Manure and Fertilizer Inputs to Land in the Chesapeake Bay Watershed, 1950–2012

Scientific Investigations Report 2018–5022

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

Cover: Soybean farm in northern Maryland, August 15, 2014. Photograph by Alex Demas, U.S. Geological Survey.

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83).

Abbreviations

AU	Animal unit
BMP	Best management practice
CBP	Chesapeake Bay Program
CBPO	EPA Chesapeake Bay Program Office
COA	Census of Agriculture
EPA	U.S. Environmental Protection Agency
HUC	Hydrologic unit code
HUC8	8-digit hydrologic unit
N	Total Nitrogen
NAWQA	USGS National Water-Quality Assessment Project
NWALT	National Water-Quality Assessment Wall-to-Wall Anthropogenic Land-Use Trends
P	Total Phosphorus
TMDL	Total Maximum Daily Load
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

Manure and Fertilizer Inputs to Land in the Chesapeake Bay Watershed, 1950–2012

By Jennifer L.D. Keisman[1], Olivia H. Devereux[2], Andrew E. LaMotte[1], Andrew J. Sekellick[1], and Joel D. Blomquist[1]

Abstract

Understanding changing nutrient concentrations in surface waters requires quantitative information on changing nutrient sources in contributing watersheds. For example, the proportion of nutrient inputs reaching streams and rivers is directly affected by when and where those nutrients enter the landscape. The goal of this report is to contribute to the U.S. Geological Survey's efforts to describe spatial and temporal patterns in nutrient inputs to the landscape in the Chesapeake Bay watershed, thereby informing efforts to understand changes in riverine and estuarine conditions. The magnitude, spatial variability, and changes over time in nutrient inputs from manure and fertilizer were evaluated in the context of changes in land use and agricultural practices from 1950 through 2012 at three spatial scales: the entire Chesapeake Bay watershed, the 53 8-digit hydrologic units (HUC8s) that are contained within the watershed, and a set of 7 regions that were determined by aggregating geographically similar HUC8s. The expected effect of agricultural best management practices (BMPs) on agricultural nutrient inputs from 1985 through 2012 was also investigated. Nitrogen (N) and phosphorus (P) inputs from manure increased gradually over time at the scale of the entire watershed. Fertilizer-N inputs showed steeper increases, with greater inter-annual fluctuations. Fertilizer-P inputs were less variable, increasing moderately from 1950 through the mid-1970s, and declining thereafter. Nutrient inputs and farming practices varied geographically within the watershed, with implications for the potential impact of these inputs on downstream water quality and ecosystem health. Both temporal and spatial patterns in the intensity of agricultural nutrient inputs were consistent with the magnitude and concentration of livestock and poultry populations and the intensity of row crop agriculture. Reported implementation of the animal and land-use change BMPs that were evaluated were expected to have little effect on agricultural N inputs. Animal BMPs were expected to have a more measurable impact on manure-P inputs, particularly in areas with large poultry populations. Understanding these patterns is important for explaining the changes that have been observed in nutrient loads to the rivers and streams of the Chesapeake Bay watershed, and their impacts on the water quality and ecosystem health of Chesapeake Bay itself.

Introduction

The Chesapeake Bay watershed covers about 64,000 square miles (mi^2), stretching across seven jurisdictions made up of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) as well as Washington, D.C. The watershed drains into an estuary covering a surface area of about 4,400 mi^2, with a mean depth of about 21.3 feet (ft) (Kemp and others, 2005). Pressures such as increasing population, agricultural production, and urban development across the watershed have degraded water quality and living resources in the Chesapeake Bay, leading to the establishment of a Total Maximum Daily Load (TMDL) regulating the amount of nitrogen, phosphorus, and sediment that jurisdictions may discharge into the watershed's rivers, streams, and tidal waters (U.S. Environmental Protection Agency, 2010). In order to comply with the Chesapeake Bay TMDL, jurisdictions are implementing best management practices (BMPs) designed to reduce the amount of nitrogen, phosphorus, and sediment draining to tidal waters.

Nitrogen (N) and phosphorus (P) inputs from agriculture (for example, manure and inorganic fertilizer combined) currently constitute the largest source of nutrient inputs to the landscape in the Chesapeake Bay watershed (Boesch and others, 2001; U.S. Environmental Protection Agency, 2010a), as well as the predominant source of nutrients delivered to Chesapeake Bay (Ator and others, 2011). Manure inputs can occur in feed lots, manure storage structures, or pasture, or can be applied to cropland as fertilizer, while inorganic fertilizer is generally applied to cropland. Understanding the absolute magnitude and spatial variability of manure and inorganic fertilizer inputs can inform further analysis of the relative impact of nutrient loads to Chesapeake Bay from different regions; a pound of N or P applied to land in the far western edge of the watershed does not have the same impact on Chesapeake Bay's water quality as a pound applied to land closer to the

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Bay's shoreline (Linker and others, 2013). Variable landscape conditions including soil erodibility, soil drainage properties, physiographic region, and rainfall patterns also lead to the variable contributions from uplands to streams and the Bay (Ator and Garcia, 2016). Understanding how the amount and location of manure and fertilizer inputs have changed over time may help managers understand the causes of improving or degrading water quality across the watershed, thereby informing their decisions regarding the future level of implementation and placement of BMPs.

Purpose and Scope

The purpose of this report is to document the magnitude of N and P inputs to land from manure and inorganic fertilizer from 1950 through 2012 in the Chesapeake Bay watershed, and to describe changes in spatial variability over time. Inputs from other sources, such as biosolids from wastewater treatment plants that may be spread on fields in agricultural areas, are not considered in this report. Land-use change is explored – as are temporal and spatial patterns in agricultural land use and farming practices contributing to manure and fertilizer inputs – in order to better understand observed patterns in manure and fertilizer inputs. Both the amount of past implementation (1985–2012) and the expected effects of BMPs that directly affect manure and fertilizer inputs are also described. The term "expected effects" refers to the effects of BMPs as estimated from modeling scenarios provided by the Chesapeake Bay Program (CBP). The actual effects of these BMPs on nutrient inputs from manure and fertilizer may not yet be fully realized.

Inputs of N and P from manure and fertilizer are presented for the Chesapeake Bay watershed as a whole, and at the subbasin, or 8-digit, scale of the Watershed Boundary Dataset (U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013). These subbasins were delineated using science-based hydrologic principles and assigned unique hydrologic unit codes (HUCs). There are a total of 53 8-digit scale hydrologic units (HUC8s) in the Chesapeake Bay watershed (fig. 1; table 1). HUC8s are also aggregated to seven categories corresponding to key regions of interest within the watershed (table 2). Changes in N and P inputs are compared with changes in agricultural land-use practices, such as the cultivation of crops and animal populations, and with the reporting of certain agricultural BMPs between 1985 and 2012.

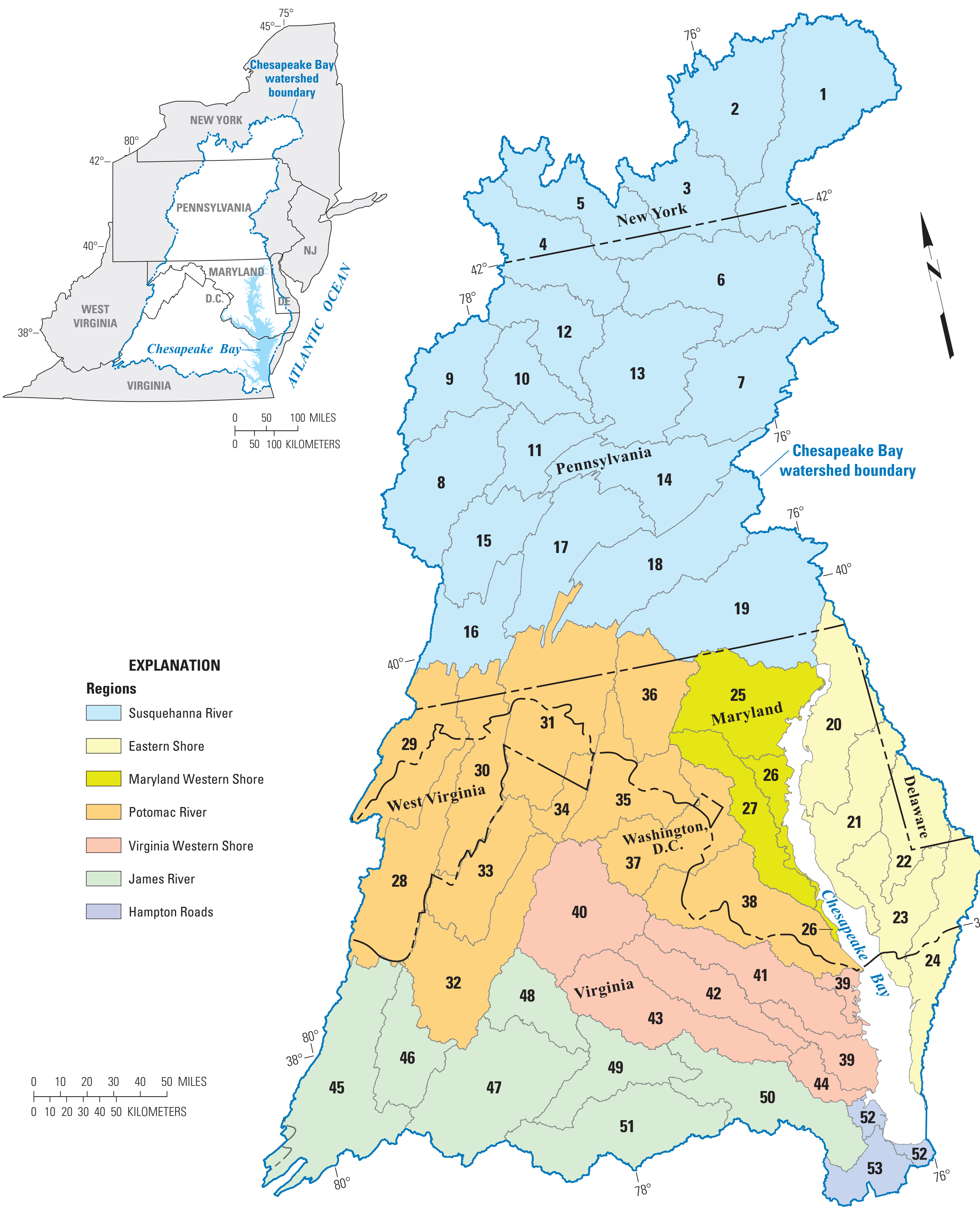

Figure 1. Location of the Chesapeake Bay watershed, with 8-digit hydrologic units (HUC8s) and aggregated regions identified. [Integers shown for each HUC8 correspond to those listed in table 1.]

Table 1. 8-Digit hydrologic units (HUC8s) of the Chesapeake Bay watershed, grouped by region. The column labeled "HUC8 number" corresponds to those on the map of the Chesapeake Bay watershed shown in figure 1; the column labeled "8-digit code" contains the U.S. Geological Survey 8-digit identifier for each HUC8.

Region	HUC8 name	HUC8 number	8-digit code	Area (square miles)
Susquehanna	Upper Susquehanna	1	02050101	2,287
	Chenango	2	02050102	1,606
	Owego-Wappasening	3	02050103	1,044
	Tioga	4	02050104	1,382
	Chemung	5	02050105	1,210
	Upper Susquehanna-Tunkhannock	6	02050106	2,004
	Upper Susquehanna-Lackawanna	7	02050107	1,766
	Upper West Branch Susquehanna	8	02050201	1,597
	Sinnemahoning	9	02050202	1,034
	Middle West Branch Susquehanna	10	02050203	784
	Bald Eagle	11	02050204	773
	Pine	12	02050205	981
	Lower West Branch Susquehanna	13	02050206	1,810
	Lower Susquehanna-Penns	14	02050301	1,448
	Upper Juniata	15	02050302	991
	Raystown	16	02050303	962
	Lower Juniata	17	02050304	1,450
	Lower Susquehanna-Swatara	18	02050305	1,876
	Lower Susquehanna	19	02050306	2,482
Eastern Shore	Chester-Sassafras	20	02060002	1,083
	Choptank	21	02060005	801
	Nanticoke	22	02080109	791
	Tangier	23	02080110	651
	Pocomoke-Western Lower Delmarva	24	02080111	842
Maryland Western Shore	Gunpowder-Patapsco	25	02060003	1,303
	Severn	26	02060004	294
	Patuxent	27	02060006	879
Potomac	South Branch Potomac	28	02070001	1,480
	North Branch Potomac	29	02070002	1,343
	Cacapon-Town	30	02070003	1,205
	Conococheague-Opequon	31	02070004	2,277
	South Fork Shenandoah	32	02070005	1,672
	North Fork Shenandoah	33	02070006	1,034
	Shenandoah	34	02070007	352
	Middle Potomac-Catoctin	35	02070008	1,237
	Monocacy	36	02070009	970
	Middle Potomac-Anacostia-Occoquan	37	02070010	1,255
	Lower Potomac	38	02070011	1,350

Table 1. 8-Digit hydrologic units (HUC8s) of the Chesapeake Bay watershed, grouped by region. The column labeled "HUC8 number" corresponds to those on the map of the Chesapeake Bay watershed shown in figure 1; the column labeled "8-digit code" contains the U.S. Geological Survey 8-digit identifier for each HUC8.—Continued

Region	HUC8 name	HUC8 number	8-digit code	Area (square miles)
Virginia Western Shore	Great Wicomico-Piankatank	39	02080102	516
	Rapidan-Upper Rappahannock	40	02080103	1,557
	Lower Rappahannock	41	02080104	1,002
	Mattaponi	42	02080105	904
	Pamunkey	43	02080106	1,460
	York	44	02080107	220
James	Upper James	45	02080201	2,211
	Maury	46	02080202	838
	Middle James-Buffalo	47	02080203	2,023
	Rivanna	48	02080204	768
	Middle James-Willis	49	02080205	945
	Lower James	50	02080206	1,250
	Appomattox	51	02080207	1,606
Hampton Roads	Lynnhaven-Poquoson	52	02080108	176
	Hampton Roads	53	02080208	401

Table 2. Watershed regions: size and area distribution.

[HUC8, 8-digit hydrologic unit]

Region	Number of HUC8s	Acres	Square miles	Percent of total
Susquehanna	19	17,591,020	27,486	43
Eastern Shore	5	2,667,233	4,168	6
Maryland Western Shore	3	1,585,094	2,477	4
Potomac	11	9,070,399	14,173	22
Virginia Western Shore	6	3,621,594	5,659	9
James	7	6,169,892	9,640	15
Hampton Roads	2	369,345	577	1
Total	**53**	**41,074,577**	**64,180**	**100**

Methods

Data on land use, farmland area and use, cultivated crop types, livestock and poultry numbers, and manure and fertilizer inputs were combined to investigate changing spatial patterns over time in agricultural nutrient inputs and factors affecting those inputs (table 3). Patterns were explored at three spatial scales – the Chesapeake Bay watershed, HUC8, and seven regions of interest – and for 2 time periods: the entire period of record (1950–2012) and the most recent 30 years of record (1982–2012). Sizes and locations of HUC8s were obtained from the Watershed Boundary Dataset (WBD), a nationally standardized collection of hydrologic unit data developed and maintained cooperatively by the U.S. Department of Agriculture (USDA), the U.S. Geological Survey (USGS), and the Environmental Protection Agency (EPA). Data on reported BMP implementation for the years 1985–2012, along with the results of modeling scenarios described below, were used to explore the expected effects of BMP implementation on nutrient inputs to the watershed for each year from 1985 to 2012.

Land Use, Crops, and Animals

Changes in land use from 1982 to 2012 were described based on the USGS National Water-Quality Assessment Wall-to-Wall Anthropogenic Land-Use Trends (NWALT) dataset (Falcone, 2015). NWALT land use classes were aggregated to four major categories as follows: "developed" and "semi-developed" classes were combined into one "developed"

Table 3. Sources of data used in this report.

Data	Source	Time period
Fertilizer use	Sekellick, 2017	1-year increments 1950–2012
Manure production	Sekellick, 2017	5-year increments 1950–2012
Crop acres and yields; animal populations	LaMotte, 2015	5-year increments 1950–2012
Land use, land-use change	Falcone, 2015	1974, 1982, 1987, 1992, 2012
Best management practice implementation	Devereux and others, 2017	1-year increments 1985–2012

category; "low use" and "very low use, conservation" classes were combined into one "natural" category; the "crops" and "pasture/hay" production subclasses were combined into an "agriculture" category; and the "wetlands," "mining/extraction," and "grazing potential" production subclasses were combined into an "other" category. The proportion of land in each of these four categories was evaluated at both the watershed scale and the HUC8 scales. To further explore changes in agricultural land use and agricultural practices, data from the USDA Census of Agriculture (COA) were used to quantify changes in the amount of cropland and pasture, in crops cultivated, and in animal populations (LaMotte, 2015). The COA reports data at the county scale. To facilitate analysis at the HUC8 scale, COA data were re-allocated from county to HUC8s by distributing the animal inventory equally across the agricultural pixels of a county, and then summing by HUC8. This assumed that animals were co-located with cropland and pasture.

Certain crop types tend to be co-located with livestock and (or) poultry populations, which may have implications for both manure and commercial fertilizer usage (Beegle, 2013). To illustrate this pattern for the Chesapeake Bay watershed, crop data from the COA were grouped into the following categories: forage (hay, alfalfa, and silage hay), silage corn, grain corn, and soybeans. To compare livestock and poultry populations with crop types, animals were grouped into cows (beef, dairy, other), hogs, and poultry (layers, pullets, broilers, and turkeys).

In order to evaluate the relative contribution of each animal to total animal biomass in the watershed, the head counts for five animal types (cows, poultry, horses, sheep, and hogs) were converted to animal units (AUs) using methods developed by the CBP Partnership (table 4) (Chesapeake Bay Program, 2013), with some modifications to accommodate differences between the animal categories used by the CBP and those used in the USGS dataset. For example, the average of the CBP's animal unit conversion assumptions for layers and pullets was used to estimate chicken AUs in the USGS dataset.

Fertilizer and Manure Inputs to Land

Changes in manure and fertilizer-N and -P inputs as well as in N and P input intensity (a measure of nutrient input per acre of cropland) were compared within and among the

Table 4. Animal number to animal unit (AU) conversion assumptions used by the Chesapeake Bay Program (Chesapeake Bay Program, 2013), and revised assumptions used and described in the Methods section of this report.

[CBP, Chesapeake Bay Program; USGS, U.S. Geological Survey; N/A, not applicable]

Animal type	Animals per AU, CBP	Animals per AU, USGS
Broilers	455	455
Layers	250	N/A
Pullets	352.5	N/A
Chickens	N/A	301.25
Turkeys	67	67
Angora goats	15.38	N/A
Milk goats	15.38	N/A
Beef	1.14	1.14
Dairy	0.74	0.74
Other cattle	2.08	2.08
Hogs and pigs for breeding	2.67	2.67
Hogs for slaughter	9.09	N/A
Horses	1	1
Sheep and lambs	10	10

53 HUC8s and seven regions. Data on fertilizer and manure inputs to the Chesapeake Bay watershed were obtained from Sekellick (2017). Historical crop, agricultural land-use, livestock, and poultry data were derived from the USDA COA for the Census Years from 1950 through 2012. These data are a subset of the data presented in LaMotte (2015). The NWALT dataset was used to derive areas that were defined as agricultural. NWALT consists of five land-use rasters covering the years 1974, 1982, 1992, 2002, and 2012. Agricultural pixels were defined based on NWALT second-level classes 43 (crops), 44 (pasture/hay), and 45 (grazing potential). Crop pixels were defined by NWALT second-level class 43 (crops). County-level census input estimates were evenly distributed across agricultural or crop pixels for each county by dividing the county total by the number of thematic pixels. Pixels (and their associated agricultural census values) were then summed for each 8-digit HUC and each of the seven distinct regions in the Chesapeake Bay watershed. Examining changes at both

the HUC8 scale and the regional scale provided an additional layer of information on geographic shifts in nutrients within the watershed.

Temporal and spatial patterns in the magnitude of manure and inorganic fertilizer inputs to the Chesapeake Bay watershed were evaluated for 1950–2012. At finer geographic scales within the watershed, changes in manure and fertilizer inputs between 1982 and 2012 were evaluated in order to coincide (approximately) with the 1985–2012 period for which the CBP had evaluated nutrient inputs and BMP implementation. Changes in input amounts during 1992, 2002, and 2012 for N (Appendix 1) and for P (Appendix 2) were compiled as supplementary material to support further analysis to explain observed changes in water quality. Linear regression was performed in R3.3.2 (R Core Team, 2016) to explore relations between fertilizer usage and the cultivation of different crop types across the watershed.

Best Management Practices

Data on the reported implementation of BMPs were retrieved from the Chesapeake Bay Program Office (CBPO) databases in July 2016 (Chesapeake Bay Program, 2013). These datasets were collected for use as inputs to the Phase 5.3.2 version of the CBP's Chesapeake Bay Watershed Model (U.S. Environmental Protection Agency, 2010). The Chesapeake Bay jurisdictions report the BMP data to the CBPO annually. The spatial scale varies depending on the BMP, state preference, and year. Some BMPs are reported at very specific scales, such as county, whereas others are reported at the HUC4 scale. The CBPO disaggregates the BMP data to the CBP Phase 5.3.2 Watershed Model land-river segments. BMPs were further assigned to HUC8s according to the HUC8 in which most of the land-river segment's area was located. Both the spatial and temporal distribution in BMP implementation from 1985 (the first year for which these data are available) to 2012, as well as their expected effects, were quantified. The resulting dataset includes the BMP name, the amount of that BMP implemented, land-use or animal type, and HUC8 to which the implementation was assigned.

To estimate the expected effect of BMP implementation on changes in N and P over time, output from the CBP Phase 5.3.2 Scenario Builder (Chesapeake Bay Program, 2013) was also obtained from the CBPO and allocated to the HUC8 scale. Output consisted of the results of a set of "No Action" and "Progress" scenarios run for each year between 1985 and 2012. No Action scenarios produced manure and fertilizer input datasets consistent with real-world estimates, based on the assumption that no BMPs were in place in each given year. In the Progress scenarios, manure and fertilizer input datasets were modified by applying assumptions of the effect of reported BMPs, based on the expectation that all BMPs reported by and credited to the jurisdictions were in place and functioning.

Only the animal and agricultural land-use change BMPs that affect nutrient inputs to land were included in this analysis. There are three animal BMPs tracked by the states that reduce N and (or) P inputs to the land by reducing the nutrient concentration in animals' manure: changes in feed for poultry and swine, and dairy precision feeding and (or) forage management. Feed changes for poultry and swine include phytase, an enzyme added to animal feed to increase the amount of P that can be absorbed into the animal's biomass. This increased efficiency of P absorption enables manufacturers to add less P to the feed, and also reduces the P content of manure (Chesapeake Bay Program, 2015). The intensity and effect of swine phytase implementation was not evaluated because implementation was not reported by the major jurisdictions until after 2012. Another animal BMP – manure transport – also affects local manure inputs. Manure can be transported from the location in which it was generated by the animal, to another location to be applied to the land. This is commonly done in areas that have a high number of animals and little row cropland. Manure may be transported among farms and out of the watershed.

For purposes of estimating the effect of poultry phytase implementation on manure-P inputs to the land, the CBP gradually increased the calculated benefit of phytase implementation over a 5-year period from 1997 through 2002 as follows: benefits were assumed to begin for all poultry as of 1997, and the full effect of that implementation (indicated by a reduction in P content of manure) was gradually phased in between 1997 and 2002. The credited reduction in the P content of poultry manure due to phytase implementation was increased from 4 percent to 21 percent for broilers and turkeys, and from 3 percent to 16 percent for layers and pullets (fig. 2).

The agricultural land-use change BMPs described in this report eliminate the manure and fertilizer applied to cropland, hay, and pasture land uses by converting these lands to agricultural land uses that do not receive manure or fertilizer, and (or) to natural land uses like forest or wetlands, thereby eliminating manure and fertilizer input to these areas. Land-use changes over time for reasons other than BMP implementation are excluded; thus, the intensity and expected effects

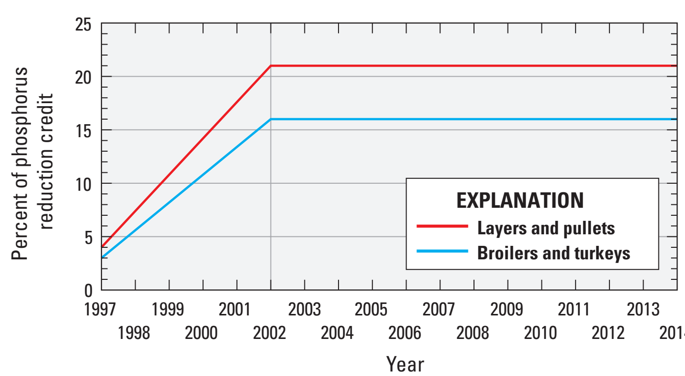

Figure 2. Phasing in of reduction credit for poultry phytase implementation, 1997–2002.

of BMP implementation described are distinguished from the effects of other changes in land use such as urban development or re-forestation. The total amount of BMP acres in a HUC8 can exceed the total agricultural area because more than one type of BMP can occur on the same acre of land.

Results

Land Use/Land-Use Change

In 1982, 58 percent of the watershed was considered to be in a "natural" condition (parks and other areas showed no evidence of regular human usage; Falcone, 2015), with the remainder divided between agriculture (28 percent), urban development (11 percent), or other uses (3 percent). About 6 percent of the watershed's total area was developed between 1982 and 2012 (about 4 percent from natural areas and 2 percent from agriculture). Overall, developed land area increased by about 49 percent – from about 4.58 million acres to about 6.83 million acres - between 1982 and 2012.

Consistent with the pattern at the watershed scale, most Chesapeake HUC8s were dominated by natural areas in both 1982 and 2012 (fig. 3; table 5). However, eight HUC8s[3] contained a greater proportion of land in agriculture than in any other use in 1982, and six HUC8s[4] contained more area in developed than in either the natural, agricultural, or other land-use categories.

All 53 HUC8s experienced some degree of urbanization between 1982 and 2012; in most of these cases urbanization occurred through the development of both agricultural and natural lands. However, the proportion of land in agriculture was unchanged or had increased slightly (less than 0.5 percent) in three[5] HUC8s by 2012. In these cases, development of natural areas accounted for urbanization. Natural land area was unchanged or increased (up to 2 percent) in five HUC8s[6]. In these cases, urbanization occurred through development of agricultural areas.

By 2012, a total of 13 HUC8s contained more developed land than agricultural land. These HUC8s were categorized as "predominantly urban" in order to reflect the differential impact that development had on their manure and fertilizer input patterns.

[3] Chester-Sassafras, Choptank, Lower Susquehanna, Middle Potomac-Catoctin, Monocacy, Nanticoke, Shenandoah, Tangier.

[4] Gunpowder-Patapsco, Hampton Roads, Lynnhaven-Poquoson, Middle Potomac-Anacostia-Occoquan, Patuxent, Severn.

[5] North Branch Potomac, Sinnemahoning, Upper West Branch Susquehanna.

[6] Chenango, Nanticoke, Pine, Tioga, Upper Susquehanna.

Fertilizer and Manure Inputs to Land

N inputs to land in the Chesapeake Bay watershed from manure and inorganic fertilizer combined increased by over 90 percent between 1950 and 1982, and peaked at about 960 million pounds in 2000 before decreasing to 812 million pounds in 2012. Increases over time in P inputs were less dramatic (about 13 percent) between 1950 and 1982, but P inputs decreased by about 26 percent between 1982 and 2012.

Temporal shifts in agricultural N and P inputs were largely driven by changing patterns in inorganic fertilizer use (fig. 4). Fertilizer-N inputs increased sharply from 1950–71, after which they declined by 14 million pounds from 1971 to 2012, but with inter-annual fluctuations of as much as 117 million pounds. Fertilizer-P inputs increased by about 27 million pounds from 1950 to 1971 and then declined by about 106 million pounds, with inter-annual fluctuations of as much as 27 million pounds. Estimates of manure inputs were derived directly from livestock and poultry populations (Sekellick, 2017), and it was assumed that manure remained where it was produced (the potential impact of manure transport is discussed later in this report). Based on this assumption, manure inputs increased moderately and gradually over time, in concert with animal populations.

The greater variability observed in fertilizer inputs reflects a more complex matrix of drivers, such as crop type, acreage, and projected yields, as well as fertilizer prices, weather, and manure availability (Stuart and others, 2015).

1950–82

N inputs from agriculture increased from 1950 to 1982 in 50 out of the 53 HUC8s throughout the watershed (not shown), and in all regions of the watershed in general (table 6). P inputs increased in 25 HUC8s, and in 4 out of 7 regions, with the greatest percent increase occurring in the Eastern Shore region. The largest percent decrease was seen in the Hampton Roads (Virginia) region, reflecting the highly urban nature of the Lynnhaven-Poquoson and Hampton Roads HUC8s.

1982–2012

In contrast to the prior period, 25 HUC8s (about half) experienced increasing agricultural N inputs from 1982 to 2012, with a narrower distribution and a median change close to zero (fig 5). Only seven HUC8s had increased P inputs; changes ranged from a decrease of 7.9 million pounds to an increase of 1.2 million pounds.

Reductions in both N and P inputs resulted primarily from a decline in fertilizer use (fig. 6); inputs of N and P from manure increased over this period in almost half of the HUC8s studied. The changes in the spatial distribution of inputs

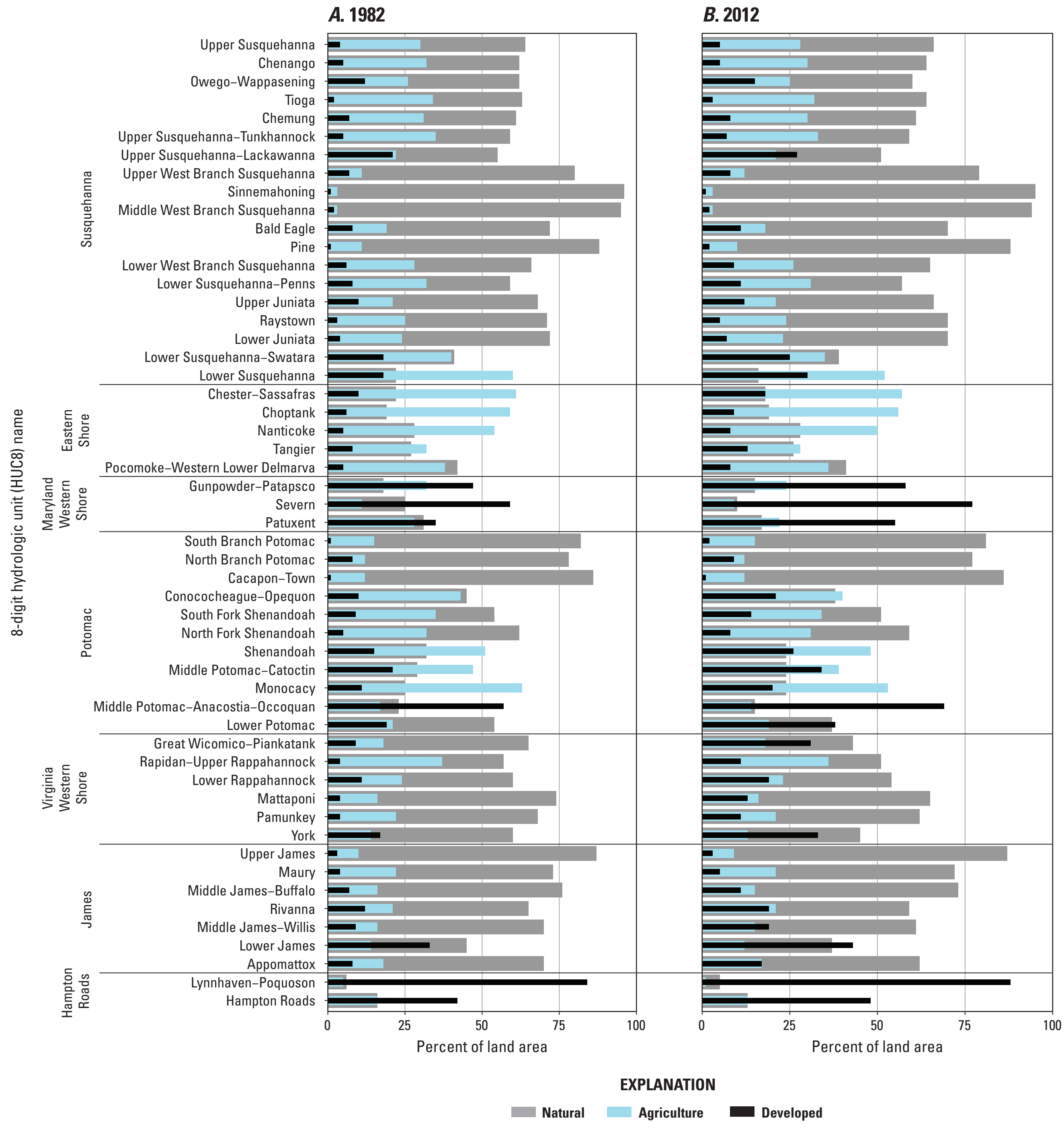

Figure 3. Reported implementation of agricultural land-use change best management practices (BMPs) for major regions of the Chesapeake Bay watershed, 1985–2012. [Bars represent accumulated implementation as of a given year; the black line represents the percent of the total (as of 2012) BMP implementation for all regions.]

Table 5. Percent of land area in each land-use class in the Chesapeake Bay watershed, 1982 and 2012.

[HUC8, 8-digit hydrologic unit]

Region	HUC8 name	Natural (percent)		Developed (percent)		Agriculture (percent)		Other (percent)	
		1982	2012	1982	2012	1982	2012	1982	2012
Susquehanna	Upper Susquehanna	64	66	4	5	30	28	1	1
	Chenango	62	64	5	5	32	30	1	1
	Owego-Wappasening	62	60	12	15	26	25	0	0
	Tioga	63	64	2	3	34	32	1	1
	Chemung	61	61	7	8	31	30	1	1
	Upper Susquehanna-Tunkhannock	59	59	5	7	35	33	1	1
	Upper Susquehanna-Lackawanna	55	51	21	27	22	21	1	1
	Upper West Branch Susquehanna	80	79	7	8	11	12	2	2
	Sinnemahoning	96	95	1	1	3	3	0	0
	Middle West Branch Susquehanna	95	94	2	2	3	3	0	0
	Bald Eagle	72	70	8	11	19	18	0	1
	Pine	88	88	1	2	11	10	0	0
	Lower West Branch Susquehanna	66	65	6	9	28	26	0	0
	Lower Susquehanna-Penns	59	57	8	11	32	31	1	1
	Upper Juniata	68	66	10	12	21	21	1	1
	Raystown	71	70	3	5	25	24	1	1
	Lower Juniata	72	70	4	7	24	23	1	0
	Lower Susquehanna-Swatara	41	39	18	25	40	35	1	1
	Lower Susquehanna	22	16	18	30	60	52	1	1
Eastern Shore	Chester-Sassafras	22	18	10	18	61	57	7	7
	Choptank	19	19	6	9	59	56	16	16
	Nanticoke	28	28	5	8	54	50	14	14
	Tangier	27	26	8	13	32	28	33	33
	Pocomoke-Western Lower Delmarva	42	41	5	8	38	36	15	15
Maryland Western Shore	Gunpowder-Patapsco	18	15	47	58	32	24	2	3
	Severn	25	10	59	77	11	9	4	4
	Patuxent	31	17	35	55	28	22	5	6
Potomac	South Branch Potomac	82	81	1	2	15	15	1	1
	North Branch Potomac	78	77	8	9	12	12	2	2
	Cacapon-Town	86	86	1	1	12	12	1	1
	Conococheague-Opequon	45	38	10	21	43	40	1	1
	South Fork Shenandoah	54	51	9	14	35	34	1	1
	North Fork Shenandoah	62	59	5	8	32	31	2	1
	Shenandoah	32	24	15	26	51	48	2	2
	Middle Potomac-Catoctin	29	24	21	34	47	39	3	3
	Monocacy	25	24	11	20	63	53	2	3
	Middle Potomac-Anacostia-Occoquan	23	15	57	69	17	14	2	2
	Lower Potomac	54	37	19	38	21	19	6	6

Table 5. Percent of land area in each land-use class in the Chesapeake Bay watershed, 1982 and 2012.—Continued

[HUC8, 8-digit hydrologic unit]

Region	HUC8 name	Natural (percent)		Developed (percent)		Agriculture (percent)		Other (percent)	
		1982	2012	1982	2012	1982	2012	1982	2012
Virginia Western Shore	Great Wicomico-Piankatank	65	43	9	31	18	18	8	8
	Rapidan-Upper Rappahannock	57	51	4	11	37	36	2	2
	Lower Rappahannock	60	54	11	19	24	23	5	5
	Mattaponi	74	65	4	13	16	16	6	6
	Pamunkey	68	62	4	11	22	21	6	6
	York	60	45	17	33	14	13	9	9
James	Upper James	87	87	3	3	10	9	1	1
	Maury	73	72	4	5	22	21	2	2
	Middle James-Buffalo	76	73	7	11	16	15	1	1
	Rivanna	65	59	12	19	21	21	2	2
	Middle James-Willis	70	61	9	19	16	15	4	5
	Lower James	45	37	33	43	14	12	8	8
	Appomattox	70	62	8	17	18	17	4	4
Hampton Roads	Lynnhaven-Poquoson	6	5	84	88	5	1	5	5
	Hampton Roads	16	13	42	48	16	13	25	26

Table 6. Changes over time in agricultural nitrogen (N) and phosphorus (P) inputs to seven distinct regions of the watershed, 1950–2012 (regions are defined in table 2).

Region	N Input (million pounds)			N-Input change, in percent		P Input (million pounds)			P-Input change, in percent	
	1950	1982	2012	1950–82	1982–2012	1950	1982	2012	1950–82	1982–2012
Susquehanna	201	350	321	74	-8	91	100	70	10	-30
Eastern Shore	34	135	144	296	6	24	38	31	60	-19
Maryland Western Shore	19	27	22	42	-19	7.8	7.3	5.6	-6	-23
Potomac	116	212	198	82	-7	54	60	48	12	-20
Virginia Western Shore	36	68	58	88	-14	21	20	11	-5	-45
James	41	66	62	61	-6	19	20	15	6	-26
Hampton Roads	1.8	3.8	7.1	114	89	1.4	1.2	1.2	-19	6
Total	**449**	**863**	**812**	**92**	**-6**	**218**	**247**	**182**	**13**	**-26**

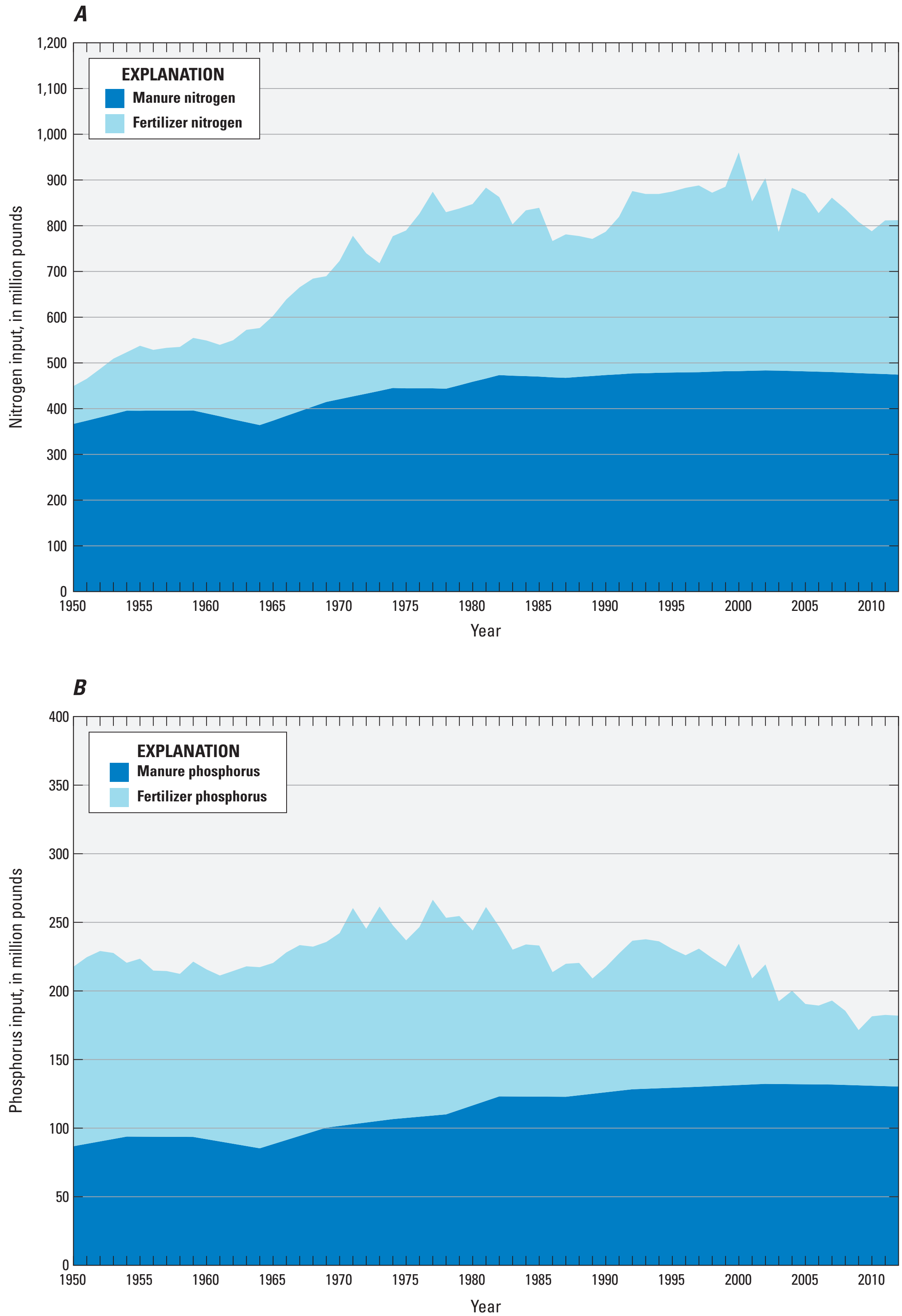

Figure 4. *A*, nitrogen, and *B*, phosphorus inputs to the Chesapeake Bay watershed from manure and fertilizer, 1950–2012. [Note difference in scales of y axes.]

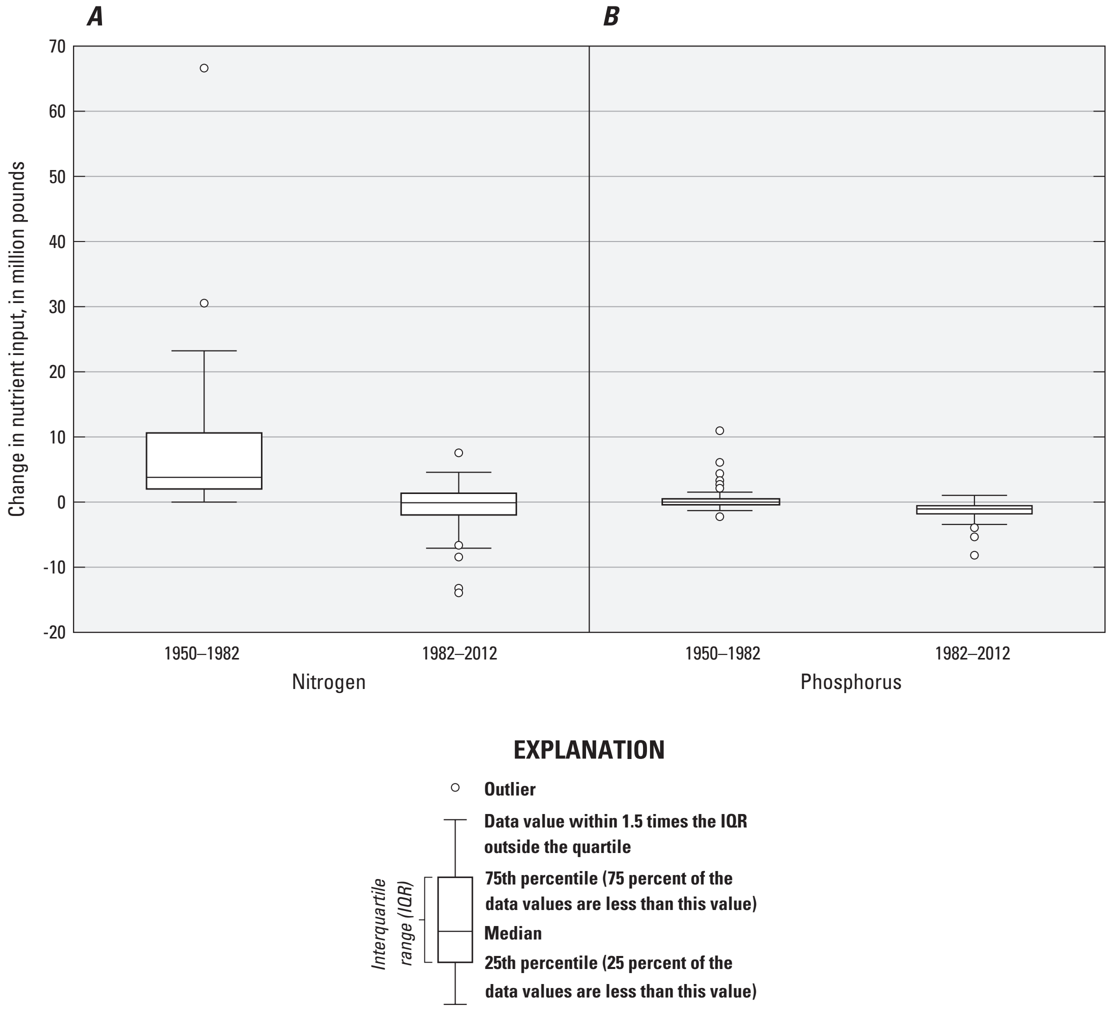

Figure 5. Range and variability of the change in agricultural *A*, nitrogen inputs, and *B*, phosphorus inputs from 1950–82 and 1982–2012 in the Chesapeake Bay watershed at the 8-digit hydrologic unit (HUC8) scale.

throughout the watershed during this period are also shown in figure 6. For example, manure-N inputs in the upper part of the Susquehanna region declined by about 30 million pounds, whereas manure-N inputs in HUC8s in the lower Susquehanna region increased by about 26 million pounds. The Potomac region also experienced a shift in the spatial distribution of manure inputs, in this case from the eastern HUC8s to the western HUC8s.

Agricultural Land Use and Farming Practices

In 1950, there were about 23.3 million acres (36,500 mi^2) of land in farms in the Chesapeake Bay watershed, of which 3.4 million acres were in permanent pasture and 11.2 million acres were in cropland. Sixty-seven percent of cropland was further categorized as harvested cropland. Between 1950 and 1982, acres of land in farms declined 37 percent, acres of land in permanent pasture declined 60 percent, and acres of total cropland (“harvested cropland” + “pastured cropland” + “other cropland”) declined 21 percent. The amount of cropland and the amount of land in farms continued to decline between 1982 and 2012, whereas acres of permanent pasture increased (table 7). Farms lost an additional 13 percent of land area overall, with steeper declines in cropland. The amount of total cropland declined to a greater degree than did the amount of harvested cropland.

The distinction between total cropland and harvested cropland is relevant for understanding patterns in manure and fertilizer inputs. The COA’s “harvested cropland” category includes only the acreage from which crops were harvested and (or) hay was cut in a given Census year. The “total cropland” category also includes land on which crops were planted but failed to mature, as well as additional lands that could have been used for crops but were not in the given Census

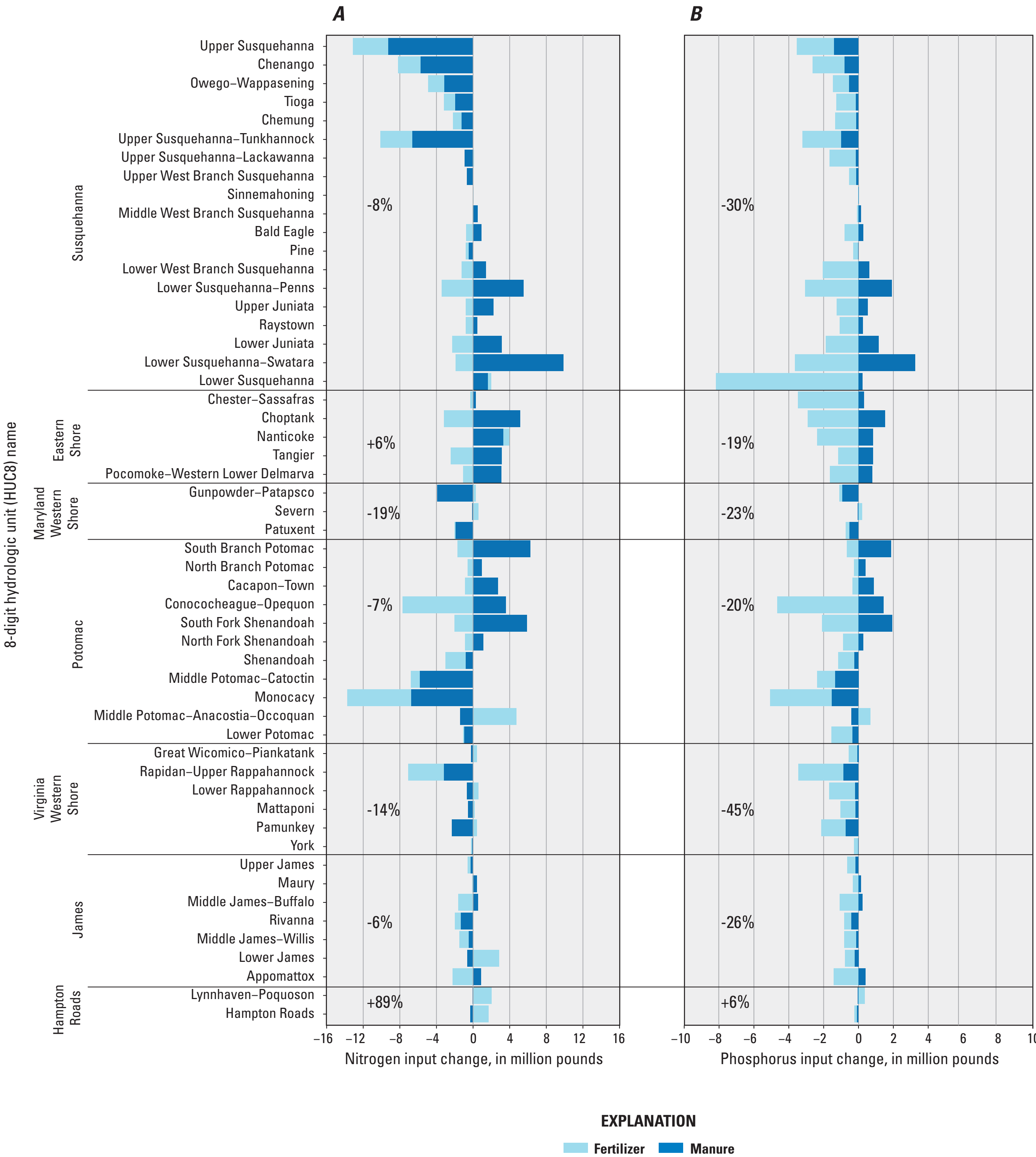

Figure 6. Change in agricultural *A*, nitrogen inputs, and *B*, phosphorus inputs for each 8-digit hydrologic unit (HUC8) in the Chesapeake Bay watershed from 1982 to 2012. [Note difference in scale of x-axes. Values represent the net percent (%) change in nitrogen and phosphorus inputs for each region.]

Table 7. Changes in farmland area (acres) in the Chesapeake Bay watershed, 1950–2012 (LaMotte, 2015).

Year	Land in farms	Permanent pasture	Total cropland	Harvested cropland
1950	23,334,852	3,377,433	11,159,254	7,482,192
1954	22,088,307	3,731,581	9,984,922	7,391,219
1959	20,311,352	3,312,373	9,416,986	6,853,237
1964	18,611,753	3,208,865	8,739,063	6,456,300
1969	15,334,086	1,431,457	8,792,797	5,558,307
1974	14,510,378	1,425,626	8,524,465	6,027,832
1978	14,948,207	1,368,512	8,919,869	6,448,196
1982	14,612,749	1,334,687	8,771,036	6,693,000
1987	13,611,260	1,209,840	8,490,874	6,061,504
1992	12,680,759	1,106,232	8,072,613	5,942,293
1997	13,307,174	1,161,225	8,340,054	6,259,273
2002	13,045,746	1,380,533	7,872,550	6,087,411
2007	12,578,008	1,920,215	7,010,680	5,855,584
2012	12,671,236	2,072,482	6,732,108	5,992,953

year (U.S. Department of Agriculture, National Agricultural Statistics Service, 2014). Where manure availability exceeds crop need, it may be applied to other cropland and pasture in addition to harvested cropland (MacDonald and others, 2009; Ribaudo and others, 2003; Kellogg and others, 2000). However, purchasing fertilizer in excess of crop need has an economic cost. Thus, changes in fertilizer inputs may be more closely tied to harvested cropland than to total cropland.

Of the 789,000 acres of harvested cropland acreage lost in the watershed between 1950 and 1982, the vast majority (637,000 acres, or 81 percent) was lost from the Susquehanna region of the watershed. These losses and additional losses from the Potomac, James, and Maryland Western Shore regions were partly counteracted by gains in the Eastern Shore and the Virginia Western Shore regions (table 8).

The same patterns were observed at the HUC8 scale: acres of harvested cropland increased in just 12 of the 53 HUC8s from 1950 to 1982, 10 of which were located in either the Eastern Shore or Virginia Western Shore regions. The period from 1982 to 2012 also showed increases in 12 of the 53 HUC8s. However, spatial variability shifted: previous gains in harvested cropland were reversed on the Eastern Shore and Virginia Western Shore, and increases were instead distributed among the Susquehanna (three HUC8s), James (three HUC8s), and Potomac (six HUC8s) regions. The continuing urbanization of the Maryland Western Shore and the Hampton Roads (Virginia) regions was reflected in additional losses of more than 30 percent of harvested cropland between 1982 and 2012.

Harvested cropland in the Chesapeake Bay watershed is divided among approximately 25 crop types (LaMotte, 2015). Six of these – barley, corn, hay, oats, soybeans, and wheat – accounted for between 96 and 99 percent of acres harvested in any given Census year (table 9). In this context, “acres harvested” represents the sum of acres reported for each crop in the COA whereas “harvested cropland” represents the acres of cropland that are allocated to harvested crops each year. Harvesting more than one crop each year on the same acreage (double cropping) can result in more “acres harvested” than “harvested cropland.”

Between 1950 and 2012, the prevalence of barley, oats, and wheat declined throughout the watershed, whereas the proportion of harvested acres dedicated to corn, hay, and soybeans increased from 67 to 88 percent of all acres harvested. Although the remaining 19 crops accounted for 1 percent or less of acres harvested in the Chesapeake Bay watershed, some of these were more prominently represented at local scales. Between 1950 and 2012, harvested cropland declined by about 20 percent, whereas acres harvested declined 11 percent. In other words, more intensive use of cropland may have

Table 8. Changes in spatial variability of harvested cropland in the Chesapeake Bay watershed in 1950, 1982, and 2012.

Region	Harvested cropland (acres)			Change in harvested cropland (percent)			
				Regional change		Contribution to watershed change	
	1950	1982	2012	1950–1982	1982–2012	1950–1982	1982–2012
Susquehanna	3,657,711	3,021,069	2,710,568	-17	-10	-81	-44
Eastern Shore	816,855	1,046,129	934,303	28	-11	29	-16
Maryland Western Shore	321,082	243,995	169,273	-24	-31	-10	-11
Potomac	1,623,361	1,362,971	1,272,728	-16	-7	-33	-13
Virginia Western Shore	482,212	568,846	482,495	18	-15	11	-12
James	534,202	407,856	394,851	-24	-3	-16	-2
Hampton Roads	46,767	42,135	28,735	-10	-32	-1	-2

Table 9. Percentage of acres harvested for six dominant crop types in the Chesapeake Bay watershed, 1950–2012.

Year	Harvested cropland	Acres harvested	Percent of acres harvested					
			Barley	Corn	Hay	Oats	Soybeans	Wheat
1950	7,482,192	6,963,107	4	25	40	8	2	17
1954	7,391,219	7,014,994	4	26	41	9	4	12
1959	6,853,237	6,612,321	4	25	43	8	6	10
1964	6,456,300	6,261,867	4	27	43	6	8	9
1969	5,558,307	5,209,184	5	32	39	5	9	7
1974	6,027,832	5,980,615	4	35	35	4	11	9
1978	6,448,196	6,302,192	4	36	38	3	12	5
1982	6,693,000	6,893,963	3	38	34	3	14	7
1987	6,061,504	6,281,869	3	33	39	3	14	7
1992	5,942,293	6,312,714	3	31	37	2	17	8
1997	6,259,273	6,507,061	2	31	38	1	18	8
2002	6,087,411	6,275,296	2	30	42	1	17	7
2007	5,855,584	6,033,221	2	34	39	1	17	7
2012	5,992,953	6,174,823	2	32	37	1	19	8

partially compensated for the reduction of agricultural land allocated to crop production in the watershed.

Patterns of nutrient inputs and decisions regarding crop cultivation may be affected by the magnitude of animal biomass, as well as by the production of different animal types. Biomass (in AUs) was relatively stable in the watershed between 1950 and 2012, despite the declines in farmland in general, and in permanent pasture acreage in particular, that occurred. Whereas changes in animal biomass between Census years ranged from -11 to +23 percent, the net change over the entire period was less than 1 percent. The proportion of AUs represented by cows declined by about 11 percent from 1950 to 2012, whereas the proportion of AUs represented by poultry increased by about 14 percent (table 10). The concentration of nutrients varies among animal types; for example, poultry manure contains a higher P fraction per pound than cow manure (American Society of Agricultural and Biological Engineers, 2005).

The coupled nature of crop and animal production is reflected in the changing nature of corn and hay production across the watershed. Whereas acres harvested of corn grown for grain (“grain corn”) changed less than 1 percent between 1950 and 2012, cultivation of corn grown for silage (“silage corn”) increased from 295,518 to 491,518 acres harvested, or about 66 percent. Similarly, in 1950, silage hay accounted for 1 percent of all hay acres harvested. By 2012, that proportion had increased to 21 percent.

The spatial variability in cultivation of both major crop groups and animal groups in 1982 and 2012 is shown in figure 7. Poultry and poultry feed (grain corn and soybeans) dominate agricultural land on the Eastern Shore; about 45 percent of the entire watershed’s poultry inventory, 35 percent of its soybean acreage, and 24 percent of its grain corn acreage were produced in this region in 2012. Cultivation of forage and silage crops was more broadly distributed across the remaining five regions, as were cow populations. The Lower Susquehanna HUC8 contains large proportions of all three animal groups (including 41 percent of the entire watershed’s hog inventory) and all four crop types.

Table 10. Annual percentage of animal biomass (in animal units) for the five major animal types produced in the Chesapeake Bay watershed, 1950–2012.

Year	Animal units	Animal biomass (percent)				
		All cows	All poultry	Horses	Sheep	Hogs
1950	2,946,787	74	4	7	2	14
1954	3,003,566	82	3	1	1	13
1959	2,984,522	80	2	3	2	13
1964	2,665,731	86	3	0	1	10
1969	3,281,758	65	22	2	1	10
1974	2,929,712	79	8	2	1	10
1978	2,965,039	73	10	3	1	14
1982	3,239,750	72	11	3	1	13
1987	3,133,925	69	14	3	1	13
1992	3,181,345	67	15	3	1	14
1997	3,216,803	65	18	3	0.5	13
2002	3,160,248	63	17	5	0.5	14
2007	3,055,029	62	19	5	0.4	14
2012	2,963,812	63	18	6	0.5	13

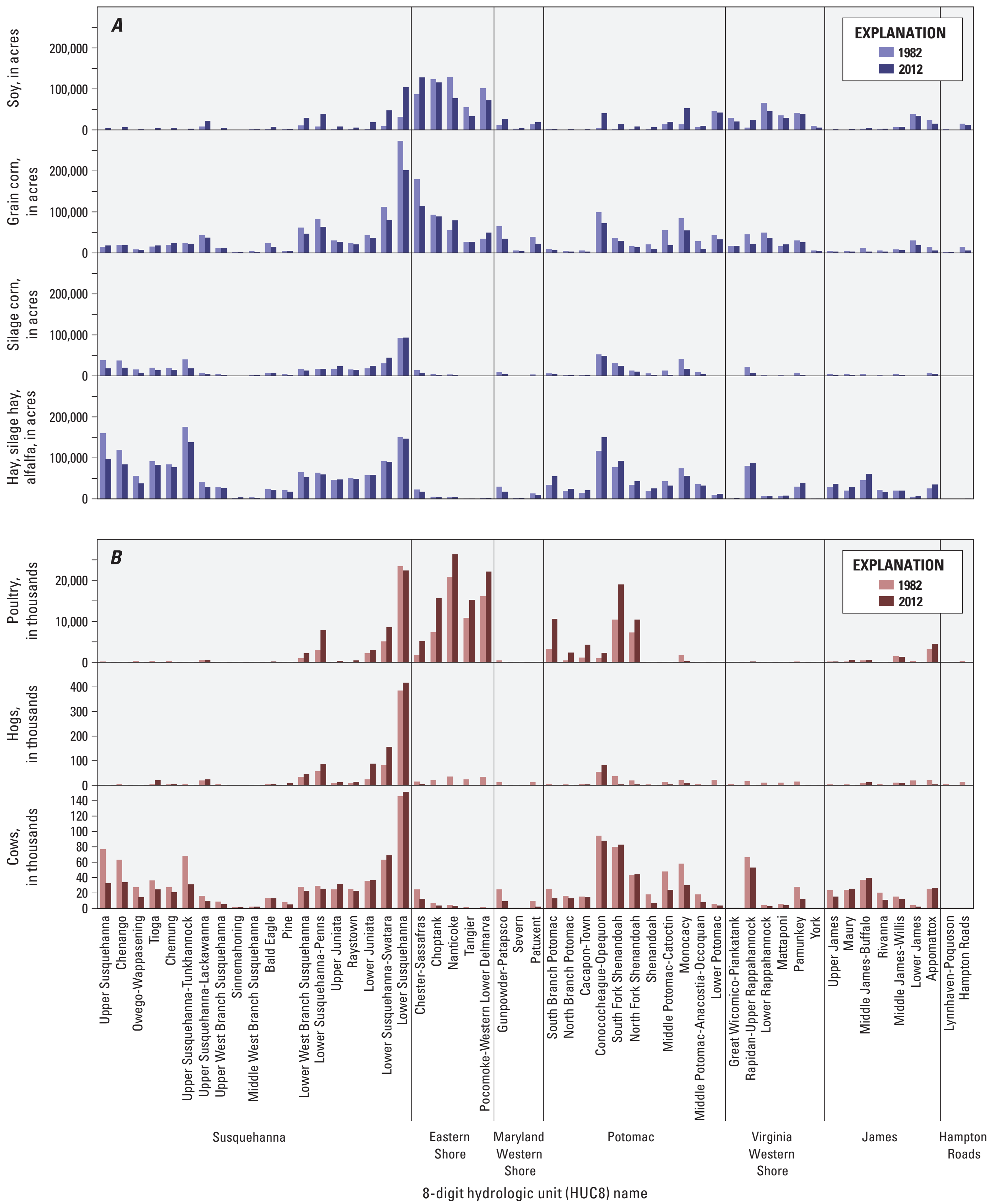

Figure 7. Spatial variability of *A*, major crop groups, and *B*, major animal groups in the Chesapeake Bay watershed in 1982 and 2012. [Note difference in scale of x-axes.]

Nutrient Input Intensity

Declines over time in pasture and cropland, combined with stable or increasing animal inventories and fertilizer inputs and the changing proportion of crops harvested per acre of harvested cropland, indicate that the amount of N and P input per acre of total cropland ("nutrient input intensity") may have increased over time. The spatial pattern of nutrient input intensity on agricultural acreage across the watershed in 1982 is shown in figure 8. N input intensity increased in all 7 regions of the watershed (table 11), and in 44 HUC8s between 1982 and 2012 (fig. 9). During the same period, P input intensity increased in 4 regions and 22 HUC8s across those regions. Five of the HUC8s with increasing P input intensity were clustered in the Maryland Western Shore and the Hampton Roads (Virginia) regions, where sharp declines in agricultural land coincided with gains in fertilizer-P use associated with new residential development. Elsewhere, the input intensity of fertilizer-P declined whereas manure-P input intensity either increased (Susquehanna, Eastern Shore, Potomac, James) or was stable (Virginia Western Shore).

Relating Agricultural Practices to Fertilizer and Manure Inputs

Manure inputs in any given HUC8 are a direct result of local animal populations, therefore they are not expected to vary as a result of changes in either the amount of cropland or the crops being cultivated. However, because nutrient requirements differ among crop types, changes in fertilizer inputs over time may be more closely related to changes in crop production. This relation may be confounded by the availability of animal manure; where appropriate and economical, manure can reduce the need for commercial fertilizer (MacDonald and others, 2009). Alternatively, excess manure must be disposed of and may be spread on cropland in excess of crop nutrient need or transported to other areas.

Corn has a high N requirement relative to other major agronomic crops (Basden and others, 2006), and it is often suggested that increases in corn cultivation in particular result in increased fertilizer-N inputs. In the case of the Chesapeake Bay watershed, fertilizer-N inputs increased each year from 1950 to 1974 on harvested cropland across all HUC8s, independent of the amount of acreage in any given crop, including corn. However, commercial fertilizer-N usage leveled off at the watershed scale during the mid-1970s, indicating a shift that may have tied fertilizer inputs more closely to crop need.

When data prior to 1974 were excluded from the analysis[7], HUC8s with a greater proportion of harvested cropland in grain corn tended to have greater fertilizer-N input intensity per acre of harvested cropland, but the relation was weak but significant ($r^2 = 0.18$, $p<0.001$) and visual inspection revealed a deviation from this tendency in the more urbanized HUC8s. When the 13 predominantly urban HUC8s identified previously were excluded, this relation improved ($r^2 = 0.31$, $p<0.001$) (fig. 10*A*). In contrast, there was a very slight (but still significant) negative correlation between silage corn cultivation and fertilizer-N input intensity ($r^2 = 0.12$, $p<0.001$) (fig. 10*B*). Silage corn tends to be grown in close proximity to cow production, and its high N requirements may be met more by applications of readily available manure than by the purchase of inorganic fertilizer.

[7] Lynnhaven-Poquoson was also excluded; its fertilizer-N application intensity is an order of magnitude greater than any other HUC8 in the post-1974 period.

Effects of Best Management Practice (BMP) Implementation on Manure and Fertilizer Inputs

This section describes the aggregated expected effect of the four BMPs that affect nutrient inputs to land. Land-use change BMPs, dairy precision feeding and (or) forage management, and manure transport can have direct effects on both N and P inputs; poultry phytase reduces the P content of manure. Local manure transport can reduce manure input in one HUC8 while increasing it in another HUC8. Reports of manure transport implementation indicate that of the approximately 2.6 billion pounds of poultry manure transported between 1998 and 2012, about 35 percent was transported out of the Chesapeake Bay watershed (Devereux and others 2017).

Expected Reductions in Fertilizer and Manure Inputs

BMPs were expected to have a relatively minor impact on N and P inputs from manure and fertilizer between 1985 and 2012. The modeling scenarios generated by use of the CBP's Phase 5.3.2 Scenario Builder indicated that a reduction in N inputs to land of about 41 million pounds (3.6 percent), and 9 million pounds (3.9 percent) in P inputs to land would have occurred in the Chesapeake Bay watershed between 1985 and 2012 without any implementation of BMPs (No Action scenario). It is important to note that Scenario Builder estimates N and P inorganic fertilizer based on crop need, resulting in different estimates of the magnitude of fertilizer use than those described earlier in this report. In spite of this discrepancy, Scenario Builder simulations are useful for estimating relative (percent) changes in fertilizer use due to changes on the landscape.

When reported BMP implementation was considered (Progress scenario), an additional 0.8-percent decrease in N inputs (9 million pounds), and an additional 5.2-percent decrease in P inputs (12 million pounds) were predicted (fig. 11). Lower fertilizer usage accounted for 8.9 of the expected 9-million-pound additional reduction in agricultural N inputs. Some of the nutrient reduction is due to the loss of agricultural land, which has the effect of reducing fertilizer inputs. With fewer crops, there is less fertilizer purchased and

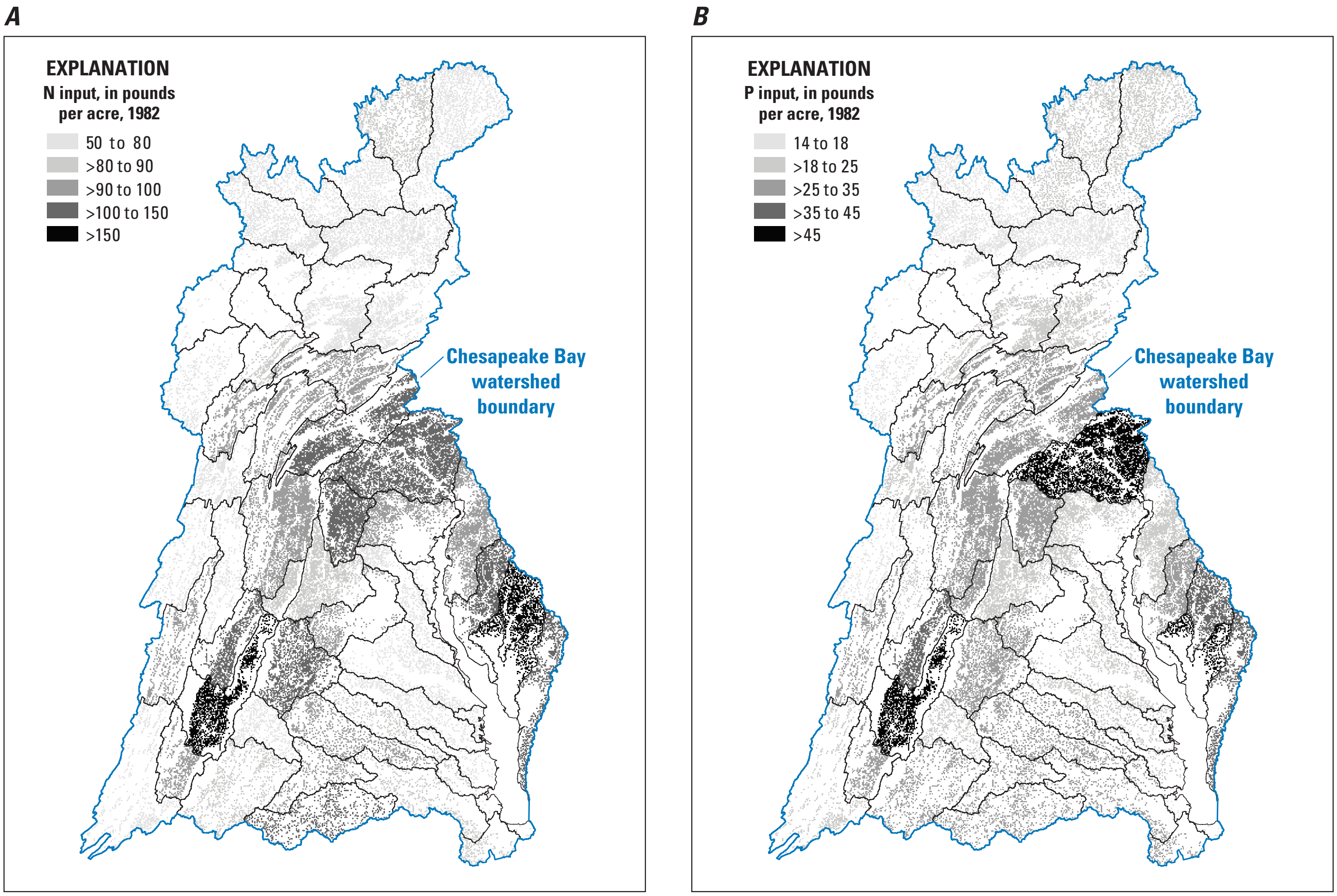

Figure 8. Input intensity of *A*, nitrogen (N) and *B*, phosphorus (P) on agricultural acres in the Chesapeake Bay watershed in 1982. [Inputs are the sum of manure and fertilizer in pounds per acre of cropland.]

applied. Where animal populations do not change, the manure is still applied to land, sometimes at a higher application rate than is required by the crop.

Reductions in manure-P usage were solely responsible for the expected additional reduction in agricultural P inputs; the model actually simulated a small (3-percent) increase in fertilizer-P inputs as a result of BMP implementation. This result reflects the simulated effect of manure transport out of the watershed; farmers may replace manure P with commercial fertilizer according to crop need.

BMPs were expected to generate negligible additional change (less than 0.5 percent) in N inputs in 33 out of the 53 HUC8s in the Chesapeake Bay watershed. Among the remainder, BMPs reduced N inputs by anywhere from 0.6 to 4 percent, with the greatest reduction expected in the Choptank HUC8 (table 12).

Lower fertilizer-N inputs were the sole driver of these small expected N reductions – more than compensating for increasing manure-N inputs – in five of the seven Chesapeake regions (table 13), and were the primary driver (accounting for more than half) of expected N-input reductions in 41 HUC8s distributed across all regions of the watershed. The Progress scenario predicted increased manure-N inputs as a result of BMP implementation in 25 HUC8s. This result is likely due to the transport of manure into these HUC8s from basins with excess manure production.

In the Susquehanna and Eastern Shore regions, expected N reductions were almost evenly split between manure and fertilizer sources. In the Susquehanna region, larger than expected manure-N reductions in the Swatara and Lower Susquehanna HUC8s accounted for the greater influence of manure on N reductions in this region. In the Eastern Shore region, larger than expected decreases in manure-N inputs in the Nanticoke, Tangier, and Pocomoke-Western Lower Delmarva countered relatively small increases in manure-N inputs in the Chester-Sassafras and Choptank HUC8s.

Expected reductions in P inputs from implementation of these four BMPs (poultry feed additives, dairy precision feeding, manure transport, and land-use change) ranged from no appreciable change in 17 HUC8s up to an additional 51-percent reduction in the Sinnemahoning HUC8. In contrast to N-input changes, decreases in manure-P inputs were the

Table 11. Intensity of agricultural nutrient inputs to seven major regions in the Chesapeake Bay watershed in 1950, 1982, and 2012.

Region	Nitrogen-input intensity (pounds per acre of total cropland)			Phosphorus-input intensity (pounds per acre of total cropland)		
	1950	1982	2012	1950	1982	2012
Susquehanna	40	93	103	18	27	23
Eastern Shore	31	123	144	22	35	31
Maryland Western Shore	36	86	119	15	23	30
Potomac	45	104	140	21	29	34
Virginia Western Shore	45	90	111	26	27	21
James	41	88	133	19	26	31
Hampton Roads	30	84	240	25	26	42
Chesapeake Bay watershed	**40**	**98**	**121**	**20**	**28**	**27**

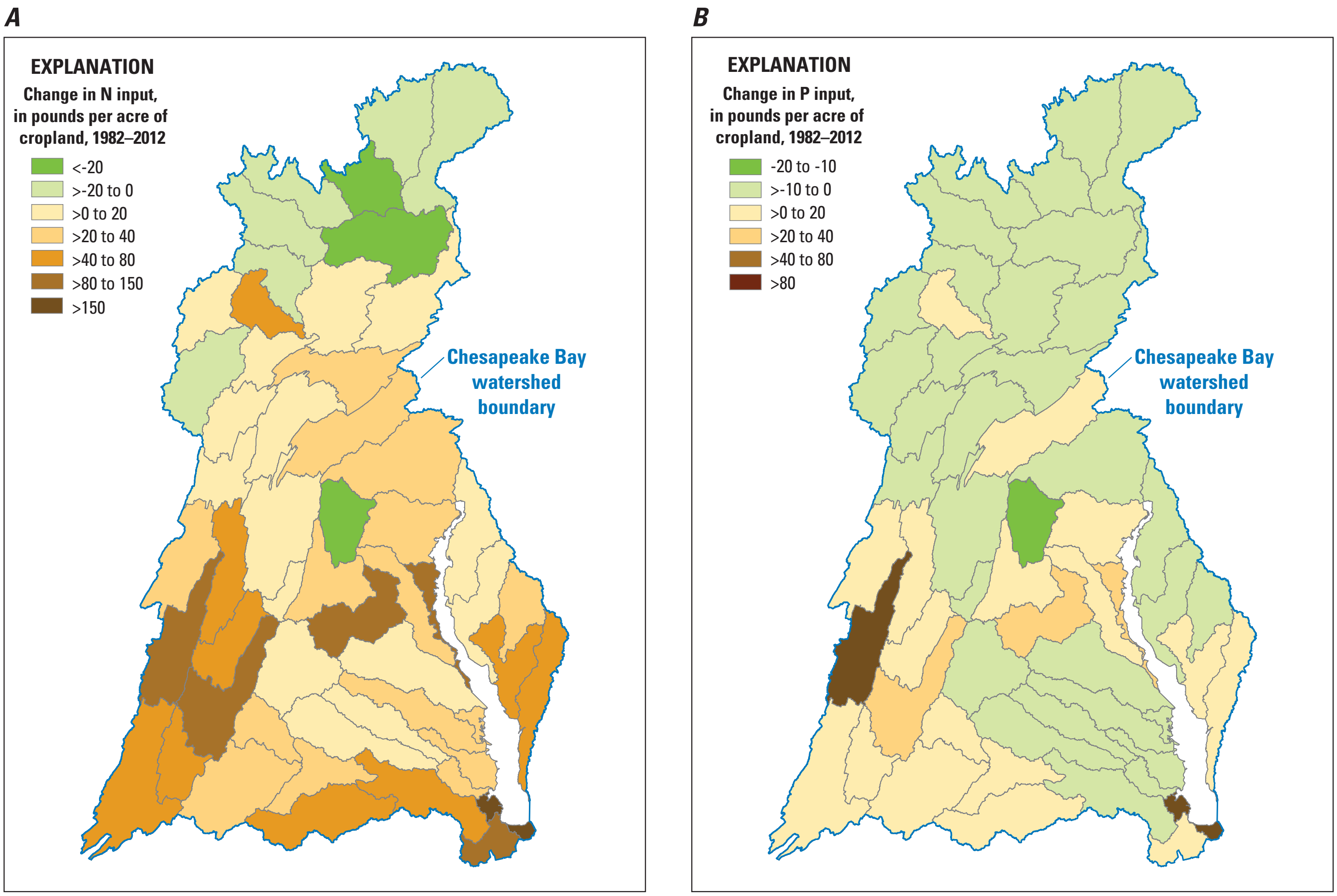

Figure 9. Input intensity change from 1982 to 2012 for *A*, nitrogen (N) and *B*, phosphorus (P) in the Chesapeake Bay watershed. [Inputs are the sum of manure and fertilizer in pounds per acre of cropland.]

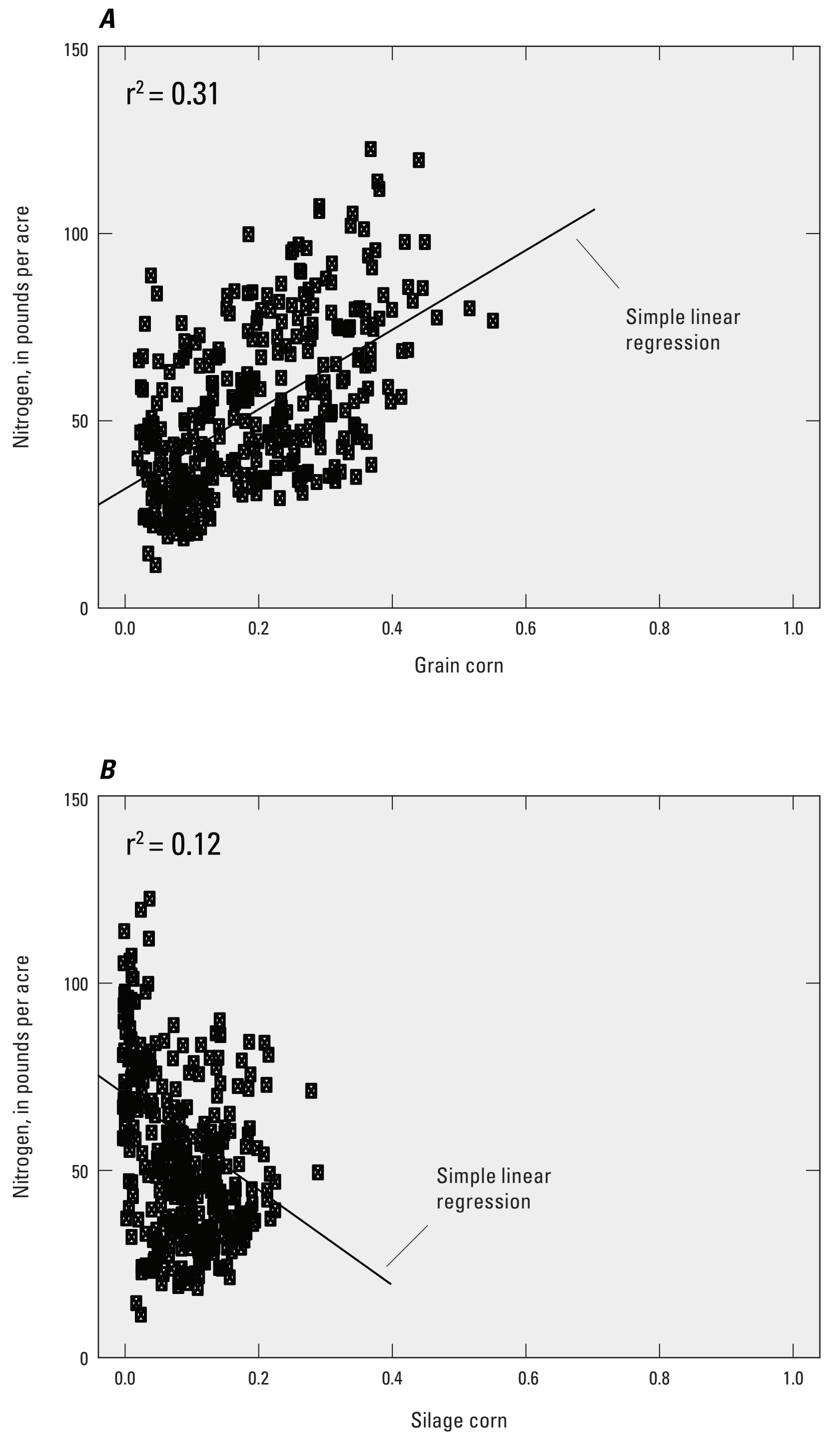

Figure 10. Nitrogen fertilizer use on harvested cropland by proportion of cropland devoted to *A*, grain corn, and *B*, silage corn in the Chesapeake Bay watershed. [Data are by Census of Agriculture for each 8-digit hydrologic unit (HUC8) from 1974 to 2012. Predominantly urban HUC8s are excluded.]

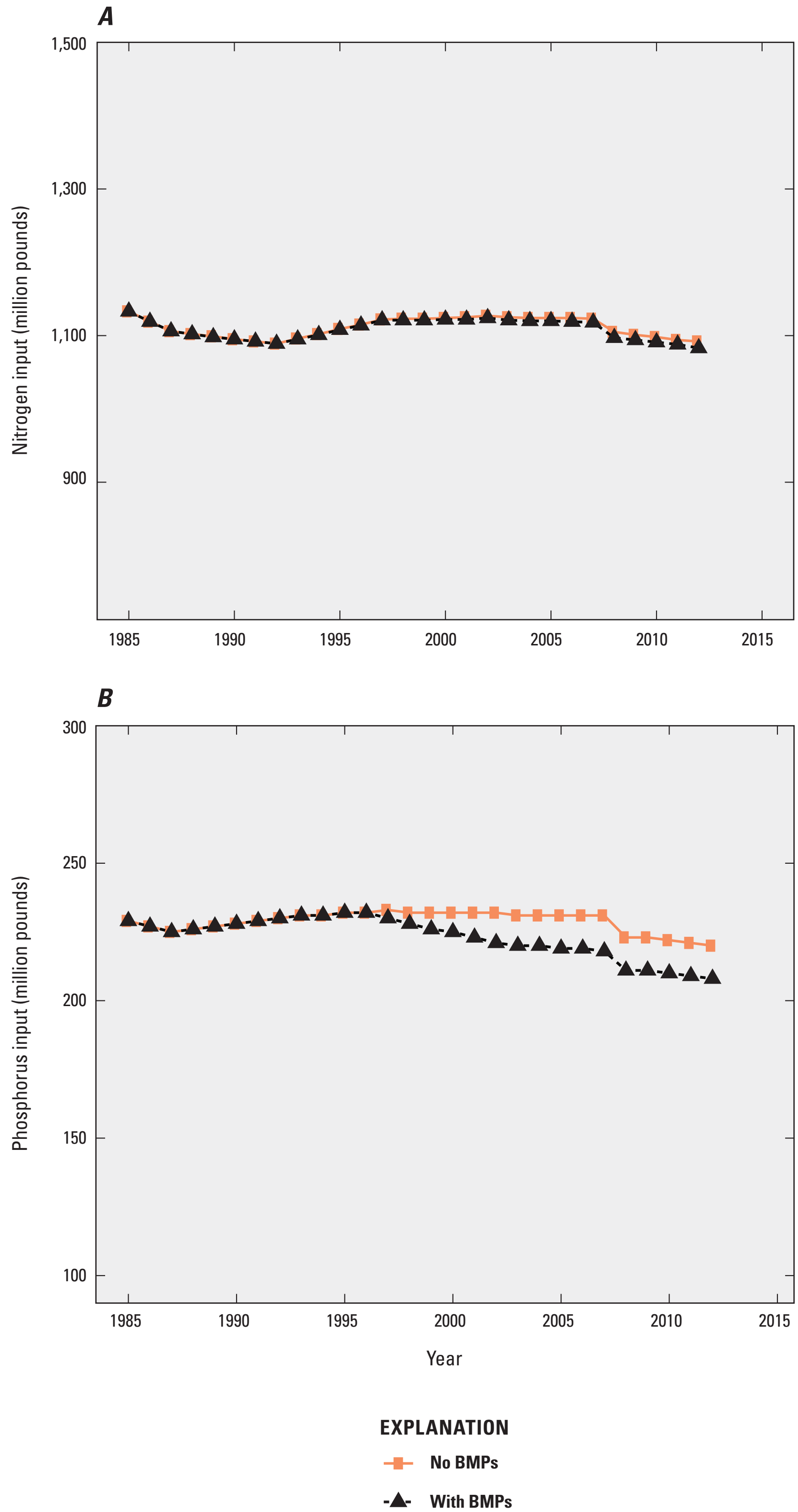

Figure 11. Expected effect of best management practices (BMPs) on *A*, nitrogen (N) and *B*, phosphorus (P) applications to land in the Chesapeake Bay watershed, 1985–2012. [Note difference in scales of y axes.]

Table 12. Expected change in nitrogen (N) and phosphorus (P) applications in the Chesapeake Bay watershed with and without best management practice (BMP) implementation, 1985–2012.

[HUC8, 8-digit hydrologic unit; ND, not determined]

Region	HUC8 name	Change in N applied, 1985–2012 (percent)		Change in P applied, 1985–2012 (percent)	
		Without BMPs	With BMPs	Without BMPs	With BMPs
Susquehanna	Upper Susquehanna	-41	-42	-48	-49
	Chenango	-37	-38	-42	-42
	Owego-Wappasening	-36	-37	-45	-45
	Tioga	-9	-9	-6	-8
	Chemung	-23	-23	-29	-29
	Upper Susquehanna-Tunkhannock	-28	-28	-40	-40
	Upper Susquehanna-Lackawanna	-8	-9	-2	-3
	Upper West Branch Susquehanna	-8	-8	-22	-22
	Sinnemahoning	169	169	225	173
	Middle West Branch Susquehanna	ND	ND	ND	ND
	Bald Eagle	0	-1	5	4
	Pine	ND	ND	ND	ND
	Lower West Branch Susquehanna	-13	-13	3	0
	Lower Susquehanna-Penns	-2	-3	25	16
	Upper Juniata	26	25	36	35
	Raystown	-4	-4	1	0
	Lower Juniata	-3	-4	6	2
	Lower Susquehanna-Swatara	15	14	33	26
	Lower Susquehanna	-6	-7	-4	-11
Eastern Shore	Chester-Sassafras	-5	-6	5	0
	Choptank	26	22	22	12
	Nanticoke	0	-3	-14	-24
	Tangier	6	3	-5	-19
	Pocomoke-Western Lower Delmarva	6	5	6	-6
Maryland Western Shore	Gunpowder-Patapsco	-22	-22	-34	-34
	Severn	ND	ND	ND	ND
	Patuxent	-4	-4	-26	-26
Potomac	South Branch Potomac	25	22	62	39
	North Branch Potomac	-3	-3	17	8
	Cacapon-Town	16	15	29	19
	Conococheague-Opequon	4	3	5	2
	South Fork Shenandoah	7	5	7	-3
	North Fork Shenandoah	8	6	2	-6
	Shenandoah	-21	-21	-31	-31
	Middle Potomac-Catoctin	-19	-19	-32	-32
	Monocacy	-30	-30	-30	-31
	Middle Potomac-Anacostia-Occoquan	17	17	-21	-21
	Lower Potomac	11	11	-11	-11

Table 12. Expected change in nitrogen (N) and phosphorus (P) applications in the Chesapeake Bay watershed with and without best management practice (BMP) implementation, 1985–2012.—Continued

[HUC8, 8-digit hydrologic unit; ND, not determined]

Region	HUC8 name	Change in N applied, 1985–2012 (percent)		Change in P applied, 1985–2012 (percent)	
		Without BMPs	With BMPs	Without BMPs	With BMPs
Virginia Western Shore	Great Wicomico-Piankatank	3	3	-27	-27
	Rapidan-Upper Rappahannock	-8	-8	-11	-12
	Lower Rappahannock	-3	-3	-21	-22
	Mattaponi	7	7	-20	-20
	Pamunkey	-4	-4	-27	-28
	York	17	17	-54	-54
James	Upper James	-4	-4	-18	-19
	Maury	19	19	7	6
	Middle James-Buffalo	18	18	2	1
	Rivanna	-17	-17	-33	-33
	Middle James-Willis	-21	-21	-29	-33
	Lower James	25	25	-14	-14
	Appomattox	16	16	1	-5
Hampton Roads	Lynnhaven-Poquoson	ND	ND	ND	ND
	Hampton Roads	-6	-6	-28	-29
Chesapeake Bay watershed		**-4**	**-4**	**-4**	**-9**

Table 13. Spatial variability in expected changes in manure and fertilizer inputs due to best management practice (BMP) implementation in the Chesapeake Bay watershed, 1985–2012.

[N, nitrogen; P, phosphorus]

Region	Change due to BMPs, 1985–2012 (pounds)			
	Manure N	Fertilizer N	Manure P	Fertilizer P
Susquehanna	-1,252,690	-1,589,212	-4,133,321	154,201
Eastern Shore	-1,367,777	-1,853,734	-4,807,370	435,302
Maryland Western Shore	0	-9,074	-6,953	527
Potomac	1,716,842	-4,702,115	-3,449,915	-256,347
Virginia Western Shore	71,244	-124,050	-38,681	-2,112
James	386,729	-618,295	-376,222	22,473
Hampton Roads	4,089	-9,348	-8,175	2,630

sole driver of expected P reductions in 5 of the 7 Chesapeake regions and accounted for the majority of expected reductions in 42 HUC8s. Implementation of these BMPs was expected to increase fertilizer-P usage in all but 2 regions[8], and in 26 HUC8s distributed across all 7 regions of the watershed.

Animal Best Management Practice (BMP) Implementation

The reductions in manure-N and manure-P inputs described above can be fully attributed to animal BMPs, as only these BMPs affect nutrient concentrations and (or) amounts of manure. However, based on BMP implementation reported to the CBP (Devereux and others, 2017), rates for dairy precision feeding/forage management were so low that it would be unlikely that they affected manure nutrient concentrations (table 14). The 100-percent implementation level of poultry phytase is more likely to have affected manure-P reductions, although increasing poultry populations could theoretically mask the overall effect of phytase on manure-P inputs from poultry. Because manure transport can also affect local manure-P inputs, expected reductions cannot be attributed solely to poultry phytase implementation in this dataset. However, the greatest expected reductions in manure-P inputs tend to occur in those HUC8s containing the largest poultry populations (fig. 12).

The most notable exception to this pattern is the Sinnemahoning HUC8. Results from the Scenario Builder model indicated that manure-P inputs in the Sinnemahoning increased almost hundredfold, even with BMP implementation, between 1985 and 2012. However, based on data from LaMotte (2015), this analysis indicated that the Sinnemahoning ranked among the lowest for poultry inventories among all HUC8s in the watershed in 2012. Between 2007 and 2012, its poultry inventory declined from 2,483 to 1,792 individuals, and livestock populations also remained low. This anomaly was caused by a protocol used by the CBP to account for poultry populations that were reported only at the state level in the USDA COA due to privacy restrictions. The LaMotte (2015) dataset included only those animals that were reported at the county scale, whereas the CBP used an algorithm to allocate poultry reported at the state level to local areas around the watershed. As a result, the CBP Phase 5.3.2 Scenario Builder dataset assumed a large allocation of poultry to Cameron County, Pennsylvania (thus to the Sinnemahoning HUC8), whereas LaMotte (2015) did not.

[8]The Potomac and Virginia Western Shore.

Land-Use Change Best Management Practices (BMPs)

Between 1985 and 2012, reported implementation of agricultural land-use change BMPs increased from 60 to about 651,000 acres per year across the watershed, for an accumulated total of almost 4.5 million acres in 2012. However, 85 percent of the cumulative increase occurred during the last 6 years of the period, from 2006 to 2012 (fig. 13). Although major jurisdictions have reported BMP implementation to the CBP since the late 1990s, the establishment of the Chesapeake Bay TMDL in 2010 provided incentive to improve BMP reporting. At that time, jurisdictions were permitted to update past reporting of BMP implementation as far back as 2006 (Chesapeake Bay Program Watershed Technical Work Group, 2013). In recent years, the CBP has developed new tools to improve the counting and reporting of BMP implementation, however, verification of historical BMP implementation records remains challenging (National Research Council, 2011). It is likely that the increase in implementation observed in recent years is at least partially a consequence of increased reporting rather than increased implementation.

The vast majority of land-use change BMP acreage was located in the regions including the most agricultural acreage (the Susquehanna, Potomac, and Eastern Shore regions). However, when implementation was adjusted to account for the amount of eligible[9] acreage in each HUC8, the resulting measure of implementation intensity of land-use change BMPs (such as implementation per acre of eligible land) in the agricultural sector varied both within and among regions, from as low as 2.6 percent in the Chenango HUC8 to as much as 32 percent in the Sinnemahoning HUC8 (fig. 14), and did not necessarily occur in those HUC8s with the most agricultural activity. For example, the lower part of the Susquehanna region and the central part of the Potomac region have relatively high agricultural N- and P-input intensities (see figure 8), but show some of the lowest agricultural land-use change BMP implementation intensities (percent of eligible acres).

[9]Acres determined to be appropriate for implementation of agricultural land-use change BMPs.

Table 14. Dairy precision feeding implementation rates in the Chesapeake Bay watershed, 2007–12 (Devereux and others, 2017).

[BMP, best management practice]

Year	BMP	Region	Amount implemented (animal units)	Animal units available	Percent implementation
2007	Dairy precision feeding; forage management	Susquehanna	352	29,166	1
2008	Dairy precision feeding; forage management	Susquehanna	3,634	39,186	9
2009	Dairy precision feeding; forage management	Susquehanna	6,724	38,589	17
2010	Dairy precision feeding; forage management	Susquehanna	1,710	72,043	2
2011	Dairy precision feeding; forage management	Susquehanna	3,199	31,351	10
2012	Dairy precision feeding; forage management	Susquehanna	5,541	514,766	1
2012	Dairy precision feeding; forage management	Potomac	98	69,645	0

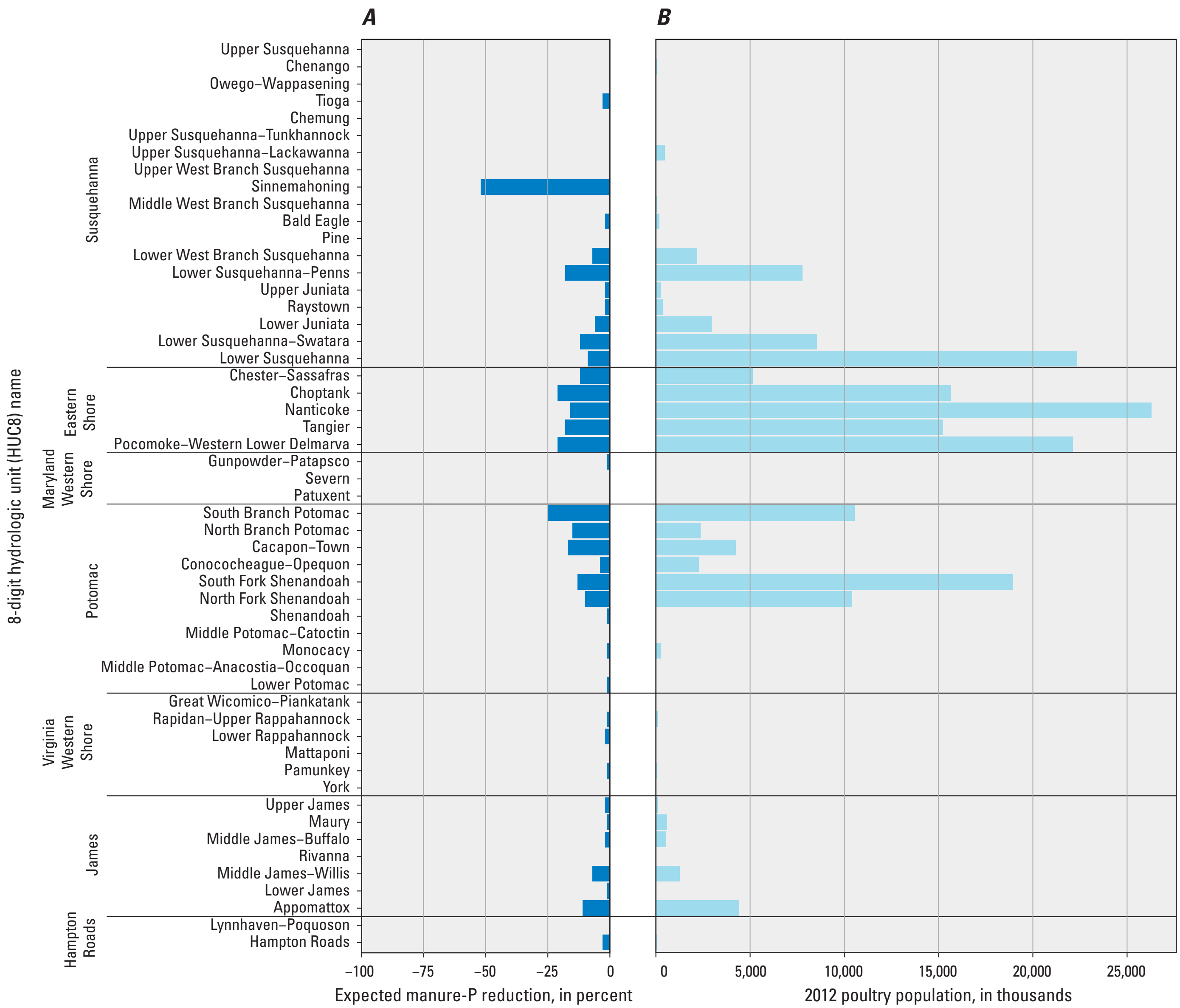

Figure 12. *A*, expected percent change in manure-phosphorus (manure-P) applications due to best management practices (BMPs) from 1985 to 2012 (dark blue bars), and *B*, 2012 poultry populations (light blue bars) in the Chesapeake Bay watershed. [In general, BMP effects on manure-P inputs were expected only in basins where poultry populations were located. Exceptions were the Tioga, Upper Susquehanna-Lackawanna, and Sinnemahoning Basins.]

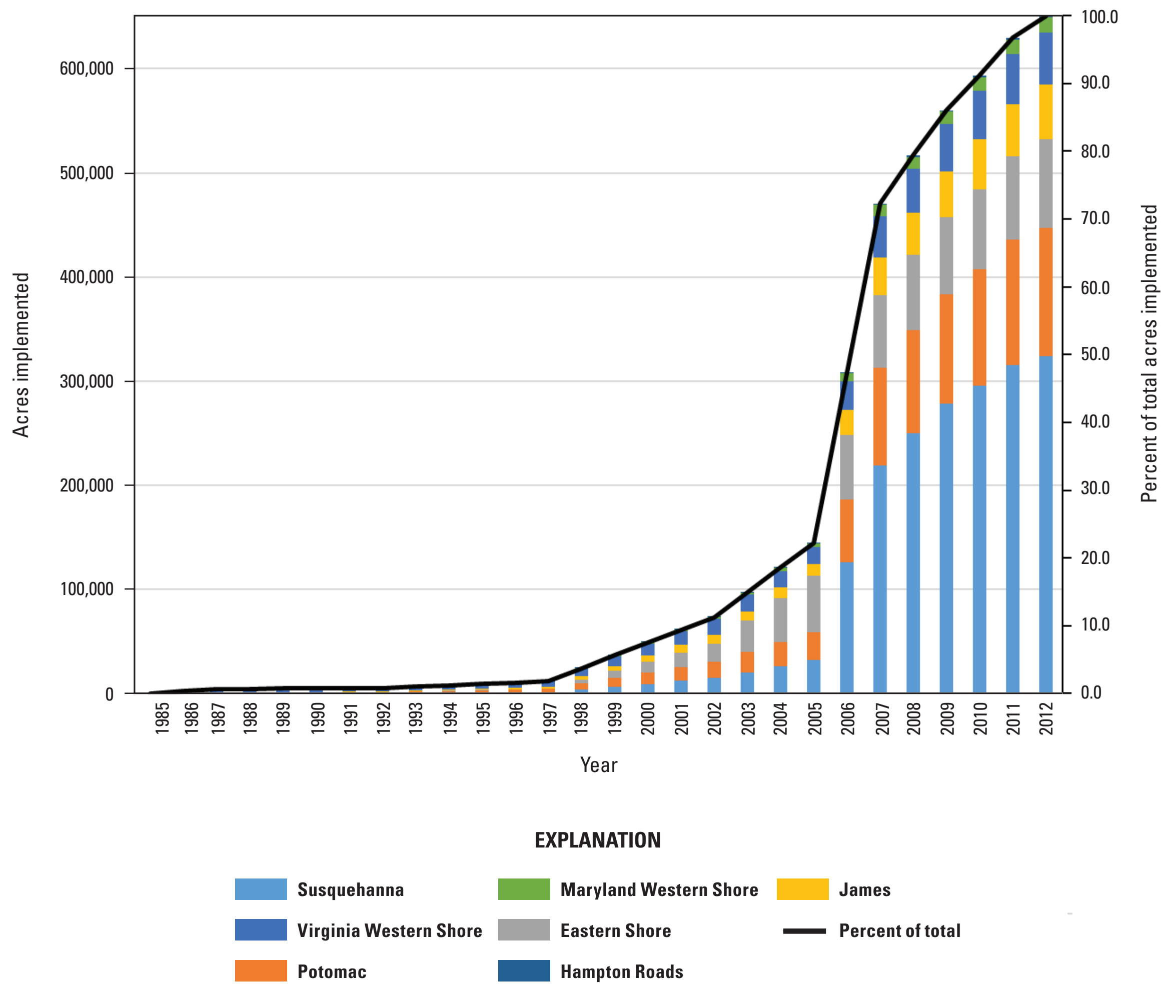

Figure 13. Reported implementation of agricultural land-use change best management practices (BMPs) for major regions of the Chesapeake Bay watershed, 1985–2012. [Bars represent annual implementation; black line represents the cumulative total of BMP acreage for all regions.]

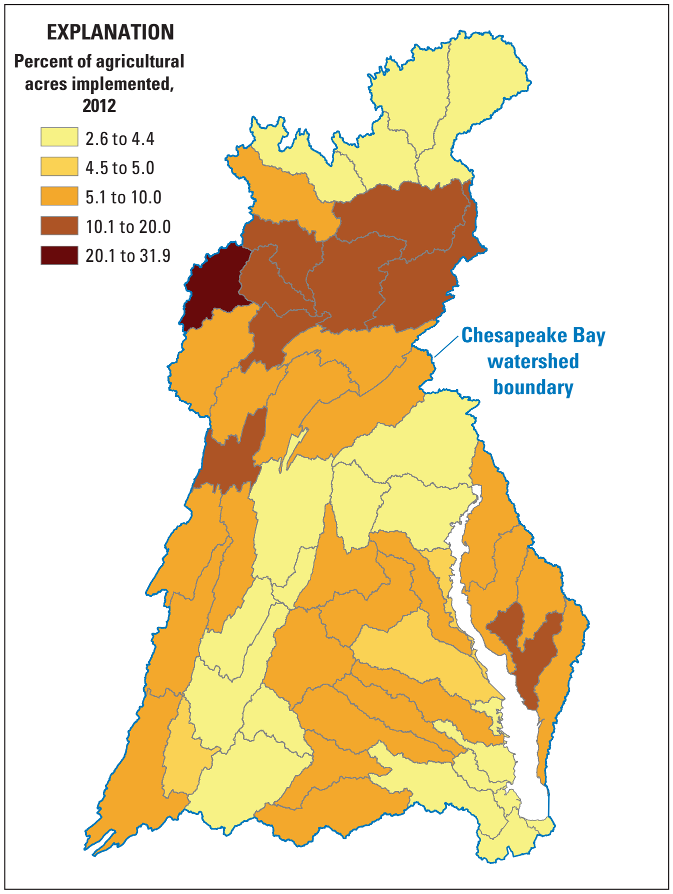

Figure 14. Implementation of agricultural land-use change best management practices (BMPs) as of 2012 (percent of eligible acres) in the Chesapeake Bay watershed.

Summary

The U.S. Geological Survey (USGS) serves as an integral part of the effort to advance the understanding of factors affecting aquatic conditions in the Chesapeake Bay watershed and estuary. Understanding temporal and spatial patterns in manure and fertilizer inputs, as well as in associated agricultural practices, enables further interpretation of the results of research on changes in riverine and estuarine aquatic conditions. To that end, this report evaluates the magnitude and spatial variability of nitrogen (N) and phosphorus (P) inputs from manure and fertilizer from 1950 through 2012 at three spatial scales: the entire Chesapeake Bay watershed, 7 regions within the watershed, and the 53 8-digit hydrologic units (HUC8s) that are contained within the watershed. Changes over time in natural, developed, and agricultural land use were also characterized, as were temporal and spatial variability in agricultural land-use practices such as livestock and poultry populations, and the cultivation of different crop types. Relations between land-use change, agricultural practices, and manure and fertilizer inputs were explored. In addition, data on the reported implementation of land-use change and animal best management practices (BMPs) from 1985–2012 were used to describe temporal and spatial patterns in BMP implementation intensity, and modeling scenarios from the Chesapeake Bay Program (CBP) Scenario Builder were used to estimate the expected effect of these BMPs on manure and fertilizer inputs across the watershed.

Inputs of N and P to the watershed from manure increased moderately and steadily between 1950 and 2012, reflecting a small increase in animal inventory as measured in Animal Units (AUs), but with a shift from cows to poultry. Fertilizer-N inputs increased dramatically but experienced large inter-annual variability, whereas inputs of fertilizer-P decreased slightly. Patterns were more varied at the HUC8 scale, particularly in the latter part of the data record. Fertilizer inputs decreased in most areas throughout the Bay watershed from 1982–2012, whereas manure input increased in almost half of the HUC8s studied. Manure inputs also were re-distributed, most notably from the northern to the southern Susquehanna region, and from the central to the western part of the Potomac region. These patterns were consistent with changes in farming practices. Decreases in pasture and cropland were

accompanied by reduced agricultural nutrient inputs per acre of farmland in some areas, whereas other areas experienced an increase in the intensity of agricultural practices even as the actual amount of land in farms declined. Greater intensity of N inputs tended to occur in row-crop-dominated regions and in areas that saw large increases in poultry populations, whereas N-input intensity was lower and was more likely to decline over time in regions dominated by forage crops and cows. Nutrient input patterns in predominantly urban HUC8s deviated from those in predominantly agricultural HUC8s.

Exploratory analysis of this dataset identified a positive correlation between fertilizer-N use and the proportion of acres planted in grain corn. The proportion of acres planted in silage corn did not exhibit this pattern. Corn silage is usually produced in close proximity to cow populations, possibly increasing the usage of manure rather than fertilizer for meeting crop N requirements. These findings can be used to evaluate whether increased cultivation of corn, which often has greater N requirements than other crops, results in larger fertilizer-N inputs.

Finally, the reported implementation of BMPs that affect agricultural nutrient inputs was expected to reduce N inputs by less than 1 percent, and P inputs by just over 5 percent, across the watershed. The greater influence on P inputs, due almost entirely to reduced manure-P inputs, was concentrated in areas with high poultry populations, and most likely resulted from the addition of the phytase enzyme to poultry feed. Reported implementation of agricultural land-use change BMPs increased substantially after 2005, but this may have been at least partially due to improved mechanisms for BMP reporting rather than solely due to increased implementation on the ground. Implementation of land-use change BMPs also varied geographically, ranging from less than 3 percent to just over 30 percent of eligible acres. The intensity of land-use change BMP implementation was not consistently aligned with areas experiencing the greatest intensity of manure and fertilizer nutrient inputs.

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Appendix 1

Inputs of nitrogen (N) to the Chesapeake Bay watershed's 53 8-digit hydrologic units (HUC8s) from manure, fertilizer, and the two sources combined. Inputs, as well as changes in those inputs, between the decades 1992–2002 and 2002–12 are provided.

Appendix 1. Inputs of nitrogen (N) to the Chesapeake Bay watershed's 53 8-digit hydrologic units (HUC8s) from manure, fertilizer, and the two sources combined. Inputs, as well as changes in those inputs, between the decades 1992–2002 and 2002–12 are provided.

Region	HUC8 name	HUC8 code	Manure-N (million pounds)					Fertilizer-N (million pounds)					Combined (million pounds)	
			1992	2002	2012	Change 1992–2002	Change 2002–12	1992	2002	2012	Change 1992–2002	Change 2002–12	Change 1992–2002	Change 2002–12
Susquehanna	Upper Susquehanna	02050101	13.10	10.98	7.68	-2.12	-3.29	6.80	5.48	3.43	-1.31	-2.05	-3.43	-5.35
	Chenango	02050102	11.33	9.52	7.81	-1.81	-1.71	6.86	5.44	4.30	-1.42	-1.14	-3.24	-2.85
	Owego-Wappasening	02050103	5.37	4.83	3.61	-0.54	-1.21	2.48	2.90	1.29	0.42	-1.61	-0.12	-2.82
	Tioga	02050104	7.71	7.33	7.01	-0.38	-0.32	3.71	2.86	3.14	-0.85	0.27	-1.23	-0.05
	Chemung	02050105	5.36	4.99	4.67	-0.38	-0.32	4.82	3.86	4.12	-0.96	0.27	-1.34	-0.05
	Upper Susquehanna-Tunkhannock	02050106	13.56	11.04	7.47	-2.52	-3.58	4.70	5.71	3.95	1.01	-1.76	-1.51	-5.34
	Upper Susquehanna-Lackawanna	02050107	3.84	3.85	3.93	0.01	0.08	4.75	7.19	6.53	2.44	-0.66	2.44	-0.58
	Upper West Branch Susquehanna	02050201	1.87	1.78	1.42	-0.10	-0.35	1.64	2.93	1.68	1.29	-1.25	1.19	-1.61
	Sinnemahoning	02050202	0.31	0.30	0.31	-0.01	0.01	0.15	0.25	0.19	0.10	-0.07	0.09	-0.05
	Middle West Branch Susquehanna	02050203	0.52	0.68	1.04	0.16	0.36	0.24	0.37	0.26	0.13	-0.11	0.30	0.25
	Bald Eagle	02050204	3.30	3.72	4.30	0.42	0.58	2.01	3.04	2.16	1.03	-0.88	1.45	-0.30
	Pine	02050205	1.59	1.59	1.32	0.00	-0.27	0.71	0.84	0.65	0.13	-0.19	0.13	-0.46
	Lower West Branch Susquehanna	02050206	8.63	9.88	10.09	1.25	0.21	5.53	9.09	6.73	3.56	-2.36	4.81	-2.15
	Lower Susquehanna-Penns	02050301	12.24	14.24	16.57	2.00	2.33	6.52	9.45	7.73	2.93	-1.72	4.93	0.60
	Upper Juniata	02050302	5.81	6.48	7.74	0.67	1.27	3.43	4.72	4.00	1.29	-0.72	1.96	0.55
	Raystown	02050303	5.45	5.04	5.93	-0.41	0.88	2.94	3.56	3.29	0.62	-0.28	0.21	0.61
	Lower Juniata	02050304	11.77	14.22	14.13	2.45	-0.09	4.67	5.89	4.46	1.22	-1.43	3.66	-1.51
	Lower Susquehanna-Swatara	02050305	24.81	28.42	33.18	3.61	4.76	9.30	13.42	12.57	4.12	-0.85	7.73	3.91
	Lower Susquehanna	02050306	74.36	72.62	75.15	-1.74	2.53	27.94	46.15	37.27	18.22	-8.89	16.48	-6.36
Eastern Shore	Chester-Sassafras	02060002	5.93	6.34	7.34	0.41	1.00	36.78	34.39	24.54	-2.39	-9.85	-1.98	-8.85
	Choptank	02060005	7.11	8.76	12.49	1.65	3.72	24.99	21.36	15.52	-3.62	-5.84	-1.97	-2.12
	Nanticoke	02080109	23.05	25.21	24.48	2.17	-0.73	17.88	18.16	15.53	0.28	-2.63	2.45	-3.36
	Tangier	02080110	10.76	10.88	12.99	0.12	2.11	8.05	7.61	4.07	-0.44	-3.54	-0.32	-1.43
	Pocomoke-Western Lower Delmarva	02080111	14.33	14.95	17.35	0.61	2.40	14.92	14.41	9.32	-0.51	-5.09	0.11	-2.68
Maryland Western Shore	Gunpowder-Patapsco	02060003	5.41	4.04	2.66	-1.37	-1.38	12.83	13.26	10.50	0.43	-2.76	-0.94	-4.14
	Severn	02060004	0.22	0.17	0.13	-0.05	-0.04	1.38	1.42	1.34	0.04	-0.08	-0.01	-0.12
	Patuxent	02060006	2.27	1.61	1.14	-0.66	-0.47	9.22	7.99	6.23	-1.23	-1.75	-1.89	-2.23

Appendix 1. Inputs of nitrogen (N) to the Chesapeake Bay watershed's 53 8-digit hydrologic units (HUC8s) from manure, fertilizer, and the two sources combined. Inputs, as well as changes in those inputs, between the decades 1992–2002 and 2002–12 are provided.—Continued

Region	HUC8 name	HUC8 code	Manure-N (million pounds)					Fertilizer-N (million pounds)					Combined (million pounds)	
			1992	2002	2012	Change 1992–2002	Change 2002–12	1992	2002	2012	Change 1992–2002	Change 2002–12	Change 1992–2002	Change 2002–12
Potomac	South Branch Potomac	02070001	12.52	14.11	15.01	1.59	0.90	1.94	1.73	1.17	-0.21	-0.55	1.38	0.35
	North Branch Potomac	02070002	4.25	4.91	5.03	0.66	0.12	1.08	1.20	0.73	0.11	-0.47	0.77	-0.35
	Cacapon-Town	02070003	5.53	6.59	7.17	1.06	0.57	1.01	1.04	0.55	0.03	-0.49	1.09	0.08
	Conococheague-Opequon	02070004	24.35	26.48	26.16	2.13	-0.31	16.08	17.72	12.21	1.64	-5.51	3.77	-5.82
	South Fork Shenandoah	02070005	38.06	41.11	35.33	3.05	-5.78	11.88	11.57	9.46	-0.32	-2.10	2.73	-7.88
	North Fork Shenandoah	02070006	20.84	22.94	19.55	2.10	-3.39	4.39	4.26	3.86	-0.13	-0.40	1.97	-3.79
	Shenandoah	02070007	3.16	3.01	2.75	-0.15	-0.25	2.42	2.70	1.76	0.28	-0.94	0.13	-1.19
	Middle Potomac-Catoctin	02070008	11.26	8.83	7.13	-2.43	-1.70	10.25	10.20	8.58	-0.05	-1.63	-2.47	-3.33
	Monocacy	02070009	10.92	9.19	6.69	-1.73	-2.51	18.80	17.40	11.29	-1.40	-6.11	-3.13	-8.62
	Middle Potomac-Anacostia-Occoquan	02070010	3.13	2.77	2.43	-0.35	-0.34	9.34	11.17	10.76	1.83	-0.41	1.48	-0.75
	Lower Potomac	02070011	1.94	1.61	1.23	-0.33	-0.38	11.11	11.08	9.11	-0.04	-1.97	-0.37	-2.35
Virginia Western Shore	Great Wicomico-Piankatank	02080102	0.24	0.21	0.18	-0.02	-0.03	3.70	3.45	3.92	-0.25	0.48	-0.28	0.45
	Rapidan-Upper Rappahannock	02080103	13.87	13.06	11.54	-0.81	-1.51	11.26	10.23	9.12	-1.03	-1.11	-1.84	-2.63
	Lower Rappahannock	02080104	1.04	1.05	0.78	0.01	-0.27	10.06	9.52	10.67	-0.54	1.15	-0.53	0.89
	Mattaponi	02080105	1.29	1.16	0.96	-0.13	-0.21	6.19	5.04	5.86	-1.14	0.81	-1.27	0.61
	Pamunkey	02080106	5.77	5.06	4.38	-0.72	-0.67	11.55	9.33	9.72	-2.22	0.38	-2.94	-0.29
	York	02080107	0.13	0.11	0.10	-0.02	-0.00	1.45	1.34	1.24	-0.12	-0.10	-0.14	-0.10
James	Upper James	02080201	5.32	4.87	5.03	-0.45	0.16	3.43	3.63	2.45	0.20	-1.18	-0.25	-1.02
	Maury	02080202	5.29	5.58	5.71	0.29	0.13	2.11	2.08	1.78	-0.04	-0.30	0.25	-0.17
	Middle James-Buffalo	02080203	8.21	7.77	8.16	-0.45	0.39	5.55	5.12	3.81	-0.43	-1.32	-0.88	-0.92
	Rivanna	02080204	3.61	2.79	2.76	-0.82	-0.03	1.83	1.68	1.32	-0.15	-0.35	-0.97	-0.39
	Middle James-Willis	02080205	4.43	4.57	4.01	0.14	-0.56	3.00	3.17	2.44	0.16	-0.73	0.30	-1.29
	Lower James	02080206	1.87	1.52	0.83	-0.35	-0.69	10.55	9.79	9.62	-0.76	-0.17	-1.11	-0.86
	Appomattox	02080207	9.20	9.99	9.07	0.79	-0.92	6.89	6.29	4.79	-0.61	-1.50	0.19	-2.42
Hampton Roads	Lynnhaven-Poquoson	02080108	0.05	0.01	0.01	-0.04	0.00	1.89	2.67	2.13	0.78	-0.54	0.74	-0.54
	Hampton Roads	02080208	0.73	0.67	0.35	-0.06	-0.32	5.59	5.13	4.61	-0.46	-0.53	-0.52	-0.85

Appendix 2

Inputs of phosphorus (P) to the Chesapeake Bay watershed's 53 8-digit hydrologic units (HUC8s) from manure, fertilizer, and the two sources combined. Inputs, as well as changes in those inputs, between the decades 1992–2002 and 2002–12 are provided.

Appendix 2. Inputs of phosphorus (P) to the Chesapeake Bay watershed's 53 8-digit hydrologic units (HUC8s) from manure, fertilizer, and the two sources combined. Inputs, as well as changes in those inputs, between the decades 1992–2002 and 2002–12 are provided.

Region	HUC8 name	HUC8 code	Manure-P (million pounds)					Fertilizer-P (million pounds)					Combined (million pounds)	
			1992	2002	2012	Change 1992–2002	Change 2002–12	1992	2002	2012	Change 1992–2002	Change 2002–12	Change 1992–2002	Change 2002–12
Susquehanna	Upper Susquehanna	02050101	2.39	2.21	1.60	-0.18	-0.61	2.31	1.35	0.54	-0.95	-0.81	-1.13	-1.40
	Chenango	02050102	2.01	1.87	1.57	-0.15	-0.30	2.19	1.26	0.64	-0.93	-0.62	-1.08	-0.90
	Owego-Wappasening	02050103	1.03	1.02	0.76	-0.01	-0.26	0.81	0.70	0.19	-0.11	-0.51	-0.12	-0.80
	Tioga	02050104	1.50	1.70	1.62	0.20	-0.08	1.28	0.67	0.48	-0.62	-0.19	-0.42	-0.30
	Chemung	02050105	1.09	1.10	1.03	0.01	-0.07	1.62	0.93	0.65	-0.70	-0.28	-0.69	-0.30
	Upper Susquehanna-Tunkhannock	02050106	2.87	2.51	1.65	-0.37	-0.86	1.62	1.17	0.52	-0.45	-0.66	-0.82	-1.50
	Upper Susquehanna-Lackawanna	02050107	0.96	1.00	1.05	0.03	0.06	1.59	1.38	0.86	-0.20	-0.52	-0.17	-0.50
	Upper West Branch Susquehanna	02050201	0.44	0.43	0.34	-0.01	-0.10	0.54	0.56	0.22	0.02	-0.34	0.01	-0.40
	Sinnemahoning	02050202	0.07	0.07	0.07	0.00	0.00	0.05	0.04	0.03	0.00	-0.02	0.00	0.00
	Middle West Branch Susquehanna	02050203	0.11	0.14	0.25	0.03	0.10	0.08	0.08	0.03	-0.01	-0.04	0.03	0.10
	Bald Eagle	02050204	0.69	0.80	0.98	0.11	0.17	0.69	0.62	0.28	-0.07	-0.34	0.04	-0.20
	Pine	02050205	0.32	0.40	0.32	0.08	-0.08	0.25	0.17	0.09	-0.07	-0.09	0.01	-0.20
	Lower West Branch Susquehanna	02050206	2.15	2.61	2.73	0.46	0.12	1.91	1.87	0.88	-0.03	-1.00	0.42	-0.90
	Lower Susquehanna-Penns	02050301	3.45	4.04	4.83	0.59	0.80	2.25	1.94	1.01	-0.31	-0.93	0.28	-0.10
	Upper Juniata	02050302	1.13	1.32	1.63	0.19	0.31	1.18	0.96	0.52	-0.22	-0.44	-0.03	-0.10
	Raystown	02050303	1.15	1.14	1.40	-0.02	0.27	1.02	0.74	0.43	-0.28	-0.31	-0.30	0.00
	Lower Juniata	02050304	2.77	3.77	3.68	1.00	-0.09	1.62	1.22	0.58	-0.40	-0.64	0.60	-0.70
	Lower Susquehanna-Swatara	02050305	6.57	7.90	9.12	1.33	1.22	3.15	2.64	1.65	-0.51	-0.99	0.82	0.20
	Lower Susquehanna	02050306	21.85	20.67	21.23	-1.17	0.56	8.98	9.25	4.97	0.27	-4.27	-0.91	-3.70
Eastern Shore	Chester-Sassafras	02060002	1.44	1.62	1.91	0.18	0.30	7.57	5.94	3.47	-1.64	-2.46	-1.46	-2.20
	Choptank	02060005	2.07	2.55	3.67	0.47	1.12	5.00	3.51	2.22	-1.49	-1.28	-1.02	-0.20
	Nanticoke	02080109	7.00	7.50	7.28	0.51	-0.22	3.12	2.27	1.35	-0.85	-0.92	-0.35	-1.10
	Tangier	02080110	3.29	3.27	3.89	-0.03	0.62	1.66	1.32	0.66	-0.34	-0.66	-0.37	0.00
	Pokomoke-Western Lower Delmarva	02080111	4.39	4.47	5.19	0.08	0.72	3.68	3.01	1.35	-0.67	-1.66	-0.59	-0.90
Maryland Western Shore	Gunpowder-Patapsco	02060003	1.36	0.97	0.62	-0.38	-0.35	2.83	2.29	2.70	-0.53	0.41	-0.92	0.10
	Severn	02060004	0.05	0.04	0.03	-0.01	-0.01	0.31	0.24	0.41	-0.07	0.16	-0.08	0.10
	Patuxent	02060006	0.58	0.40	0.26	-0.18	-0.14	1.98	1.38	1.57	-0.60	0.20	-0.78	0.10

Appendix 2. Inputs of phosphorus (P) to the Chesapeake Bay watershed's 53 8-digit hydrologic units (HUC8s) from manure, fertilizer, and the two sources combined. Inputs, as well as changes in those inputs, between the decades 1992–2002 and 2002–12 are provided.—Continued

Region	HUC8 name	HUC8 code	Manure-P (million pounds)					Fertilizer-P (million pounds)					Combined (million pounds)	
			1992	2002	2012	Change 1992–2002	Change 2002–12	1992	2002	2012	Change 1992–2002	Change 2002–12	Change 1992–2002	Change 2002–12
Potomac	South Branch Potomac	02070001	3.95	4.33	4.52	0.38	0.19	0.87	0.33	0.28	-0.54	-0.05	-0.16	0.10
	North Branch Potomac	02070002	1.14	1.35	1.44	0.21	0.09	0.36	0.22	0.16	-0.14	-0.06	0.07	0.00
	Cacapon-Town	02070003	1.67	1.90	2.16	0.23	0.27	0.37	0.19	0.12	-0.18	-0.08	0.05	0.20
	Conococheague-Opequon	02070004	5.97	6.83	6.66	0.86	-0.17	4.71	3.50	1.90	-1.21	-1.60	-0.35	-1.80
	South Fork Shenandoah	02070005	11.28	12.12	10.41	0.84	-1.71	3.51	3.04	1.39	-0.47	-1.65	0.37	-3.40
	North Fork Shenandoah	02070006	6.13	6.68	5.67	0.54	-1.01	1.30	1.12	0.57	-0.18	-0.56	0.37	-1.60
	Shenandoah	02070007	0.84	0.82	0.71	-0.02	-0.11	0.91	0.60	0.34	-0.31	-0.26	-0.33	-0.40
	Middle Potomac-Catoctin	02070008	2.80	2.27	1.80	-0.53	-0.47	2.50	2.13	1.76	-0.36	-0.38	-0.89	-0.80
	Monocacy	02070009	2.50	2.32	1.55	-0.18	-0.76	4.14	3.13	1.81	-1.01	-1.32	-1.19	-2.10
	Middle Potomac-Anacostia-Occoquan	02070010	0.83	0.73	0.62	-0.10	-0.11	2.54	2.52	2.48	-0.01	-0.05	-0.12	-0.20
	Lower Potomac	02070011	0.58	0.42	0.32	-0.16	-0.10	2.78	2.36	1.49	-0.41	-0.87	-0.57	-1.00
Virginia Western Shore	Great Wicomico-Piankatank	02080102	0.06	0.05	0.05	-0.01	-0.01	1.10	0.91	0.57	-0.19	-0.34	-0.20	-0.30
	Rapidan-Upper Rappahannock	02080103	3.95	3.61	3.31	-0.33	-0.30	3.34	2.70	1.33	-0.64	-1.37	-0.97	-1.70
	Lower Rappahannock	02080104	0.27	0.26	0.21	-0.01	-0.05	2.98	2.51	1.56	-0.47	-0.94	-0.48	-1.00
	Mattaponi	02080105	0.35	0.30	0.26	-0.05	-0.04	1.83	1.33	0.85	-0.50	-0.48	-0.55	-0.50
	Pamunkey	02080106	1.66	1.46	1.17	-0.20	-0.29	3.42	2.46	1.42	-0.96	-1.04	-1.16	-1.30
	York	02080107	0.03	0.02	0.02	-0.01	0.00	0.43	0.35	0.19	-0.08	-0.16	-0.09	-0.20
James	Upper James	02080201	1.50	1.38	1.38	-0.12	0.00	1.02	0.93	0.38	-0.09	-0.55	-0.20	-0.50
	Maury	02080202	1.57	1.67	1.69	0.10	0.02	0.63	0.55	0.26	-0.08	-0.29	0.03	-0.30
	Middle James-Buffalo	02080203	2.52	2.34	2.54	-0.17	0.20	1.63	1.34	0.57	-0.30	-0.76	-0.47	-0.60
	Rivanna	02080204	1.08	0.84	0.79	-0.24	-0.05	0.54	0.43	0.20	-0.10	-0.23	-0.34	-0.30
	Middle James-Willis	02080205	1.32	1.32	1.18	0.01	-0.14	0.88	0.82	0.37	-0.06	-0.44	-0.05	-0.60
	Lower James	02080206	0.64	0.51	0.26	-0.14	-0.24	3.07	2.50	1.49	-0.56	-1.02	-0.70	-1.30
	Appomattox	02080207	2.65	2.94	2.72	0.29	-0.22	2.03	1.64	0.72	-0.39	-0.92	-0.10	-1.10
Hampton Roads	Lynnhaven-Poquoson	02080108	0.02	0.00	0.00	-0.02	0.00	0.50	0.63	0.38	0.13	-0.25	0.12	-0.20
	Hampton Roads	02080208	0.26	0.24	0.12	-0.02	-0.12	1.61	1.30	0.73	-0.31	-0.56	-0.33	-0.70

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