse River Estuary (*12, 30, 31*). Some studies estimate that up to 90% of the manure nitrogen produced by swine volatilizes and is deposited downwind (*32*). Consequently, efforts to manage water quality impacts from animal production in North Carolina have generally emphasized nitrogen management (*33*).

Molar ratios of nitrogen:phosphorus (N:P) in animal feeds and manures suggest the potential for animal waste production to drive excess phosphorus loadings in the Cape Fear and Neuse River basins. Molar N:P ratios in feeds (from Table 5, neglecting natural forages but including supplemental phosphate) consumed by hogs, turkeys, broiler chickens, other chickens, and cattle average 5.3, 8.5, 8.2, 8.4, and 17.5, respectively. Molar N:P ratios for animal manures average 6.7, 6.1, 8.2, 6.5, and 8.8, respectively (Table 7).

The relative phosphorus enrichment of animal manures contrasts with molar N:P ratios in river waters. When one considers nutrients that are biologically available to algae and aquatic macrophytes (nitrate-N, ammonia-N, and orthophosphate-P), the average molar N:P ratio for the Cape Fear River is 22.7 (*11*) and 24.9 for the freshwater Neuse River (*34*). The average N:P ratio for phytoplankton is on the order of 11:1 (*35*), suggesting that animal wastes are phosphorus-enriched while the freshwater Cape Fear and Neuse Rivers are relatively nitrogen-enriched in comparison to the nutritional requirements of phytoplankton (*35, 36*). Thus, wastes generated by the animal industries in these basins pose the potential for phosphorus-driven eutrophication in these rivers.

Phosphorus loading can stimulate eutrophication in several ways. Phosphorus loading can relieve phosphorus limitation in receiving waters, thus stimulating plant growth directly (*36*). Experimental bioassays have demonstrated that the upper Neuse Estuary at New Bern is often phosphorus-limited (*31*) and the Cape Fear River Estuary is phosphorus-limited during spring and other periods (*37*). Phosphorus loading has been implicated in recent blooms of toxic algae in North Carolina's coastal waters (*19*). Phosphorus loading in excess of relative needs can also create nitrogen limitation, thus favoring blooms of nitrogen-fixing blue green algae, which has been a serious water quality problem in North Carolina's recent past (*18, 20*).

Recent studies of the effects of nitrogen and phosphorus loadings on blackwater river plankton communities have demonstrated significant stimulation of both autotrophic and heterotrophic communities (*38*). Organic and inorganic nutrient concentrations as low as 1 mg/L N or P were capable of producing significant effects. This means that even relatively minor increases in nutrient loadings from new nutrients imported to feed animals may drive algal blooms and increased BOD, which are already problems in North Carolina's rivers.

We consider the cumulative and chronic effects of very large nutrient imports to the Cape Fear and Neuse River basins to pose major challenges for water quality management. Large-scale waste lagoon breaches have already caused massive acute nutrient loadings and subsequent algal blooms in receiving waters in North Carolina (*15, 39*). Nitrogen loading in these river basins is already driving eutrophication problems. Although phosphorus moves through coastal plain ecosystems more slowly, primarily in association with sediments, the very large quantities and relatively high ratios of phosphorus to nitrogen suggest that phosphorus imports will ultimately create significant water quality problems as well. As intensive livestock operations spread into other states, particularly if they concentrate in small areas, the import of large quantities of animal feeds to support them will generate major new nutrient loading problems in other river basins as well.

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