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1. Introduction

This document describes software tools for the calculation of NANI (Net Anthropogenic Nitrogen Inputs) and NAPI (Net Anthropogenic Nitrogen Inputs). Hong et al. (2013) and version 3 of the documentation provided a description and guide to running version 3 of NANI calculator toolbox. This version still focusses primarily on NANI but also describes the additional tools added to estimate NAPI. Detailed descriptions of NANI and its application have been given in Howarth et al. (1996, 2006, 2012) and Swaney et al (2012). NANI estimates from the Toolbox have been used in several other studies as well, including Sprague and Gronberg (2012), Costello et al. (2015), Sinha and Michalak (2016). An introduction to the NANI calculator toolbox and documentation of version 1 and 2 of NANI toolbox can be found in Hong et al. (2011, 2012) and on the web (http://www.eeb.cornell.edu/biogeo/nanc/nani/NANI_NAPI_Calculator_Toolbox_Version_3.1_Documentation.docx).

Briefly, NANI estimates the human-controlled nitrogen inputs to a watershed and has been shown to be a good predictor of riverine nitrogen export across watersheds of the U.S., Europe, and Asia on a large scale, multiyear average basis. It is typically calculated as the sum of four major components: atmospheric N deposition, fertilizer N application, agricultural N fixation, and N in net food and feed imports. The net food and feed imports in turn are composed of crop and livestock N production, representing negative fluxes removing N from watersheds, and livestock and human N consumption, positive fluxes adding N to watersheds. NANI is detailed enough to incorporate available data on individual crops, livestock, and people into a mass balance approach (Figure 1.1), but simple enough to be calculated with a relatively small set of parameters that are estimated from existing literature.

Since its first introduction, alternative methods for calculating NANI have been proposed by numerous researchers. The NANI calculator toolbox attempts to incorporate various NANI calculations proposed in the earlier literature so that any large-scale assessment may be evaluated without regional discrepancies in methods, assumptions, or data sources.
Alternative NANI calculations may be selected by the user and tested through a sensitivity analysis. Howarth et al. (2006) describe calculations of NANI and its components for the 16 northeastern U.S. watersheds and discuss their underlying assumptions. NANI calculation by the version 1 of NANI toolbox, applied at the national scale as reported in Hong et al. (2011), was very close to that in Howarth et al. (2006), and produced comparable NANI values for the 16 northeastern U.S. watersheds. The second version of the toolbox was developed for application in catchments of the transnational Baltic Sea drainage basin (Hong et al., 2012), where substantial differences in agricultural practices and dietary preferences are exhibited among the European countries whose watersheds comprise the basin, as well as variations and gaps in the data collected by different countries. The changes made in the toolbox (allowing spatial variation of NANI parameters, distributing regional data into smaller spatial units, and accepting auxiliary data sets) did not affect the NANI calculation for the U.S.

Hong et al. (2013) describe additional changes in the NANI calculation for the U.S. watersheds (referred to as version 3, or “v3”) incorporating most of the earlier considerations and suggestions from the previous studies. Several updates and new features were added to the toolbox as well, including porting the NANI GIS tools to ArcGIS Python (ArcPy) and developing a functional form of the NANI toolbox called “NANI function” for repeated calculations of NANI with varying parameters, useful for sensitivity or Monte Carlo analysis. These new features are described below, as well as step-by-step walkthrough of the NANI calculation for the U.S. watersheds as reported in Hong et al. (2013).

Because phosphorus inputs are also useful for watershed and regional studies, the procedures developed for nitrogen were modified to estimate the corresponding phosphorus components, resulting in the net anthropogenic phosphorus input (NAPI) toolbox. NAPI calculations are similar to but simpler than NANI calculations in that they rely on estimates of P content of agricultural commodities, but do not include values for atmospheric deposition, and there is no analog in phosphorus for N fixation, so this term is also absent.

The toolboxes rely on agricultural census data, which vary in format from year to year, requiring slightly different versions of the extraction tools to extract the desired data from census years from the periods 1987-97, 2002-2007, and 2012. When the required data are extracted from the census data, they can be further manipulated using NANI and NAPI calculation tools.

2. Input watershed map

The NANI and NAPI calculator toolboxes calculate NANI or NAPI and their components from a map of watershed(s) that can be read by ESRI’s ArcGIS software. In Hong et al. 2013, we used a total of 106 U.S. watersheds (Figure 2.1), including:

- 16 northeastern US watersheds (Howarth et al. 2006)
- 12 southeastern US watersheds (Schaefer and Alber 2007)
- 18 Lake Michigan watersheds (Han and Allan 2008)
• 18 Western US watersheds (Schaefer et al. 2009)
• 42 Mississippi watersheds (Goolsby et al. 1999)

Note that some Mississippi watersheds are nested (for example, the “Cedar R at Cedar Falls” watershed is part of the “Iowa R at Wapello” watershed). For the nested watersheds, each polygon used in this study represents the net area, instead of the whole watershed area. After running the toolbox, watershed-level NANI and its components were calculated manually.

Figure 1.1. Overview of NANI /NAPI and their components (modified from Hong et al. 2011). Only NANI includes terms for atmospheric deposition and crop fixation.

Alternatively, each component of NANI or NAPI may be extracted for each county or parish in the region specified, and the results used as-is or aggregated by the user to meet their particular needs.
3. Updates on NANI GIS tools

The NANI GIS tools calculate the proportions of various regions (political or gridded) in which data are collected that fall into areas of interest such as watersheds. In versions 1 and 2 of the toolbox, the NANI GIS tools were implemented in ArcGIS using VBA (Visual Basic for Applications). Starting from ArcGIS 10, installation of VBA requires a license code, and ArcGIS 10 will be the last version with VBA support. As an alternative, we ported the NANI GIS tools to ArcGIS Python (ArcPy). In the following sections we show how to set up the new NANI GIS tools within ArcGIS, and provide walkthrough for running “Calculate Map Proportions” tool for calculating county and grid proportions falling into each of the 106 U.S. watersheds. Another NANI GIS tool, “Distribute Map Data,” which was implemented in the NANI toolbox, version 2, (applied to Baltic Sea catchments) to distribute regional data into smaller spatial units, was not used in this study, but its use is demonstrated in Appendix A.1. We also developed an Excel VBA version of the same procedure, which requires using a GIS software but not ArcGIS VBA. This procedure allows land use-based allocation of data, instead of area-based; see Hong et al. (2013) for detailed discussion. We describe this procedure in Appendix A.2.

3.1. Setting up NANI GIS tools

To set up the NANI GIS tools running as ArcPy scripts, download the compressed file “NANI_GIS_Tools.zip” and unzip it. Start ArcGIS, open ArcToolbox panel (click on the Toolbox icon), right-click on “ArcToolbox,” and select “Add Toolbox...” (Figure 3.1.1). Locate the toolbox file “NANI GIS Tools.tbx” from the unzipped folder, and a new toolbox “NANI GIS Tools” will be added to the ArcToolbox panel (Figure 3.1.2). Double-clicking “Calculate Map Proportions” and “Distribute Map Data” will open the user interface for the corresponding tools (Section 3.2 and Appendix A.1, respectively).
Figure 3.1.1. Adding NANI GIS tools to ArcToolbox.

Figure 3.1.2. NANI GIS tools added to ArcToolbox.
3.2. Calculating county proportions

The “Calculate Map Proportions” tool (Figure 3.2.1) can be used to calculate the proportions of the U.S. counties falling into each of the 106 watersheds. The input maps needed for this analysis are the watershed map “US_Counties.shp” and the U.S. county map “US_Watersheds_V3.shp” available on the toolbox webpage. The “Calculate Map Proportions” tool (Section 3.1) can be opened and specified as shown below:

![Figure 3.2.1. Calculating county proportions.](image)

Note that, unlike the VBA-based tools, the user does not have to add the input maps to ArcMap to select the input map names. Specify the names of the watershed and county maps (“US_Watersheds_V3.shp” and “US_Counties.shp,” respectively) and their unique identifiers (“W_CODE” and “FIPS,” respectively). Since the extraction tools require the county proportion table to have state and county names, “STATE” and “COUNTY” should be selected as additional output field names (Figure 3.2.1). In this example, the output table and map names are specified as “Cnty_Prop.txt” and “Cnty_Prop.shp,” respectively. More details of tool specification are in the documentation of version 1 ([http://www.eeb.cornell.edu/biogeo/nanc/nani/NANI_Calculator_Toolbox_Documentation.pdf](http://www.eeb.cornell.edu/biogeo/nanc/nani/NANI_Calculator_Toolbox_Documentation.pdf))
Running the tool generates a text file “Cnty_Prop.txt” used as inputs to the extraction and accounting tools. While the tool is running, its progress is displayed in a separate window (Figure 3.2.2), which also reports any errors encountered during the execution.

![Figure 3.2.2. Tool execution progress window for “Calculate Map Proportions” tool.](image)

3.3. Calculating grid proportions

The proportions of CMAQ (Community Multiscale Air Quality) grid cells falling into each of the 106 watersheds were calculated using the “Calculate Map Proportions” tool (Figure 3.3.1). The input maps needed for this analysis are the watershed map “US_Counties.shp” and the CMAQ grid map “grid_pg_all_years_prj.shp” available on the toolbox webpage. The “Calculate Map Proportions” tool (Section 3.1) are opened and specified as shown in Figure 3.3.1. Running the tool generates a text file “Grid_Prop.txt” used as inputs to the extraction and accounting tools.
As noted earlier, the particular tool required to extract data depends on the census year because the data format of the agricultural census has changed over time. Separate tools are used for the 1997 agricultural census (reporting years 1987 through 1997), the 2007 census (data for 2002-2007), and the 2012 census (data for 2007 and 2012). As of this writing, the 2017 ag census data are not fully available, so it remains to be seen whether a new extraction tool will be required for this dataset. No independent tools are needed for extracting needed to estimate NAPI, because both NANI and NAPI require the same basic crop and livestock data; NANI and NAPI calculations are handled separately after basic data are extracted, so the NANI and NAPI calculator tools are separate. We did create separate NANI and NAPI extraction tools for fertilizer.

4.1. Extracting crop data

Crop data in 1987, 1992, and 1997 can be extracted from the 1997 Agricultural Census using the NANI extraction tool “NANI_Extraction_Tool_V3_Ag_Census_Crops_97_92_87.xlsm” (Figure 4.1.1). Before running the extraction tool, the county proportion table “Cnty_Prop.txt”
generated in Section 3.2 is imported as an input worksheet. Two more items “nonalfalfa hay harvested quantity” (Row 39) and “peanuts for nuts harvested quantity” (Row 47) are listed, in addition to those extracted in version 1 of the extraction tool, to be used by the accounting tool. (Changes made from version 1 of the extraction tool are noted in highlighted cells.) Clicking the “Extract” button generates the output “Ag_Census_Crops_97_92_87” worksheet, which is used as input to the accounting tool.

Figure 4.1.1. Extracting crop data from the 1997 agricultural census for years 1987, 1992, and 1997.

Crop data in 2002 and 2007 are extracted from the 2007 Agricultural Census using the NANI extraction tool “NANI_Extraction_Tool_V3_Ag_Census_Crops_07_02.xlsm” (Figure 4.1.2). The Agricultural Census data for these years were obtained from Desktop Data Query Tool version 1.02 (Figure 4.1.2). The tool can be downloaded from https://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Desktop_Application/index.asp. Before running the extraction tool, the county proportion table “Cnty_Prop.txt” generated in Section 3.2 is imported as an input worksheet. Two more items “nonalfalfa hay harvested quantity” (Row 39) and “peanuts for nuts harvested quantity” (Row 47) are listed, in addition to those extracted in version 1 of the extraction tool, to be used by the accounting tool. (Changes made from version 1 of the extraction tool are noted in highlighted cells.) Clicking the “Extract” button generates the output “Ag_Census_Crops_07_02” worksheet, which is used as input to the accounting tool. For the 2012 Agricultural Census (2012 and 2007), data are extracted using the NANI extraction tool “NANI_Extraction_Tool_V3.1_Ag_Census_Animals_12_07.xlsm”. The setup is essentially identical to that from the 2007 census, but the number of data worksheets is 55, due to changes in reporting format (Figure 4.1.3). The Agricultural Census data for this year was obtained from Desktop Data Query Tool version 2.0. The tool can be downloaded from https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Desktop_Application/
(Note that Data Query Tool version 2.0 does not provide Ag Census data for 2002. The 2002 data can only be obtained using version 1.02.)

Figure 4.1.2. Extracting crop data from the 2007 agricultural census for years 2002 and 2007.

Figure 4.1.3. Extracting crop data from the 2012 agricultural census for years 2007 and 2012.
4.2. Extracting livestock data

Livestock data in 1987, 1992, and 1997 are extracted from the 1997 Agricultural Census using the NANI extraction tool “NANI_Extraction_Tool_V3_Ag_Census_Animals_97_92_87.xlsm” (Figure 4.2.1). Before running the extraction tool, the county proportion table “Cnty_Prop.txt” generated in Section 3.2 is imported as an input worksheet. Two more items “expected beef and dairy calves” (Row 63) and “estimated beef and dairy calves” (Row 64) are listed, in addition to those extracted in version 1 of the extraction tool, to be used by the accounting tool. (Changes made from version 1 of the extraction tool are noted in highlighted cells.) Clicking the “Extract” button generates the output “Ag_Census_Animals_97_92_87” worksheet, which is used as input to the accounting tool.

Figure 4.2.1. Extracting livestock data from the 1997 agricultural census for years 1987, 1992, and 1997.

Livestock data from the 2007 Agricultural Census (2002 and 2007) are extracted using the NANI extraction tool “NANI_Extraction_Tool_V3_Ag_Census_Animals_07_02.xlsm” (Figure 4.2.2). Before running the extraction tool, the county proportion table “Cnty_Prop.txt” generated in Section 3.2 is imported as an input worksheet. Two more items “expected beef and dairy calves” (Row 63) and “estimated beef and dairy calves” (Row 64) are listed, in addition to those extracted in version 1 of the extraction tool, to be used by the accounting tool. (Changes made from version 1 of the extraction tool are noted in highlighted cells.) Clicking the “Extract” button generates the output “Ag_Census_Animals_07_02” worksheet, which is used as input to the accounting tool.
Data from the 2012 census (2012 and 2007) are extracted from Agricultural Census using the NANI extraction tool “NANI_Extraction_Tool_V3.1_Ag_Census_Animals_12_07.xlsm”. As with the crop extraction tool, the format is similar to extracting from the 2007 census, but there are 55 data worksheets instead of 56, due to changes in reporting formats, etc.

Figure 4.2.2. Extracting livestock data from the 2007 agricultural census for years 2002 and 2007.
Figure 4.2.3. Extracting livestock data from the 2012 agricultural census for years 2007 and 2012.

4.3. Extracting Census data

Population in 1990, 2000 and 2010 are extracted from the US Census using the NANI extraction tool “NANI_Extraction_Tool_V3.1_Census.xlsm” (Figure 4.3.1). Before running the extraction tool, the county proportion table “Cnty_Prop.txt” generated in Section 3.2 is imported as an input worksheet. There have been no changes in the list of extraction items from earlier versions of the extraction tool. Clicking the “Extract” button creates the output “Census” worksheet, which is used as input to the accounting tool.

Figure 4.3.1. Extracting Census data from the US censuses of 1990, 2000 and 2010.

4.4. Extracting fertilizer data

Fertilizer data can be extracted from USGS and IPNI nutrient input estimates (previously obtained from Ruddy et al. 2006; now available in Gronberg and Spahr (2012) for the years through 2006) using the NANNI extraction tool “NANI_Extraction_Tool_V3.1_Fertilizer.xlsm” (Figure 4.4.1), and the NAPI extraction tool “NAPI_Extraction_Tool_V3.1_Fertilizer.xlsm” (Figure 4.4.2). For 2012, we obtained estimates following the methodology of Gronberg and Spahr, using state level data from AAPFCO, either published in their annual reports, or available from the IPNI NUGIS database (IPNI, 2012), and incorporated these into the tool database. Before running the extraction tool, the county proportion table “Cnty_Prop.txt” generated in Section 3.2 is imported as an input worksheet. There have been no changes in the list of extraction
categories from earlier versions of the extraction tool; agricultural fertilizer, non-agricultural fertilizer, and total fertilizer use are available. Clicking the “Extract” button generates the output “USGS” worksheet, which is used as input to the accounting tool.

Details of the fertilizer calculations and a comparison with updated county-level estimates from Brakebill and Gronberg (2017) are shown in Appendix A.3

Figure 4.4.1. Extracting N fertilizer data from USGS and other nutrient input estimates using the NANI fertilizer extraction tool.
4.5. Extracting N deposition

N deposition is extracted from CMAQ deposition estimates (Schwede et al. 2009) using the NANI extraction tool “NANI_Extraction_Tool_V3_CMAQ.xlsm” (Figure 4.5.1). Before running the extraction tool, the grid proportion table “Grid_Prop.txt” generated in Section 3.3 is imported as an input worksheet. There have been no changes in the list of extraction items since version 1 of the extraction tool. Clicking the “Extract” button generates the output “CMAQ” worksheet, used as input to the accounting tool.
5. NANI and NAPI accounting tools

NANI, NAPI, and their components are calculated from proportion tables generated in Section 3 and various datasets extracted in Section 4. NANI calculations use the NANI accounting tool “NANI_Accounting_Tool_V3.1.xlsm”; NAPI calculations use the NAPI accounting tool “NAPI_Accounting_Tool_V3.1.xlsm”. Opening the appropriate accounting tool, the following worksheets can be imported as inputs:

- “Ag_Census_Crops_12_07”: crop data extracted from the 2012 Agricultural Census for 2007 and 2012 (Section 4.1)
- “Ag_Census_Crops_07_02”: crop data extracted from the 2007 Agricultural Census for 2002 and 2007 (Section 4.1)
- “Ag_Census_Crops_97_92_87”: crop data extracted from the 1997 Agricultural Census for 1987, 1992, and 1997 (Section 4.1)
- “Ag_Census_Animals_12_07”: livestock data extracted from the 2012 Agricultural Census for 2007 and 2012 (Section 4.2)
- “Ag_Census_Animals_07_02”: livestock data extracted from the 2007 Agricultural Census for 2002 and 2007 (Section 4.2)
- “Ag_Census_Animals_97_92_87”: livestock data extracted from the 1997 Agricultural Census for 1987, 1992, and 1997 (Section 4.2)
- “Census”: population extracted from Census for 1990 and 2000 (Section 4.3)
- “USGS”: fertilizer estimates extracted from USGS nutrient input estimates (Section 4.4)
- “CMAQ”: N deposition extracted from CMAQ deposition estimates (Section 4.5) (NANI only)
The following sections provide step-by-step walkthrough of NANI calculations performed using the NANI accounting tool. The corresponding calculations for NAPI are performed using the NAPI accounting tool, except that there are no atmospheric deposition or fixation components for NAPI.

5.1. N in net food and feed imports

5.1.1. Crop N, P production

Crop N production is calculated in the “Crops” worksheet of the NANI accounting tool (Figure 5.1.1.1). Changes made in the crop calculation from version 1 include: (1) corn protein content (9.5% protein = 1.5% N) following David et al. (2010), (2) 50% loss of pasture production assumed following the “take half-leave half rule” (NRCS guideline for pasture management at http://www.nrcs.usda.gov/), and (3) addition of peanuts as a crop of regional importance. Details of these changes are discussed in Hong et al. (2013) and noted in highlighted cells of the “Crops” worksheet (Figure 5.1.1.1). Clicking the “Crops” button generates the output crop N production from Column O of the “Crops” worksheet.

5.1.2. Livestock N, P consumption

Livestock N consumption is calculated in the “Animals” worksheet of the NANI accounting tool (Figure 5.1.2.1). Since version 3 of the calculation, the livestock list from Han and Allan (2008) has been used instead of that from Boyer et al. (2002), as noted in the highlighted cells of the “Animals” worksheet. Han and Allan (2008) did not include “goat,” so its parameters were estimated from Boyer et al. (2002). Clicking the “Animals” button generates the output livestock N consumption from Column O of the “Animals” worksheet. Although livestock N production is also reported in this worksheet based on the difference method, in version 3 the livestock N production is estimated based on the animal products and calculated in the “Animal_N_Prd” worksheet (Section 5.1.3; see Hong et al. 2013 for detailed discussion).
Figure 5.1.1.1. Calculating crop N production.

Figure 5.1.2.1. Calculating livestock N consumption.
5.1.3. Livestock N, P production

In version 3 of the calculation, livestock N production is calculated in the “Animal_N_Prd” worksheet of the NANI accounting tool (Figure 5.1.3.1) by taking the product-based approach instead of the difference method, considering its potential utility in future scenario analyses (e.g., dietary scenarios related to egg and milk consumption) (Hong et al. 2013). N in the edible portion of pigs and chickens was estimated from Heinz and Hautzinger (2007), and those from all other products were from Han et al. (2009). Changes made in the livestock calculation from version 1 are noted in highlighted cells of the “Animal_N_Prd” worksheet (Figure 5.1.3.1). Clicking the “Animal N Products” button generates the output livestock N production from Column K of the “Animal_N_Prd” worksheet.

Figure 5.1.3.1. Calculating livestock N production.

5.1.4. Human N, P consumption

Human N consumption is calculated in the “People” worksheet of the NANI accounting tool (Figure 5.1.4.1). Human N intake rate was estimated at 6.21 kg-N/person/yr using U.S. statistics on daily protein consumption, as noted in the highlighted cell of the “People” worksheet (Figure 5.1.4.1). Clicking the “People” button generates the output human N consumption from Column I of the “People” worksheet.

The N in net food and feed imports is calculated in the “Food_Feed_N” worksheet of the NANI accounting tool (Figure 5.1.4.2) as human N consumption (Section 5.1.4) + livestock N consumption (Section 5.1.2) – livestock N production (Section 5.1.3) – crop N production (Section 5.1.1). The crop N production may be further disaggregated into crop N production for human food and crop N production for livestock feed, each of which is reported as output in
the “Crop” worksheet (Figure 5.1.1.1). Since version 3 NANI calculation uses livestock N production based on products, the worksheet name containing relevant information (“Animal_N_Prd”) is specified in the “Food_Feed_N” worksheet, as noted in the highlighted cell (Figure 5.1.4.2). Clicking the “Net Food and Feed Imports” button generates the output N in net food and feed imports from Column I of the “Food_Feed_N” worksheet.

5.2. Agricultural N fixation

Version 3 of the NANI calculation uses yield-based agricultural N fixation (Han and Allan 2008) instead of area-based (Boyer et al. 2002). The yield-based approach, as described in detail in Meisinger and Randall (1991), estimates crop N fixation as the product of yield estimated from harvested quantities and the percentage of this N that can be attributed to fixation:

\[ F = H \times c \times \frac{D}{100} \times \frac{N}{100} \times \frac{P}{100} \times (1+b) \]

(5.2.1)

where: 
- \( F \) = crop N fixation (kg-N)
- \( H \) = harvested quantities as reported in Agricultural Census
- \( c \) = conversion factor to kg
- \( D \) = percent dry matter
- \( N \) = percent N in dry matter
- \( P \) = percent of harvested N that can be attributed to fixation
- \( b \) = nonharvested N as the fraction of harvested N
When the yield-based approach is applied (as noted in the highlighted cells of the “Ag_N_Fix” worksheet for soybeans, alfalfa hay, nonalfalfa hay, and peanuts; Figure 5.6.1), item names for the corresponding harvested quantities (“H” in Equation 5.2.1) are specified in Column B, conversion factors to kilograms (“c” in Equation 5.2.1) in Column E, and the rest of coefficients in Column F. Nonalfalfa hay areas were assumed to have 25% leguminous plants such as clovers (NRCS 2007; Campbell and Collar 1993), and this fraction is also incorporated in Column F (Cell F4). Detailed discussion on the yield-based approach and its parameter estimation can be found in Hong et al. (2013). When the area-based approach is applied (for cropland pasture and snap beans, since the Agricultural Census does not report harvested quantities for them), item names for crop areas are specified in Column B, conversion factors to square kilometers in Column E, and area-based fixation rates (kg-N/km²/yr) in Column F. Clicking the “Agricultural N Fixation” button generates the output agricultural N fixation from Column K of the “Ag_N_Fix” worksheet.
5.3. Fertilizer N, P application

Fertilizer N application is calculated in the “Fert_N_App” worksheet of the NANI accounting tool (Figure 5.3.1). There have been no changes in the “Fert_N_App” worksheet since version 1 of the accounting tool; the “Fert_P_App” worksheet in the NAPI accounting tool is modeled on the corresponding Fert_N_App worksheet. Clicking the “Fertilizer N Application” button generates the output fertilizer N application from Column J of the “Fert_N_App” worksheet. The corresponding button in the Fert_P_App serves the same function.
5.4. Atmospheric N deposition

Atmospheric (oxidized) N deposition is calculated in the “Atm_N_Dep” worksheet of the NANI accounting tool (Figure 5.4.1). There has been no change in the “Atm_N_Dep” worksheet since version 1 of the accounting tool. Clicking the “Atmospheric N Deposition” button generates the output atmospheric N deposition from Column J of the “Atm_N_Dep” worksheet. There are no corresponding calculations for P deposition, which is assumed to be negligible.

![Atmospheric N Deposition](image)

Figure 5.4.1. Calculating atmospheric N deposition.

5.5. N, P in non-food crop export

N in non-food crop export is calculated in the “Non_Food_Crops” worksheet of the NANI accounting tool (Figure 5.5.1). There has been no change in the “Non_Food_Crops” worksheet from version 1 of the accounting tool. Clicking the “Non Food Crops” button generates the output non-food crop N export from Column N of the “Non_Food_Crops” worksheet.
The corresponding calculation for P in non-food crop export is done in the “Non_Food_Crops” worksheet of the NAPI accounting tool (Figure 5.5.1), which as in other modules, is modelled on the corresponding N module in the NANI accounting tool. Clicking the “Non Food Crops” button generates the output non-food crop P export from Column N of the “Non_Food_Crops” worksheet.

5.6. NANI and NAPI

NANI is calculated in the “NANI” worksheet of the NANI accounting tool (Figure 5.6.1) as: atmospheric (oxidized) N deposition (Section 5.4) + fertilizer N application (Section 5.3) + agricultural N fixation (Section 5.2) + N in net food and feed imports (Section 5.1) – N in non-food crop export (Section 5.5). There have been no changes in the “NANI” worksheet since version 1 of the accounting tool. Clicking the “NANI” button generates the output NANI from Column I of the “NANI” worksheet.

The corresponding value for NAPI is calculated in the “NAPI” worksheet of the NAPI accounting tool (Figure 5.6.1) as: fertilizer P application (Section 5.3) + P in net food and feed imports (Section 5.1) – P in non-food crop export (Section 5.5). Clicking the “NAPI” button creates the output NAPI from Column I of the “NAPI” worksheet.

6. Other features of the NANI/NAPI accounting tools

6.1. Calculating NANI/NAPI all at once

In version 3 of the NANI calculator toolbox, a new worksheet “All_At_Once” is added (Figure 6.1.1), where NANI and its components can be calculated all at once by clicking “NANI All At Once” button. This option remains in the current version of the NANI and NAPI calculator toolboxes. For example, to calculate NANI, the user should provide the name of the worksheet in which NANI is calculated (“NANI” shown in Figure 5.6.1), and all other worksheets needed for
NANI calculation are located by the toolbox. For example, the “Crops” worksheet name is specified in the “Food_Feed_N” worksheet (Figure 5.1.4.2), which in turn is specified in the “NANI” worksheet (Figure 5.6.1).

6.2. Tabulating NANI/NAPI variables

The NANI and NAPI calculator toolboxes can produce many outputs, not all of which are used in the calculation of NANI or NAPI. It can be time-consuming for the user to locate the desired outputs reported in various worksheets of the toolbox and rearrange them in a format convenient for the user. The “NANI_Var” worksheet of the NANI calculator toolbox can be used to extract the NANI-related outputs and organize them in a tabular format (Figure 6.2.1). Specify in Column C whether each variable should be reported or not, and provide in Cell E2 the name of the worksheet where NANI is calculated (“NANI” shown in Figure 5.6.1); all other worksheets needed for NANI calculation are located by the toolbox. For example, the “Crops” worksheet name is specified in the “Food_Feed_N” worksheet (Figure 5.1.4.2), which in turn is

![NANI.xls](image-url)

Figure 5.6.1. Calculating NANI.
Figure 6.1.1. Calculating NANI and its components all at once.

specified in the “NANI” worksheet (Figure 5.6.1). If a tabular format is desired, specify “output format” as “Column.” Specifying the output format as “Row” produces individual output values reported in each row. (The “Row” formatted output is used as input to the NANI function, as described in Section 7.) If it is desired to disaggregate the output variables into types (e.g., N production by each crop), specify “disaggregate by types” as “Yes.” Clicking the “Report NANI Variables” button produces the output NANI variables from Column H of the “NANI_Var” worksheet.
6.3. Tabulating NANI and NAPI parameters

As with tabulating NANI-related variables (Section 6.2), NANI parameters can be tabulated in the “NANI_Par” worksheet of the NANI calculator toolbox (Figure 6.3.1). Again, specify in Column C whether each parameter should be reported or not, and provide in Cell E2 the name of the worksheet where NANI is calculated (“NANI” shown in Figure 5.6.1). If a tabular format is desired, specify “output format” as “Column.” Specifying the output format as “Row” produces individual parameter values reported in each row. (The “Row” formatted output is used as input to the NANI function, as described in Section 7.) If it is desired to report constant parameters (i.e., with no spatial variation across watersheds) for each watershed, specify “repeat constant parameter in row format” as “Yes.” If it is specified as “No,” spatially constant parameters will be reported only once representing all watersheds. Clicking the “Report NANI Parameters” button produces the output NANI parameters from Column H of the “NANI_Par” worksheet.
7. NANI and NAPI functions

Functional forms of the calculator toolboxes, referred to as the “NANI function” and “NAPI function”, have been developed for the toolbox package (Figure 7.1). The functions are useful for sensitivity or Monte Carlo analyses that involve running the calculations repeatedly using different parameter sets. Unlike the NANI calculator toolbox that includes all the original databases in its package, the NANI function calculates NANI from watershed-based input variables that need to be generated by the toolbox. Different NANI parameters and variables can be specified for each watershed and for each year. The NANI function has smaller package size (less than 2 MB in this study as opposed to > 1 GB) and allows the user to perform repeated NANI calculations quickly. On the other hand, it lacks the flexibility of the NANI calculator toolbox, e.g., changing the list of crops used for the calculation of crop N production.

The NANI function, implemented as a Visual Basic function in an Excel file “NANI_Function.xlsm,” takes two input files, “NANI_Par.csv” that contains a list of NANI parameters (e.g., corn N content) and “NANI_Var.csv” that contains NANI variables (e.g., fattened cattle density). These files can be created by exporting the outputs generated in the “NANI_Par” (Figure 6.3.1) and “NANI_Var” (Figure 6.2.1) worksheets of the NANI calculator toolbox, respectively, as comma-delimited text files. After clicking the “Report NANI
Parameters” and “Report NANI Variables” buttons, respectively, save the outputs in Columns H to L as csv files. These files should be stored in the same folder where the Excel file “NANI_Function.xlsm” is located.

The NANI function accepts a string variable as an input argument and returns NANI or its components as specified by the user. In its simplest form, the user may just call the function without any argument: “=NANI()”, returning NANI calculated using the default NANI parameters and variables as given in the “NANI_Par.csv” and “NANI_Var.csv” files, respectively (Figure 7.1; see Cell C19 of the “Notes_and_Examples” worksheet). An output variable may be specified as an argument, for example: “=NANI(output = NANI_FDFD),” returning N in net food and feed imports instead of NANI. A full list of reserved argument names for NANI parameters and variables can be found in the “List_of_Parameters” and “List_of_Variables” worksheets, respectively. A specific watershed name and/or year number to be returned can also be specified, for example as: “=NANI(output = NANI_FERT | watershed = SAC | year = 2002),” returning fertilizer N application for the watershed “SAC” in the year of 2002. (More than one argument can be specified by linking them with a pipe character, |.) Any NANI parameters and variables can be modified by using operation characters, for example: “=NANI(NANI_NDEP = 150 | NANI_NFIX_CFXR (soybeans) / 2),” returning NANI calculated with the atmospheric N deposition set to 150 kg-N/km²/yr and with the soybean N fixation rate reduced by half of its original value. All the crop type and livestock group names that can be used as arguments of the NANI function can be found in the “List_of_Types” worksheet.

A full description of the NANI function is given in the “Notes_and_Examples” worksheet of the “NANI_Function.xlsm” file (Figure 7.1). The NANI function was used for the sensitivity analysis reported in Hong et al. (2013). Visual Basic example code for using the NANI function in a Monte Carlo analysis is also included in the “NANI_Function.xlsm” file.
This Excel file contains a Visual Basic function "NANI" that accepts a string variable as an input argument and returns NANI or its components as specified by the user.

To use this function as its current form, two input files "NANI_Param.txt" (containing NANI parameters such as wheat N content) and "NANI_Var.txt" (containing NANI variables such as oxidized N deposition) should be stored in the same folder where this Excel file can be found.

The function "NANI" is intended to be used in a spreadsheet-free environment.

However, there is one line of code that uses an Excel-specific command:

```vba
stringPathName = Left(ThisWorkbook.FullName, InStrRev(ThisWorkbook.FullName, ")")
```

which finds the path name of this Excel file (so that it can locate the input text files).

To be used in other platforms, this code should be replaced with other ways of finding the name of the path containing the input files. In its simplest form, the user may just call the function without any argument:

Example of string argument: N/A (no argument)

Result of calling NANI function: 589.5185191

Note that the NANI function is called using the expression "=NANI("") in Cell C19.

Without any argument, NANI will be calculated using the default parameters and variables (stored in the input text files) and a matrix of NANI values with the size of (number of watersheds) x (number of years) will be returned. The NANI value of the first watershed (PEN) in the first year (2007) is reported in Cell C19. In Excel, an array of

Figure 7.1. NANI function.
A. Appendices

A.1. Distributing map data

This section describes the use of the NANI GIS tool “Distribute Map Data,” implemented as an ArcPy script, that was previously an ArcGIS VBA-based tool in version 2 of the NANI calculator toolbox (Hong et al. 2012). We ported the NANI GIS tools to ArcPy because ArcGIS 10 will be the last version with VBA support. Even though the “Distribute Map Data” tool is not used in version 3.1 of the calculation of NANI for the U.S. watersheds, we demonstrate its use for distributing country-based crop production data into extended ISPRA grid cells of corresponding countries. Interested readers may refer to Section 5.3.5 and Figure 5.3.5.B of the documentation of NANI calculator toolbox version 2 for more detailed information (http://www.balticnest.org/download/18.2beb0a011325eb5811a8000153756) and comparing the ArcPy-based user interface (Figure A.1.1) with that of VBA-based tool.

Here, the NANI GIS tool “Distribute Map Data” (Section 3.1) is opened, and the data sum table “CNTR_SUM_BL_RU_Added_Rev_05.csv” (containing country-based crop production values in 1000 tonnes), the country map “11_For_Crop_Distribution_Final_02.shp” for the counties around the Baltic sea catchments, and the extended ISPRA grid “Extended_Crop_Rev_02.shp” used as inputs (refer to version 2 documentation for description of these inputs). All the optional additional field names are selected, except for “Shape_Leng” and “Shape_Area.” Running the tool generates an output shapefile “Crop_Dist.shp” that can subsequently be used as input to other NANI tools. Figure A.1.2 below shows the tool execution progress window for the “Distribute Map Data” tool.
Figure A.1.1. Distributing map data.
A.2. Excel VBA-based “Calculate Map Proportions” tool

The Excel VBA-based “Calculate Map Proportions” tool was developed as an alternative to the corresponding tool based on ArcGIS VBA. Since this procedure requires the user to manually process the input maps using a GIS software, running ArcPy-based NANI GIS tools (Section 3) is generally an easier and more straightforward alternative. However, the Excel VBA-based tool is more flexible in that it provides the user an option of generating a proportion table based on land use, instead of simple areas.

As a demonstration of using the Excel VBA-based tool to calculate the proportions of the U.S. counties falling into each of the 106 watersheds (Section 3.2), Figure A.2.1 shows the shapefile “US_Counties_LU.shp” that is required to be prepared by the user. The user is responsible for creating a field in the map’s attribute table containing correct areas for each data polygon (in this example, “DT_AREA”). Optionally, the user can also create more fields with areas of any land use types (in this example, “DT_AREA_U,” “DT_AREA_F,” and
“DT_AREA_A” containing areas of urban, forest, and agricultural land use types, respectively, calculated from 1992 National Land Cover Data publicly available at http://www.mrlc.gov/ using an ArcToolbox tool “Tabulate Area”). The user should also create a field in the watershed map (in this example, “US_Watersheds_V3.shp” shown in Figure A.2.2) containing correct watershed areas (“WT_AREA”). Land use areas do not need to be calculated in the watershed map. The user then should intersect the data and watershed maps, for example using an ArcToolbox tool “Intersect” (“US_Counties_LU_Interceptor.shp” shown in Figure A.2.3), and create another field containing areas of intersected polygons (“IT_AREA”). Again, the user has the option of adding more fields with areas of the same land use types as created in the data map (in this example, “IT_AREA_U,” “IT_AREA_F,” and “IT_AREA_A,” which correspond to the “DT_AREA_U,” “DT_AREA_F,” and “DT_AREA_A” fields created in the county map “US_Counties_LU.shp”).

Figure A.2.1. An example of U.S. county map prepared by the user.
Figure A.2.2. An example of watershed map prepared by the user.

Figure A.2.3. An example of intersect map prepared by the user.
After these maps are prepared, add their attribute tables (dbf files) to the Excel proportion tool “NANI_GIS_Tool_Excel_Version.xlsm.” The specification of “Map_Prop” tab shown in Figure A.2.4 below corresponds to that of ArcGIS-based tool (Figure 3.2.1), except for the additional (optional) inputs specifying the columns containing the land use areas that can be used when land use-based allocation of data is desired. In this example, “data distribution weight” and “intersect distribution weight” are specified as “DT_AREA_A” and “IT_AREA_A,” respectively, to generate a proportion table based on agricultural land use (“Cnty_Prop_Ag.txt” included in the toolbox package), instead of simple areas. Likewise, specifying them as “DT_AREA_U” and “IT_AREA_U,” respectively, generates a proportion table based on urban use (“Cnty_Prop_Urban.txt”). These proportion tables can be imported into the extraction and accounting tools and used just like the simple area-based proportion tables. Note that when these optional inputs are left blank, the proportion table generated by running this tool (“Cnty_Prop.txt”) is the same as that created from ArcPy-based “Calculate Map Proportions” tool discussed in Section 3.2 (Figure 3.2.1).

Figure A.2.4. Excel VBA-based “Calculate Map Proportions” tool.
A.3. N and P fertilizer calculations and comparisons

County-level fertilizer use is not available from USDA statistics, so previous versions of the toolbox obtained these from other sources:

- version 2.0: 1987-2001 Fertilizer data obtained from Ruddy et al. (2006)
- version 3.0: 1987-2006 Fertilizer data were initially obtained from John W Brakebill, USGS (personal communication). The data for this period were later published by the USGS (Gronberg and Spahr, 2012)

As estimates were unavailable for other years at the time, the following procedure, used by previous researchers, was used in estimating county agricultural fertilizer use. For a given year:

1) Obtain state-level estimates of total fertilizer and agricultural fertilizer usage, county-level agricultural expenditures on fertilizer (US census of agriculture), and county level population (US census of population)

2) Calculate county-level agricultural fertilizer use assuming that the total used in the state is distributed over counties in proportion to expenditures:

\[ f_{ij} = \frac{F_i e_{ij}}{E_i} \]

Where \( f_{ij} \) = the mass of fertilizer (N or P equivalent, kg) consumed in county \( j \) of state \( i \), \( F_i \) is the total fertilizer consumed in agricultural production in state \( i \) (equal to the sum over all counties), \( e_{ij} \) is the expenditure on agricultural fertilizer in county \( j \) of state \( i \), and \( E_i \) is the total state expenditure on agricultural fertilizer.

To estimate non-agricultural use at the county level, the total non-agricultural consumption at the state level, \( F_{Ni} \), is calculated as: \( F_{Ni} = F_N - F_i \)

Where \( F_N \) is the total fertilizer use in state \( i \).

Following Gronberg and Spahr (2006), the non-agricultural fertilizer is assumed to be distributed over counties in proportion to “effective population”:

\[ f_{Nij} = \frac{F_{Ni} p_{ij}}{P_i} \]

Where \( f_{Nij} \) = the mass of fertilizer (N or P equivalent, kg) consumed in county \( j \) of state \( i \), \( F_{Ni} \) is the total fertilizer consumed in agricultural production in state \( i \) (equal to the sum over all counties), \( p_{ij} \) is the “effective population” of county \( j \) of state \( i \), and \( P_i \) is the sum of \( p_{ij} \) over all counties in state \( i \).

Ruddy et al (2006) originally developed the procedure of using “effective population”, a nonlinear function of population density, to account for observed insensitivity of nonagricultural fertilizer purchases to population density in areas of higher population density. Effective population, \( p_{ij} \), is calculated from actual county population (censused population) \( p_{cij} \), and county area, \( a_{ij} \) (km\(^2\)) as:

\[ p_{ij} = a_{ij} \min \left( \frac{p_{cij}}{a_{ij}}, 700 \right)^{1.3} \]

The above procedure was used to estimate county-level fertilizer in 1997, 2002, 2007, and 2012.

Brakebill and Gronberg (2017) recently updated the county level fertilizer estimates through 2012. Their dataset contains county-level estimates of nitrogen and phosphorus from fertilizer, for both farm
and nonfarm uses, for the conterminous United States based on state-level farm and nonfarm nitrogen and phosphorus that were derived from the Association of American Plant Food Control Officials (AAPFCO) commercial fertilizer sales data, as was done previously. In their study, computations for 2007 - 2012 estimates use the methods of Gronberg and Spahr (2012), and data for 1987 - 2006 are exactly those published in Gronberg and Spahr, 2012. Comparison between the v3.1 fertilizer data and those in the latest Brakebill and Gronberg dataset for the six census years considered are shown in figures A3.1 and A3.2. While the agreement between datasets is excellent (and prior to 1997, exact), a few discrepancies in individual counties exist, generally due to differing assumptions about county area or population. Future versions of the fertilizer toolbox will incorporate the Brakebill and Gronberg (2017) data and use the above methodology to estimate future year fertilizer estimates.
Figure A3.1. Comparison of county total N fertilizer use estimates from NANI fertilizer toolbox v3.1 (x axis) with those from Brakebill and Gronberg (2017) (y axis). Agreement is excellent, and is exact in 1987-1992. Relative difference are highest in counties of very low fertilizer use, generally corresponding to regions of high population density and little agricultural activity. Note log scales.
Figure A3.2. Comparison of county agricultural N fertilizer use estimates from NANI fertilizer toolbox v3.1 (x axis) with those from Brakebill and Gronberg (2017) (y axis). Agreement is excellent in all years. Note log scales.
A.4. Reported errors and their solutions

Memory issues in the Calculator Toolboxes
Problem: It has been reported that in some versions of Excel, clicking on the “Report NANI Variables” button in the “NANI_Var” worksheet of the NANI Calculator Toolbox (version 3) causes a “Procedure too large” error:

![Microsoft Visual Basic for Applications](image)

According to Microsoft Office Development Center website (https://msdn.microsoft.com/en-us/library/office/gg251481.aspx), this error occurs when the code for the problematic procedure exceeds 64K when compiled.

Resolution: This problem was resolved by breaking the problematic procedure into two smaller parts.

Extraction Tool errors
Problem: NANI_Extraction_Tool_V3.1_Ag_Census_Crops_12_07.xlsm or NANI_Extraction_Tool_V3.1_Ag_Census_Animals_12_07.xlsm fails to complete the extraction, with the following error message:
- Run-time error ‘9’
- Subscript out of range

And the debug tools points to the following line in module Extract for the run-time error:

```vba
ReDim strSignString(1 To lngSignNum) As String
```

Resolution: The problem originates from an issue with special characters when migrating the excel worksheets between computers. The original idea was that the user can use simple user-defined equations to manipulate the extracted raw data, for example adding two variables or multiplying some coefficients. The multiplication character "*" can be used for the latter case instead of using the special character, "×", for multiplication, but so can the special character. When an Excel file (more specifically, Visual Basic code embedded in it) moves from one system
to another (from Windows to Mac, for example), some special characters (like "×", the multiplication symbol, not "x") used in the code are not recognized and changed into something else. This occurs when embedding arithmetic calculations in the calculations for desired output. The line of the error: "ReDim strSignString(1 To lngSignNum) As String" itself is not the problem; the problem is that the variable "lngSignNum" typically becomes zero (because of the issue described above), leading to the error message. For example, in one instance, we found that changing line 950 in the VBA code as follows fixed the problem:

\[
\text{lngGetMultiplicationSignLoc01} = \text{InStr(strExtractItem(I), "委")}
\]

to:

\[
\text{lngGetMultiplicationSignLoc01} = \text{InStr(strExtractItem(I), "×")}
\]
B. References


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