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Case study for evaluating campus sustainability: nitrogen balance for the University of Minnesota

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Abstract American ecologists recently began to address the ecology of cities. Concurrently, higher education institutions have developed sustainability education programs and instituted sustainability policies and projects. This paper draws together these two disparate areas by examining the nitrogen (N) budget of the Twin Cities campus of the University of Minnesota. We addressed the question: what were the annual inputs, outputs and internal cycles of N on the University of Minnesota Twin Cities campus? We found that 508 Mg N yr-1 were brought into the campus and 494 Mg N yr-1 were emitted from the University of Minnesota campus. The largest N inputs were abiotic fixation (conversion of N_2 to NO_x by combustion) and food for humans and animals. The largest N output was NO_x, followed by wastewater. Our results expand the understanding of the ecology of institutions within an urban area and provide an opportunity for improving urban ecology education and environmental policy at educational institutions.

Keywords Urban ecology · Campus ecology · Nitrogen budget · Campus sustainability

Introduction

Ecologists recently started to examine the ecology of cities in the United States. For example, major integrative urban ecosystem projects are now underway in Phoenix, AZ, and Baltimore, MD. These new projects started integrating traditional ecological

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information with social and economic data to reveal novel insights regarding the functioning of human ecosystems (Collins et al. 2000; Grimm et al. 2000; Zipperer et al. 2000; Grove and Burch 1997). Several studies examined flows of energy and nutrients through cities (Boyd et al. 1981; Baker et al. 2001; Faerge et al. 2001; Decker et al. 2000). Baker et al. (2001), for example, developed a comprehensive nitrogen (N) balance for the Phoenix, AZ metropolitan area. This balance showed that N was accumulating in soils and groundwater, that riverine export was a tiny fraction of total N input, and that the main route of N from the ecosystem was volatilization and gas transport.

Concurrently, sustainability initiatives have also sprung up on college and university campuses around the world. These projects, also called "greening the campus" projects, include actions such as innovative architectural design, campus environmental audits, sustainable development plans, and environmental policies. Students and faculty support these initiatives for altruistic or scientific reasons and administrators have also found that implementing sustainability goals can reduce operational costs. Researchers working on sustainability issues link the university environment and sustainable development (van Weenen 2000; Clugston and Calder 1999; Orr 1994); examine the financial incentives for reducing environmental impacts (National Wildlife Federation 1998); describe successful programs and recommend ways to start and improve programs (Creighton 1998; Keniry 1995).

Environmental and sustainability policies have been adopted by an increasing number of institutions. For example, over 265 college presidents in over 40 countries in five continents have signed the Tallois Declaration, a document pledging the importance of sustainability to higher education (Clugston and Calder 1999). In addition, a group of 56 colleges and universities in New Jersey recently agreed to reduce greenhouse gas emissions by 3.5%. Several schools have also signed on to the Chicago Climate Exchange.

When sustainability projects begin at colleges or universities, attempts are often made to quantify college and university impacts on the environment. At the time of this writing 1,262 campus environmental assessments have been completed at institutions worldwide (Campus Sustainability Assessment Project 2005). These assessments include environmental and sustainability assessments of differing types, greenhouse gas emissions assessments and ecological footprint assessments.

The link between campus sustainability and urban ecology, however, has yet to be explored. This paper expands the campus sustainability concept and links it with urban ecology through development of a N balance for the University of Minnesota, Twin Cities Campus. Applying a N budget to a campus shows how a human institution directly affects a biogeochemical cycle. We asked: What were the inputs, outputs and internal cycles of N on the University of Minnesota Twin Cities campus? What impact have ongoing sustainability projects and practices had on the N budget? And, what direction does the N balance point us toward in respect to future sustainability practices? Our results expand the understanding of the ecology of institutions within an urban area. The results can also be used to see how a university can be used as a 'living lab' for adaptive management, using student research and analysis to provide feedback to guide the institution's sustainability efforts over time.

Study area: University of Minnesota's Twin Cities campus

The University of Minnesota's Twin Cities Campus (University) is one of the largest universities in the country, with nearly 45,000 students and 15,000 staff. The University is a land grant institution that includes a medical school, veterinary school, and agriculture school. The campus is composed of three units in the local Twin Cities area. The West and

East Bank portions of the Minneapolis campus straddle the Mississippi River near downtown Minneapolis; the St. Paul campus is located 6 km east of the Minneapolis campus. The entire campus (all three units) occupies 401 ha and includes 200 buildings (University of Minnesota 1998). The campus is located in an urban area with access to significant city bus service. The campus also includes over 20,000 parking spaces.

Located in the Upper Midwest, USA, the climate is that of hot summers and cold winters. Because of the amount of heating and cooling required for the climate, as well as the energy requirements of research buildings, energy use for campus buildings is a major expense for the University. In 2002, the Twin Cities campus spent over $46 million US dollars on energy, which amounts to approximately 37% of the facilities management budget.

Materials and methods

System boundary

The Twin Cities Campus consists of the buildings and grounds of the East Bank, West Bank, and St. Paul Campuses. The campus, as analyzed, does not include experiment stations located some distance from campus, or a few buildings within the campus not managed by the University's facilities management department. Our system boundary is conceptual, rather than strictly geographic because students, faculty and staff commute and travel outside the boundaries of the campus and much of the energy used on campus is generated off site. We included within the "boundary" of the University N emissions incurred through travel by campus personnel. Travel includes commuting to campus, airline travel by faculty and staff that was reimbursed by a University budget, and international airline travel by students on study abroad programs. These actions are considered central to the conduct of University business and the conceptual boundary represents the working environment of the campus. We also included N in food both consumed and excreted on campus. Outside the scope of the project is the "embodied" N involved in the production and transportation of materials to the campus.

Subsystems

The University campus ecosystem was divided into four subsystems: near-surface atmosphere, human metabolism, animal metabolism, and landscape. Each N input entered one or more subsystems. The N was then transferred to another subsystem or exported from the university system. This N budget is based on "reactive" N (Galloway et al. 1996), which includes organic N, ammonium and nitrate. All N inputs and outputs were converted to Mg N yr-1. Savanick (2006) details how to use this approach as a class research project.

In the near-surface atmosphere subsystem, combustion processes fix N_2, forming NO_x through abiotic fixation. The NO_x formed is an input of reactive N to the near-surface atmosphere. This NO input moves by advection and dispersion to the regional atmosphere. This dispersion represents an export of reactive N from the campus ecosystem. Consequently, combustion-related N is considered both an input and output to and from the near surface atmospheric subsystem. Combustion-related N emissions in this subsystem include building-related energy N emissions, transportation-related emissions, and waste-related emissions.

Building-related emissions include emissions from energy used to heat campus buildings on site and emissions related to electricity generation by the local utility, Xcel Energy, and used on campus. The University operates three steam-generating plants using natural gas and coal to produce heat. Xcel Energy, the local utility, receives approximately 50% of its energy from coal, 30% from nuclear power, 4% from wind, 14% from Manitoba hydropower, and 3% from other sources such as biomass, oil, other hydropower plants, and garbage burning in the Upper Midwest, according to Xcel Energy Media Relations.

Transportation-related emissions include NO_x from commuters (including those in single-occupant vehicles, carpools, and utilizing the bus service) as well as emissions from University owned vehicles and campus busses. In addition, the transportation subsystem includes emissions from airline travel by faculty and staff as well as study abroad travel by students.

Waste-related emissions included N emissions from the incineration of University waste. All non-recycled waste from the campus was sent to the Hennepin Energy Resources Co. (HERC) in downtown Minneapolis where it was incinerated for energy recovery. Combustion of this waste produces NO_x emissions. Because this incinerator also produces electricity, energy generated from combustion of this waste is credited in the budget.

The human metabolism subsystem includes N in protein imported to campus as human food, as 16% of protein is composed of N. The output from this subsystem is N in human waste that is exported in wastewater through the sanitary sewer system.

The animal metabolism subsystem includes N imported to the campus as protein in animal food. Nitrogen in animal waste is exported from this subsystem. The wastes from agricultural animals are collected, spread on the agricultural fields as fertilizer or composted off-site. The non-agricultural animal waste is assumed to be included in the University's solid waste that is incinerated after it leaves the University, as no other waste collection system is in place. Animal products containing N are also exported from this system. These include meat and milk products sold through the dairy store and meat sciences.

The landscape subsystem includes N imported in commercial fertilizer, N fixed by biological fixation in the agricultural field, and N in atmospheric deposition. Outputs include N in harvested agricultural crops, N in surface water runoff from agricultural fields and campus landscaping, as well as denitrification and volatilization.

Data sources

Data were collected by analyzing published documents, unpublished internal reports, and by interviewing University staff and vendors. Interviews were completed by phone, in person, or by email. Data sources for each input and output to the system are detailed in Table 1. Where data was not available, we needed to estimate the flux based on published rates. Where possible, 2002 data were used in the analysis. Where 2002 data were not available, we calculated the mean of the most recent 3 years as an estimate of 2002 data. In the cases where three years data were not available, we used the most recent data available.

Results

Near surface atmosphere subsystem

Heat and Electricity for Buildings For the years 1998 and 1999 the mean emissions from the campus steam plants were 140 Mg N yr-1 (Savanick 2004). Two years of data were used in this analysis because of a major steam plant renovation in 1997. The University also buys electricity from Xcel Energy. Using Xcel Energy's system-wide emission rate of 1.52 g NO_x/kWh provided by Xcel Energy, the mean annual N output from the energy

Table 1 Data sources

Data	Source
Input	
Abiotic fixation	Calculated from output
Human food	FTE data from John Kelly, Institutional Research and Reporting; Protein consumption rate from Borrud et. al. (1996)
Agricultural animal food	Animal waste data from Tom Warnke, Director of University Agricultural Experiment Station; Animal numbers were reported to the Minnesota Pollution Control Agency.
Research animal food	Animal numbers from Roland Gunther, Research Animal Resources; Estimated food requirements by examining pet food nitrogen content.
Commercial fertilizer	Agricultural fertilizer rate and nitrogen content from Tom Warnke, Director of University Agricultural Experiment Station; Landscaping turf fertilizer Rates and nitrogen content from Doug Lauer, University Landcare.
Biological fixation	Agricultural field contents from Tom Warnke, Director of University Agricultural Experiment Station; Nitrogen fixation rates from Minnesota Department of Agriculture (1993).
Deposition	N deposition rate from National Atmospheric Deposition Program, NRSP-3/National Trends Network (2003).
Output	
Combustion: campus steam plant	Emissions Data reported to Minnesota Pollution Control Agency (Minnesota Pollution Control Agency 2001).
Combustion: local utility	kWh purchased from Excel Energy data from University Energy Management; Xcel Energy's system-wide emission rate from Xcel Energy.
Combustion: waste	University waste data from University Waste Management;Waste combustion N emission rate from Jake Smith, Hennepin County Environmental Services.
Combustion: commuters	Estimated number of travelers from University of Minnesota Research and Reporting; Distances traveled estimated by University of Minnesota Transit Services; Emissions factor for cars from Minnesota Pollution Control Agency (2001); Emissions factor for buses from Adam Harrington, Manager, Metro Transit; Assumed 2 people per carpool.
Combustion: airline travel	Number of trips from University Travel; Estimated distance per trip based on travel agency estimates; Emissions factor from Roos et. al. (1997).
Wastewater	Estimated human N waste rate from Baker et. al. (2001).
Animal waste	Agricultural animal waste amounts from Tom Warnke, Senior Admin Director of the University Agricultural Experiment Station; Estimated N content from Minnesota Department of Agriculture (1993); Research animal waste calculated from the numbers of animal and N conversion rate.
Agricultural and animal output	Agricultural field output calculated from calculation amounts of N in crop (Savanick 2004); Animal output calculated from animal numbers and N conversion rate.
Surface water	Surface water N from agricultural fields estimated by Gyles Randall, Southern Research and Outreach Center; Surface water N from campus landscape rate estimated from campus area and N removal rate for the Twin Cites (Brezonik and Stadelmann 2002).
Volatilization	Agricultural fertilizer volatilization estimate from based on Schlesinger (1992); landscape volatilization estimate assumed to be same.

generated by Xcel Energy between 1997 and 1998 and used on the University of Minnesota campus was 139 Mg N yr-1 (Savanick 2004).

Waste The University sent all non-recycled waste to the Hennepin Energy Resources Co. (HERC). In 2002, the HERC plant burned 3.19×10^{8} kg of waste which generated 248,312 kWh of energy; it also emitted approximately 520 Mg of NO_x, according to Jake Smith from Hennepin County Environmental Services. The University sends 4,824,321 kg of waste per year to the HERC facility or 1.5% of the total waste burned at the facility. Burning this amount of waste emitted 2 Mg N yr-1. Some of this waste was used to generate electricity. Since the University generated 1.5% of the waste burned at the HERC facility, we assumed that 1.5% of the energy generated (or 3,759,000 kWh) was generated from University waste. This reduced the N emission attributed to the University's energy generation, resulting in a net estimate of 0.7 Mg N yr-1 from waste combustion (Savanick 2004).

Transportation According to John Kelly from University of Minnesota Institutional Research and Reporting, in 2002, 65,874 students, staff and faculty were in residence at the University. According to William Stahlmann, Senior Administrative Director of University of Minnesota Transit Services, 32% of the students, staff, and faculty drove single occupant vehicles to campus; another 32% walked to campus; 24% rode the bus; 7% used a carpool and 5% rode bicycles. The University Transportation Service estimated that the average commuter travels 28.8 km/day, according to a 1999 transportation grant application.

Single-occupant vehicle (SOV) commuters were estimated to emit 0.44 g N/km driven (Minnesota Pollution Control Agency 2001); carpoolers were assumed to be two occupants per carpool. Bus riders were estimated to emit 0.1 g N per passenger km traveled (Savanick 2004); this passenger rate could be low if university bus riders were assumed to ride during rush hours only, according to Adam Harrington, Manager, Route & System Planning, Metro Transit, the organization responsible for the regional bus service. Using these assumptions, commuters traveling by SOV are estimated to have emitted 69 Mg N yr-1; commuters traveling by carpool emitted 15 Mg N yr-1; commuters traveling by bus emitted 17 Mg N yr-1 (Savanick 2004). The total commuter emissions were estimated at 101 Mg N yr-1 (Table 2).

University personnel used campus cars and vans for approximately 7,280,000 km of official university travel. The mean campus vehicle fleet is number is 525 vehicles and are driven 6,250 km/year, according to Bill Roberts, Director, Campus Fleet Services. Using a mean N emission rate of 0.44 g/km (Minnesota Pollution Control Agency 2001), 3 Mg N yr-1 were emitted by campus vehicles.

The University's bus service transports personnel among the units of the Twin Cities campus. These buses logged 831,243 km in fiscal year 2002, according to William Stahlmann, Senior Administrative Director of Transit Services. Using United States Environmental Protection Agency (1995) statistics for average NO_x emissions for large diesel and light diesel vehicles, the buses at the University of Minnesota generated 8.75 g NO_x/km, for a total of 2 Mg N yr-1. The total N emissions from campus transportation (campus vehicles and buses) was 5 Mg N yr-1 (Table 2).

According to Kathleen Stoner, from University Travel, University staff and faculty complete 17,100 airline travel trips each year and approximately 10–12% of this travel is international. According to Stoner, a reasonable average domestic round trip would be 2,560 km. According to Mellisa Guttig from Carlson Wagonlit Travel, a travel agent who works with University personnel on international travel, a reasonable average international

Table 2 Combustion-related N output from the University of Minnesota, Twin Cities campus

Source	N emissions (Mg N/yr)
Heat and electricity	
Campus steam plant	140
Local utility	139
Subtotal	279
Commuting	
Single occupant vehicles	69
Carpool	15
Commuter bus	17
Subtotal	101
Campus transport	
Campus cars/vans	3
Campus buses	2
Subtotal	5
Airline travel	10
Waste	0.7
TOTAL	396

round-trip would be 12,800 km, equivalent to the distance from Minneapolis to London. Using an average NO_x conversion rate of 0.425 g NO_x per passenger km (Roos et al. 1997), 8 Mg N yr-1 were emitted from University employee airline travel (Savanick 2004). This estimate is probably low because it only accounts for faculty and staff travel paid by a University account. Travel that was not reimbursed by the University, for instance student travel for conferences and federal employee travel, was not included.

Students also traveled for study abroad programs. In the 2002–2003 school year, 1,294 students traveled internationally on such programs. Using the same average international round trip distance of 12,800 km provided by Gutting and a rate of 0.425 g NO_x per passenger km, 2 Mg N yr-1 were emitted due to student study aboard travel. Thus, the total amount of N emitted from staff and student airline travel was 10 Mg N yr-1 (Table 2).

A total of 396 Mg N yr-1 was emitted from the campus from combustion-related sources. Of this total, emissions from heat and electricity use accounted for 279 Mg N yr-1 (71%); emissions from commuter transportation accounted for 101 Mg N yr-1 (26%); campus vehicle emissions accounted for 5 Mg N yr-1 (0.01%); airline travel emissions accounted for 10 Mg N yr-1 (0.03%); emissions from the combustion of waste accounted for 0.7 Mg N yr-1 (<0.01%) (Table 2).

Human metabolism subsystem

N in food was either purchased on campus or was brought to campus by students, staff, or faculty. University Dining Service (UDS) served 10,000 meals per day at its dining hall and retail outlets (Paulin 1999). Many students, staff and faculty also brought food to campus. We used full-time equivalent (FTE) data for staff, faculty and student populations and assumed that personnel on campus consume one third of their food on campus. Campus N demand was assumed to be one third of each FTE's daily average requirement for N, for 5 days a week, 52 weeks/year. Using data from (Borrud et al. 1996), we estimated that protein intake for individuals over 20 years old (most students, faculty and staff) was 95 g/day for males and 63 g/day for females. Protein in human food was converted to N, as 16% of protein is N (Ensminger 1992). Using the above assumptions, the 31,484 FTE males and 34,390 female students, staff and faculty consume 72 Mg N yr-1. N in human waste leaves the campus system as sewage in wastewater. Following Baker et al. (2001), about 90% of N consumed by humans enters the sewage system. Thus, N in sewage accounts for 65 Mg N yr-1.

Animal metabolism subsystem

Food Inputs The agriculture, veterinary, and biomedical units house animals on campus for research and educational purposes. Animals are handled as agricultural or research animals, depending on the department utilizing the animals. In this section, we estimated N consumption by agricultural animals. First, we used published data on agricultural waste generation rates. A protein conversion ratio was then used to calculate the amount of protein in food needed to generate the amount of N in waste. Protein conversion ratios are the amount of protein in feed divided by the amount of protein in meat, milk and eggs produced (Hammond 1991). Agricultural animals on campus are estimated to have consumed 20 Mg N yr-1 (Table 3).

The university also houses laboratory animals that are not part of the agricultural school. For research livestock where data were available the approach outlined above was followed. We assumed that other animals (lab rats, etc.) were fed commercially available pet food using feeding guidelines based on size. These figures were then used to calculate the amount of waste using average protein conversion ratios for each animal. Animals of 30 count or less were considered negligible N sources due to their small size and/or number. Using the above assumptions, campus research animals consumed an estimated 19 Mg N yr-1 (Table 4). Agricultural and research animals combined consumed 39 Mg N yr-1.

Outputs Outputs from the animal metabolism subsystem were agricultural waste (manure), animal agricultural products, and animal waste exported in the waste disposal system. According to Tom Warnke, Senior Administrative Director of University Agricultural Experiment Station, the University generated 4,560 m^3 of liquid manure and 18,240 m^3 of

Table 3 Campus agricultural animal food, waste, and agricultural output

Animal[a]	Weighted animal count[b]	Annual N in food (Mg N/yr)	Protein conversion ratio[c] (%)	Annual N in waste[d] (Mg N/yr)	Other annual N output (e.g. meat/milk/carcasses) (Mg N/yr)
Dairy cows	81	10	24	7.6	2.5
Beef cows	83	5.4	14	4.6	0.8
Swine	108	1.9	17	1.6	0.3
Horses	25[e]	1.6[g]	12[f]	1.4	0.2
Sheep	13[g]	0.8[g]	7	0.7	0.1
TOTAL		20		16	3.9

[a] Chickens and turkeys also contributed a negligible amount of N to food and waste (Savanick 2004)

[b] Animal count was adjusted to standardize the weight of animals by using Minnesota Pollution Control Agency animal units

[c] Ensminger 1992

[d] Minnesota Department of Agriculture 1993

[e] Minnesota Agricultural Statistics Service 2003

[f] Assume same conversion ratio as average ruminant

[g] Used estimate for beef waste production, weighted by animal unit

dry waste each year and 3.8 Mg N yr-1 was spread on agricultural fields. Agricultural waste was stored in an animal waste handling facility and composted off site. Of the 16 Mg N yr-1 of animal manure produced on campus, 12 Mg N yr-1 were sent off site for composting.

Dairy products from agricultural animals are sold to the public at the campus Dairy Store. In addition, all of the other milk produced on campus is sold as a commodity, according to Bill Hanson of the University Animal Science Dairy Barn. Meat was also sold to the public from the Meat Science Department. Because no data were available on the amounts of meat and milk sold, we assumed the amount of animal products exported from the campus would be similar to production agriculture, based on protein conversion rates (as used above in the waste assessment). The estimated amount of N exported as animal products, along with animal carcasses was 6.9 Mg N yr-1 (3.9 Mg N yr-1 from agricultural animal output (Table 3) and 3 Mg N yr-1 from research animal output (Table 4)).

N in non-agricultural research animal feces was assumed to enter the solid waste disposal system, as no other waste collection system is in place. Solid waste was burned at the Hennepin County's waste incinerator, the Hennepin Energy Resource Co. (HERC) facility, along with the rest of the University's waste. Assuming the protein conversion ratios listed above, 16 Mg N yr-1 were sent to the HERC plant in waste from research animals. This is considered a transfer between two campus subsystems, as this animal waste is assumed incinerated along with the rest of the campus refuse.

N in food for research and agricultural animals accounts for 39 Mg N yr-1. Transfers to the landscape subsystem accounts for 3.8 Mg N yr-1 and 16 Mg N yr-1 is transferred to near atmospheric subsystem as it is burned along with the rest of the University waste. Outputs from the animal metabolism subsystem were 12 Mg N yr-1 N in waste compost removal and 6.9 Mg N yr-1 in agricultural output (meat and milk) (Table 5).

Table 4 Research animal N in food and waste

Animal	Animal count[c]	N consumed in food (Mg N/yr)	Protein conversion ratio[d]	N in waste (Mg N/yr)	N output (carcasses) (Mg N/yr)
Mice	30,000	2.5	22[e]	1.9[g]	0.6
Poultry	2,000	1.3	26	1.0	0.3
Goats[a]	350	2.8	12[f]	2.5	0.3
Cow/horse	50	9.6	14	8.3	1.3
Non-human primates[b]	120	0.9	22[e]	0.7	0.2
Sheep	55	1.0	7	0.9	0.1
Pig	50	0.9	17	0.7	0.2
TOTAL		19		16	3

[a] Assumed 57 kg

[b] Assumed 45 kg

[c] Number does not include agricultural animals or vet school patients

[d] Source: Hammond (1991); adapted from Rumsey (1984); original data from Cunha (1982)

[e] Assumed average non-ruminant

[f] Assumed average ruminant

[g] Calculated using average N in feed

Table 5 Animal metabolism subsystem N budget

Input source	Mg N/yr	Subsystem transfer	Mg N/yr	Output source	Mg N/yr
Agricultural animal food	20	Agricultural animal waste to landscape subsystem	3.8	Agricultural animal waste compost removal	12
Research animal food	19	Research animal waste to near atmosphere subsystem	16	Agricultural and research animal products and output	6.9
TOTAL	39		20		19

Landscape subsystem

Input Inputs to the landscape subsystem include biological fixation, application of commercial fertilizer, atmospheric deposition, and application of manure to agricultural fields. Soybeans and alfalfa were planted to fix N in agricultural fields. Crops on the University of Minnesota fields contain 13 ha of soybeans and 0.8 ha of alfalfa, according to Tom Warnke, Senior Administrative Director of the University Agricultural Experiment Station. We estimated N fixation by summing N left in crop residue on the agricultural fields (0.7 Mg N/year), obtained by using published nutrient management credits from the Minnesota Department of Agriculture (1993), and N harvested from crops (5.1 Mg N/year), detailed in the next section. The total was 5.8 Mg N yr-1 due to biological fixation (Savanick 2004).

N deposition on campus was assumed the same as that at the closest monitoring station of the National Atmospheric Deposition Program, located at Cedar Creek, 45 km northwest of campus. The Cedar Creek deposition rate was 11.4 kg N ha-1 yr-1 (National Atmospheric Deposition Program (NRSP-3)/National Trends Network 2003). Thus, 4.7 Mg N yr-1 were deposited on the 401 ha of the campus landscape each year.

Data on the amount of N applied to the agricultural fields were obtained from fertilizer records by Tom Warnke, Senior Administrative Director of the University Agricultural Experiment Station. A total of 2.0 Mg N yr-1 was applied to the campus fields from agricultural fertilizer. In addition, commercial fertilizer was applied to campus lawns at a rate of 97.5 kg/ha, according to Doug Lauer from University Landcare. At this rate, Landcare staff applied 4.3 Mg N yr-1 in commercial fertilizer to the 44.6 ha of campus turf. The total amount of N from both the agricultural and landscaping commercial fertilizer input to the Twin Cities campus system was 6.3 Mg N yr-1.

Internal Cycles According to Tom Warnke, Senior Administrative Director of the University Agricultural Experiment Station, 3.8 Mg N yr-1 were applied to the agricultural fields from animal manure. This was considered a transfer between the animal metabolism and landscape campus subsystems.

In addition, University Landcare composts over 905 kg of yard waste every year, according to an internal University study of the composition of University waste completed in 1990. This material includes leaves, weeds, and grass clippings. Once composted, it is used again for landscaping projects. Woody yard waste is also chipped and used as mulch on campus, according to Doug Lauer from Landcare. As the N in this compost is used again on the campus landscape, it is considered an internal cycle of N within the landscape subsystem and is not included in the calculations for transfers between subsystems.

Output Outputs from the landscape subsystem include the removal of agricultural crops from the agricultural fields, volatilization of fertilizer, fertilizer runoff from agricultural fields and the campus lawns in storm water. Removing crops from agricultural fields exports N. Although the agricultural fields are experimental plots, we assumed that crop removal rates were similar to those of production agriculture. Since production agriculture statistics were unavailable for Ramsey county, we also assumed that crop yield was similar to adjacent Anoka and Washington counties, which were similar in soil type, according to Rick Hansen from the Minnesota Department of Agriculture. On the St. Paul campus, an estimated 5.1 Mg N yr-1 were removed through the removal of agricultural crops (Table 6).

Typically, 10% of the N in fertilizer applied to agricultural fields volatilizes (Schlesinger 1992). Baker et al. (2001) assumed the same percentage of volatilization for urban areas for the Central Arizona–Phoenix region N budget. Using this same assumption for this study, volatilization of N fertilizer from the St. Paul agricultural field emitted 0.2 Mg N yr-1 to the atmosphere. An additional 0.4 Mg N yr-1 volatilized from the landscaping fertilizer and 0.4 Mg N yr-1 volatilized from the application of manure to the agricultural fields. Volatilization, therefore, accounts for a total of 1.0 Mg N yr-1 from the entire campus.

Fertilizer runs off the agricultural fields through a tile drainage system that connects to the storm water system and drains to surface water. Management, soil type and other local conditions affect rates of runoff and subsurface flow. For this analysis, we assume that 20% of the fertilizer input to agricultural fields runs off in the tile system for a corn-soybean rotation in South Central Minnesota, based on an estimate by Dr. Gyles Randall from the Southern Research and Outreach Center, University of Minnesota. Using this assumption, an estimated 1.2 Mg N yr-1 leaves the 71 ha of agricultural fields through the tile drainage system and enters surface water.

Storm water also runs off the rest of the campus landscape and discharges into the Mississippi River. Brezonik and Stadelmann (2002) estimated that urban stormwater in Minneapolis exports about 20 kg N ha-1 yr-1. The Twin Cities campus, less the agricultural fields, is 330 ha; thus, the estimated stormwater runoff from the urban areas in the campus was 6.6 Mg N yr-1. The total amount on N exported through surface water runoff on the entire campus was 7.8 Mg N yr-1.

A total of 21 Mg N yr-1 was inputted to the landscape subsystem. Of this total, 5.8 Mg N yr-1 was due to biological fixation, 6.3 Mg N yr-1 was due to commercial fertilizer for the agricultural fields and campus landscaping, 4.7 Mg N yr-1 was due to atmospheric deposition, and 3.8 Mg N yr-1 was due to the application of animal waste on agricultural fields (internal cycle). A total of 14 Mg N yr-1 was outputted from the subsystem. Of this total, 5.1 Mg N yr-1 was due to removal of agricultural crops, 1.0 Mg N yr-1 was due to volatilization of fertilizer, and 7.8 Mg N yr-1 was due to N export in surface water (Table 7).

In summary, the total inputs to the University system were 508 Mg N yr-1. Of this total, abiotic fixation accounted for 380 Mg N yr-1 (75%); food for humans accounted for 72 Mg

Table 6 University of Minnesota crop summary

Crop	Hectares	N removed with Crop (Mg N/yr)[a]
Soybeans	13	2
Corn	19	2
Barley	6.3	0.3
Wheat	5.9	0.4
Oats	4.5	0.2
Rye	1.6	0.1
Alfalfa	0.8	0.1
TOTAL		5.1

[a] Savanick 2004

Table 7 Landscape subsystem N budget

Input source	Mg N/yr	Output source	Mg N/yr
Biological fixation	5.8	Agricultural crop removal	5.1
Commercial fertilizer (agriculture and landcape)	6.3	Volatilization	1.0
Deposition	4.7	Surface water	7.8
Internal cycle from animal metabolism subsystem	3.8		
TOTAL	21		14

N yr-1 (14%); food for animals accounted for 39 Mg N yr-1 (8%); the importation of commercial fertilizer accounted for 6.3 Mg N yr-1 (1%); biological fixation accounted for 5.8 Mg N yr-1 (1%); atmospheric deposition accounted for 4.7 Mg N yr-1 (1%). The total outputs from the University system were 494 Mg N yr-1. Of this total, combustion-derived NO_x accounted for 396 Mg N yr-1 (80%); wastewater accounted for 65 Mg N yr-1 (13%); the removal of animal waste accounted for 12 Mg N yr-1 (2%); the removal of animal outputs accounted for 6.9 Mg N yr-1 (1%); the export of agricultural crops accounted for 5.1 Mg N yr-1 (1%); surface water export accounted for 7.8 Mg N yr-1 (2%); Denitrification and volatilization accounted for 1.0 Mg N yr-1 (<1%) (Fig. 1).

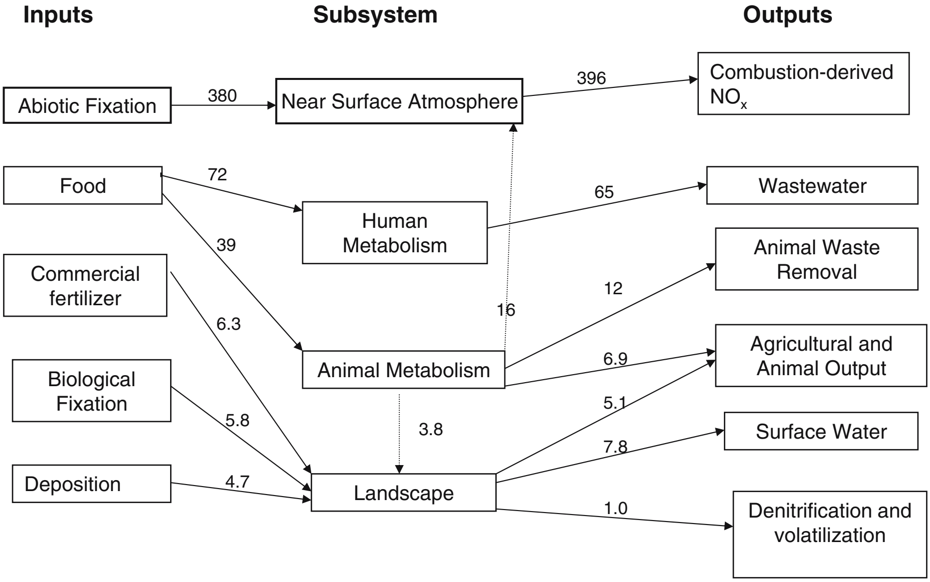

Fig. 1 2002 University of Minnesota N budget. Modified for campuses, based on Baker et al. (2001). All values in Mg N yr-1. *Dotted lines* represent a transfer between subsystems

Discussion

Major fluxes

Humans mediated all of the inputs and outputs to and from our study site, with the exception of atmospheric deposition. Humans imported food, deliberately planted N-fixing plants in the campus agricultural fields, and spread fertilizer on the landscape. In addition, humans deliberately exported N through animal waste compost removal, agricultural crops, and wastewater. Inadvertently, humans fixed N through abiotic fixation through burning fossil fuels for energy and transportation. Humans also contributed N runoff inadvertently into surface water and influenced volatilization by applying fertilizer to the landscape.

The largest input to the campus system was abiotic fixation (380 Mg N yr-1). The second largest was imported human and animal food (111 Mg N yr-1). Much smaller inputs were commercial fertilizer (6.3 Mg N yr-1), biological fixation by crops (5.8 Mg N yr-1) and deposition (4.7 Mg N yr-1) (Fig. 2). The largest N output from the campus system was the transport of NO_x from campus via dispersion and advection (396 Mg N yr-1) (Fig. 3). The second largest output was N in wastewater (65 Mg N yr-1). Additional N was exported through animal waste compost removal (12 Mg N yr-1), combustion of animal waste in the HERC facility (16 Mg N yr-1), agricultural output from fields and animal products (12 Mg N yr-1); agricultural and lawn runoff (7.8 Mg N yr-1) and volatilization of fertilizer (1.0 Mg N yr-1) (Fig. 3).

In the landscaping subsystem, inputs were 21 Mg N yr-1 and outputs were 14 Mg N yr-1, leaving 7 Mg N yr-1 (33% of the subsystem inputs) stored in this subsystem. This suggests that organic matter in soils is building up on the campus landscape and/or that N is retained in the campus plant biomass.

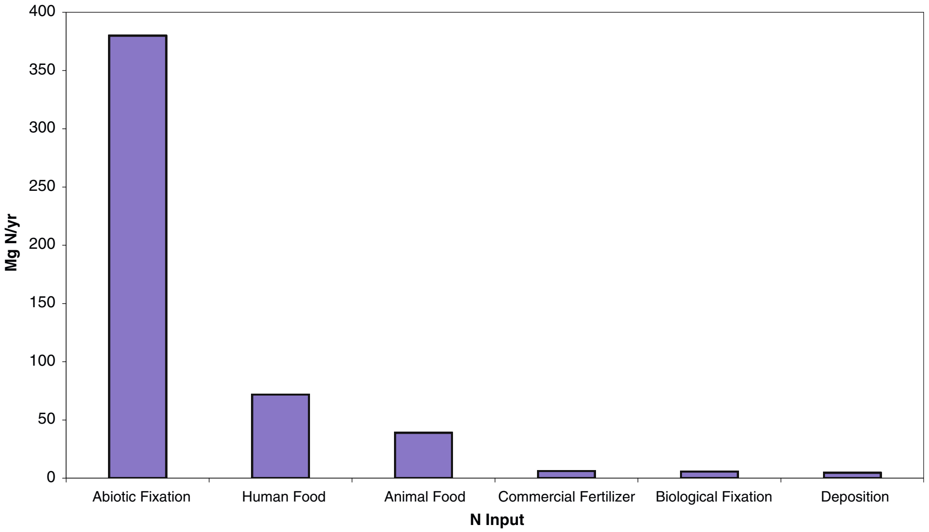

Fig. 2 Inputs to the University of Minnesota system

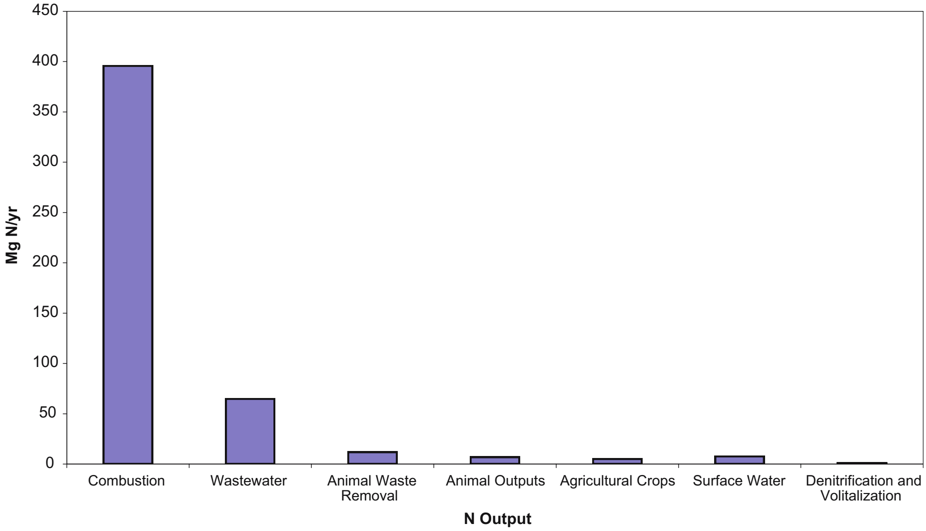

Fig. 3 Outputs from the University of Minnesota system

Data quality

The quality of the data involved in this study varies in quality (Table 8). Generally, the university has good records for materials that are purchased, such as airplane tickets and electricity. Data from legally mandated monitoring, such as measured emissions from campus steam plants, enumeration of agricultural animals, and the amount of agricultural animal waste, are also probably quite accurate. However, except for NO_x emissions, which are measured directly, most N fluxes need to be modeled as a function of some enumerated quantity and an appropriate coefficient. For example, livestock waste production is based on the number of animals (measured), export of animal products and literature-based protein conversion ratios. For a few fluxes we had to rely entirely on estimation. For example, the University did not measure N leaving the university in storm water in 2002, so we estimated stormwater N export from an export coefficient developed for the Twin Cities and the total land area of the University.

Table 8 shows major N fluxes (>10 Mg N/yr), the method of quantification, and the assessed accuracy. Fluxes calculated from direct measurements were assumed to be of good accuracy. Most fluxes are a combination of an enumerated value and an estimated value; these fluxes are considered of moderate accuracy. Our assessment of quality is qualitative, based on expert judgment.

The importance of accuracy for a given flux to our overall N balance depends on both the quality of the flux and its magnitude. For example, even a 5% variance in combustion data (20 Mg N yr-1) would be larger than the N inputs from commercial fertilizer, biological fixation, and deposition combined. In this study, the combustion-related N inputs from the campus steam plant and the local utility are considered of high accuracy and the combustion-related emissions from transportation are considered of moderate accuracy.

There are several places where improved methodology would improve the overall campus N balance (Table 8). The human food input (72 Mg N yr-1) is large but not well quantified. The weakest part of the estimate is the number of meals consumed on campus.

Table 8 Summary of fluxes, methods of quantification and assessed accuracy

Source	N flux (Mg N/yr)	Method of quantification	Assessed accuracy
Inputs			
Campus steam plant, abiotic fix	140	Computed from output	High
Local utility, abiotic fixation	123	Measured output−animal waste	High
Human food	72	Enumerated FTEs × est. consumption	Moderate
Single occupant vehicles	69	Computed from output	Moderate
Agricultural animal food	20	Calculated from animal waste+animal products	High
Research animal food	19	Estimate	Moderate
Commuter bus	17	Computed from output	Moderate
Carpool	15	Computed from input	Moderate
Airline travel	10	Computed from output	Moderate
Other	23	Various	Moderate
TOTAL INPUTS	508		
Outputs			
Campus steam plant	140	Direct measurement	High
Local utility	139	Direct measurement	High
Single occupant vehicles	69	Enumerated travelers × assumed miles × emissions factor	Moderate
Human waste	65	Computed from food input	Moderate
Commuter bus	17	Enumerate travelers × estimated distance × emissions factor	Moderate
Agricultural animal waste	12	Measured waste × estimated N content	High
Carpool	15	Enumerated carpoolers × est. distance × emissions factor	Moderate
Airline travel	10	Enumerated trips × est. distance per trip × emissions factor	Moderate
Other	27	Various	Moderate
TOTAL OUTPUTS	494		

Fluxes<10 Mg/yr are not included

Similarly, estimates of emissions by land transportation (in the aggregate, 106 Mg N yr-1) are based on an assumed average commuting distance, not specific information in the travel surveys. Utilizing campus surveys could reduce both of these uncertainties. The wastewater flux (human waste) is also large (65 Mg N yr-1) but also has high uncertainty. This flux could be improved by direct measurement of wastewater N leaving the institution.

Implications for sustainability

The N balance is a tool that can be used to evaluate the effect of sustainability initiatives that have been implemented and those that are being currently envisioned for the future. Energy generation, energy efficiency, transportation and landscaping practices are all typical sustainability practices that are in place at university campuses and all impact the N budget.

At the University of Minnesota, N emissions from combustion comprise the largest source of N output. Emissions from energy production for heat and electricity are the largest source of N. For the past ten years, extensive energy efficiency programs have been

Table 9 Effect of current sustainability projects on the nitrogen budget

Practice	Effect	Additional N output without program (Mg N/yr)
WALDO energy efficiency program	Decreased energy use by 23% over 10 years	64
Bus pass program and other incentives to increase bus ridership	University commuters utilize bus transport ten times that of the Twin Cities population	111

in place. For example, the University implemented the WALDO, “window, wall and door” program that identifies the conditions of buildings and identifies priorities for upgrades (University of Minnesota 2002). Through these types of energy efficiency efforts, the University has reduced the energy use per square foot by 23% in ten years, according to Mary Gerads of University Energy Management. If the energy efficiency program had not been in place, 64 Mg more N/yr would have still been emitted (Table 9).

Even with an active energy efficiency program, energy production for heat and electricity accounted for 74% of total Mg N yr-1 emissions. Because energy use is a large source of N emissions, reducing energy use has a large impact on N emissions. According to Gerads, the University Energy Management likely could reduce energy use by 10% and might be able to reduce energy by 20%. If energy were reduced 10%, then the University would reduce total N emissions by 28 Mg N yr-1. Reducing energy emissions by 20% would reduce total N emissions by 56 Mg N yr-1 (Table 10). In fiscal year 2007, University Departments will be responsible for the cost of energy to their buildings; the energy management personnel believe that this could be an incentive to reduce energy use even further.

The source of energy used also plays a large part in the amount of N emissions. At the University, the mix of fuel used in the campus steam plants as well as the mix of fuel used by the local utility has a direct effect on N output. The campus steam plant, in the time of this study, emitted N from burning natural gas and coal. Currently, the University is working on developing a biomass-burning project using waste oat hulls. The preliminary results show that NO_x emissions may increase slightly, according to Gerads. In addition, the University buys energy from Xcel Energy, which produces electricity by burning coal, natural gas and producing nuclear and hydro energy. The nuclear and hydro energy generation did not emit N, but did pose other environmental concerns.

Some colleges and universities are addressing the environmental issues associated with energy by purchasing renewable energy. The University of Colorado and Connecticut

Table 10 Effect of potential sustainability practices on N output

Practice	Effect	Potential N output reduction (Mg N/yr)
10% increase in building energy efficiency	10% reduction of energy use	28
20% increase in building energy efficiency	20% reduction of energy use	56
Purchase of 10% renewable energy	10% reduction on energy-related N output	14

College increased student fees to pay for green energy. The University of Pennsylvania, Penn State and Carnegie Mellon University purchased Pennsylvania wind power. If 10% of the energy purchased by the University of Minnesota were derived from wind, which does not produce NO_x emissions, the University would reduce N emissions by 14 Mg N yr-1 (Table 10).

Commuting to campus accounted for about 20% of NO_x emissions. Single-occupant vehicle (SOV) commuters accounted for 32% of the commuting population, but emit for 68% of the commuting N emissions. At the present time, the University has actively sought to reduce SOV commuting through promoting bicycling, carpooling and promoting the local bus service. Special rate carpool parking, bike lockers and bike racks are available. In addition, in 2001, the university implemented a subsidized bus pass program for students and employees; as a result, bus pass sales have been increasing steadily as is bus ridership. Even at the current rate, University commuters utilized bus transportation at a rate 10 times higher than the general Twin Cities community (24 vs 2.5%) (Savanick 2004). If University staff and students followed the transportation pattern of other Twin Cities commuters, the University's commuting N emissions would be 111 Mg N yr-1, or twice as high as it currently is, a strong incentive to continue the heavily discounted bus fare program (Table 9).

In addition to energy use, N export from campus through storm water runoff has a direct impact on local rivers and lakes. Although the quantities of N that are exported via runoff from agricultural fields and lawns is a small fraction of the N emitted by combustion, N pollution of stormwater has a major impact on local lakes. Under the National Pollutant Discharge Elimination System (NPDES) Phase II stormwater program, the campus now has a permit for stormwater discharge and is moving forward rapidly with implementation of "best management practices" (BMPs), including improved lawn management, rain gardens, infiltration basins and housekeeping practices. Stormwater runoff on the St. Paul campus is now being monitored, allowing the overall effect of stormwater practices to be evaluated over time. Facilities management is now working a faculty research group to study BMPs developed on campus. In addition, a collaborative student, faculty and facilities management project is currently working to restore a campus wetland. Future collaborative research is expected to reduce the amount and storm water coming from the campus as well as reduce the pollutant load of this storm water. This collaboration has the potential to showcase storm water education and research and reduce the N pollutant load to local water. The stormwater education component shows how a N budget can be used as an educational tool to educate students about urban N dynamics as well as a way for the University to monitor the progress in reducing institutional environmental impacts.

Conclusion

We calculated that 508 Mg N yr-1 entered and 494 Mg N yr-1 were emitted from the University of Minnesota, Twin Cities campus system. The largest sources of input to the N budget were abiotic fixation and food for humans and animals. The largest sources of output were heat and electricity for campus buildings, followed by commuter transportation to campus. The N balance model was useful in evaluating the impact of individual measures on N outputs by comparing alternative potential measures and evaluating the impact of sustainability programs already implemented.

Campus sustainability has moved beyond the "feel good" stage and requires rigorous, quantitative evaluation of planned and implemented measures. We propose that N balances, along with energy and carbon balances and dollars, are useful, readily measured metrics that can be used to as a first step toward this rigorous, quantitative evaluation of the impact of campus sustainability efforts. At educational institutions, the N budget may also be used as a pedagogical tool for students to learn about urban N dynamics.

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