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Estimated Anthropogenic Nitrogen and Phosphorus Inputs to the Land Surface of the Conterminous United States—1992, 1997, and 2002

Scientific Investigations Report 2012–5241

U.S. Department of the Interior
U.S. Geological Survey

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By Lori A. Sprague and Jo Ann M. Gronberg

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:
Sprague, L.A., and Gronberg, J.M., 2013, Estimated anthropogenic nitrogen and phosphorus inputs to the land surface of the conterminous United States—1992, 1997, and 2002: U.S. Geological Survey Scientific Investigations Report 2012–5241, 14 p.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)

Estimation of Anthropogenic Nitrogen and Phosphorus Inputs to the Land Surface of the Conterminous United States—1992, 1997, and 2002

By Lori A. Sprague and Jo Ann M. Gronberg

Abstract

Anthropogenic inputs of nitrogen and phosphorus to each county in the conterminous United States and to the watersheds of 495 surface-water sites studied as part of the U.S. Geological Survey National Water-Quality Assessment Program were quantified for the years 1992, 1997, and 2002. Estimates of inputs of nitrogen and phosphorus from biological fixation by crops (for nitrogen only), human consumption, crop production for human consumption, animal production for human consumption, animal consumption, and crop production for animal consumption for each county are provided in a tabular dataset. These county-level estimates were allocated to the watersheds of the surface-water sites to estimate watershed-level inputs from the same sources; these estimates also are provided in a tabular dataset, together with calculated estimates of net import of food and net import of feed and previously published estimates of inputs from atmospheric deposition, fertilizer, and recoverable manure. The previously published inputs are provided for each watershed so that final estimates of total anthropogenic nutrient inputs could be calculated. Estimates of total anthropogenic inputs are presented together with previously published estimates of riverine loads of total nitrogen and total phosphorus for reference.

Introduction

This report describes how anthropogenic nitrogen and phosphorus inputs to each county in the conterminous United States and to the watersheds of 495 surface-water sites studied as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program were estimated and provides the resulting tabular data in Microsoft Excel format. Riverine loads of total nitrogen and total phosphorus that previously were calculated for the same sites in Mueller and Spahr (2006) also are provided in the dataset for reference.

In a hypothetical watershed over the long term—where initial anthropogenic inputs of nitrogen and phosphorus are "new" inputs of fertilizer, biological fixation by crops (for nitrogen only), atmospheric deposition (for nitrogen only), and imported human food and livestock feed; and final outputs are riverine export, basin storage or volatilization, and crop export—nutrients in crops and human and livestock waste are internally recycled (fig. 1). In this long-term cycle, total anthropogenic nutrient input over *n* years is

$$\sum_{i=1}^{n} AI_i = \sum_{i=1}^{n} Fert_i + \sum_{i=1}^{n} Fix_i + \sum_{i=1}^{n} Atm_i + \sum_{i=1}^{n} FoodImp_i + \sum_{i=1}^{n} FeedImp_i \qquad (1)$$

where

- AI_i is the total anthropogenic nutrient input to the watershed from years *i* to *n*,
- $Fert_i$ is the input from fertilizer from years *i* to *n*,
- Fix_i is the input from biological fixation by crops from years *i* to *n* (nitrogen only),
- Atm_i is the input from atmospheric deposition from years *i* to *n* (nitrogen only),
- $FoodImp_i$ is the input from imported food from years *i* to *n*, and
- $FeedImp_i$ is the input from imported feed from years *i* to *n*.

Over shorter time steps (such as a year), however, livestock waste is not always completely recycled; manure is often used to fertilize crops and pasture in succeeding time steps (for example, Year 2 in fig. 1). In these locations, the assumption that livestock waste represents only the internal recycling of "new" inputs of fertilizer, biological fixation by crops, atmospheric deposition, and food and feed inputs could lead to an underestimation of watershed inputs during a given time step. In this short-term cycle, the total anthropogenic nutrient input during year *i* is

$$AI_i = Waste_{i-1} + Fert_i + Fix_i + Atm_i + FoodImp_i + FeedImp_i \qquad (2)$$

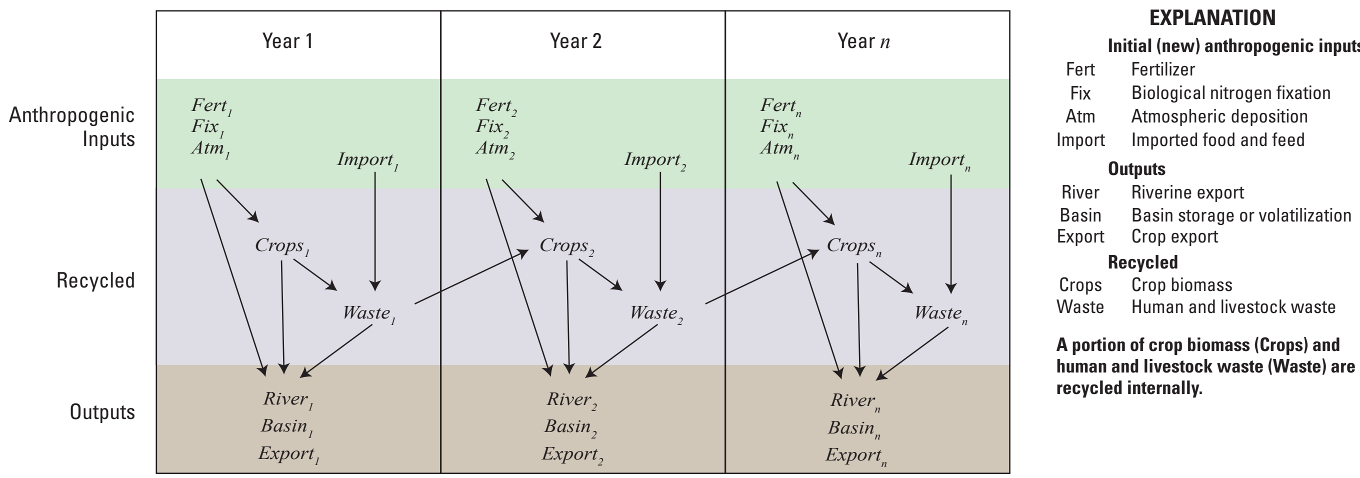

Figure 1. Nitrogen mass balance in a closed system over a long-term cycle.

where

AI_i is the total anthropogenic nutrient input to the watershed in year *i*,

$Waste_{i-1}$ is the input from waste (recoverable livestock manure) in year *i-1*,

$Fert_i$ is the input from fertilizer in year *i*,

Fix_i is the input from biological fixation by crops in year *i* (nitrogen only),

Atm_i is the input from atmospheric deposition in year *i* (nitrogen only),

$FoodImp_i$ is the input from imported food in year *i*, and

$FeedImp_i$ is the input from imported feed in year *i*.

Because riverine loads are reported on an annual basis in Mueller and Spahr (2006), corresponding anthropogenic nutrient inputs also were estimated on an annual basis for this study. Equation 2 was used to estimate inputs during this annual time step.

The purposes of this report are to (1) describe the estimation of anthropogenic nutrient inputs in the United States during 1992, 1997, and 2002 and (2) provide those estimates in a tabular dataset. Estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms (kg), are provided for each county in the conterminous United States. Separate estimates are listed for biological fixation by crops (for nitrogen only), human consumption, crop production for human consumption, animal production for human consumption, animal consumption, and crop production for animal consumption. Estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms, also are provided for the watersheds of 495 NAWQA surface-water sites in the conterminous United States. Separate estimates are listed for biological fixation by crops (for nitrogen only), animal consumption, human consumption, crop production for animal consumption, crop production for human consumption, animal production for human consumption, net import of food, and net import of feed. Estimates of inputs from atmospheric deposition (derived from data in Ruddy and others, 2006), fertilizer (derived from data in Gronberg and Spahr, 2012), and recoverable manure (derived from data in Kellogg and others (2000) and Robert Kellogg, U.S. Department of Agriculture, written commun., 2011) are also provided for each watershed, so that final estimates of anthropogenic nutrient inputs could be calculated (county-level estimates of these inputs already are available from the cited reports). Riverine loads of total nitrogen and total phosphorus that previously were calculated for the same sites in Mueller and Spahr (2006) also are provided in the watershed dataset.

Estimation of Anthropogenic Nutrient Inputs

In the following section, the estimation of each input source in equation 2 is described.

Waste

The variable $Waste_{i-1}$ in equation 2 represents the waste from a previous time step that is used in the current time step to fertilize crops. Human waste is generally not used to fertilize crops, so waste inputs to the next time step are assumed to be composed solely of livestock manure. Livestock manure is subject to spillage, volatilization, runoff, and other losses after generation in the previous time step and before subsequent application to agricultural fields in the current time step. To account for those losses, annual estimates of recoverable manure nutrients were used as estimates of $Waste_{i-1}$. Nitrogen and phosphorus in recoverable manure were estimated at a county level for 1992 and 1997 by Kellogg and others (2000) and at a six-digit hydrologic unit code (HUC6) level for 2002 (Robert Kellogg, U.S. Department of Agriculture, written commun., 2011) using the number of animal units for confined livestock, a factor for manure recoverability, and estimates of the pounds of nutrients per ton of manure after nutrient losses during collection, transfer, storage, and treatment:

$$\begin{aligned} &\text{Recoverable manure nutrients} \\ &= \text{tons of manure per animal} \\ &\times \text{number of confined animal units} \\ &\times \text{manure recoverability factor} \\ &\times \text{nutrients per ton of manure after losses} \end{aligned} \tag{3}$$

Recoverability factors represent the proportion of the excreted manure that could reasonably be expected to be collected from confinement facilities and applied to the land surface (Kellogg and others, 2000). Losses included volatilization of nitrogen, spillage, and runoff; only waste treatment technologies that are in common practice were considered in estimating these losses (Kellogg and others, 2000). The derivation and limitations of the various factors used in equation 3 are further detailed in Kellogg and others (2000). These estimates do not include the portion of manure from unconfined livestock that provides some degree of fertilization on pasturelands. In these areas, the estimates of $Waste_{i-1}$ are likely biased low. The extent to which livestock operations use off-farm land to dispose of livestock waste is not available from the Census of Agriculture (Kellogg and others, 2000), so the recoverable manure was assumed to be applied equally on all cropland and pastureland within each county or HUC6.

In the mass balance shown in equation 2, $Waste_{i-1}$ represents waste inputs from the prior year, whereas $Fert_i$, Fix_i, Atm_i, $FoodImp_i$, and $FeedImp_i$ are represented as inputs from the current year. The time step associated with a cycle of nutrient inputs → crops → waste → outputs, however, does not perfectly align with the progression from January to December within a single year. Different crops are grown at different times throughout the year, and waste is generated on a continuous basis throughout the year. As a result, recoverable manure generated in a given year using crops grown in the previous year may be applied together with “new” inorganic fertilizer to some portion of the crops grown later in the same year. The true total amount of recoverable manure applied within a single 12-month period from January to December likely includes some of the manure generated in the previous 12-month period and some of the manure generated in the current 12-month period; annual estimates from either 12-month period would be imperfect representations of the true amount. The annual data provided by the Census of Agriculture does not provide sufficient resolution to determine the relative chronology of manure generation and crop production in a given 12-month period. In addition, the Census of Agriculture is only conducted every 5 years. Because of these data constraints, estimates of all inputs in equation 2 (including $Waste_{i-1}$) were based on data from the same year. For correspondence with the timing of the Census of Agriculture and the estimates of riverine load from Mueller and Spahr (2006), the inputs were estimated for 3 years—1992, 1997, and 2002.

Fertilizer

Nitrogen and phosphorus inputs from fertilizer (including farm and nonfarm uses) were derived from sales and expenditures data from the Association of American Plant Food Control Officials and the U.S. Census of Agriculture as described in Ruddy and others (2006). County-level, annual data on nutrient inputs from fertilizer originally were available from Ruddy and others (2006). These data were recalculated after discovering a processing error in the nonfarm and farm allocation; updated data are available in Gronberg and Spahr (2012).

Biological Fixation by Crops

Following Alexander and others (2008), the annual biological fixation of nitrogen was estimated for soybeans, alfalfa hay, and non-alfalfa hay, the major nitrogen-fixing crops in the United States. In 2007, soybeans and total hay composed 20.6 and 18.8 percent, respectively, of the total harvested crop acreage in the United States (U.S. Department of Agriculture, 2009). County-level data on soybean production and harvested acreage of alfalfa and total hay for 1992, 1997, and 2002 were obtained from the U.S. Department of Agriculture Census of Agriculture (U.S. Department of Commerce, 1995; U.S. Department of Agriculture, 1999, 2004). The harvested acreage of total hay was not available directly from the 1997 Census of Agriculture; instead, it was calculated as the sum of alfalfa hay, small grain hay, tame hay (excluding alfalfa and small grain), and wild hay. The harvested acreage of non-alfalfa hay for 1992, 1997, and 2002 was calculated as the difference between total hay and alfalfa hay harvested acreages. Data reported in the Census of Agriculture as “Withheld to avoid disclosing data for individual farms” were treated as a value of zero.

County-level, annual biological fixation was estimated for soybeans as the product of county-level soybean production and the nitrogen fixation rate of 0.91 kg/bushel (Alexander and others, 2008; McIsaac and others, 2002); and for alfalfa and non-alfalfa hay as the product of the respective county-level harvested acreage, a conversion factor of 0.40468564224 hectare (ha)/acre, and the nitrogen fixation rate of 218 kg/ha/yr for alfalfa or 116 kg/ha/yr for non-alfalfa hay (Alexander and others, 2008; McIsaac and others, 2002) (table 1). Total annual biological nitrogen fixation in each county was estimated as the sum of soybean fixation, alfalfa hay fixation, and non-alfalfa hay fixation.

Table 1. Fixation rates used in the calculation of biological nitrogen fixation by crops (modified from Alexander and others, 2008; McIsaac and others, 2002).

Crop	Crop unit	Nitrogen fixation rate, in kilograms per crop unit
Soybeans	Production, in bushels	0.91
Alfalfa hay	Harvested area, in hectare[1]	218
Non-alfalfa hay	Harvested area, in hectare[1]	116

[1]Harvested area originally in acres; converted to hectare using a conversion factor of 0.40468564224 hectare per acre.

Atmospheric Deposition

Nitrogen inputs from atmospheric deposition were derived from wet deposition of nitrate and ammonium data from the National Atmospheric Deposition Program and processed as described in Ruddy and others (2006). Atmospheric ammonia and organic nitrogen largely are derived from volatilization of animal waste and fertilizer. Because these emissions may redeposit during the same year in close proximity to the emission source (Prospero and others, 1996), deposition of ammonia and organic nitrogen were assumed to be recycled from other inputs in the same region and were not included as inputs in this study (Howarth and others, 1996; Jordan and Weller, 1996). County-level, annual data on atmospheric deposition of nitrate and ammonium are available from Ruddy and others (2006).

Food and Feed Import

The import of agricultural products for human food and livestock feed can be an important source of anthropogenic nutrients in a watershed (Jordan and Weller, 1996). Net import of food and feed was estimated as the balance between (1) nutrient consumption by humans and animals and (2) nutrients provided by crops grown for human and animal consumption and animals produced for human consumption in the watershed on an annual basis:

$$\text{Net import of food} = \text{human consumption} - \text{crop production for human consumption} - \text{animal production for human consumption} \quad (4)$$

$$\text{Net import of feed} = \text{animal consumption} - \text{crop production for animal consumption} \quad (5)$$

where

$$\text{human consumption} = \text{population} \times \text{human intake rate} \quad (6)$$

$$\begin{aligned}&\text{crop production for human consumption} \\ &= \text{sum of (crop production} \\ &\times \text{nutrient content of the crop} \\ &\times \text{(percent of crop to human food/100)} \\ &\times \text{(1–(percent loss in processing of human food/100)))}\end{aligned} \quad (7)$$

$$\begin{aligned}&\text{animal production for human consumption} \\ &= \text{sum of (animal consumption – animal excretion)} \\ &\times \text{(1– (percent loss in human consumption/100))} \\ &= \text{sum of ((number of animals × animal intake rate)} \\ &\text{– (number of animals × animal excretion rate))} \\ &\times \text{(1–(percent loss in human consumption/100)))}\end{aligned} \quad (8)$$

$$\begin{aligned}&\text{animal consumption} \\ &= \text{sum of (number of animals × animal intake rate)}\end{aligned} \quad (9)$$

$$\begin{aligned}&\text{crop production for animal consumption} \\ &= \text{sum of (crop production} \\ &\times \text{nutrient content of the crop} \\ &\times \text{(percent of crop to animal feed/100)} \\ &\times \text{(1–(percent loss in processing of animal feed/100)))}\end{aligned} \quad (10)$$

A negative value for net import of food or feed indicates that more crops and (or) animals were produced than were consumed by humans and animals in the watershed, representing a net export of food or feed; a positive value indicates that more crops and (or) animals were consumed by humans and animals than were produced in the watershed, representing a net import of food or feed. A positive value, or a net import of food or feed, would lead to human and (or) livestock waste inputs to the watershed in excess of the human and (or) livestock waste derived from crops grown in the watershed. Therefore, positive values for net import of food or feed were considered “new” anthropogenic inputs and were included in equation 2. A negative value, or a net export of food or feed, indicates that some portion of the crops grown in the watershed were exported out of the watershed; because exported crops are derived from the initial inputs of fertilizer, fixation, atmospheric deposition, or recoverable manure in the watershed during the same year, they represent recycled nutrients and thus were excluded from equation 2.

Total imports of food or feed cannot be directly estimated. They can only be estimated via equations 4 and 5 as a net value—that is, as net import or export. This limitation can be illustrated with an example: let human consumption be 100 kg and crop production for human consumption be 75 kg. If all the crops produced for human consumption were consumed by people in the watershed, an additional 25 kg would be imported to meet the consumption needs of people in the watershed. However, there may be situations where some of the crops produced for human consumption in a watershed are exported, even when enough people are present in the watershed to potentially consume all of those crops. As an alternative scenario, let 15 kg of the 75 kg produced be exported to another watershed (say, potatoes exported to other parts of the Nation)—total import of “new” nutrients would then be 40 kg to compensate for this export. However, the net import, calculated from equation 4, is 25 kg in both scenarios. Because the actual value of exported crops is not known, the actual value of total imports cannot be directly estimated. Only net import can be calculated. Thus, the estimation of anthropogenic nutrient inputs to a watershed in equation 2 may be an underestimate.

Each of the terms used to calculate net import or export of food and feed in equations 4 and 5, represented individually by equations 6–10, is further detailed below.

Human Consumption

As shown in equation 6, human consumption of nitrogen and phosphorus was estimated as the product of population and the human intake rate. County-level population data for 1992, 1997, and 2002 were obtained from the time series of intercensal estimates by county, calculated by the U.S. Census Bureau (2000, 2008). Human intake rates used in equation 6 were reported by David and Gentry (2002) and are shown in table 2.

Table 2. Human intake rates used in the calculation of human consumption (modified from David and Gentry, 2002).

Nutrient	Human intake rate, in kilograms per year
Nitrogen	4.53
Phosphorus	0.46

Animal Consumption

As shown in equation 9, animal consumption of nitrogen and phosphorus was estimated as the product of the number of animals and the animal intake rate for a livestock group, summed across all livestock groups in each county in each year (1992, 1997, 2002). County-level data on the number of animals were obtained from livestock population data in the 1992, 1997, and 2002 Censuses of Agriculture (U.S. Department of Commerce, 1995; U.S. Department of Agriculture, 1999, 2004). These livestock population data in 1992 and 1997 are a subset of those also used in Ruddy and others (2006); assumptions that went into estimating nondisclosed values are described therein. Similar assumptions were used for the livestock population data in 2002 (Barbara Ruddy, U.S. Geological Survey, written commun., 2010). The animal intake rates used in equation 9 were reported by Van Horn (1998) and are shown in table 3. The feed amounts accounted for in table 3 represent approximately 90 percent of the estimated livestock feed grain and concentrate consumption by animals in the United States (Van Horn, 1998).

Crop Production for Human and Animal Consumption

As shown in equations 7 and 10, crop production of nitrogen and phosphorus was estimated as the product of (1) crop production amounts (in units of bushels, tons, and so forth), (2) the nutrient content of the crop (in kilograms of nutrients per crop unit), (3) the percentage of the crop used for human food or animal feed, and (4) a factor accounting for loss during storage and processing. The resulting product then was summed across all crop groups in each county for each year (1992, 1997, 2002). County-level data on crop production for 1992, 1997, and 2002 were obtained from the Census of Agriculture (U.S. Department of Commerce, 1995; U.S. Department of Agriculture, 1999, 2004). Data reported in the Census of Agriculture as "Withheld to avoid disclosing data for individual farms" were treated as a value of zero. County-level data on pasture acreage were obtained from the Enhanced National Land Cover Dataset 1992 (NLCDe 92) (Nakagaki and others, 2007) for 1992 and from the National Land Cover Dataset 2001 (NLCD01) (LaMotte, 2008a,b,c,d) for 1997 and 2002. County boundaries from 1990 were used for all years. As a result, the 2002 pasture value for Broomfield County, Colo., was distributed among the four counties from which land was used to create Broomfield County in 2001.

With the exception of pasture, the nutrient content of each crop group was reported by Kellogg and others (2000). Values for the nutrient content of pasture were reported in Hong and others (2011), as used in Boyer and others (2002) (for nitrogen), and in Russell and others (2008) (for phosphorus). These values are shown in table 4. With the exception of pasture, the distribution of crops between human food and animal feed and the factors accounting for loss during storage and processing were reported in Jordan and Weller (1996);

Table 3. Animal intake rates used in the calculation of animal consumption (modified from Van Horn, 1998).

[Time step of dry mass value = day, animal intake rate = average dry mass × (average content of dry mass/100)*365 days*0.45359237 kilograms per pound. Time step of dry mass value = life cycle, animal intake rate = average dry mass × (average content of dry mass/100)*0.45359237 kilograms per pound)]

Livestock, as designated in this report	Livestock, as designated in Van Horn (1998)	Average dry mass, in pounds	Time step of dry mass value	Average nitrogen content of dry mass, in percent	Average phosphorus content of dry mass, in percent	Animal intake rate for nitrogen, in kilograms per animal per year	Animal intake rate for phosphorus, in kilograms per animal per year
Milk cows	Dairy cows	48	Day	2.72	0.50	216	40
Beef cattle	Beef steer	21	Day	1.92	0.40	67	14
Layers	Hens	194	Day	2.624	0.65	0.84	0.21
Broilers	Broilers	8.4	Life cycle	3.36	0.65	0.13	0.025
Turkeys	Turkeys	51.88	Life cycle	2.64	0.65	0.62	0.15
Total hogs	Hogs	711	Life cycle	2.64	0.55	8.5	1.8

Table 4. Conversion factors used to estimate crop production for animal and human consumption (modified from Hong and others, 2011; Russell and others , 2008; Boyer and others, 2002; Kellogg and others, 2000; Jordan and Weller, 1996).

[n/a, not available; --, not applicable; cwt, hundredweight; bu, bushels; lb, pounds; NLCD, National Land Cover Dataset; NLCDe, Enhanced National Land Cover Dataset; US, United States; excl, excluding]

Crop[1]	1992 Census of Agriculture crop variable name	1997 Census of Agriculture crop variable name	2002 Census of Agriculture crop variable name	Crop unit	Nutrient content of crop, in kilograms of nutrients per crop unit	
					Nitrogen	Phosphorus
Corn, grain	Corn for grain or seed (bushels)	Corn, grain—production, measured in bu	Corn, grain—production, measured in bu	Bushels	0.36	0.07
Corn, silage	Corn for silage/ green chop (tons, green)	Corn, silage—production, measured in tons	Corn, silage—production, measured in tons	Tons	3.22	0.48
Soybeans	Soybeans for beans (bushels)	Soybeans—production, measured in bu	Soybeans—production, measured in bu	Bushels	1.61	0.16
Sorghum, grain	Sorghum for grain or seed (bushels)	Sorghum, grain—production, measured in bu	Sorghum, grain—production, measured in bu	Bushels	0.44	0.08
Sorghum, silage	Sorghum for silage, harvested (tons, green)	Sorghum, silage—production, measured in tons	Sorghum, silage—production, measured in tons	Tons	6.70	1.11
Barley	Barley for grain (bushels)	Barley—production, measured in bu	Barley—production, measured in bu	Bushels	0.41	0.08
Wheat	Wheat for grain (bushels)	Wheat—production, measured in bu	Wheat—production, measured in bu	Bushels	0.56	0.10
Wheat, winter	n/a	n/a	Wheat, winter—production, measured in bu	Bushels	0.46	0.09
Wheat, spring, durum	n/a	Wheat, spring, durum—production, measured in bu	Wheat, spring, durum—production, measured in bu	Bushels	0.59	0.10
Wheat, spring (excl durum)	n/a	Wheat, spring (excl durum)—production, measured in bu	Wheat, spring (excl durum)—production, measured in bu	Bushels	0.63	0.10
Oats	Oats for grain (bushels)	Oats—production, measured in bu	Oats—production, measured in bu	Bushels	0.27	0.05
Rye	Rye for grain, Harvested (bushels)	Rye—production, measured in bu	Rye—production, measured in bu	Bushels	0.49	0.08
Rice	Rice (cwt)	Rice—production, measured in cwt	Rice—production, measured in cwt	Cwt	0.57	0.13
Peanuts	Peanuts for nuts (pounds)	Peanuts—production, measured in lb	Peanuts—production, measured in lb	Pounds	0.02	0.00
Sugarbeets, sugar	Sugar beets for sugar (tons)	Sugarbeets, sugar—production, measured in tons	Sugarbeets, sugar—production, measured in tons	Tons	2.16	0.43
Potatoes	Irish potatoes (cwt)	Potatoes—production, measured in cwt	Potatoes—production, measured in cwt	Cwt	0.16	0.03
Sweet potatoes	--	Sweet potatoes—production, measured in cwt	Sweet potatoes—production, measured in cwt	Cwt (1997 and 2002)	0.11	0.02
Sweet potatoes	Sweet potatoes, Harvested (bushels)	--	--	Bushels (1992)	0.06	0.01
Forage, hay	Hay-all (tons, dry)	n/a	Forage, hay—production, measured in tons	Tons	13.11	4.51
Forage, alfalfa, hay	n/a	Forage, alfalfa, hay—production, measured in tons	Forage, alfalfa, hay—production, measured in tons	Tons	22.86	2.14
Forage, small grain, hay	n/a	Forage, small grain, hay—production, measured in tons	Forage, small grain, hay—production, measured in tons	Tons	11.61	2.03
Forage, tame (excl alfalfa and small grain)	n/a	Forage, tame (excl alfalfa and small grain), hay—production, measured in tons	Forage, tame (excl alfalfa and small grain), hay—production, measured in tons	Tons	8.98	6.94
Forage, wild, hay	n/a	Forage, wild, hay—production, measured in tons	Forage, wild, hay—production, measured in tons	Tons	8.98	6.94
Pasture	Data from 1992 NLCDe	Data from 2001 NLCD	Data from 2001 NLCD	Acres	9.07	5.00

Table 4. Conversion factors used to estimate crop production for animal and human consumption (modified from Hong and others, 2011; Russell and others , 2008; Boyer and others, 2002; Kellogg and others, 2000; Jordan and Weller, 1996).—Continued

[n/a, not available; --, not applicable; cwt, hundredweight; bu, bushels; lb, pounds; NLCD, National Land Cover Dataset; NLCDe, Enhanced National Land Cover Dataset; US, United States; excl, excluding]

Crop[1]	Percent of crop to human food	Percent of crop to animal feed	Percent loss of human food during storage and processing	Percent loss of animal feed during storage and processing	Notes
Corn, grain	4	96	10	10	--
Corn, silage	0	100	--	0	--
Soybeans	2	98	10	10	--
Sorghum, grain	0	100	--	0	--
Sorghum, silage	0	100	--	0	Production data not available in 1992; used harvested data instead for 1992.
Barley	3	97	10	10	--
Wheat	61	39	10	10	Values for the nutrient content of wheat are the average of the nutrient contents of individual wheat types reported in Kellogg and others (2000).
Wheat, winter	61	39	10	10	--
Wheat, spring, durum	61	39	10	10	--
Wheat, spring (excl durum)	61	39	10	10	--
Oats	6	94	10	10	--
Rye	17	83	10	10	Production data not available in 1992; used harvested data instead for 1992.
Rice	100	0	10	--	Values for the nutrient content of rice were in units of bags in Kellogg and others (2000). 1 bag of rough or milled rice = 100 U.S. pounds = 1 cwt (U.S. Department of Agriculture, 1992).
Peanuts	50	50	10	10	--
Sugarbeets, sugar	0	100	--	0	--
Potatoes	100	0	10	--	Values for the nutrient content of potatoes were in units of bags in Kellogg and others (2000). 1 sack of potatoes = 100 U.S. pounds = 1 cwt (U.S. Department of Agriculture, 1992). Assumed 1 sack = 1 bag.
Sweet potatoes	100	0	10	--	Values for the nutrient content of sweet potatoes were in units of bushels in Kellogg and others (2000). 1 bushel of sweet potatoes = 55 U.S. pounds = 0.55 cwt (U.S. Department of Commerce, 1995).
Sweet potatoes	100	0	10	--	Production data not available in 1992; used harvested data instead for 1992.
Forage, hay	0	100	--	0	Values for the nutrient content of forage hay are the average of the nutrient content of individual forage hay types reported in Kellogg and others (2000).
Forage, alfalfa, hay	0	100	--	0	--
Forage, small grain, hay	0	100	--	0	--
Forage, tame (excl alfalfa and small grain)	0	100	--	0	--
Forage, wild, hay	0	100	--	0	--
Pasture	0	100	--	0	--

[1]When all individual components of total wheat (wheat, winter; wheat, spring, durum; wheat, spring (excl durum)) or total hay (forage, alfalfa, hay; forage, small grain, hay; forage, tame (excl alfalfa and small grain); forage, wild, hay) were available, individual components were used in lieu of their totals. When all individual components were not available, the total values for wheat and hay were used.

these values are shown in table 4. Because pasture is grazed by livestock and typically is not harvested, percent of crop to animal feed was assumed to be 100, and loss during storage and processing was assumed to be zero for this study. Pasture acreage was derived from land cover code 81 (pasture/hay–areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops), so its inclusion may have resulted in an unknown amount of double-counting of inputs from seed or hay crops that were also included in crop production estimates through data on hay production from the Census of Agriculture. The approach used here follows precedent established in Boyer and others (2002) and in Russell and others (2008).

Animal Production for Human Consumption

As shown in equation 8, animal production for human consumption (milk, meat, eggs, organs, and so forth) was estimated as the difference between animal consumption and animal excretion, multiplied by a factor accounting for loss due to spoilage and inedible components. Animal consumption was estimated as described in the preceding section “Animal Consumption.” Animal excretion was estimated by using the same county-level data on the number of animals, together with animal excretion rates reported in Van Horn (1998) and shown in table 5. Following Boyer and others (2002), loss due to spoilage and inedible components was assumed to be 10 percent.

The animal excretion rates used in this study are different than those used in Ruddy and others (2006), which were modified from Goolsby and others (1999) (table 6). The animal excretion rates used in Ruddy and others (2006) often exceed the animal intake rates reported in Van Horn (1998) and used here (table 6). There are several other published values for typical animal intake rates that could have been used instead (see comparison in Boyer and others, 2002), but those in Van Horn (1998) were selected because they are based on the most recent agricultural practices in the United States (Boyer and others, 2002).

Determination of Individual Nutrient Inputs to the Watersheds of NAWQA Surface-Water Sites

For determination of total nutrient inputs to the watersheds of the NAWQA surface-water sites, county-level annual estimates of nutrient inputs were mapped to specific land uses within each county by using NLCDe 92 and then summed for the area within each watershed, using tools from Price and others (2010). NLCDe 92 is a composite of USGS NLCD 92 (U.S. Geological Survey, 2000) and USGS enhanced Land Use and Land Cover (LULC) data (Price and others, 2007). NLCD 92 is based on interpretation of Landsat satellite Thematic Mapper imagery captured from the late 1980s through early 1990s and was supplemented with a variety of ancillary data (Vogelmann and others, 2001). The LULC dataset represents conditions compiled from aerial photographs taken in the 1970s to mid-1980s (U.S. Geological Survey, 1990). County- or HUC6-level estimates of farm and nonfarm fertilizer, biological nitrogen fixation, recoverable manure, human and animal consumption, and crop and animal production were allocated by land use as shown in table 7. Atmospheric deposition was assumed to be distributed over the county, and an area-weighted sum was computed for each watershed. Although more recent land-cover data are available through NLCD01, only NLCDe 92 was used for allocation of nutrient inputs. Various methodological differences resulted in substantially different pixel-by-pixel labeling in the two NLCD datasets, much of which probably is not genuine land-cover change (U.S. Environmental Protection Agency, 2007). County boundaries from 1990 were used for all spatial allocations. There were some significant changes to the counties during the 1990s and early 2000s (U.S. Census Bureau, 2002), but only a few required data modification for allocation to the watershed. The human consumption value in 2002 for Broomfield County, Colo., was allocated by percent-estimated detached population (U.S. Census Bureau, 2002) among the four counties from which land was used to create Broomfield County in 2001. Also, Miami-Dade, Fla., was processed as Dade, Fla.

Following Mueller and Spahr (2005, 2006) and as detailed in table 8, the mean of multiple years was used as the estimate of watershed inputs of fertilizer and atmospheric deposition, which were measured annually. This was done for correspondence with the riverine loads in Mueller and Spahr (2006), which were reported as the mean of the annual loads estimated during the NAWQA high-intensity data collection period. The estimates of inputs of biological nitrogen fixation, recoverable manure, and net food and feed imports or exports were for a single year—the year of the Census of Agriculture closest to the NAWQA high-intensity data collection period.

Total Anthropogenic Nutrient Inputs to Watersheds

Once the individual inputs to each watershed had been quantified, anthropogenic inputs were calculated as

$$\textit{Anthropogenic inputs of nitrogen} = Waste + Fert + Fix + Atm + FoodImp + FeedImp \qquad (11)$$

$$\textit{Anthropogenic inputs of phosphorus} = Waste + Fert + FoodImp + FeedImp \qquad (12)$$

There are important limitations in this estimation of total anthropogenic nutrient inputs. The equations do not include natural nutrient inputs, because the loss of anthropogenic inputs (those most likely to be managed) is of interest in the companion analysis of riverine export. The anthropogenic sources in these equations, however, do not include inputs from long-term storage of anthropogenic nutrients (such as inputs from soils or groundwater), the import of livestock manure for application

Table 5. Animal excretion rates used in the calculation of animal production for human consumption (modified from Van Horn, 1998).

Livestock, as designated in this report	Livestock, as designated in Van Horn (1998)	Animal excretion rate, in pounds per animal per year		Animal excretion rate, in kilograms per animal per year	
		Nitrogen	Phosphorus	Nitrogen	Phosphorus
Milk cows	Dairy cows	367	65	166	29
Beef cattle	Beef steer	129	23	58.5	10
Layers	Hens	1,205[1]	376[1]	546.6[1]	171[1]
Broilers	Broilers	0.157	0.026	0.0712	0.012
Turkeys	Turkeys	0.87	0.194	0.39	0.0880
Total hogs	Hogs	12.878	2.082	5.8414	0.9444

[1]Per 1,000 animals.

to agricultural fields (such as from confined animal feedlots outside of the watershed), or the application of biosolids derived from the treatment of human waste to agricultural fields. Anthropogenic inputs from these sources therefore are routinely excluded from quantification of anthropogenic nutrient inputs to watersheds (for example, see Russell and others, 2008; Boyer and others, 2002; David and Gentry, 2002; McIsaac and others, 2002; Howarth and others, 1996; Jordan and Weller, 1996). First, the origin (anthropogenic or natural) of nutrient inputs from long-term storage are difficult to identify even on a small scale; national-scale information does not currently (2010) exist. Second, because agricultural data from individual farms is not disclosed to protect the privacy of farm owners, the agricultural data used in this report are county level. In most cases, it is not economically feasible to transport manure throughout an entire county (Kellogg and others, 2000), so transport of manure among counties is likely to be low compared to transport over smaller distances within counties. Third, biosolids are used on less than one percent of the Nation's agricultural land (U.S. Environmental Protection Agency, 2011). There are other important limitations to this approach. The equations assume that nutrient mineralization and immobilization are in equilibrium. Because of limited information on crop uptake, animal intake, and animal excretion, certain crops or animals that are important in a given county or watershed might not be included in the estimation of total anthropogenic nutrient inputs. Lastly, the human consumption estimates were allocated equally across all urban land; a large proportion of human-waste inputs, however, likely enter watersheds in more localized areas through discharge from wastewater-treatment plants.

Many previous studies using the net anthropogenic nitrogen input (NANI) or net anthropogenic phosphorus input (NAPI) approach for estimating anthropogenic nutrient inputs have assumed that livestock waste represents only the internal recycling of "new" inputs of fertilizer, biological fixation by crops, and atmospheric deposition (for example, see Russell and others, 2008; Boyer and others, 2002; David and Gentry, 2002; McIsaac and others, 2002; Howarth and others, 1996; Jordan and Weller, 1996). In this study, livestock waste derived from prior (and therefore independent) inputs of fertilizer, biological fixation by crops, and atmospheric deposition is included as an input because it is ultimately used to grow crops together with "new" inputs of fertilizer, biological fixation by crops, and atmospheric deposition. This waste input term is represented by recoverable livestock waste, the proportion of excreted manure that could reasonably be expected to be collected from confinement facilities and subsequently applied to the land surface after losses from volatilization of nitrogen, spillage, and runoff. Because of the inclusion of recoverable livestock waste as an input, anthropogenic nutrient inputs estimated in this study are not directly comparable to anthropogenic nutrient inputs estimated using the "NANI" or "NAPI" approach. More generally, methods used to estimate nutrient inputs to watersheds vary considerably, depending in part on the objective of the studies. For example, some studies include livestock waste as an input—either as excreted manure (Bosch and Allan, 2008) or as recoverable manure (MacDonald and Bennett, 2009; Lanyon and others, 2006; Stewart and others, 2005)—but may not include food and feed imports (MacDonald and Bennett, 2009; Lanyon and others, 2006; Stewart and others, 2005). Careful consideration should be given to estimation methods when comparing results from different studies.

Description of the County-Level Nutrient-Input Dataset

The county-level nutrient-input data described in this report are in the dataset Nutrient_input_county.xlsx that is available online at *http://pubs.usgs.gov/sir/2012/5241/excel/Nutrient_input_county.xlsx*. This dataset contains estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms, for each county in the conterminous United States. Separate estimates are listed for biological fixation by crops (for nitrogen only), human consumption, crop production for human consumption, animal production for human consumption, animal consumption, and crop production for animal consumption. (Note that county-level estimates of atmospheric deposition inputs are available in Ruddy and others, 2006; county-level estimates of fertilizer are available in Gronberg and Spahr, 2012; and county-level estimates of recoverable manure inputs in 1992 and 1997 are available in Kellogg and others, 2000). Counties are identified by State, county, and Federal Information Processing System (FIPS) code. The data are sorted alphabetically by State, and numerically by FIPS code within each State. The area (in square kilometers) is listed for each county. For consistency and ease in reporting, county boundaries were kept the same throughout the period of record presented in this dataset, even though several changes occurred. For example,

Table 6. Comparison between the animal intake and excretion rates used in this study and the animal excretion rates used in Ruddy and others (2006).

Livestock, as designated in this report	Livestock, as designated in Van Horn (1998)	Livestock, as designated in Ruddy and others (2006)	Animal intake rate used in this study from Van Horn (1998), in kilograms per animal per year[1]		Animal excretion rate used in this study from Van Horn (1998), in kilograms per animal per year[2]		Animal excretion rate from Ruddy and others (2006), in kilograms per animal per year	
			Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Milk cows	Dairy cows	Milk cows	216	40	166	29	74.5	12
Beef cattle	Beef steer	Beef cattle	67	14	58.5	10	54.8	19
Layers	Hens	Chickens and hens	0.84[3]	0.21[3]	546.6[3]	171[3]	0.55[3]	0.2[3]
Broilers	Broilers	Pullets and broilers	0.13	0.025	0.0712	0.012	0.37	0.1
Turkeys	Turkeys	Tom turkeys and hen turkeys (separately)	0.62	0.15	0.39	0.0880	0.54	0.20
Total hogs	Hogs	Hogs and pigs	8.5	1.8	5.8414	0.9444	9.9	4.4

[1]Also reported in table 3.

[2]Also reported in table 5.

[3]Per 1,000 animals.

Table 7. Land-cover classifications used for allocation of nutrient inputs within a county or hydrologic unit.

[NLCD, National Land Cover Data; LULC, Land Use and Land Cover; --, not applicable]

Enhanced National Land Cover Data 1992 classification	Nutrient input category: Farm fertilizer	Nonfarm fertilizer	Biological nitrogen fixation	Recoverable manure	Human consumption	Animal consumption	Crop production for human and animal consumption	Animal production for human consumption
Agricultural land								
Orchards/vineyards/other	X	--	--	--	--	--	X	--
LULC orchards/vineyards/other[1]	X	--	--	--	--	--	X	--
Pasture/hay	X	--	X	X	--	X	X	X
Row crops	X	--	X	X	--	X	X	X
Small grains	X	--	--	X	--	X	X	X
Fallow	X	--	--	X	--	X	X	X
Grassland/herbaceous	--	--	--	X	--	X	X	X
Urban land								
Low intensity residential	--	X	--	--	X	--	--	--
LULC residential[1]	--	X	--	--	X	--	--	--
NLCD/LULC forested residential[1]	--	X	--	--	X	--	--	--
Urban/recreational grasses	--	X	--	--	X	--	--	--

[1]Revised classification of the NLCD dataset as described in Nakagaki and others (2007).

Table 8. Time periods used for determining annual riverine loads and watershed inputs (modified from Mueller and Spahr, 2005).

[NAWQA, National Water-Quality Assessment program]

NAWQA study-unit group (start year)	Riverine load modeling period (water years): Model calibration	Load estimation	Nutrient-input period (calendar years): Fertilizer and atmospheric deposition	Biological nitrogen fixation, recoverable manure, and net food and feed imports
1991	1993–1996	1994–1995	1993–1995 mean	1992
1994	1996–1999	1997–1998	1996–1998 mean	1997
1997	1999–2001	2000–2001	1999–2001 mean	2002

South Boston City, Va. (FIPS 51780), was merged into Halifax County, Va. (FIPS 51083), in 1995, but nutrient inputs in this dataset are presented separately for South Boston City through 2001. Although its boundaries did not change, Dade County, Fla. (FIPS 12025), was renamed Miami-Dade County in 1997 and assigned a new FIPS code (12086). In this dataset, the new name and FIPS code are used throughout the time period (1982–2001).

Description of the Watershed-Level Nutrient-Input Dataset

The nutrient-input data for the watersheds of each of the 495 surface-water sites studied as part of the USGS NAWQA Program are in the dataset Nutrient_input_watershed.xlsx that is available online at *http://pubs.usgs.gov/sir/2012/5241/excel/Nurient_input_watershed.xlsx*. This dataset contains estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms. Separate estimates are listed for biological fixation by crops (for nitrogen only), human consumption, crop production for human consumption, animal production for human consumption, animal consumption, crop production for animal consumption, net import of food, and net import of feed. Estimates of inputs from atmospheric deposition (derived from data in Ruddy and others, 2006), fertilizer (derived from data in Gronberg and Spahr, 2012), and recoverable manure (derived from data in Kellogg and others, 2000, and Robert Kellogg, U.S. Department of Agriculture, written commun., 2011) are also provided so that final estimates of anthropogenic nutrient inputs also could be calculated and presented. Watersheds are identified by the USGS site identifier, the site name, the NAWQA study unit in which the site is located, and the study-unit start year during the first cycle of the NAWQA program. The study-unit start year was used to determine the years used for each input data series (see table 8). The area (in square kilometers) also is listed for each watershed.

Because the county-level fertilizer inputs and the watershed area for some sites have been updated since the publication of Mueller and Spahr (2005), watershed areas, inputs of atmospheric deposition, and inputs of fertilizer for these watersheds may be slightly different here than reported in Mueller and Spahr (2005).

Summary

The purposes of this report were to (1) describe the estimation of anthropogenic nutrient inputs in the United States during 1992, 1997, and 2002 and (2) provide those estimates in a tabular dataset. Estimates of nitrogen (as N) and phosphorus (as P) anthropogenic inputs are provided for each county in the conterminous United States in a tabular dataset. Separate estimates are listed for biological fixation by crops (for nitrogen only), human consumption, crop production for human consumption, animal production for human consumption, animal consumption, and crop production for animal consumption. Estimates of nitrogen (as N) and phosphorus (as P) inputs also are provided for the watersheds of 495 National Water-Quality Assessment Program surface-water sites in the conterminous United States in another tabular dataset. Separate estimates are listed for biological fixation by crops (for nitrogen only), animal consumption, human consumption, crop production for animal consumption, crop production for human consumption, animal production for human consumption, net import of food, and net import of feed. Estimates of inputs from atmospheric deposition, fertilizer, and recoverable manure are also provided for each watershed so that final estimates of anthropogenic nutrient inputs may be calculated (county-level estimates of these sources already are available from previous studies). Riverine loads of total nitrogen and total phosphorus that previously were calculated for the same sites also are provided in the watershed dataset.

Acknowledgments

The authors thank Neil Dubrovsky, Nancy Baker, and Tammy Ivahnenko for their helpful reviews of this report.

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Publishing support provided by:
Denver Publishing Service Center, Denver, Colorado

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