WebPanel 1. Synthesis and analysis of the US nitrogen inventory

More than 913 000 individual peer-reviewed publications, referring to nitrogen (N) input in the US, were generated by our search engine-based queries. The vast majority (>99.9%) of papers identified in this way were too focused in scope or geographic area to be included in this synthesis. National-level N input estimates were, for the most part, taken directly from peer-reviewed literature or government publications (for a complete list, see WebTable 1). However, in some cases (eg for several estimates of non-cultivated biological N fixation [BNF], sewage wastewater, and inorganic N deposition) peer-reviewed estimates/models were re-analyzed to extract US-specific information. Here, we provide a description of the methods used for (1) extrapolation of N input estimates/models that were developed at scales smaller than the conterminous US, or (2) subsampling of N input estimates/models that were developed for scales larger than the continental US.

Non-cultivated BNF

Jordan and Weller (1996) provided two estimates of non-agricultural BNF (Table 1). For the lower estimate (0.5 Tg N yr^{-1}), we assumed a constant non-agricultural N fixation rate of 1 kg N ha^{-1} yr^{-1} for US Geological Survey (USGS) Water Resource Regions (2-digit Hydrologic Unit Codes [HUC-2s]) east of the Mississippi River and 0.5 kg N ha^{-1} yr^{-1} for HUC-2s west of the Mississippi River (Jordan and Weller 1996). For the higher estimate (12.2 Tg N yr^{-1}), we assumed a constant 1 kg N ha^{-1} yr^{-1} for everywhere except western arid USGS Water Resource Regions (California, Great Basin, Colorado, and Texas–Gulf–Rio Grande). For these four regions, we assumed a constant N fixation rate of 25 kg N ha^{-1} yr^{-1} (Jordan and Weller 1996).

Estimates of non-cultivated BNF calculated according to terrestrial ecosystem types (Cleveland *et al.* 1999) in Table 1 were developed by applying BNF rates of 5%, 15%, and 25% N-fixer coverage for specific ecosystem types to Level I ecoregions (www.epa.gov/wed/pages/ecoregions/na_eco.htm). WebTable 2 presents the pairings of Level I ecoregions with ecosystem type as described in Cleveland *et al.* (1999).

Non-cultivated BNF utilized the correlation between BNF and evapotranspiration (Cleveland *et al.* 1999) in Table 1, including the following regression models:

Conservative estimate:

$$\text{BNF (kg N ha}^{-1}\text{ yr}^{-1}) = 0.102 * \text{evapotranspiration (cm yr}^{-1}) + 0.524 \quad (1)$$

Central estimate:

$$\text{BNF (kg N ha}^{-1}\text{ yr}^{-1}) = 0.234 * \text{evapotranspiration (cm yr}^{-1}) - 0.172 \quad (2)$$

Upper-bound estimate:

$$\text{BNF (kg N ha}^{-1}\text{ yr}^{-1}) = 0.367 * \text{evapotranspiration (cm yr}^{-1}) - 0.754 \quad (3)$$

We downloaded global data (0.5 × 0.5 degrees grid resolution) describing actual evapotranspiration (http://climate.geog.udel.edu/~climate/html_pages/README.wb_ts2.html) to construct these estimates.

Synthetic N fertilizer

Many of the estimates regarding synthetic N fertilizer application in the US share common links to a single data source. Two such estimates (Ruddy *et al.* 2006; IFA 2011) share a link to fertilizer sales data compiled by the American Association of Plant Food Control Officials (www.aapfco.org). Three estimates (Bouwman *et al.* 2009; Liu *et al.* 2010; FAO 2011) are based on or have been modeled using data collected by the Food and Agricultural Organization of the United Nations (FAO; www.fao.org). One estimate, provided in the National Nutrient Loss and Soil Carbon (NNLSC) database, derives from surveys of ~75 000 farms and 15 major crops for 1997 (Potter *et al.* 2006).

Agricultural BNF

Methods used to estimate agricultural BNF included in the N inventory fall into three categories. The first method relies on mechanistic models – applying laboratory- or field-based data to model BNF as a function of crop type and limiting environmental factors, most commonly soil N availability (negative effect on BNF), moisture (positive effect), and temperature (non-linear effect; Liu *et al.* 2011) – to calculate agricultural BNF. The process-based estimate included in this inventory originates from the Environmental Policy Integrated Climate (EPIC) model, a process-based model of crop production that includes an N-fixing component for several N-fixing crop types (Potter *et al.* 2006). The EPIC model has been used to produce a national, spatially explicit estimate of agricultural BNF based on 1997 crop and soil conditions as part of the NNLSC database (Potter *et al.* 2006).

The second method applies a crop-specific per-area BNF rate to the area planted with that crop. National- and county-specific estimates derive from area planted with N-fixing crops described in databases maintained by the US Department of Agriculture (USDA) or the FAO (WebTable 1; Jordan and Weller 1996; Smil 1999; Howarth *et al.* 2002; Liu *et al.* 2010; SAB 2011).

The third method uses a crop yield-based approach and assumes that all N acquired by the plant during the growing season originates from agricultural BNF (Bouwman *et al.* 2009). Other recently developed regional or crop-specific models combine crop yield with measured data describing the fraction of N acquired by BNF relative to N assimilated from the soil (Han and Allan 2008; Herridge *et al.* 2008).

Atmospheric N deposition

Accurate source attribution of atmospheric N deposition is extremely difficult (Holland *et al.* 2005). For atmospheric deposition datasets that do not designate the origin of deposited N, we assume that either (1) 50% of the estimate is new N and 50% is recycled N, or (2) the NO_y component of deposition represents new N and the NH_x component represents recycled N (Holland *et al.* 2005). These approximations have been used in previous N assessments to designate N sources (eg Howarth *et al.* 2002; Holland *et al.* 2005), although future research on deposition source attribution is clearly needed. Finally, in order to estimate total N deposition from inorganic N deposition, we assumed that organic N deposition is 30% of total N deposition and augmented estimates of inorganic N deposition accordingly (Neff *et al.* 2002).

Data for atmospheric N deposition to the US originate from one of two sources. Data collected as part of the National Atmospheric Deposition Program (NADP; http://nadp.sws.uiuc.edu/) and/or the Clean Air Status and Trend Network (CASTNET; http://epa.gov/castnet/javaweb/index.html) provide information for four of the estimates (Jordan and Weller 1996; Holland *et al.* 2005; Ruddy *et al.* 2006). Data from these networks have been extrapolated from point measurements (250 NADP sites and 86 CASTNET sites) to estimate national-level N deposition. Although these estimates are based on observed data, the networks of sites

continued

WebPanel 1. – *continued*

used to construct the estimates are sparse and often located in areas with minimal human impact. Large-scale models based on data from industrial and agricultural emissions to the atmosphere form the basis of the remaining estimates (Howarth *et al*. 2002; Dentener 2006; Bouwman *et al*. 2009; USEPA 2010a). Modeled estimates have the advantage of including spatial patterns of deposition not captured by monitoring sites, and can help inform the selection of future monitoring locations.

Atmospheric N deposition estimates provided by the TM3 model (Dentener *et al*. 2006) are global in extent for 1993. We downloaded gridded data (5 × 3.75 degrees) available from the Oak Ridge National Laboratory (Dentener 2006) and, after downscaling data to 30 arcseconds (to minimize data exclusion at US boundaries), used Spatial Analyst in ArcMap 9.3 (ESRI Inc, Redlands, CA) to estimate US-specific atmospheric N deposition.

Livestock manure

Estimates of confined feedlot manure N ultimately derive from livestock population data collected for the USDA Census of Agriculture (USDA 2011). Differences among datasets reflect differences in methods used to translate animal populations into land application of manure and to account for volatilization/leaching (up to 50% of manure N produced on feedlots [Bouwman *et al*. 2005b]). Kellogg *et al*. (2000) and Ruddy *et al*. (2006) provided county-level data on feedlot manure N input to the US for 1982, 1987, 1992, and 1997. The best estimate incorporates a wide range of livestock categories, considers farm-specific life cycles of livestock (eg only the time spent on a feedlot by cattle for slaughter is considered), includes any supplemental N compounds added to feed (Stanton and Whittler 2006), and accounts for N loss to ammonia (NH_3) volatilization (Kellogg *et al*. 2000; Ruddy *et al*. 2006).

Wastewater

We estimated point-source inputs of non-industrial wastewater from the US population in 2000 (280 million). We used a constant per capita N excretion rate (6.1 kg N person^{-1} yr^{-1}), the fraction of the population connected to a centralized sewage system (~80% of the US population; USEPA 2011), and a fractional removal of N during the wastewater treatment process (~46%; WebPanel 1; Van Drecht *et al*. 2009). Although N removal in septic systems can be extremely variable and depend on the system's age, capacity, and technology (USEPA 2012), we assumed a similar fractional removal of N (46%) in on-site septic tanks to that of centralized treatment for the estimate of N input from septic system leaching.

Spatial distribution of N inputs

We compiled the spatial distribution of new N inputs, the magnitude of new human-mediated N input above background levels, and the largest human-mediated N source for the US from the 1990s to the early 2000s (Figures 3 and 4; WebFigure 1). For these estimates, we chose spatial datasets that offered complete coverage of the conterminous US land area, the highest spatial resolution, and complete metadata describing data acquisition and representation. To facilitate comparisons across datasets, we summarized inputs at the spatial resolution of the 8-digit Hydrologic Unit Code (HUC-8; Seaber *et al*. 1987) using the Zonal Statistics tool in the Spatial Analyst feature of ArcMap 9.3.

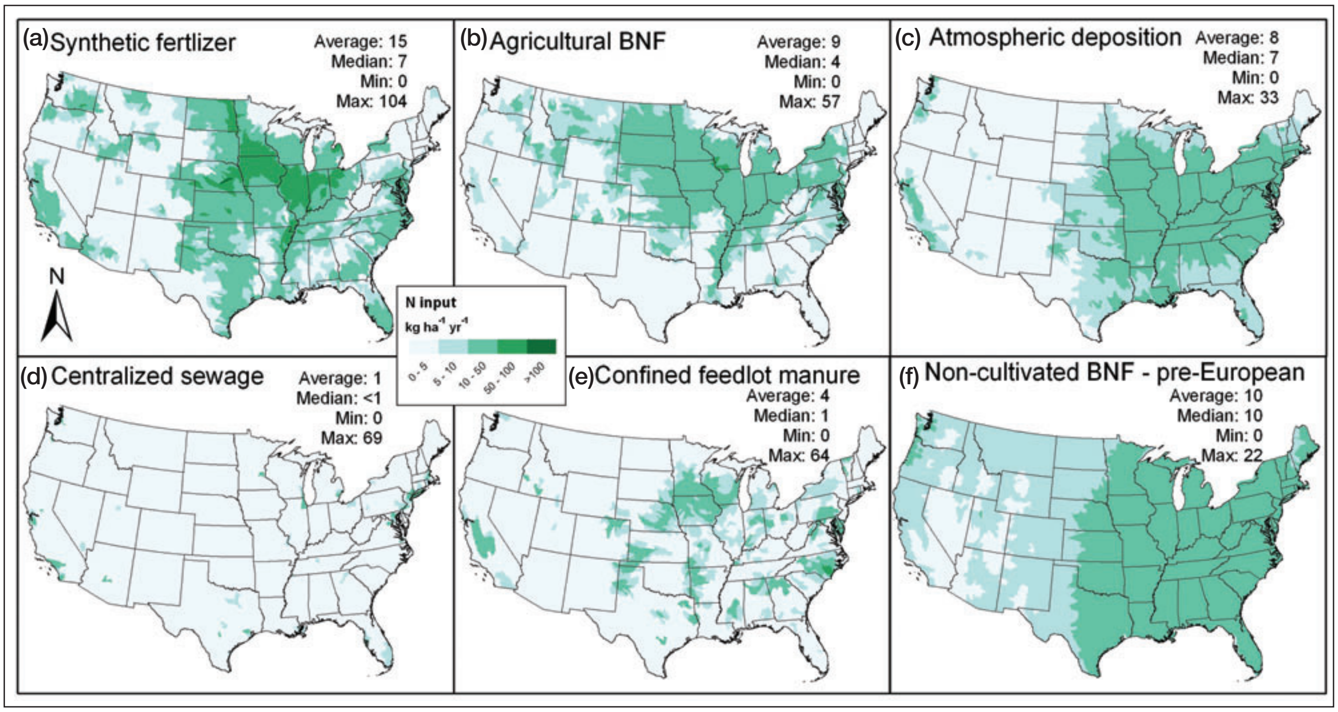
For agricultural N inputs (synthetic fertilizer, agricultural BNF, and confined feedlot manure), we used county-level data for 1997 (Ruddy *et al*. 2006; USDA 2011). All county-level estimates originate from Ruddy *et al*. (2006) except agricultural BNF, which was estimated by applying coefficients described in Smil (1999) and Howarth *et al*. (2002) to areas planted in N-fixing crops or in pasture for 1997 (USDA 2011).

We estimated the spatial distributions of non-fertilizer N inputs (non-cultivated BNF, wastewater, and inorganic N deposition) to the US using the following methods. For non-cultivated BNF, the regression model for the central estimate of non-cultivated BNF described above (Cleveland *et al*. 1999) was applied to a gridded (30-arcsecond resolution) dataset on actual evapotranspiration (derived from http://climate.geog.udel.edu/~climate/html_pages/README.wb_ts2.html) in the conterminous US. For wastewater, we applied the treatment corrected per capita excretion rate of N (2.8 kg N person^{-1} yr^{-1}; Van Drecht *et al*. 2009) to a 1-km × 1-km gridded dataset of the US population in 2000 (http://lwf.ncdc.noaa.gov/oa/climate/research/population/; rounded to the nearest 10 000). Lastly, we used 36-km × 36-km gridded data modeled by CMAQ for 2002 (USEPA 2010a) to estimate atmospheric inorganic N deposition in the US, assuming that NO_y originates primarily as new N and ammonium originates as recycled N (Holland *et al*. 2005).

We summed all new human-mediated N inputs and recycled N inputs for each HUC-8 in the US (Figure 4a). These sums represent gross input and do not account for N removed during harvest. We calculated the degree to which new human-mediated N input has increased total N input at the HUC-8 level by dividing the sum of all new human-mediated N inputs by background N input (WebFigure 1; non-cultivated BNF plus $\leq$1 kg N ha^{-1} yr^{-1} of inorganic N deposition; Boring *et al*. 1988). We identified the single largest human-mediated N input (new or recycled) by identifying the largest per area N input to each HUC-8 (Figure 3c).

Global context of N inputs to the US

On the basis of the best available estimates, new human-mediated N input to the US represents 15% of annual new human-mediated N input to Earth's land surface (WebTable 3). This suggests that human-mediated N input is currently three-fold higher in the conterminous US than would be expected if new human-mediated N input was distributed equally across Earth's land surface (the US contains 5% of global land area). In contrast to new human-mediated N input, new background N and recycled N inputs to the US are not exceptional relative to other world regions (4% and 7% of global estimates, respectively). Recycled N input is 17% of new N input in the US, whereas recycled N input is 47% of new N input to global land surfaces (WebTable 3).



WebFigure 1. *Spatial information on nitrogen (N) inputs available for the conterminous US. Spatial units are 8-digit Hydrologic Unit Codes. (a) Synthetic N fertilizer input, (b) agricultural biological N fixation (BNF), (c) atmospheric N deposition, (d) centralized sewage N, (e) confined feedlot manure N, and (f) non-cultivated BNF in pre-European times. See WebPanel 1 for data sources and method details. All N source estimates possess some level of uncertainty, with agricultural BNF, centralized sewage, confined feedlot manure, and non-cultivated BNF in pre-European times being the least certain.*

WebTable 1. Data resources available for estimating N input to the US (1990s–2000s)

Name	*Link*	*Description*	*Modeled or measured?*	*Temporal extent*	*Temporal resolution*	*Spatial extent*	*Spatial resolution*
New N							
Association of American Plant Food Control Officials	www.aapfco.org/	Fertilizer sales	Measured	1982–2001	Annual	US	County
Farm Business and Household Survey Data	www.ers.usda.gov/Data/ARMS/	Fertilizer application rates	Measured	1996–2005	Subannual	Nation/select states	Farm field/crop type
Agricultural Chemical Usage Reports	www.nass.usda.gov/Statistics_by_Subject/Environmental/index.asp	Fertilizer application by crop	Measured	1991–2010	Annual	Select states	Cropland acre
US Census Bureau Industrial Reports	www.census.gov/manufacturing/cir/historical_data/mq325b/index.html	Economy of commercial fertilizer	Measured	1941–2010	Quarterly	US	US
USGS Mineral Handbook: Nitrogen Statistics and Information	http://minerals.usgs.gov/minerals/pubs/commodity/nitrogen/index.html#myb	Economy of N consumption	Measured	1994–2010	Annual	US	US
Historical Statistics for Mineral and Material Commodities in the United States	http://minerals.usgs.gov/ds/2005/140/	Economy of N consumption	Measured	1943–2010	Annual	US	US
County-Level Estimates of Nitrogen and Phosphorus Fertilizer Use in the United States, 1945 to 1985	http://pubs.usgs.gov/of/1990/data.html	N fertilizer use	Measured/modeled	1945–1985	Annual	US	County
USDA Economic Research Service: Fertilizer Use and Price	www.ers.usda.gov/Data/FertilizerUse/	N fertilizer use by crop type	Measured	1960–2008	Annual	US	Select states
Global patterns of terrestrial biological nitrogen (N_2) fixation in natural ecosystems	www.agu.org/pubs/crossref/1999.../1999GB900014.shtml	Review of terrestrial N-fixation	Measured	--	Annual	Global	0.5 × 0.5 degrees
FERTISTAT: Fertilizer Use Statistics	www.fao.org/ag/agl/fertistat/index_en.htm	N fertilizer use by crop type	Measured	1998	Annual	Global	Crop type
Nitrogen in rock: Occurrences and biogeochemical implications	www.agu.org/pubs/crossref/2002/2002GB001862.shtml	N released during weathering	Measured	--	Annual	Global	Hectare
Global inputs of biological nitrogen fixation in agricultural systems	www.springerlink.com/content/75063j57488126/	Agricultural N-fixation	Measured	2005	Annual	Global	US
Spatial Data in Geographic Information System Format on Agricultural Chemical Use, Land Use, and Cropping Practices in the United States	http://pubs.usgs.gov/wri/wri944176/bat000.html	Agricultural N flow	Measured	1985–1991	Annual	US	County
Nitrogen in crop production: An account of global flows	www.agu.org/journals/ABS/1999/1999GB900015.shtml	Agricultural N flow	Measured/modeled	1997–2050	Annual	Global	US
A high-resolution assessment on global nitrogen flows in cropland	www.pnas.org/content/107/17/8035.full	Agricultural N flow	Modeled	2000	Annual	Global	5 arc-minutes
IFADATA: fertilizer data provided by the International Fertilizer Institute	www.fertilizer.org/ifa/ifadata/search	Synthetic N fertilizer	Measured	1961–2009	Annual	Global	US
FAOSTAT: Fertilizer data provide by the Food and Agricultural Organization of the United Nations	http://faostat.fao.org/site/575/default.aspx#ancor	Synthetic N fertilizer and industrial N	Measured	1961–2009	Annual	Global	US
Nitrogen's role in industrial systems	http://onlinelibrary.wiley.com/doi/10.1162/108819801753358517/abstract	Industrial N	Measured	1996	Annual	US	US
County-level estimates of nitrogen and phosphorus from commercial fertilizer for the conterminous US	http://pubs.usgs.gov/sir/2012/5207/	N inputs from farm and non-farm fertilizer application	Both	1987–2006	Annual	US	County
Recycled N							
Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States	www.nrcs.usda.gov/technical/NRI/pubs/manntr.html	Manure N input to agricultural systems	Measured/modeled	1982–1997	Annual	US	County

continued

WebTable 1. – *continued*

Name	*Link*	*Description*	*Modeled or measured?*	*Temporal extent*	*Temporal resolution*	*Spatial extent*	*Spatial resolution*
Models of Infectious Disease Agent Study: Poultry farms	www.epimodels.org/midas/pubsyntdata1.do	Estimates of poultry farms in US	Modeled	2008	Annual	US	Farm
US EPA Envirofact Permit Compliance System Water Discharge Permit Query form	www.epa.gov/enviro/html/pcs/pcs_query_java.html	Wastewater discharge	Measured	1970–2009	Daily	US	Point source
Discharge Monitoring Report (DMR) Pollutant Loading Tool	http://app6.erg.com/icisloader/	Wastewater discharge	Measured	2007	Annual	US	Point source
Clean Watershed Needs Survey	http://water.epa.gov/scitech/datait/databases/cwns/index.cfm	Wastewater discharge	Measured	1970–2008	Annual	US	Point source
Methods for Estimating Annual Wastewater Nutrient Loads in the Southeastern United States	http://pubs.usgs.gov/of/2007/1040/	Wastewater discharge	Modeled	2002	Annual	US	Point source
US Census Data on Small Community Housing and Wastewater Disposal and Plumbing Practices	http://water.epa.gov/infrastructure/wastewater/septic/census_index.cfm	Wastewater and septic systems	Measured	1990	Annual	US	Census reporting unit
Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050	www.agu.org/pubs/crossref/2009/2009GB003458.shtml	Urban wastewater	Modeled	1970–2050	Annual	Global	Continental
An overview of the RFF Environmental Data Inventory	www.worldcat.org/title/rff-environmental-data-inventory/clc/019292227	Point sources	Measured	1978	Annual	US	Point
Nutrient loadings to streams of the continental United States from muncipal and industrial effluent	http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2011.00576.x/abstract	Point sources	Measured/modeled	1992–2002	Annual	US	Major river basins
USGS survey of nitrate deposits in the United States	http://pubs.usgs.gov/bul/0838/report.pdf	Geologic N	Measured	Pre-1932	--	US	Survey locations by state
Toxic Release Inventory	www.epa.gov/tri/	Point sources	Measured	1987–2010	Annual	US	Individual facilities
New and recycled N							
National Atmospheric Deposition Program: National Trends Network	http://nadp.sws.uiuc.edu/ntn/	Wet deposition of NH_4^+ and NO_3^-	Measured	1978–2008	Weekly	US	Collection site
National Atmospheric Deposition Program: Atmospheric Integrated Research Monitoring Network	http://nadp.sws.uiuc.edu/airmon/	Wet deposition of NH_4^+ and NO_3^-	Measured	1992–2008	Daily	US	Collection site
County Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States	http://pubs.usgs.gov/sir/2006/5012/	TN input of fertilizer and manure; wet NH_4^+ and NO_3^-	Measured/modeled	1982–2001	Annual	US	County
USEPA Clean Air Status and Trends Network (CASTNET)	www.epa.gov/castnet/index.html	Dry deposition of inorganic N species	Measured/modeled	1986–2008	Daily	US	Collection site
Community Multiscale Air Quality (CMAQ) Modeling System	www.cmascenter.org/index.cfm	Total deposition of inorganic N species	Modeled	2002–2006, 2020	Hourly	US	4, 12, or 36 km grid
USDA Census of Agriculture	www.agcensus.usda.gov/	Fertilizer, livestock, crop harvest	Measured	1840–2007	Annual	US	State or county
Nitrogen Deposition onto the United States and Western Europe	http://daac.ornl.gov/CLIMATE/guides/nitrogen_deposition.html	Total deposition of inorganic N species	Measured/modeled	1978–1994	Annual	US	0.5 degree grid cells
Global Maps of Atmospheric Nitrogen Deposition, 1860, 1993, 2050	http://daac.ornl.gov/CLIMATE/guides/global_N_deposition_maps.html	Total deposition of inorganic N and NO_y	Modeled	1860, 1993, 2050	Annual	Global	5 × 3.75 degree cells
National Nutrient and Soil Carbon Loss Database	www.brc.tamus.edu/data-resources/national-nutrient-soil--carbon-losses	Agricultural N-fixation, inorganic and manure N fertilizers, N loss	Measured/modeled	1997	Subannual	US	Unique resource unit
Measured Annual Nutrient loads form Agricultural Environments (MANAGE)	www.ars.usda.gov/Research/docs.htm?docid=11079	Measured nutrient loads for agricultural and forest land	Measured	1952–2003	Annual	US	Farm field

continued

WebTable 1. – *continued*

Name	Link	Description	Modeled or measured?	Temporal extent	Temporal resolution	Spatial extent	Spatial resolution
US Environmental Protection Agency National Emissions Inventory	www.epa.gov/ttnchie1/trends/	Emissions of NH_3 and NO_x	Measured	1900–2008	Annual	US	US
USGS NAQWA SPARROW Model	http://water.usgs.gov/nawqa/sparrow/	N loading values	Measured/ modeled	1992/2002	Annual	US	Watershed segments
USGS attributes for NHDPlus catchments for the conterminous United States	http://water.usgs.gov/nawqa/ modeling/nhdplusattributes.html	N loading values	Measured/ modeled	2002	Annual	US	Watershed segments
Human Contributions to Terrestrial Nitrogen Flux	www.jstor.org/stable/1312895	N input and flux in the US	Measured/modeled		1990–1993	Annual	HUC-2
Reactive Nitrogen and the World: 200 Years of Change	www.bioone.org/doi/abs/10.1579/ 0044-7447-31.2.64	N input to regions of the world	Measured	1860–2050	Annual	Continental	Continental
Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050	www.agu.org/pubs/crossref/2009/ 2009GB003576.shtml	Agricultural N inputs to the world	Measured/ modeled	1970–2050	Annual	Continental	Continental
Nitrogen Use in the United States from 1961–2000 and Potential Future Trends	http://pinnacle.allenpress.com/doi/ pdf/10.1579/0044-7447-31.2.88	N flows in the US	Measured/ modeled	1961–1997	Annual	US	US
Other available resources							
The Net Anthropogenic Nitrogen Inputs (NANI)	www.eeb.cornell.edu/biogeo/nanc/ nani/nani.htm	Anthropogenic N	Measured/ modeled	1987–1997	Annual	US	Watershed Toolbox
Nutrient Use Geographic Information System (NuGIS) for the US	www.ipni.net/NuGIS	GIS-based tool for a national N balance	Modeled	1987–2007	Annual	US	HUC-8
USEPA Watershed Deposition Tool	www.epa.gov/AMD/EcoExposure/ depositionMapping.html	Tool to estimate N deposition using CMAQ output	Modeled	2002–2006, 2020	Seasonal/ annual	US	4, 12, or 36 km grid
National Geochemical Survey Database	http://tin.er.usgs.gov/geochem/	N in soil and stream sediment samples	Measured	1967–2007	--	US	Sample point
CENTURY Soil Organic Matter Model	www.nrel.colostate.edu/projects/ century5/	Model of plant and soil N dynamics	Modeled	--	Monthly	Global	Biome
Estimated anthropogenic nitrogen and phosphorus inputs to the land surface of the conterminous United States–1992, 1997, and 2002	http://pubs.er.usgs.gov/publication/ sir20125241	Net input of anthropogenic N inputs to the US	Both	1992, 1997, 2002	Annual	US	County and watershed

WebTable 2. Pairing of Level I ecoregions (www.epa.gov/wed/pages/ecoregions/na_eco.htm) with ecosystem types described in Cleveland *et al*. (1999) for estimates of non-cultivated biological N fixation (BNF)

Level I ecoregion	Cleveland et al. (1999) ecosystem type	BNF rate (kg N ha^{-1} yr^{-1}) 5%	15%	25%
North American Desert	Desert	4.84	7.81	10.78
Mediterranean California	Mediterranean Shrubland	1.52	2.51	3.51
Tropical Wet Forest	Tropical Evergreen Forest	14.73	25.40	36.07
Temperate Sierras	Temperate Forests	6.59	16.04	26.58
Southern Semi-Arid Highlands	Arid Shrubland	9.47	22.04	33.93
Great Plains	Tall/Medium/Short Grassland	2.35	2.70	3.05
Eastern Temperate Forest	Temperate Forests	6.59	16.04	26.58
Marine West Coast Forest	Temperate Forests	6.59	16.04	26.58
Northwestern Forested Mountains	Temperate Forests	6.59	16.04	26.58
Northern Forests	Temperate Forests	6.59	16.04	26.58

Notes: Subheadings of 5%, 15%, and 25% refer to percent coverage of N-fixing plant species.

WebTable 3. Comparison between best available estimates of N inputs to the US (Tables 1 and 2) and global estimates of N input to land surfaces for the 1990s–2000s

N source	*US (Tg N yr^{-1})*	*Global (Tg N yr^{-1})*	*US contribution (%)*
New human-mediated N			
Synthetic fertilizer	10.9	100.0[a]	11
Agricultural BNF	7.7	31.5[a]	24
Non-fertilizer industrial	4.4	28.5[b]	15
Atmospheric deposition	3.9	31.2[c]	13
Total:	**26.9**	**184.5**	**15**
Recycled human-mediated N			
Atmospheric deposition	3.0	52.6[a]	6
Confined feedlot manure	1.2	17.0[c]	7
Wastewater	0.8	6.0[d]	13
Total recycled N:	**5.0**	**75.6**	**7**
New background N			
Non-cultivated BNF – pre-European	8.1	195.0[e]	4
Non-cultivated BNF – contemporary	3.6	195.0[e]	2
Atmospheric deposition	<0.1	5.4[a]	<2

Notes: [a]Galloway *et al.* (2004); [b]FAO (2008); [c]Liu *et al.* (2010); [d]Van Drecht *et al.* (2009); [e]Cleveland *et al.* (1999). BNF = biological N fixation.

WebReferences

Boring LR, Swank WT, Waide JB, *et al*. 1988. Sources, fates, and impacts of nitrogen inputs to terrestrial ecosystems: review and synthesis. *Biogeochemistry* **6**: 119–59.

Bouwman AF, Van Drecht G, and Van der Hoek KW. 2005. Global and regional surface nitrogen balances in intensive agricultural production systems for the period 1970–2030. *Pedosphere* **15**: 137–55.

Bouwman AF, Beusen AWH, and Billen G. 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050. *Global Biogeochem Cy* **23**; doi:10.1029/2009gb003576.

Cleveland CC, Townsend AR, Schimel DS, *et al*. 1999. Global patterns of terrestrial biological nitrogen (N_2) fixation in natural ecosystems. *Global Biogeochem Cy* **13**: 623–45.

Dentener FJ. 2006. Global maps of atmospheric nitrogen deposition, 1860, 1993, and 2050. http://daac.ornl.gov/CLIMATE/guides/global_N_deposition_maps.html. Viewed 22 Dec 2010.

FAO (Food and Agriculture Organization of the United Nations). 2011. Fertilizer use statistics for the Food and Agriculture Organization of the United Nations. www.fao.org/ag/agl/fertistat/index_en.htm. Viewed 30 Sep 2011.

Galloway JN, Dentener FJ, Capone DG, *et al*. 2004. Nitrogen cycles: past, present, and future. *Biogeochemistry* **70**: 153–226.

Han HJ and Allan JD. 2008. Estimation of nitrogen inputs to catchments: comparison of methods and consequences for riverine export prediction. *Biogeochemistry* **91**: 177–99.

Herridge DF, Peoples MB, and Boddey RM. 2008. Global inputs of biological nitrogen fixation in agricultural systems. *Plant Soil* **311**: 1–18.

Holland EA, Braswell BH, Sulzman J, *et al*. 2005. Nitrogen deposition onto the United States and Western Europe: synthesis of observations and models. *Ecol Appl* **15**: 38–57.

Howarth RW, Boyer EW, Pabich WJ, *et al*. 2002. Nitrogen use in the United States from 1961–2000 and potential future trends. *Ambio* **31**: 88–96.

IFA (International Fertilizer Association). 2011. The International Fertilizer Association: international data on fertilizer consumption, exports, imports and production. www.fertilizer.org/ifa/ifadata. Viewed 30 Sep 2011.

Jordan TE and Weller DE. 1996. Human contributions to terrestrial nitrogen flux. *BioScience* **46**: 655–64.

Kellogg RL, Lander CH, Moffitt DC, *et al*. 2000. Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: spatial and temporal trends for the United States. Washington, DC: US Department of Agriculture. nps00-0579.

Liu JG, You LZ, Amini M, *et al*. 2010. A high-resolution assessment on global nitrogen flows in cropland. *P Natl Acad Sci USA* **107**: 8035–40.

Liu Y, Wu L, Baddeley JA, *et al*. 2011. Models of biological nitrogen fixation of legumes. A review. *Agron Sustain Dev* **31**: 155–72.

Neff JC, Holland EA, Dentener FJ, *et al*. 2002. The origin, composition and rates of organic nitrogen deposition: a missing piece of the nitrogen cycle? *Biogeochemistry* **57**: 99–136.

Potter SR, Andrews S, Atwood JD, *et al*. 2006. Model simulation of soil loss, nutrient loss, and change in soil organic carbon associated with crop production. Washington, DC: US Department of Agriculture.

Ruddy BC, Lorenz DL, and Mueller DK. 2006. County-level estimates of nutrient inputs to the land surface of the conterminous United States, 1982–2001. Reston, VA: US Geological Survey. NAQWA Scientific Investigations Report 2006–501.

SAB (Science Advisory Board to the US Environmental Protection Agency). 2011. Reactive nitrogen in the United States; an analysis of inputs, flows, consequences, and management options. Washington, DC: US Environmental Protection Agency.

Seaber PR, Kapinos FP, and Knapp GL. 1987. Hydrologic unit maps. Reston, VA: US Geological Survey. Water-Supply Paper 2294.

Smil V. 1999. Nitrogen in crop production: an account of global flows. *Global Biogeochem Cy* **13**: 647–62.

Stanton TL and Whittier J. 2006. Urea and NPN for cattle and sheep. Fort Collins, CO: Colorado State University Extension. Livestock Series Management Fact Sheet No 1.608.

USDA (US Department of Agriculture). 2011. The census of agriculture. www.agcensus.usda.gov/. Viewed 30 Mar 2011.

US EPA (US Environmental Protection Agency). 2010. Watershed deposition tool. www.epa.gov/AMD/EcoExposure/depositionMapping.html. Viewed 27 Mar 2012.

US EPA (US Environmental Protection Agency). 2011. 2011 Inventory of US greenhouse gas emissions and sinks: 1990–2009. Washington, DC: US EPA.

US EPA (US Environmental Protection Agency). 2012. Septic (onsite) systems. http://cfpub.epa.gov/owm/septic/index.cfm. Viewed 22 Feb 2012.

Van Drecht G, Bouwman AF, Harrison J, *et al*. 2009. Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050. *Global Biogeochem Cy* **23**; doi:10.1029/2009GB003458.

