APPLICATION OF HOUSEHOLD FLUX CALCULATOR IN DETERMINING VARIABILITY IN ANNUAL CARBON, NITROGEN, AND PHOSPHORUS FLUX THROUGH FALCON HEIGHTS, MINNESOTA HOUSEHOLDS

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ABSTRACT

As human population has continued to grow and become increasingly more metropolitan, urban ecosystems have become an increasingly important contributor to air and water pollution on a local, regional, and global scale. As such, households provide a useful unit of study, and quantifying environmental impacts from individual households helps provide a clearer picture of what individual household decisions have the largest impact to air and water quality.

In this study, a group of University of Minnesota research fellows conducted a series of interviews and field surveys of single-family homeowners in the city of Falcon Heights, Minnesota. The surveys were constructed by a team of faculty members and research associates, for the purpose of collecting detailed information on household consumption, behaviors, and attitudes. The survey was developed to obtain information that could be translated into quantitative data to determine overall flux of carbon (C), nitrogen (N) and phosphorus (P) as they relate to household activities and personal choices. For purposes of this thesis, we define "flux" as the quantitative measurement of inputs and outputs through the household unit, including any portions that are sequestered within or exported from the household. Surveys were conducted with 34 households; 6 or which were eliminated from this analysis due to incomplete data.

Approximately 40 variables gathered from the surveys were quantified and directly inputted into the Household Flux Calculator (HFC), a spreadsheet accounting model which was developed as part of this study to estimate the overall fluxes of C, N, and P for each household. This thesis analyzes the variability of C, N, and P flux among the households surveyed, and highlights household activities that have the greatest

influence on the inputs and outputs of household C, N, and P, with the goal of developing a better understanding of how decisions and choices made on a household level impact local, regional, and global environments.

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LIST OF ABBREVIATIONS

C	Carbon (elemental)
C_{org}	Organic Carbon
CCF	Hundred Cubic Feet
CDD	Cooling Degree Days
CFR	Code of Federal Regulations
CH_4	Methane
CO:	Carbon Monoxide
CO_2	Carbon Dioxide
dbh	Diameter at Breast Height
DO	Dissolved Oxygen
DOE	U.S. Department of Energy
EIA	Energy Information Administration
g	Gram(s)
GWP	Global Warming Potential
HDD	Heating Degree Days
HFC	Household Flux Calculator
kg	Kilogram(s)
kWh	Kilowatt Hour
L	Liter(s)
MCL	Maximum Contaminant Level
mg	Milligram(s)
mpg	Miles Per Gallon
N	Nitrogen (elemental)
N_2	Nitrogen Gas (atmospheric nitrogen)
N_{inorg}	Inorganic Nitrogen
N_{org}	Organic Nitrogen
NCDC	National Climatic Data Center
NH_4^+	Ammonium Nitrogen
NO	Nitric Oxide

NO_2	Nitrogen Dioxide
NO_3^-	Nitrate Nitrogen
NO_x	Oxides of Nitrogen (includes NO and NO_2)
NPDWR	National Primary Drinking Water Standards
NPP	Net Primary Production
NSF	National Science Foundation
P	Phosphorus (elemental)
P_{org}	Organic Phosphorus
PO_4^{3-}	Phosphate
ppm	Parts Per Million
UFORE	Urban Forest Effects Model
US	United States
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service

1. INTRODUCTION

In the fall of 2004, a group of University of Minnesota research fellows conducted a series of household interviews and field surveys in the city of Falcon Heights, Minnesota. The surveys were constructed by a team of University faculty members and research associates, with the purpose to collect detailed information on household consumption, behaviors, and attitudes. The surveys were conducted in the homeowner's residence, and consisted of a sit-down interview with the principal homeowner, and a field survey of the yard to gather biological data.

The survey was developed to obtain information that could be translated into quantitative data to determine overall household consumption and flux of carbon (C), nitrogen (N) and phosphorus (P) as they relate to household activities and personal choices. For purposes of this thesis, "flux" is defined as the quantitative measurement of inputs and outputs through the household unit, including any portions that are sequestered within or exported from the household.

The survey included six general sections:

- general household characteristics
- family characteristics and household life
- travel and transportation
- household waste
- energy consumption
- lawn management

Additionally, the survey included a qualitative component giving homeowners the opportunity to expand upon their responses, and provide further detail as to their attitudes and behaviors as they relate to their consumption patterns. A full copy of the survey (*Falcon Heights, MN - Urban Nutrient Cycling Household Study Questionnaire*) is included as Appendix A.

For purposes of this study, the boundary of a household is conceptual rather than strictly physical. The physical boundary includes the property line in the horizontal plane, the soil to the bottom of the root zone, and the atmosphere above the height of the tallest vegetation in the vertical direction. Activities that are done outside of the household physical boundary, but associated with personal choices (e.g., air transportation, automobile travel, food consumption, etc.) were also included in this study, as they constitute a major component of consumption and overall element fluxes associated with household choices.

Quantitative information from homeowner responses was collected, processed, and analyzed with the Household Flux Calculator (HFC) - a spreadsheet accounting model which was developed as part of this study to estimate fluxes of C, N, and P through a household system (Baker et al., 2007). Approximately 40 variables collected from the surveys for each household were inputted into the HFC. Once inputted, the model performs a series of calculations and conversions, ultimately generating quantitative data on overall consumption and flux of C, N, and P based on household activities. The HFC generates a separate worksheet for each household, displaying summary data tables and graphs of C, N, and P inputs and outputs associated with household activities. C, N, and P fluxes were also separated into eleven separate household categories, which were subsequently analyzed for variability and trends:

- Pets
- Lawn Maintenance
- Vehicles
- Air Travel
- Electricity[i]
- Natural Gas[ii]
- Other Energy
- Paper/Plastic
- Food
- Wastewater
- Miscellaneous

Additionally, the HFC estimates the forms of C, N, and P coming into the household (e.g., organic C [C_{org}], N_2,) and being exported from the household (e.g., carbon dioxide (CO_2), nitrous oxides (NO_x), methane (CH_4), etc.). This information is useful in that it not only estimates the total quantity of each element coming into and leaving households, but also the ultimate environmental fate of each element. Baker et al. (2007) contains a detailed description of the methodology, assumptions, and conversion factors used to develop the HFC model. Further discussion on the development of the HFC is provided in Chapter 3.

This thesis analyzes the variability of C, N, and P flux among the households surveyed. Furthermore, this thesis highlights household activities which have the greatest influence on the inputs and outputs of household C, N, and P, with the goal of developing a better understanding of how decisions and choices made on a household level impact local, regional, and global environments.

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[i] Previous 12 months of utility bills used with landowner permission.
[ii] Previous 12 months of utility bills used with landowner permission.

2. DEMOGRAPHICS

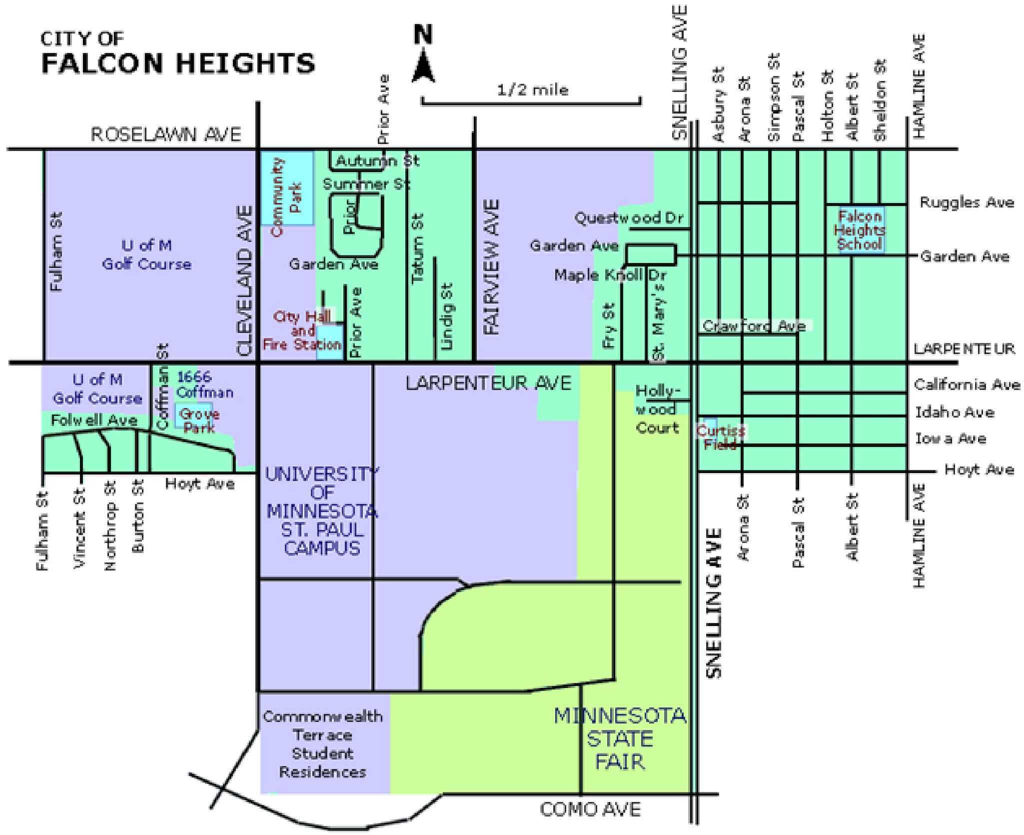
2.1 Falcon Heights, Minnesota

2.1.1 Population and Statistics

All of the survey participants are homeowners (single-family detached homes) located within the city limits of Falcon Heights, Minnesota, an inner-ring suburb of the Minneapolis-St. Paul metropolitan area. According to the 2000 United States (US) Census, Falcon Heights has a population of 5,572 and is comprised primarily of Caucasians (77.7%) and Asians (14.9%) (US Census, 2000).

The city is approximately 2.24 square miles in area with a population density of 2,487.5 persons mile^{-2}. The majority of the land mass of the city is comprised of the University of Minnesota-St. Paul campus (and associated agricultural research plots) and the Minnesota State Fairgrounds. Residential property is concentrated in the northeastern sector of the city and in smaller pockets north and west of the St. Paul campus (denoted in teal on Figure 2.1, below).

Figure 2.1: City of Falcon Heights, Overview Map (City of Falcon Heights, 2003)



Compared to the US average, the city has a substantially higher percentage of residents with a bachelor's degree or higher, 70.3% compared to 24.4%, respectively. Both the median annual household income and median value of single family owner-occupied homes exceed the national average - \$51,382 compared to \$41,994, and \$161,400 compared to \$119,600, respectively. The median age of residents is 30.9 years, compared to the US median of 35.3 years (US Census, 2000).

The US population has grown substantially more urban and metropolitan in the last several decades. Based on a US Census data from 2000, it was estimated that approximately 80 percent of the US population lives in metropolitan areas, with 50 percent of the total population living in suburban areas (Hobbs and Stoops, 2002).

This study focuses exclusively on single family homeowners (no apartment, townhouse or condominium dwellers). This demographic group represents a majority (66.2%) of all residences in the United States (US Census, 2000).

Given recent demographic trends towards urbanization and suburbanization, Falcon Heights was deemed to be representative of a significant portion of the nation's population, now and into the foreseeable future. As such, data obtained from this survey serves a base set of data that could realistically be extrapolated to a larger population pool, as well as providing a useful comparative data set for future surveys. The data provides valuable insight into the level of variability that exists between households within the same geographic area, and also what household decisions have the greatest influence on C, N, and P flux.

2.1.2 Climate

The Minneapolis-St. Paul metropolitan area, which includes Falcon Heights, is located in a temperate climate zone, characterized by a cold winter season, warm to hot summers, and moderate fall and spring seasons. The area is included within Climate Zone 1, defined by the US Department of Energy (DOE) as areas which experience < 2,000 cooling degree days (CDD) and > 7,000 heating degree days (HDD) annually (EIA, 2003).

Table 2.1 provides a summary of climate information for the Minneapolis-St. Paul metropolitan area, based on data gathered between 1971 and 2000 (NCDC, 2003).

Table 2.1: Summary of Minneapolis-St. Paul Climate Data (1971-2000)	
Normal Daily Maximum Temperature (°F)	54.7
Mean Daily Temperature (°F)	54.5
Highest Daily Maximum Temperature (°F)	105
Normal Daily Minimum Temperature (°F)	35.9
Mean Daily Minimum Temperature (°F)	35.8
Lowest Daily Minimum Temperature (°F)	-34
Normal Heating Degree Days (HDD)	7,876
Normal Cooling Degree Days (CDD)	699
Normal Precipitation (annual, inches)	29.41
Normal Snowfall (annual, inches)	55.9

2.2 Sample Group

2.2.1 Overview

Introduction letters were sent to 200 randomly selected homeowners in the City of Falcon Heights. The mailings were sent only to single-family homeowners, and did not include condominium/townhouse owners or apartment renters. These letters contained general information describing the scope and purpose of the household survey, and further informed future participants that their responses would be analyzed in comparison to those of the other participants. The homeowners were also informed that their information would remain anonymous during and after the survey was completed and data was analyzed.

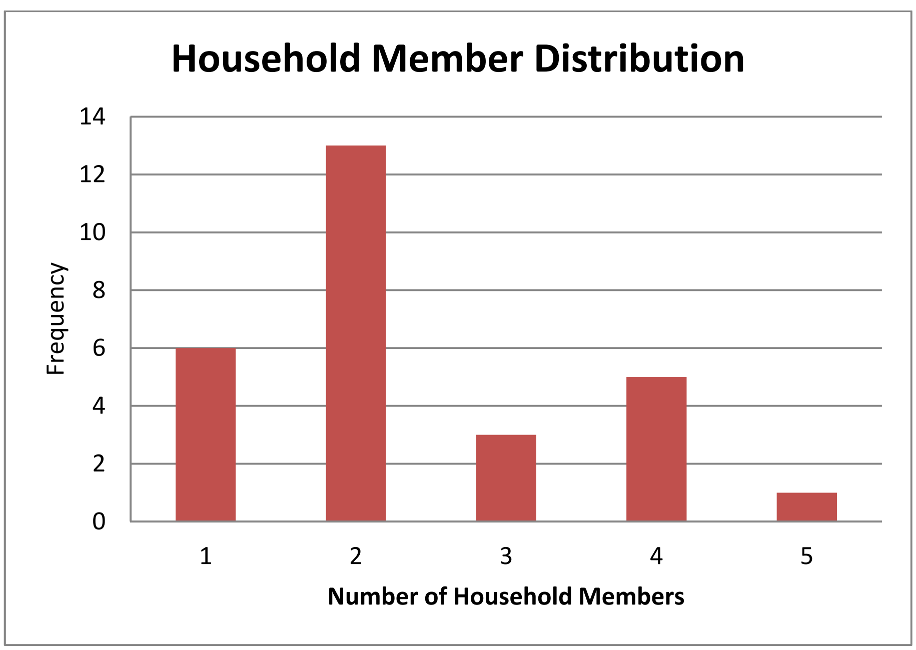
From the initial contact list, thirty-four survey participants volunteered to participate and were subsequently interviewed (see Chapter 3 for details on survey development and implementation). Of this group, six of the households were eliminated due to incomplete data. Two of the households did not consent to releasing household energy data, and four households did not provide adequate mileage estimates for the vehicle usage. As a result, the analysis presented herein is limited to a final sample group of 28 households.

Surveys were conducted in the homes of the survey participants, and consisted of a face-to-face interview with an adult resident of the household. Additionally, a field survey was implemented, to obtain information on acreage of impervious and pervious surfaces (e.g., lawns and gardens), as well as an inventory of the trees located within the property boundary.

2.2.2 Household Members

The number of household residents ranged from 1 to 5, with an average of 2.4 members per household. The vast majority of households (68%) contained only 1 or 2 household members (see Figure 2.2 below).

Figure 2.2: Household Members Distribution

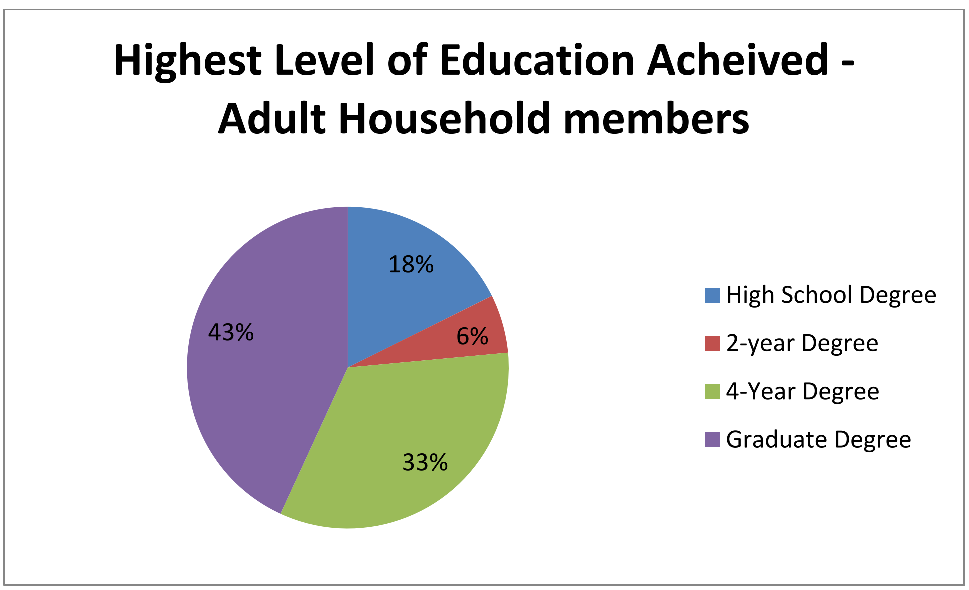


Age of the household members ranged from 6 to 88; however, of the 28 households included in this analysis, only five contained children under the age of 18.

The median age of household members was 49.0 years, which is considerably higher than the median ages of 30.9 and 35.3 for the City of Falcon Heights and the US, respectively (US Census, 2000). Additionally, all surveyed households consisted of Caucasians with no minority groups represented.[iii]

There are a total of 53 adults in the 28 households. With the exception of one household (with two adult members) which abstained from providing data, the highest level of education achieved of each adult member of the household was collected. All of the adult household members had at least high school degrees, with the vast majority completing 4-year and/or graduate degrees. A graphical representation of the highest level of education achieved for adult household members is provided in Figure 2.3, below.

Figure 2.3: Highest Level of Education Achieved – Adult Household Members

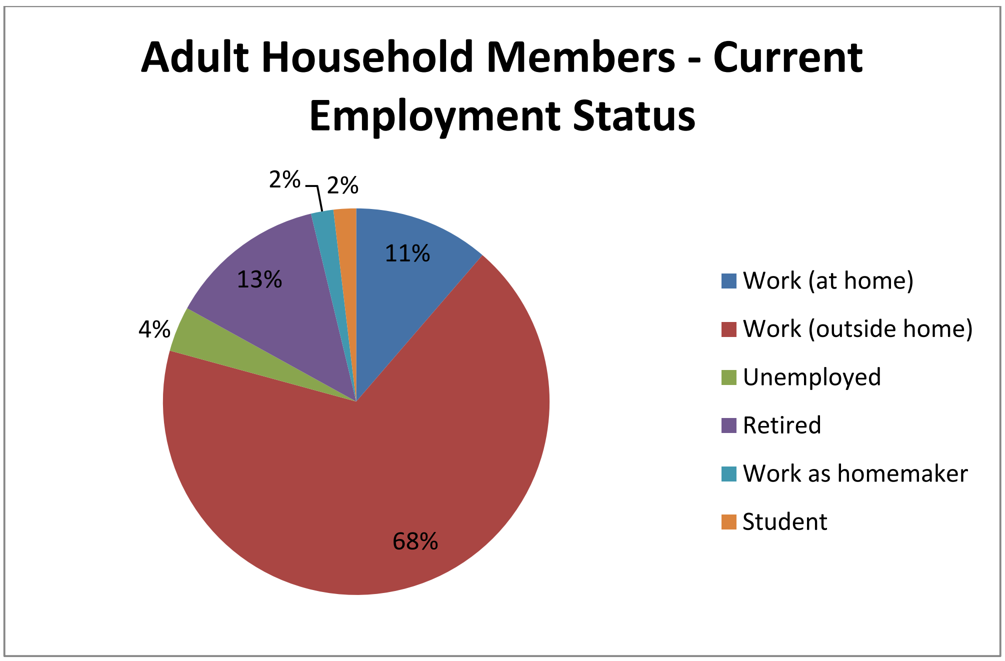


Information was also gathered on the current employment status of each adult member of the household, which was provided for all 53 adults. The majority (68%)

[iii] Of the 28 households, one did not provide data on racial composition of family members.

of the adult household members work outside the home, with sizable percentages either retired (13%) or working at a home office (11%). Less than 10% were either unemployed, working as a homemaker, or a student. A summary is provided as Figure 2.4 below.

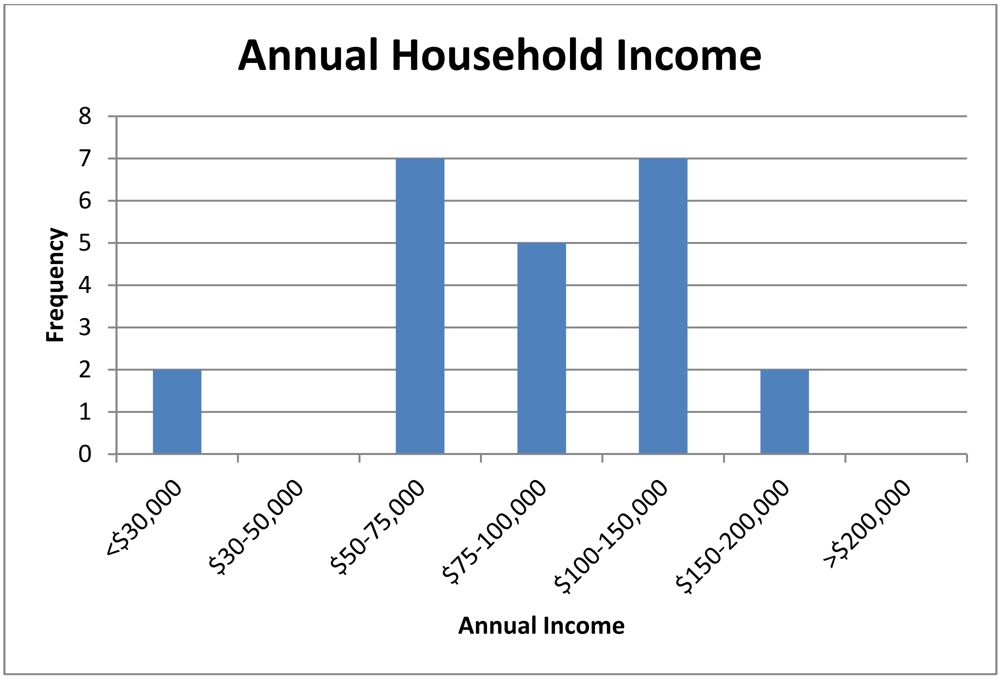
Figure 2.4: Current Employment Status of Adult Household Members



Survey participants were asked to provide household annual income levels, within bracketed income ranges. Annual household income (pre-tax) ranged from less than $30,000 annually up to $200,000. The majority of households earned between $50,000 - $150,000 per year, with two households earning less than $30,000 per year.[iv] Four households abstained from providing income data. A summary is provided below as Figure 2.5.

[iv] The two households earning less than $30,000 annually included a retired couple (Household 129) and a single, unemployed person (Household 120).

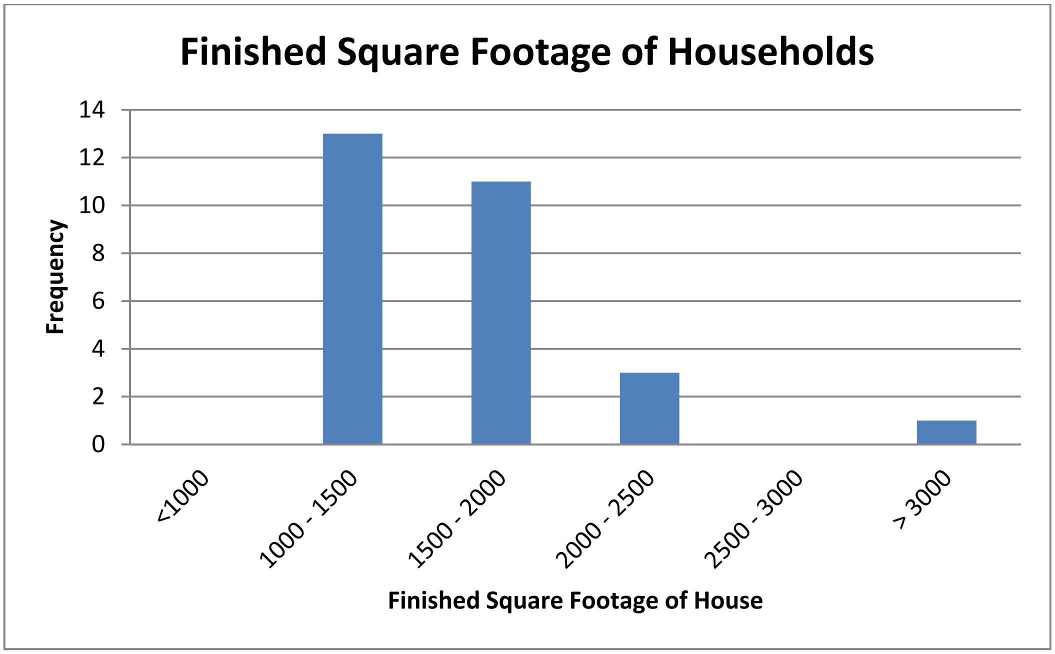
Figure 2.5: Annual Household Income Summary



2.2.3 Housing Characteristics

The finished square footage of each home, acreage of the household lot, and age of the home were obtained via publicly available municipal plat data, accessed on the Ramsey County (Minnesota) website (Ramsey County 2005). The average finished square footage of the households was 1,616 square feet, with the minimum and maximum values being 1,058 and 3,248 square feet respectively. A summary is provided below as Figure 2.6.

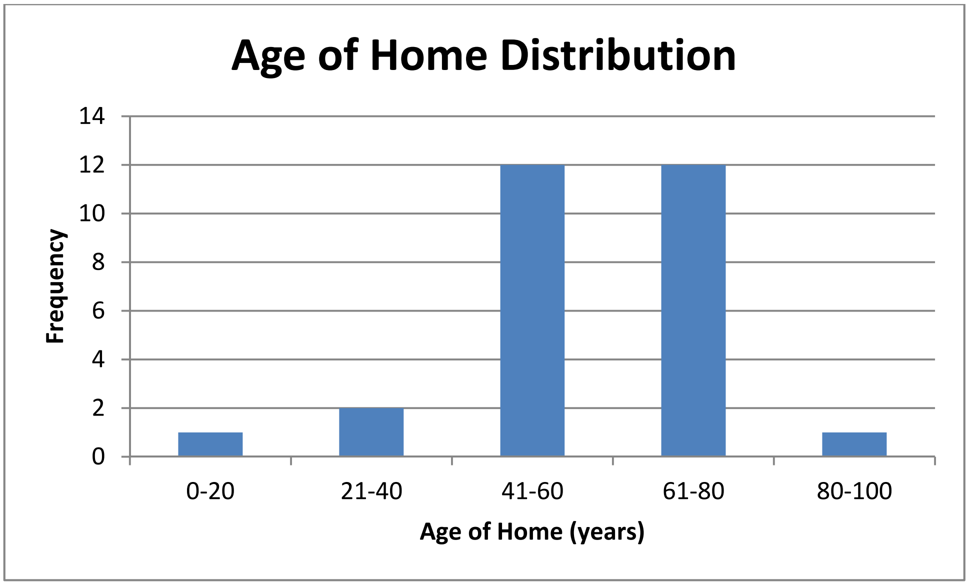
Figure 2.6: Finished Square Footage of House



The oldest and newest homes were constructed in 1915 and 1985, respectively, with the average age being 57.0 years[v]. Twenty-four of the 28 homes (85.7%) were between 40 and 80 years old at the time of the survey. Figure 2.7 provides an overview of age of homes among the survey participants.

[v] At the time of the survey (2005)

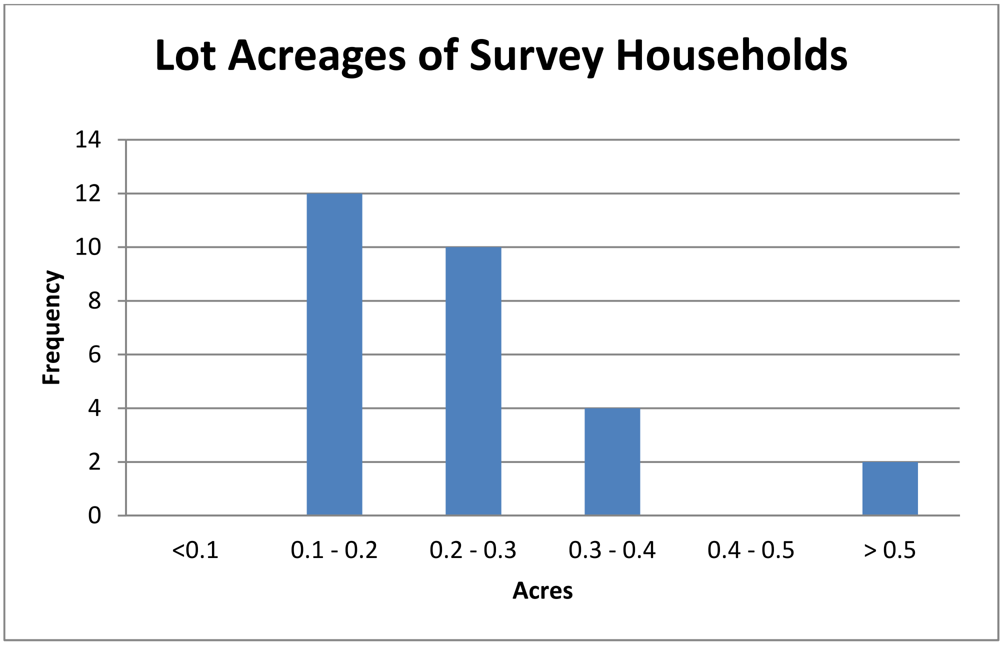
Figure 2.7: Age of Home Distribution



Within the survey group, the lot sizes varied from a minimum of 0.12 acre to a maximum of 0.50 acre, with an average of 0.24 acre[vi]. During the field component of the household surveys, additional measurements were taken to estimate square footage of impervious and pervious portions of the property (discussed in Chapter 5). Figure 2.8 below summarizes the lot acreages for the 28 households.

[vi] One acre = 43,560 square feet

Figure 2.8: Lot Acreages of Survey Households



3. SURVEY DEVELOPMENT AND IMPLEMENTATION

3.1 Overview

The survey utilized in this household study was developed by a team of University of Minnesota research scientists, professors and fellows, representing a varied interdisciplinary background; including a sociologist, landscape ecologist, soil scientist, environmental engineer, and graduate research assistants. Funding was provided by the National Science Foundation (NSF). The survey was constructed in a fashion to provide data which could be quantified and directly inputted into the HFC model, which was developed in tandem with the survey for the purpose of converting household information obtained in the interviews into quantitative input and output values of C, N, and P. A field portion of the survey was also incorporated to account for C, N, and P cycling and sequestration (or loss) from the homeowners' yards and vegetation.

In addition to information gathered from the in-house interviews, data sources included: energy bills provided by the local utility for these homes (with the consent of the homeowners), odometer readings from household cars, and information contained in municipal plat files. Certain variables were estimated based on national or regional per capita averages as described in Baker et al, 2007 (food consumption, household waste and wastewater, etc.). The field survey provided data on the approximate square footage of lawns, garden areas, and also included an inventory of the number, species, and physical characteristics of trees.

The quantitative portion of the survey consists of six general sections:

- General Household Characteristics
- Family Characteristics and Household Life
- Travel and Transportation
- Household Waste
- Energy Consumption
- Lawn Management

Material gathered from each of these sections was transcribed, recorded and organized into a database (Microsoft Excel) system. The data was then converted into a useable format for direct inputting into the HFC model. A brief description of each section of the survey, and how information obtained from it was used in the HFC are described in the remainder of this chapter. A thorough breakdown of the assumptions used to develop the HFC model is detailed in Baker et al., 2007.

3.2 General Household Characteristics

This section of the survey includes eight questions regarding general features of the house including square footage, remodeling and additions, and use and age of common household appliances. These questions were primarily devised to obtain information that would relate to patterns related to household energy consumption through heating and electricity. All homes were assumed to utilize natural gas for heating of their homes during winter months. Actual quantitative data related to natural gas and electricity usage were obtained from utility bills provided upon homeowner consent. Information collected in this section provided useful comparative data to determine the effect of square footage and the age of the home on overall household electrical and natural gas consumption.

Additionally, homeowners were questioned on their use of miscellaneous sources of household energy, including the use of fireplaces, propane, and charcoal grills. The total cords of wood (128 cubic feet), gallons of propane and pounds of charcoal consumed annually were recorded. The combustion of fossil fuels related to household energy represents an input of C_{org} into the household, and an export of CO_2 and carbon monoxide (CO).

3.3 Family Characteristics and Household Life

Several questions in the survey were devised to gather basic demographic data and some routine actions of each household resident. These included questions regarding age, gender, employment/education status, location of occupation/school, and the amount of time in a year that the family spends away from home in a second residence, if any. This information helped provide useful background data to identify consumption patterns as they related to socioeconomic factors. General demographic information for the household survey members is described in further detail in Chapter 2.

3.3.1 Food and Diet

Although survey participants were questioned as to their general eating and diet habits, actual caloric consumption of food inputs were assumed based on national average consumption of protein, fat, carbohydrate and fiber by age and sex strata obtained by the US Department of Agriculture's (USDA) Continuing Survey of Foods (USDA, 2005). Because each household in the survey pool consisted of Caucasians, average food consumption for the "white" race was used in this analysis. Food consumption for each household was computed as the sum of consumption by each resident, as determined by age range (<5, 6–11, 12–19, 10–39, 40–60, 60 and over) and gender. C conversion factors for proteins, fats, carbohydrates, and fiber were estimated from Klass 2004.

Further, respondents were asked whether they have garbage disposals, and if so, approximately how much of their food waste they dispose of in the garbage disposal. For household with garbage disposals, the amount of food waste per family member was assumed to be 0.05 kg wet weight capita^{-1} day^{-1} on a dry-weight basis (Metcalf and Eddy, Inc., 1991). Although this question does not provide unique or individualized information on C, N, and P in food waste generated by households, it does provide useful information as to the environmental fate of these elements; whether food waste ends up in wastewater, landfills or compost to be returned to the homeowner's yard.

C, N, and P from food inputs are exported from the household via excretion, respiration or disposal to landfill or garbage disposals. Composted food waste was assumed to be applied to the lawns or gardens of the households, thus becoming an export from the food system, and an input to the lawn component of the HFC model.

3.3.2 Pets

This section of the survey includes questions regarding household pets (restricted to cats and dogs); however, the HFC used in this analysis only includes input for dogs. Information was collected on the number of dogs, approximate weight, and management of pet waste. Protein, fat, fiber, moisture content and P were estimated based on an informal survey of 12 popular dry dog foods. Caloric consumption of dogs was estimated based on a formula provided by Purina

Corporation (Baker et al., 2007):

$$ME = 110(W)^{0.75}$$

Where ME = metabolizable energy, (kcal day^{-1}), and W = weight of dog (kg).

3.4 Travel and Transportation

The survey included a section to gather information related to each household member's travel activities in the 12-month period prior to the interview being conducted. This included air, automotive, motorcycle, and bus transportation. Additionally, questions were asked as to the type of transportation and distance for commuting to and from school or work to determine how many miles of transportation were due to commuting (essentially a fixed distance) and how many miles were driven for discretionary purposes.

3.4.1 Automobile Use

Quantitative data was collected for each automobile used by the household. Several details were collected on each household automobile, including: make/model, year, year of purchase, number of cylinders, number of miles on the automobile when purchased, and current number of miles. For households with automobiles that had been owned for less than two years, a follow-up letter was sent one year after the survey to obtain current mileage on each vehicle, in order to obtain more accurate estimates of annual miles driven. Of the follow-up letters sent, four were not returned; thus these households were eliminated from the analysis of variability.

For each household automobile, the average fuel economy was estimated from annual USEPA Fuel Economy guides, which provide estimated average fuel economy figures (in "miles per gallon" or mpg) for automobiles sold in the United States

(USEPA, 1978-2005). Using the annual miles driven per vehicle and the USEPA mpg rating, total number of gallons of gasoline consumed was estimated. The gallons of gasoline became a direct input into the HFC model, as the combustion of one gallon of gasoline releases 8.9 kg (19.6 pounds) of CO_2 to the atmosphere. Additionally, NO_x and CO emissions resulting from automotive transportation were based on the USEPA MOBILE 6.2 emission models. Average emissions for NO_x were 0.95 g $mile^{-1}$ and 1.22 g $mile^{-1}$ for passenger cars and light-duty trucks, respectively. The corresponding CO values are 12.4 g $mile^{-1}$ and 15.7 g $mile^{-1}$ (USEPA, 2005).

3.4.2 Air Travel

The survey participants were asked to provide information about trips made via airplane for each member of the household in the twelve months prior to the interview. For each trip, the departure and destination airports were recorded. Commercial flight routes typically follow a geodesic or "great circle" route, which is the shortest distance between two points on a sphere, which can be calculated from the departure and destination airport's latitude and longitude coordinates using the Haversine formula (Sinnot 1984). For each trip, the distance between the departure and destination airports was calculated from determining each airport's latitude and longitude coordinates, and entering the coordinates into the Haversine formula. All trips were assumed to be direct flights, as the survey did not ask about layovers. As such, this section likely underestimates total miles flown, and thus, total emissions of CO_2 and NO_x resulting from air travel.

By summing the total air travel miles for each member of the household, the total number of passenger miles was calculated for each household. Combustion of jet fuel releases 247 g of CO_2 per passenger mile for domestic flights (short range) and 277 g of CO_2 per passenger mile for international flights (long range) (EIA, 2005). NO_x emissions were estimated as 8.68 g NO_X kg^{-1} of jet fuel consumed for short range flights, and 19.6 g NO_x kg^{-1} for long-distance flights (Schulte and Schlager, 1996; Schulte et al., 1997). For each household, the total number of short-range (domestic) and long-range (international) passenger miles were estimated. These values became direct inputs into the HFC, which converts passenger miles into emissions of CO_2, and NO_x per passenger mile of air transit due to the combustion of jet fuel.

3.5 Household Waste

Survey participants were asked several questions relating to their production of solid waste, as well as their recycling of paper, plastic, glass and various metals. Given that the composition of waste to landfills varies considerably from household to household, the actual amounts of solid waste generated in the HFC were based on national and regional per capita averages.

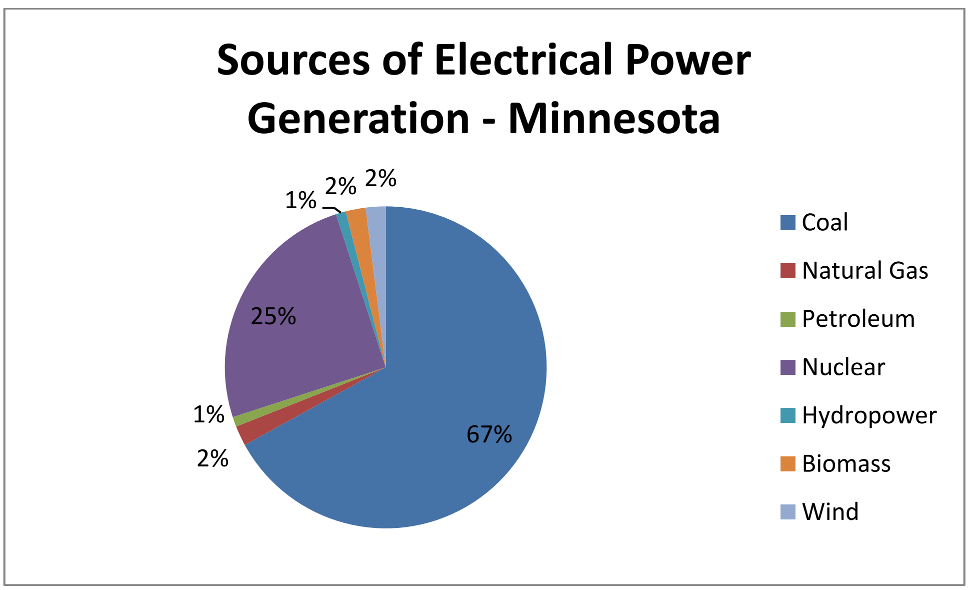
The total fluxes of paper and plastics were assumed to be 160 kg $capita^{-1}$ $year^{-1}$ and 36 kg $capita^{-1}$ $year^{-1}$, respectively. These values were derived from the sum of outputs to landfills (Beck, Inc., 1999) and residential recycling rates from the City of Minneapolis recycling program. Elemental compositions for paper and plastics were assumed from Tchobanoglous et al., 1993.

3.6 Energy Consumption

The survey contained several questions related to household energy consumption, as well as detailed questions related to the ownership and use of different appliances (air conditioning, typical thermostat settings, etc.). Survey participants were asked to sign a consent form, allowing access to their electric and natural gas bills for the past twelve months. Of the initial 34 household survey participants, two did not give their consent for this information to be released; thus, these households were not analyzed in this thesis.

For households which did give consent, natural gas (in hundred cubic feet [CCF]) and electricity usage rates (kilowatt hours or "kWh") were collected. Total CO_2 emissions related to the consumption of natural gas were based on a conversion factor of 5.47 kg CO_2 generated per CCF of natural gas consumed (EIA 2003). In Minnesota, electrical energy is primarily derived from a mixture of coal, nuclear and natural gas, with smaller percentages coming from petroleum, biomass, hydropower and wind (EIA 2002). A summary of electric power generation in Minnesota is provided below in Figure 3.1 below.

Figure 3.1: Percent Composition of Fuels Used in Minnesota Electrical Power Generation



The composite CO_2, CH_4, and NO_x emission factors for electricity generated in Minnesota (which accounts for the relative distribution of electrical energy sources displayed in Figure 3.1 above) are summarized in Table 3.1 below (EIA 2002):

Table 3.1: Composite Emission Factors, kg per kWh	
CO_2	0.69
CH_4	0.0071
NO_x	0.0112

3.7 Field Survey and Lawn Management

Information on lawn characteristics and management practices were collected via an in-house survey as well as a field survey of the homeowner's yard. Homeowners were asked about the frequency and relative application rates of fertilization, lawnmower use, and management of lawn clippings and other yard waste (branches, leaves, etc.). P and N are common nutrients in lawn fertilizer; however, no P was assumed to be inputted via fertilization, since the state of Minnesota passed legislation banning the use of P in fertilizers in urban areas (except in cases where a soil test shows a P deficiency), which became effective January 1, 2005 (Minnesota Statutes 2005).

Based on the responses related to lawn clipping management (clippings on or off) and frequency of fertilization (none, moderate, or high), the homeowners were placed into one of five lawn management categories. From these 5 categories, N fertilization rates were assumed from Milesi et al. 2005 (see Table 3.2 below).

Table 3.2: Lawn Management Summary	
Management Classification	**kg N fertilization ha^{-1} lawn $year^{-1}$**
None	0
Moderate (clippings on)	73
Moderate (clippings off)	73
High (clippings on)	146
High (clippings off)	146

Additionally, a field survey was conducted for each household. The purpose of the field survey was to determine the dimensions of all structures/impervious areas on site, and the extent and type of vegetation (lawn, garden, trees, etc.) within the property boundaries. The square footage of each lawn was estimated by physically measuring the square footages of all non-lawn components of the yard (surface areas of house/garage foundation, sidewalks/driveways, landscaped areas, etc.), and subtracting this amount from the total square footage of the lot size accessed via publicly available municipal data for the household (Ramsey County 2005). Several calculations in the HFC model, including atmospheric deposition, fertilization, consumption of lawnmower gasoline, and net primary production (NPP) were directly related to the square footage of the lawn size.

Detailed information was also collected on all trees within the homeowner's property to account for C and N sequestration, as well as the production of leaves. For each tree, five variables were collected:

- Tree Species
- Diameter at breast height (dbh, inches)
- Percent Crown Dieback

- Crown Light Exposure
- Tree Height (feet)

The height of each tree was estimated using a Suunto® clinometer (trees at least 20 feet tall) or by direct observation (trees less than 20 feet). All other variables were collected via direct observation, using rationale and criteria detailed in “The Urban Forest Effects” (UFORE) Model: Field Data Collection Manual.” (Nowak et al. 2005). A total of 344 trees were inventoried, with variability ranging from one tree to 34 trees per household lot.

NPP rates for each tree were modeled using the US Forest Service’s (USFS) UFORE model (Nowak and Crane 2000). Additionally, the UFORE model provides estimates for gross C sequestered (total C sequestered in the biomass of the tree) and net C sequestered (C sequestered in one year), based on the specific characteristics of each tree. Common tree species inventoried included maple, oak, pine, and ash. The inventory of the tree data was sent to David Nowak of the USFS for analysis and processing. Annual leaf production was estimated as 3% of total tree biomass (McPherson, 1998), and C:N:P ratios for wood biomass and leaves were assumed from Rodin and Bazilevich (1967). Areas of shrubbery were noted in the field; however, were not factored into the HFC.

3.8 Survey and HFC Limitations

3.8.1 Sample Pool Limitations

The household surveys associated with this thesis were conducted as part of a “pilot study,” to serve as a small sample pool to be analyzed with the HFC model. Pilot studies are small-scale preliminary studies conducted to check the feasibility of and/or to improve the design of further research. Since this initial survey was conducted in Falcon Heights, through the Twin Cities Household Ecosystem Project (TCHEP), members of the project team have greatly expanded the scope of the survey and use of the HFC, and have since collected data on over 3,000 households in Anoka and Ramsey Counties, Minnesota (TCHEP, 2011).

Although the initial survey and Falcon Heights sample pool provide useful data for comparative analysis among the individual households, given the limited number of households involved in this analysis (28), overall trends and patterns explored in the remainder of this thesis should be considered as preliminary and speculative. The remainder of this thesis does analyze trends, patterns, and relationships identified through data analysis; however, definitive and statistically significant correlations cannot be made due to the small sample size.

As stated above, an initial correspondence was sent to 200 households selected at random in Falcon Heights. While selected at random, the 34 respondents to the initial correspondence are seen to represent a skewed demographic. As discussed above in Chapter 2, Falcon Heights is only 77.7% Caucasian; however, all survey participants (with the exception of one, who did not disclose racial identity) identified themselves as Caucasians. Additionally, based on the demographic information summarized in Chapter 2, on average the survey participants are considerably older and earn a higher income compared to both the national and municipal average. Also, as noted above, this survey focused solely on single-family detached homeowners, and did not include condominiums, apartment dwellers, or townhouses.

While it was the intent of this project to specifically focus on Twin Cities' suburban households, further applications of the survey and HFC could be extended to gather data on a much wider swath of American society. Additional research opportunities include exploring differences between climate zones, rural versus urban households, racial groups, socioeconomic variables, and political and/or religious affiliations. Generally, as the number of survey participants increase, a wider spectrum of society would be represented. Information collected could be used for a variety of purposes ranging from local urban planning and watershed management, to national climate change and energy policy.

3.8.2 Limitations of the HFC

Although the survey was comprehensive in nature gathering data on eleven categories of household activities (see Chapter 1 above), several inputs into the HFC were computed based on national or regional per capita averages. For instance, C, N, and P related to food consumption were calculated based on age, gender, and racial strata. Additional areas that used per capita averages in the HFC model include paper and plastic consumption, garbage, and wastewater. While these sectors generally represent a small portion of the overall flux of C, N, and P, more detailed information could be collected from the surveys and directly inputted in the HFC model in order to obtain more accurate estimates.

Additional information gathered through the surveys could be refined to better estimate nutrient flux. Related to air travel, survey participants were asked to identify the starting and final airport destinations. Information related to layovers was not collected. As nutrient flux related to air travel is directly related to passenger miles traveled, we have likely underestimated nutrient flux related to this activity.

Additionally, the survey collected data on annual miles driven per household automobile. Volume of gasoline consumed per vehicle was subsequently calculated based on USEPA fuel mileage estimates for the make and model year of the vehicle. However, actual fuel mileage obtained for a specific vehicle is related to several factors (maintenance/condition of car, driving style, highway verses city driving, etc.). A more accurate estimate of gasoline consumption could be obtained by having survey participants keep a log of miles travelled and gasoline purchased over a certain time period.

4. HOUSEHOLD CARBON, NITROGEN AND PHOSPHORUS: AN OVERVIEW

C, N, and P are three elements fundamental to life and also play large roles in local, regional, and global ecosystems. Households "consume" or "convert" these three nutrients in several ways, each of which can have significant regional and global environmental consequences.

4.1 Environmental Overview

4.1.1 Global Warming/Climate Change: Carbon

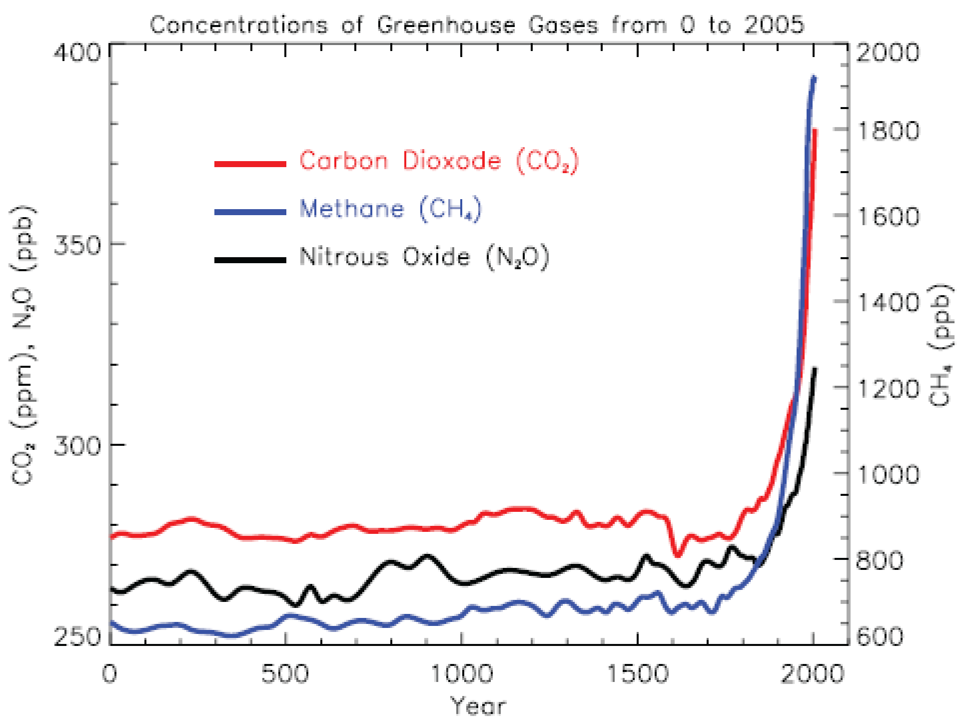
Several household activities (e.g., transportation, household energy, etc.) involve the combustion of fossil fuels, which converts C_{org} to CO_2 and CO. CO_2 is a known greenhouse gas, and anthropogenic emissions of CO_2, in particular, are widely believed to be the primary driving force contributing to global warming (IPCC 2007).

Combustion of fossil fuels also produces trace amounts of CH_4 and CO. Although only emitted in small amounts compared to CO_2, over a 100-year period, CH_4 has a global warming potential (GWP, also known as "carbon dioxide equivalent" or CO_{2e}) of 25. In other words, one kilogram of CH_4 emitted to the atmosphere has the same global warming potential as 25 kilograms of CO_2. On its own, CO has a weak GWP; however, indirect effects of CO occur through reduced hydroxyl (OH^-) levels, which leads to enhanced concentrations of CH_4 and ozone (O_3), which is also a known greenhouse gas (Forster et al. 2007).

Combustion of fossil fuels also converts atmospheric nitrogen (N_2) to oxides of nitrogen (NO or NO_2, commonly known as "NO_x"). NO_X is a critical component in the formation of urban smog and also can be converted to nitric acid in the atmosphere, contributing to acid rain. Additionally, NO_x emissions also contribute to the formation of ground-level O_3, a major component of urban smog.

Since the beginning of the industrial era (approximately 1750), the amount of greenhouse gases in the atmosphere has increased dramatically. This increase is known to be due to human activities, primarily through the combustion of fossil fuels which converts C_{org} to CO_2, and deforestation which limits the amount of atmospheric CO_2 incorporated into plant biomass (Le Treut et al. 2007, Forster et al. 2007).

Figure 4.1: Concentrations of Greenhouse Gases from 0 to 2005 (from Forster et al. 2007)



4.1.2 Water Quality Implications: Nitrogen

N is also a water quality pollutant, with implications for both human health and wildlife ecosystems alike. N (typically in the form of nitrate [NO_3^-] or ammonium [NH_4^+]) is commonly applied as a fertilizer in both urban and agricultural areas. NO_3^-

is highly soluble in water, and thus has a high potential to leach through soils and contaminate groundwater, potentially threatening municipal and private drinking water supplies. Although also soluble in water, NH_4^+ typically binds closely with soil particles and is less susceptible to leaching; however, may enter aquatic ecosystems through soil erosion, and subsequent transport of sediment to local waterbodies.

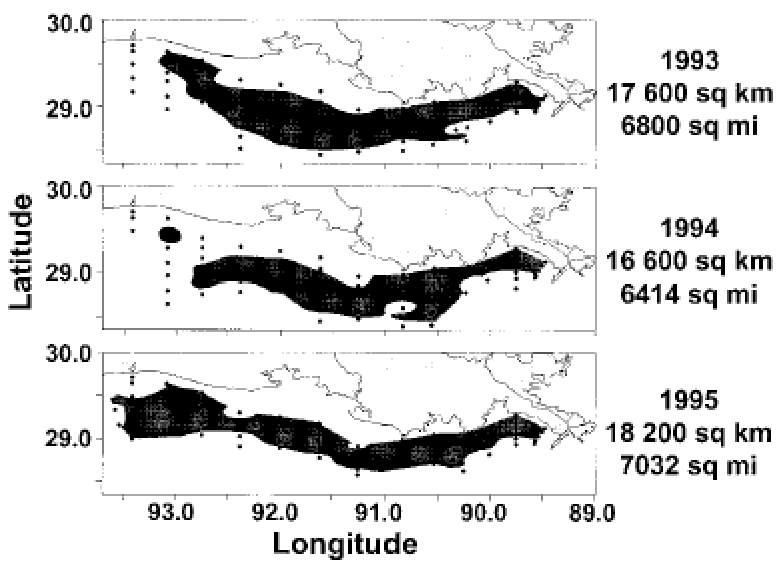
NO_3^- is a primary drinking water contaminant regulated by the USEPA. Infants below the age of six months who drink water containing nitrate in excess of the maximum contaminant level (MCL) could become seriously ill, and if untreated, may die. Common symptoms include shortness of breath and "blue baby syndrome." The current National Primary Drinking Water Regulations (NPDWR) set a MCL of 10 mg L^{-1} for nitrate (USEPA, 2011).

N is also a considerable pollutant with respect to aquatic ecosystems. In particular, N is commonly the limiting nutrient in coastal marine ecosystems (Howarth and Marino 2006). On average for the US, it is estimated that human activity probably has increased N fluxes to the coast by a factor of six (Howarth et al. 2002; Howarth 2003), and two-thirds of the nation's coastal waters are moderately or severely degraded from N pollution, which is causing extensive eutrophication (Bricker et al. 1999).

Eutrophication begins when large algal blooms form in the summer months. As N is the limiting nutrient for algae in saline coastal waters, large algal blooms often occur in the coastal deltas of large river systems with significant inputs of N from urban and agricultural sources. As the algae die off (typically in late summer/fall), they sink and begin to decay. Their decomposition consumes the water of dissolved oxygen (DO). Hypoxic conditions (DO < 2 ppm) may develop, which may cause fish to leave the area and cause stress or death to bottom dwelling organisms that cannot migrate out of the hypoxic zone.

In the US, the most common location for hypoxic conditions in coastal waters is in the Gulf of Mexico near the mouth of the Mississippi River, just off of the Louisiana coast. Excess N from the Mississippi River watershed (which is highly agricultural with many large urban population centers) ultimately drains to this location. As the nitrogen-rich freshwater from the river enters the coastal system, large algal blooms occur, ultimately leading to a hypoxic "dead zone," which forms annually to varying degrees.

Figure 4.2: Geographic Extent of Gulf of Mexico "Dead Zone" 1993-1995 (from Rabalais et al. 2001)



4.1.3 Water Quality Implications: Phosphorus

Much like N is commonly a limiting nutrient in coastal marine ecosystems, P is commonly a limiting nutrient in freshwater systems. Excess inputs of P may lead to eutrophication (Correll 1998). Eutrophic lakes may exhibit undesirable traits, including excessive growth of algae and other aquatic plants. As excess nutrients such as P are supplied, the phytoplankton community may shift to bloom-forming nuisance algae, which are harmful to other organisms (Smith 1990). Similar to the process in saltwater systems, decomposition of algal blooms can lead to foul odors and oxygen depletion, which can in turn lead to fish kills (Carpenter et al., 1998, Smith 1998). Other potential issues include the presence of toxins, unpalatability of drinking water (Lawton and Codd 1991), extirpation of native plants (Gleick 1998, Smith 1998), and loss of biodiversity (NRC 1993, Smith 1998).

4.2 C, N, and P Fluxes through Households

Based on inputted data for each household gathered from the surveys, a table and graph was generated showing the household inputs and outputs ("flux") for C, N, and P as well as their molecular forms entering and exiting the household. The quantities of C, N, and P were separated into one of eleven categories for purposes of comparative analysis:

- Pets
- Lawns/Trees
- Vehicles
- Air Travel
- Electricity
- Natural Gas
- Other Household Energy (wood, charcoal, propane, *etc.*)
- Paper/Plastic[vii]
- Food[viii]

[vii] Determined on a per capita basis (Beck 1999, Tchobanuglous et al., 1993)

- Wastewater[ix]
- Miscellaneous/Uncharacterized Sources (toilet paper, soaps, detergents)

Table 4.1 below outlines the forms of C, N, and P accounted for in this study as both "inputs to" and "outputs from" the household system.

Table 4.1: Forms of Elements		
Element	**Inputs**	**Outputs**
Carbon	C_{org}, CO_2	C_{org}, CO_2, CO, CH_4
Nitrogen	N_2, N_{org}, N_{inorg}	NO_x, N_{org}
Phosphorus	P_{org}	P_{org}

For the majority of the eleven categories analyzed, overall inputs equaled overall outputs, although the form of the element often changed as it was "consumed" by the household. For example, C_{org} from gasoline was considered as an input in household transportation; however, as it is combusted by cars, trucks, and airplanes, the C is exported in the forms of CO_2, CO, and CH_4 gases. Similarly, all C_{org} consumed by household members as food (an input) was exported from the household as either C_{org} in wastewater or respired as CO_2.

Uniquely, lawn management practices (composting, fertilization, and management of yard waste) allow the opportunity for sequestration of C, N and/or P either through accumulation of these elements in the soil, or in the biomass of on-site vegetation. Net losses of C, N, and P may also result from removing organic material (e.g., lawn clippings, raked leaves) from yards, and exporting them off-site.

C_{org} is assumed as an input to the household system for transportation (e.g., automotive gasoline, jet fuel), electric and natural gas usage, paper products and food.

[viii] Determined via algorithms based on gender and age (USDA, 2005)
[ix] Determined on a per capita basis (Baker et al. 2007)

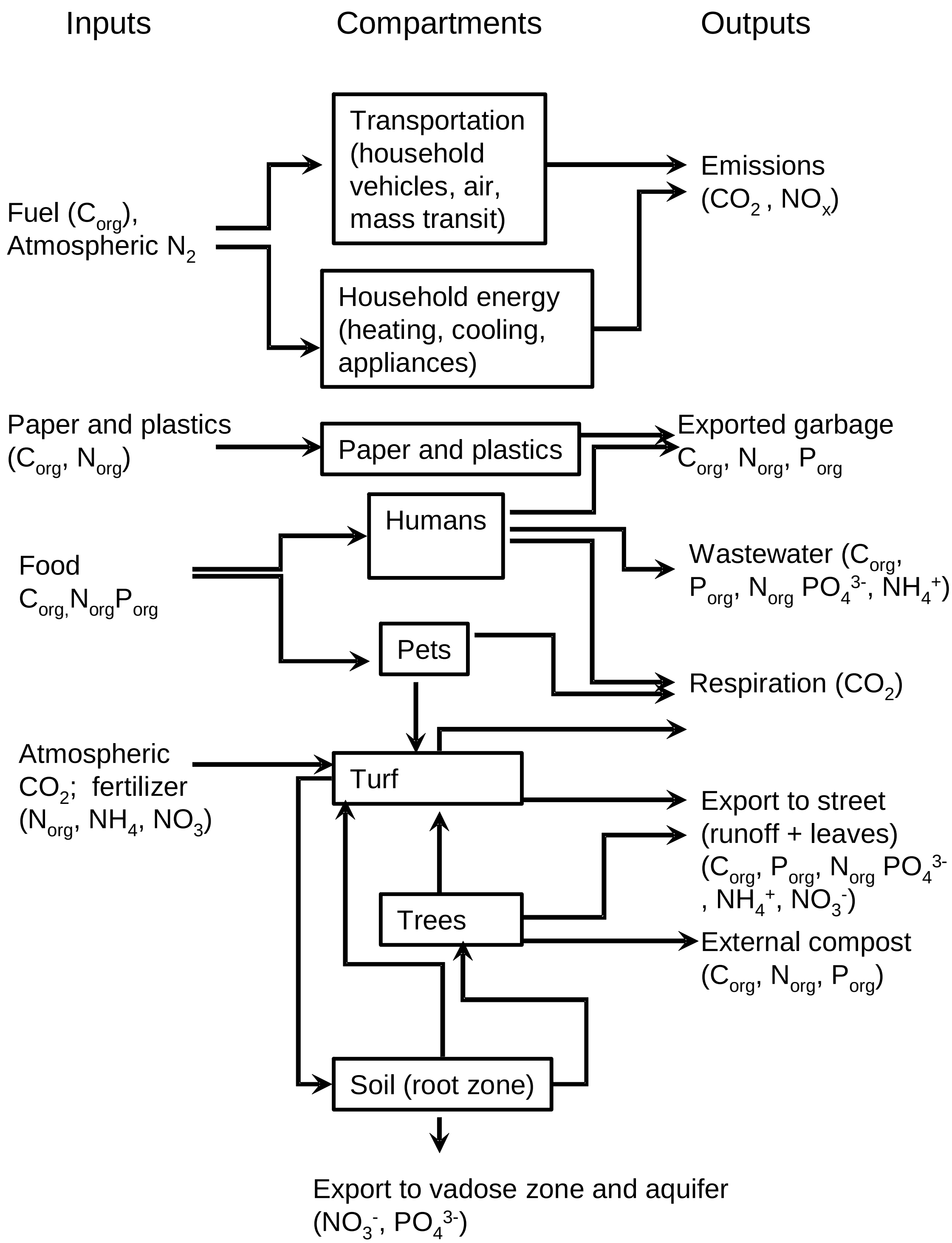
CO_2 is considered an input to lawns and tree through biomass through photosynthesis. Outputs of household C include C_{org} (in the form of human/pet waste), CO (automobiles), and CO2 (human/pet respiration, fossil fuel combustion, decomposition of organic yard materials). Trace amounts of CH_4 from the generation of electricity were also tallied; however, due to the minute quantities generated (< 0.2 kg for all households), a detailed analysis is not provided herein.

Household inputs of N include atmospheric N ($N_{2,}$ atmospheric deposition to lawns, transportation and electricity), N_{org} (pet/human food, paper products), and inorganic N (N_{inorg}) from fertilizers. Outputs include NO_x (transportation, electricity) and organic N (removed lawn waste, food/pet waste). All inputs and outputs of P were assumed to be organic P (P_{org}), resulting from food, human/pet waste, and accumulation or removal of plant biomass from the yards. As stated in Chapter 3.7 above, no inputs of P fertilizer were assumed, given the statewide ban on P fertilizers in the state of Minnesota.

Several household activities result in interrelated cycling of C, N and P. For example, composted food material and pet waste may be considered as exports from one component of the household system, but if applied to homeowners' yards become an input in the lawn system.

Figure 4.3 displays a flow chart of how consumptive household activities convert C, N, and P through urban households, and also displays some of the connectivity of some of the household components.

Figure 4.3: Flowpaths of C, N, and P through an urban household
(Baker, et al. 2007)



5. DATA ANALYSIS AND HOUSEHOLD VARIABILITY

5.1 Overview

Upon completion of the household surveys, the data were compiled and entered in spreadsheet format (Microsoft Excel). A simplified worksheet was constructed for data entry from each household to be inputted into the HFC model, which consisted of approximately 40 user-entered variables. The inputs for each household were then processed through the HFC model, which generates a separate summary worksheet for each household. This generated worksheet displays the household inputs, outputs and sequestration (if any) of C, N, and P in tabular and graphic form for each of the eleven household categories mentioned above.

Considerable variation among several key variables was observed among the 28 households used in this analysis, including:

- number of household members;
- travel/transportation characteristics;
- house and lot size;
- lawn management; and,
- household energy usage.

Each variable contributed to varying degrees to the overall fluxes of C, N, and P on a household level, and also on a per capita basis. Table 5.1 below displays the statistical ranges of some of the most important household variables analyzed.

Table 5.1: Statistical Ranges of Household Variables				
Household Variable	*Maximum Value*	*Minimum Value*	*Mean Value*	*Standard Deviation*
# Family Members	5	1	2.36	1.13
House Size (ft^2)	3,248	1,058	1,616	459
# of Automobiles	3	0	1.8	0.70
# Miles driven yr^{-1}	33,800	0	17,584	8,923
# Air passenger miles yr^{-1}	38,328	0	13,823	10,243
Natural Gas Consumption (CCF[1])	2,109	634	1,124	306
Electricity Consumption (kWh yr^{-1})	19,988	3,613	8,921	4,010
Lawn Size (acres)	0.50	0.12	0.24	0.10

[1] CCF = One hundred cubic feet

5.2 Household Transportation

5.2.1 Automobiles

Of the 28 households surveyed, only one did not own a vehicle in the 12 months prior to the survey. Three of the households had three vehicles, 16 households owned two vehicles, while the remaining nine households had one vehicle. Of the 49 total vehicles owned by the survey households, 16 were light trucks/SUVs while 33 were passenger cars. The majority of the vehicles were newer model vehicles at the time of the survey, with only six of the 49 being over ten years old. None of the survey participants owned a motorcycle and also did not report any use of mass transit (e.g., buses, light rail).

Fuel economy estimates were obtained from the USEPA Fuel Economy Guides for each vehicle (USEPA, 1978-2005), and were used to calculate the total gallons of gasoline consumed as a function of annual miles driven for each vehicle. The following table summarizes the range of fuel economy of the household vehicles.

Table 5.2: Fuel Economy of Household Vehicles

Statistic	Miles per gallon
Maximum	31.7
Minimum	14.8
Mean	23.6
Standard Deviation	4.0

After calculating the number of gallons of gasoline consumed, emissions of CO_2 were calculated based on the conversion factors described in Chapter 3.4.1. As described in Chapter 3.4.1, emissions of CO and NO_x were based on the conversion factors per mile driven for cars of light trucks/SUVs. We assumed no P inputs or outputs occurred through the combustion of automotive gasoline.

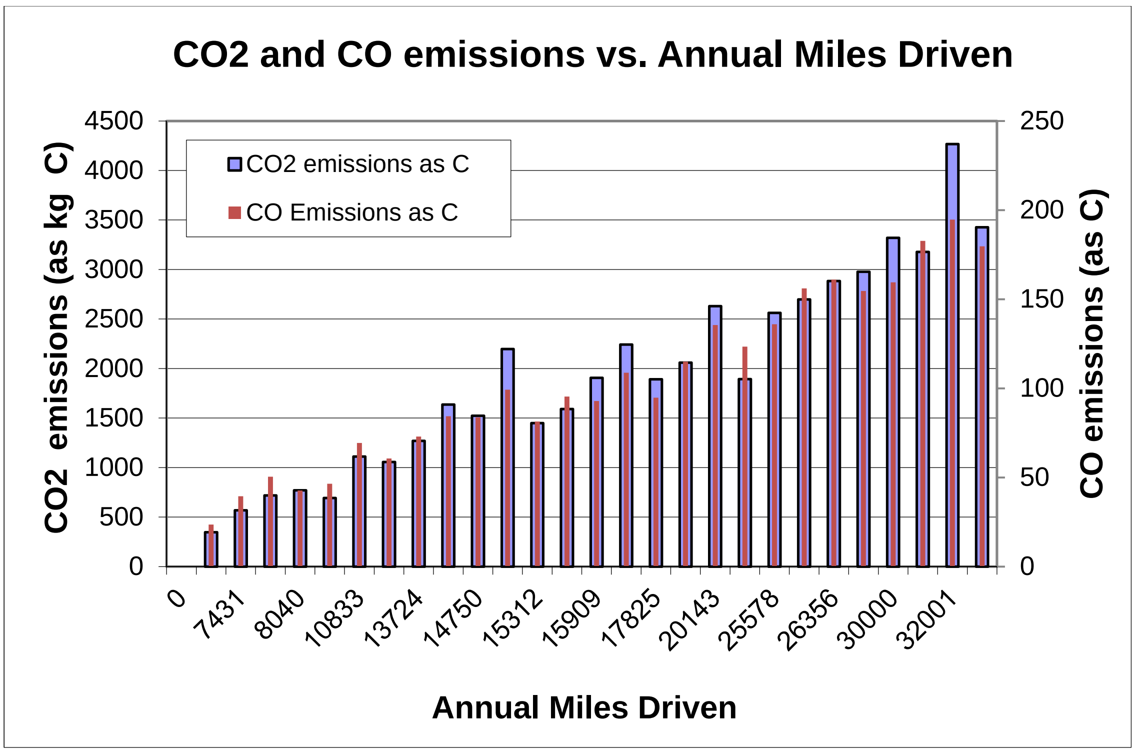
5.2.1.1 Carbon

For combustion of fossil fuels, the amount of C inputs and outputs is directly related to the quantity of the fossil fuel burned and the emission factor per unit of fossil fuel. Based on the total miles driven per vehicle per year, and the fuel mileage estimates for each vehicle, the total gallons of gasoline consumed per year was estimated, and subsequently used to calculate the input of C (in the form of C_{org}) and the outputs of C (in the forms of CO_2 and CO) for each household vehicle.

Because both vehicle mileage and annual miles driven directly determine the total amount of gasoline consumed by the household, the types of vehicles that households own and the amount of miles they drive are direct choices that impact the flux of household C. As annual miles driven increases, so does the quantity of gasoline consumed and thus, the total C consumed. All things being constant, reductions in C_{org} consumed and CO_2 and CO emitted can be made by driving vehicles with greater fuel economy ratings. The amount of miles driven per year is largely dependent on the distance between the household member(s) and their respective place of work/school, and discretionary travel.

Figure 5.1 displays the CO_2 and CO emissions for all households as a factor of annual miles driven per household.

Figure 5.1: CO_2 and CO Emissions vs. Annual Miles Driven – All Households



Based on the large variability among the households in terms of annual miles driven and the fuel economy (mpg) of household vehicle, overall CO_2 and CO emissions related to air travel vary considerably. All things being equal (i.e., annual miles driven), increased fuel economy leads to a reduction of overall CO_2 emissions. However, in this study, a near linear relationship between annual miles driven and CO2 emissions was observed (see Figure 5.2).

Figure 5.2: CO_2 vs. Annual Miles Driven – Scatter Plot

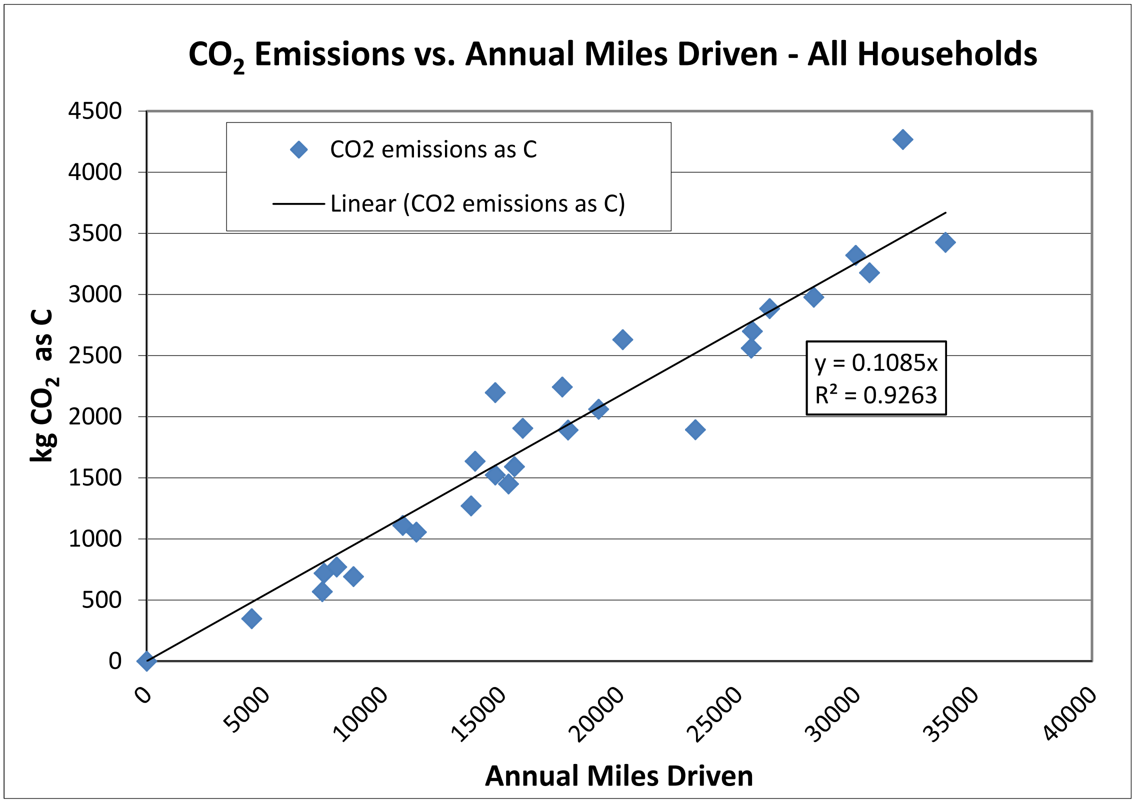


Table 5.3 provides a statistical overview of CO_2 and CO emissions related to household automotive travel.

Table 5.3: CO_2 Emissions from Household Automotive Travel		
Statistic	**CO_2 as C (kg)**	**CO as C (kg)**
Minimum	0	0
Maximum	4,267	195
Mean	1,888	102
Standard Deviation	1,049	51

5.2.1.2 Nitrogen

As described in Chapter 3.4.1, emissions of NO_x related to automobile use were directly related to miles driven, and whether the vehicle is a car or a light truck/SUV. Distribution of NO_x emissions compared to miles driven are shown in Figure 5.3, and show a similar linear relationship as CO_2 emissions (see Figure 5.2, above)

Figure 5.3: NO_x vs. Annual Miles Driven – Scatter Plot

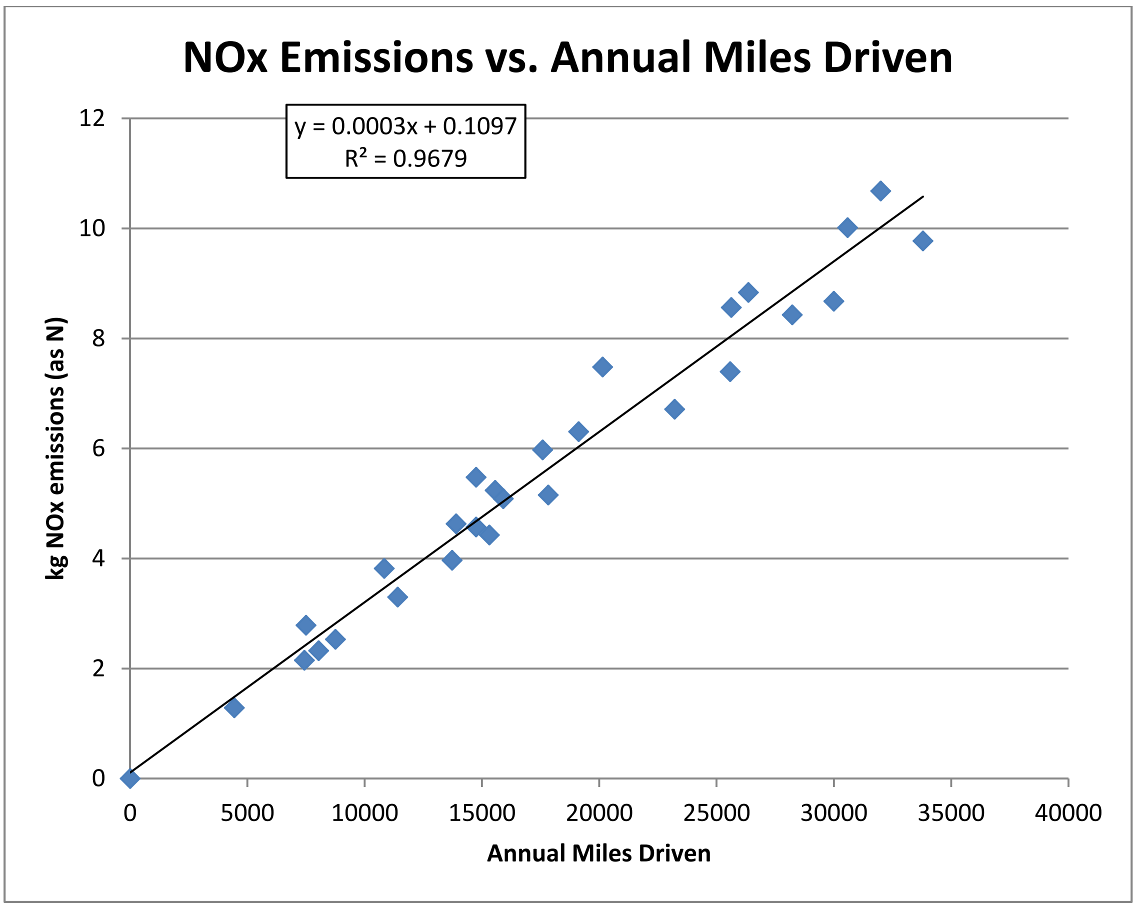


Table 5.4 provides a statistical overview of NO_x emissions related to household air travel.

Table 5.4: NO_x Emissions from Household Automotive Travel	
Statistic	**NO_x (kg)**
Minimum	0
Maximum	10.7
Mean	5.5
Standard Deviation	2.8

5.2.1.3 Phosphorus

As the amount of P in gasoline was assumed to be negligible, no inputs or outputs of P were estimated from the household automotive use.

5.2.2 Air Travel

Information regarding air travel in the 12 months prior to the survey was collected and analyzed. Survey participants provided departure and destination locations, and total mileage was estimated using the Haversine formula, as described in Chapter 3.4.2. Although the survey did not differentiate between air travel for personal or business reasons, for the purpose of this study, we have assumed that all reported information was for personal travel.

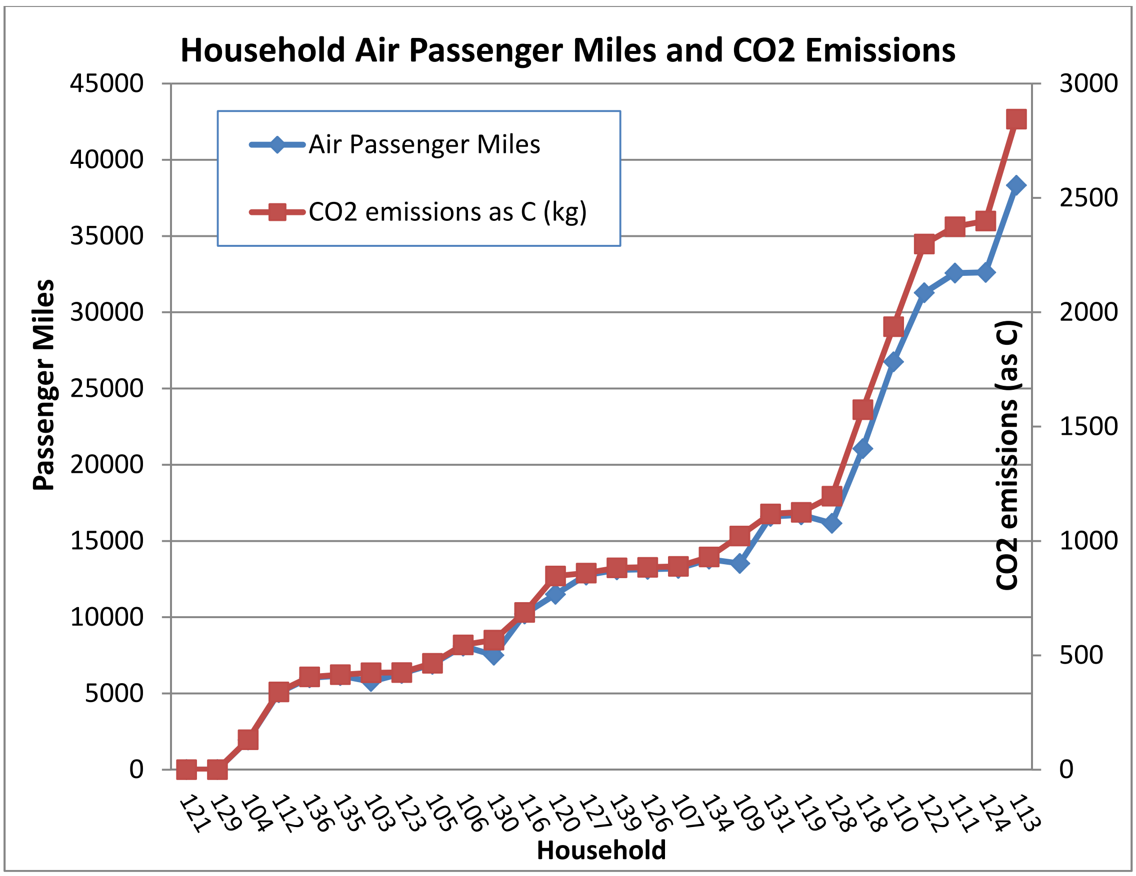
After determining the number of domestic and international passenger miles flown per household, emissions of CO_2 and NO_x were calculated based on the conversion factors described in Chapter 3.4.2. No P inputs or outputs were assumed through the combustion of jet fuel.

5.2.2.1 Carbon

As described in Baker et al. (2007), CO_2 emissions related to air travel were assumed on a per passenger mile basis for domestic and international flights. As such, carbon emissions due to air travel are directly related to the total miles flown. Air travel associated with households is largely assumed to be a discretionary activity associated with vacationing or visiting family or friends. Two of the households did not record any air travel miles in the 12 months prior to the survey. Of the remaining 26 households, nine flew between 0 and 10,000 miles, eleven flew between 10,000 and 20,000 miles, two flew between 20,000 and 30,000 miles, and four flew between 30,000 and 40,000 miles.

Figure 5.4 provides an overview of CO_2 emissions for each household based on passenger miles flown.

Figure 5.4: Household Air Passenger Miles and CO_2 Emissions



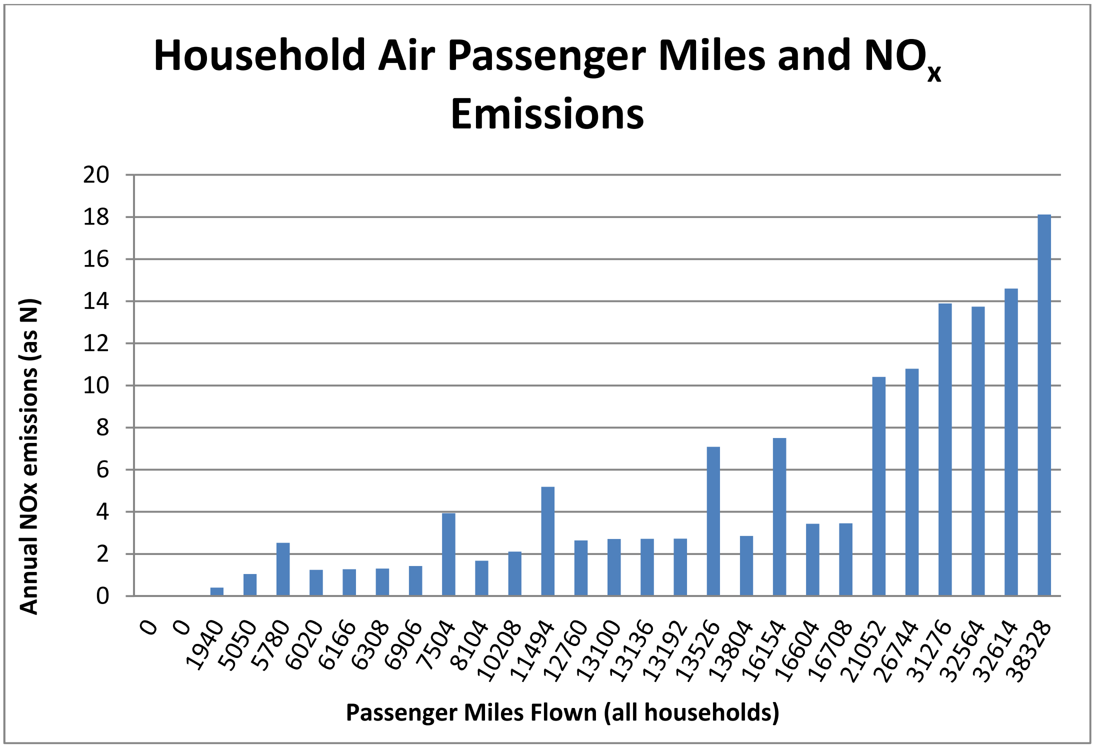
Based on the large variability among the households and the fact that emissions were estimated on a passenger mile basis, overall CO_2 emissions related to air travel vary considerably. Table 5.5 provides a statistical overview of CO_2 emissions related to household air travel.

Table 5.5: CO_2 Emissions from Household Air Travel	
Statistic	**CO_2 as C (kg)**
Maximum	2,844
Minimum	0
Average	985
Standard Deviation	760

5.2.2.2 Nitrogen

Similar to carbon emissions from air travel, emissions of NO_x were estimated on a per passenger mile basis for each household. As described in Chapter 3.4.2, emissions of NO_x were assumed as 8.68 g NO_x kg^{-1} of jet fuel burned (short-range domestic flights) and 19.6 g NO_x $kg^{-1}$of jet fuel burned (long-range international flights. As emissions of NO_x for long-range/international flights are over twice as much as those for short-range/domestic flights, households who had travelled internationally had a substantially larger amount of NOx emissions associated with air travel. Figure 5.5 displays all households' air passenger miles and corresponding NO_x emissions.

Figure 5.5: Household Air Passenger Miles and NO_x Emissions



Based on the large variability among the households and the fact that emissions are estimated on a passenger mile basis (for domestic and international flights), overall NO_x emissions related to air travel vary considerably. Table 5.6 provides a statistical summary of NO_x emissions related to household air travel.

Table 5.6: NO_x Emissions from Household Air Travel	
Statistic	**NO_x as N (kg)**
Minimum	0
Maximum	18.1
Mean	5.0
Standard Deviation	5.1

5.2.2.3 Phosphorus

As the amount of P in jet fuel was assumed to be negligible, no inputs or outputs of P were estimated for household air travel.

5.3 Household Energy

5.3.1 Electricity and Natural Gas

Information pertaining to electric and natural gas usage for the 12-month period prior to the survey was obtained from the homeowner's utility bills (with consent). With respect to energy usage, wide variability was noted among the households. For natural gas usage, the highest consuming household consumed over 3 times that of the lowest consuming household. For electric usage, the difference between the lowest and highest consuming households was a factor of 5.5. A summary of electric and natural gas usage is provided in Table 5.7, and histograms displaying individual homeowners' electric and natural gas usage are provided in Figures 5.6 and 5.7, respectively.

Table 5.7: Household Energy Usage - Summary

Statistic	Natural Gas Usage (CCF)	Electric Usage (kWh)
Maximum	2,109	19,988
Minimum	634	3,613
Average	1,079	8,062
Standard Deviation	306	4,010
High:Low Ratio	*3.33*	*5.53*

Figure 5.6: Household Electricity Usage - Distribution

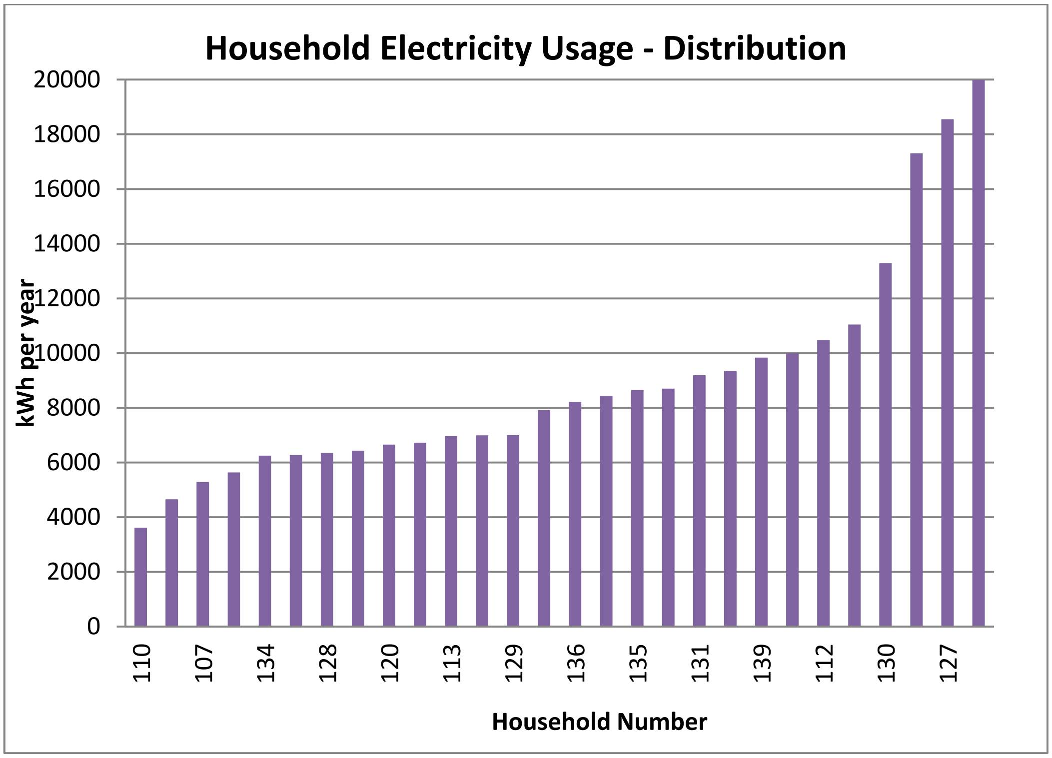
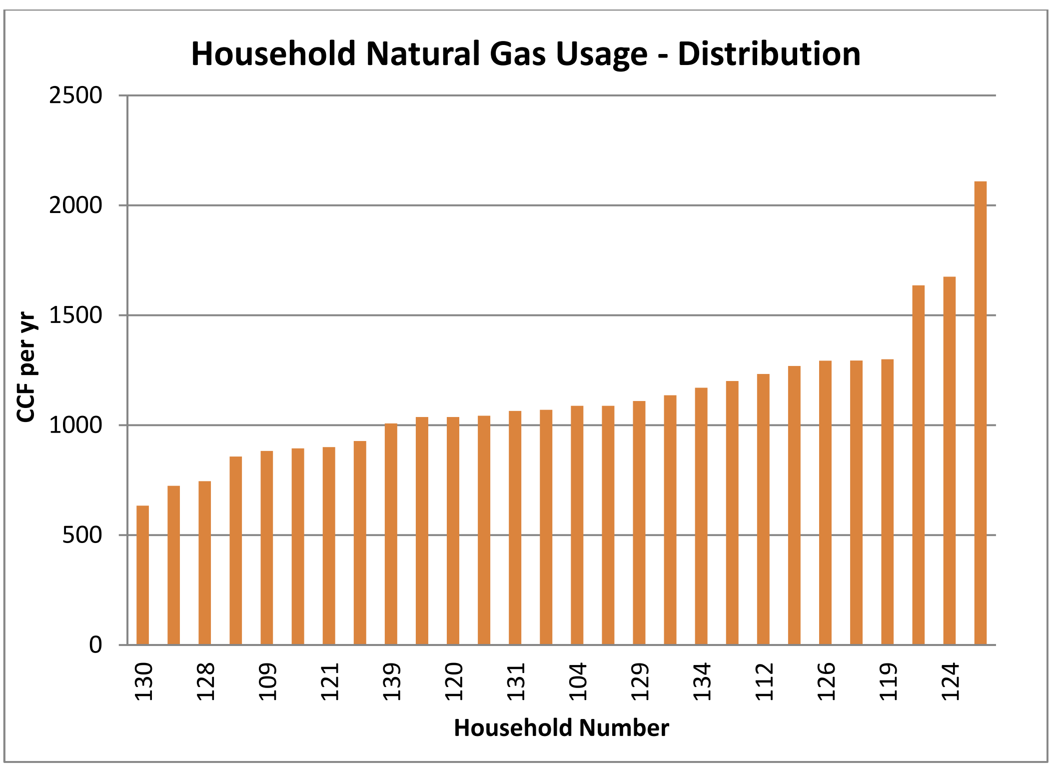


Figure 5.7: Household Natural Gas Usage - Distribution

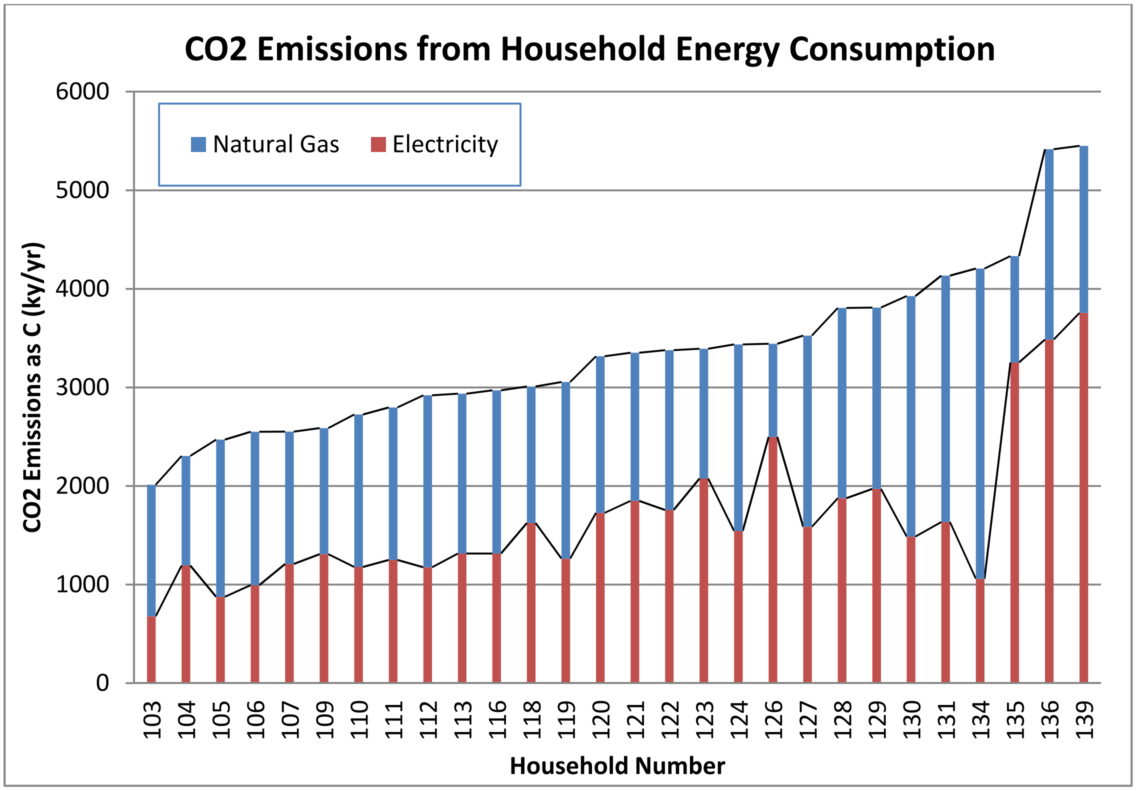


As described in Section 3.6, electricity in the state of Minnesota is primarily derived from a mixture of coal and nuclear plants, with smaller amounts from natural gas, petroleum, biomass, hydropower, and wind. Conversion factors for CO_2, CH_4, and NO_x related to electric usage account for the distribution of electric power generation sources at the time of the survey. CO_2 emissions related to natural gas consumption were derived from EIA 2003. No P inputs or outputs were assumed due to use of household energy sources.

5.3.1.1 Carbon

As emissions related to household energy usage were directly estimated from conversion factors for natural gas and electric usage, CO_2 outputs related to household energy usage show a strong correlation with consumption. The highest consuming household emitted approximately 2.7 times more CO_2 than the least consuming household (Figure 5.8).

Figure 5.8: CO_2 Emissions from Household Energy Consumption



5.3.1.2 Nitrogen

NO_x emissions from use of household electricity were estimated based on the state of Minnesota's current distribution of energy (see Figure 3.1, Chapter 3.6). Based on the current distribution of fuels used to generate electrical power in the state, 0.0112 kg of NO_x is emitted for every kWh of electrical usage. NO_x emissions from electric usage ranged from 0.04 kg yr^{-1} to 0.22 kg yr^{-1}, with an average of 0.10 kg yr^{-1}. As the amount of N in natural gas was assumed to be negligible, no inputs or outputs of N were calculated from the use of natural gas.

Distribution of NO_x emissions related to electric usage is shown in Table 5.8 below. As the rate of emissions is directly related to kWh of electricity consumed, there is a perfectly linear relationship between the two variables.

Table 5.8: NO_x Emissions from Electricity Usage

HOUSEHOLD	Electricity (kwh yr^{-1})	NOx emissions as N (kg yr^{-1})
110	3,613	0.01
118	4,654	0.01
107	5,289	0.02
122	5,637	0.02
134	6,252	0.02
105	6,276	0.02
128	6,349	0.02
121	6,435	0.02
120	6,655	0.02
123	6,726	0.02
113	6,964	0.02
106	6,994	0.02
129	7,001	0.02
116	7,910	0.03
136	8,213	0.03
119	8,440	0.03
135	8,649	0.03
124	8,702	0.03
131	9,193	0.03
104	9,344	0.03
139	9,836	0.03
126	9,991	0.03
112	10,485	0.03
109	11,047	0.03
130	13,292	0.04
111	17,309	0.05
127	18,551	0.06
103	19,988	0.06
Minimum	3,613	0.01
Maximum	19,988	0.06
Mean	8,921	0.03
Standard Deviation	4,010	0.01
High:Low Ratio	5.5	5.5

5.3.1.3 Phosphorus

As the amount of P in household energy sources was assumed to be negligible, no inputs or outputs of P were estimated from the use of electricity and natural gas.

5.3.2 Other Household Energy

Data pertaining to miscellaneous sources of combustible energy (propane, charcoal, and wood) were obtained from homeowners during the survey. Propane and charcoal are primarily used for outdoor cooking, while wood is assumed to be used to create fires in the winter months (not as a primary source of heating the home). Use of these miscellaneous sources of energy is assumed to be largely discretionary in nature, as they supplement the primary sources of household energy (natural gas and electricity, described in Chapter 5.3.1 above).

The data show wide variability in use of miscellaneous energy, with six of the households reporting no use of these sources. Of the remaining 22 households, twelve used only one of these sources, and ten used two sources (none of the households used all three). Conversion factors for CO_2 were estimated based on the content of organic C in the source material. No N or P inputs or outputs were assumed due to the use of these miscellaneous sources of household energy.

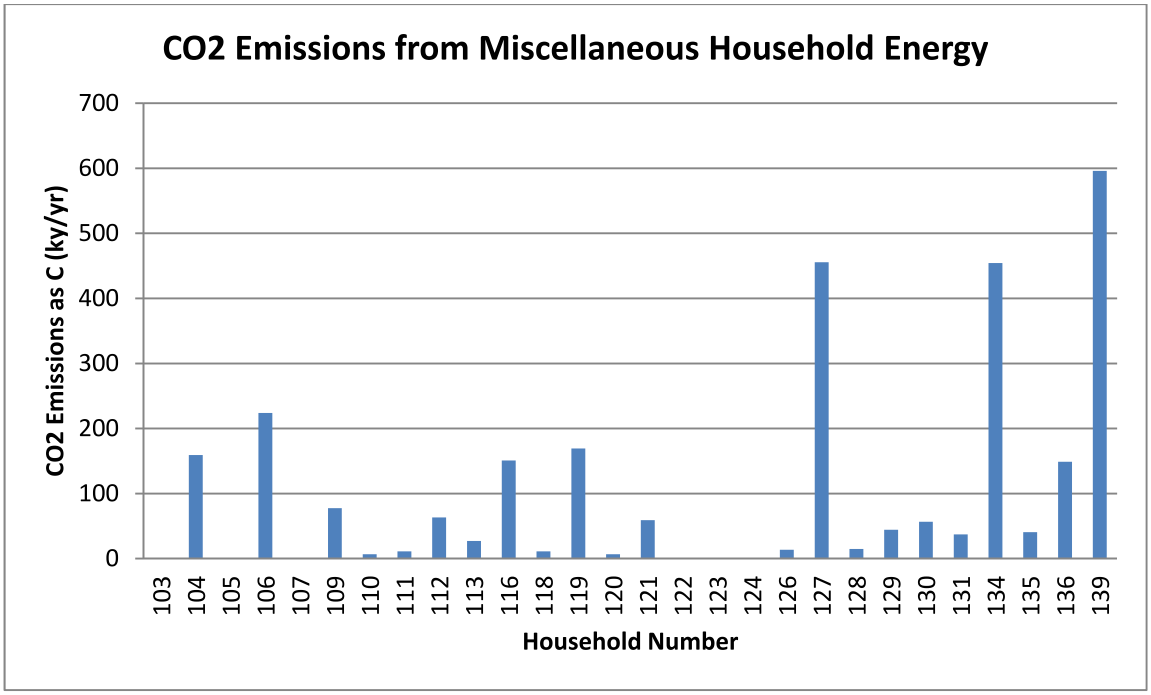
5.3.2.1 Carbon

On average, CO_2 emissions from miscellaneous energy sources comprised 3% of overall household energy; however, this percentage was between 10-15% for the 3 of the 28 households. The highest consuming household emitted nearly 600 kg of

CO_2 (as C) from miscellaneous energy sources. This is approximately 30% of the overall natural gas/electricity CO_2 emissions from the *lowest* consuming household.

CO_2 emissions resulting from miscellaneous household energy sources are shown in Figure 5.9 below.

Figure 5.9: CO_2 Emissions from Miscellaneous Household Energy



5.3.2.2 Nitrogen and Phosphorus

As the amount of N and P in propane, charcoal, and wood was assumed to be negligible, no inputs or outputs of these nutrients were estimated for miscellaneous household energy usage.

5.4 *Lawn Management*

As described previously, the survey involved a field component, which estimated the total surface area of vegetated (i.e., grass) land on the homeowner's property, as well as included a tree inventory. Lot sizes of the houses were generally modest, averaging 0.24 acre, with the largest lot being just over 0.50 acre. Lawn sizes were estimated based on measurements taken in the field and showed a similar distribution, ranging from 0.03 to 0.43 acre, averaging 0.14 acre.

5.4.1 Carbon

Inputs of C to the lawn management system include atmospheric CO_2, which is incorporated into plant biomass (grass and trees) via photosynthesis, and C_{org} from mulch, composted food waste, dog feces, and fuel used to power lawnmowers. Outputs of C include CO_2 from the decomposition of plant and organic matter (dog feces, composted food, etc.) and combustion of lawnmower gasoline, and C_{org} from the export of grass clippings or leaf litter (if removed from property). Unlike most of the variables analyzed in this study, in which nutrient inputs generally equal outputs, lawn management allows for the opportunity of net sequestration of nutrients within the biomass of onsite vegetation or soils, or depletion (net export) of nutrients over time through removal of vegetation from the household.

As described in Chapter 3.7, a tree inventory was completed on each household's property. The tree inventory was sent to David Nowak of the USFS to estimate the total C sequestered with the biomass of the tree, and the gross (annual) C sequestered. Gross (annual) sequestration rates ranged from 3 to 234 kg yr^{-1}, with an average of 92 kg yr^{-1}.

Table 5.9 provides a summary of the inventoried trees, and total and gross (annual) C sequestered in the tree biomass.

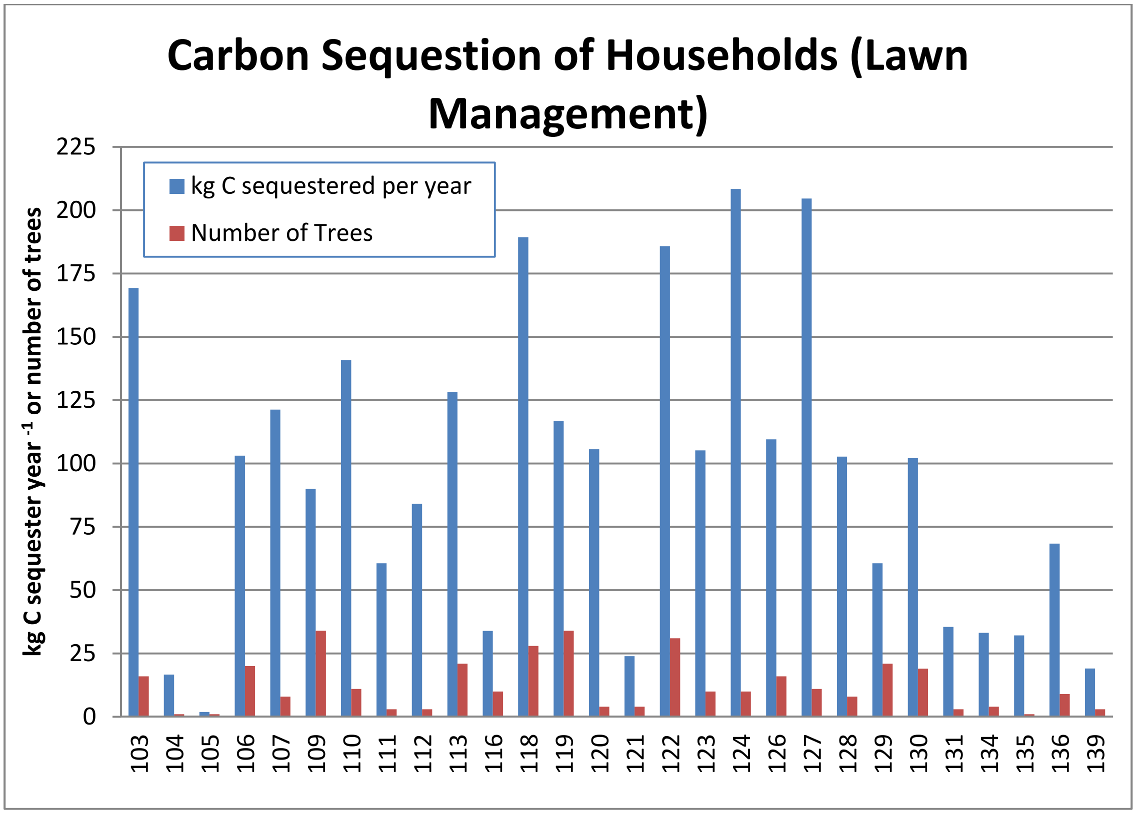
Table 5.9: Household Tree Inventory				
Household	Lot Size (acres)	Number of Trees	Total C sequestered (kg)	Gross (Annual) C sequestered (kg/yr)
103	0.21	16	3,013	105
104	0.16	1	588	18
105	0.19	1	23	3
106	0.24	20	3,337	104
107	0.20	8	1,977	52
109	0.24	34	1,743	64
110	0.31	11	5,303	144
111	0.18	3	2,251	43
112	0.18	3	4,149	52
113	0.25	21	4,013	105
116	0.33	10	4,636	113
118	0.50	28	6,880	234
119	0.50	34	7,255	204
120	0.23	4	6,780	82
121	0.12	4	748	25
122	0.19	31	4,994	186
123	0.20	10	6,012	107
124	0.14	10	9,485	223
126	0.23	16	3,000	99
127	0.38	11	6,287	167
128	0.16	8	3,407	88
129	0.23	21	3,081	62
130	0.40	19	848	57
131	0.14	3	1,084	36
134	0.24	4	4,084	58
135	0.16	1	928	24
136	0.23	9	4,174	105
139	0.14	3	505	20
Minimum		1	23	3
Maximum		34	9,485	234
Mean		12.3	3,372	92
Standard Deviation		10.2	2,423	64
High-Low Ration		34:1	412:1	78:1

Homeowners were asked as to how they manage leaves and grass clippings (removed from property or composted on-site) throughout the year. Approximately

68% of household removed leaves from their property, with the remaining households composting and/or mulching their leaves and returning it to their lawn. With respect to management of grass clippings, 21 of the households left the clippings in place, 7 removed the clippings and transported off site, and 1 composted the clippings onsite.

Although over half (15) of the households experienced an export/loss of C from the removal of grass clippings, this was largely offset by the net accumulation of C experienced from gross C sequestered in the biomass of the homeowner's trees. When factoring in gross C accumulated in tree biomass, all of the households experienced net sequestration of C. These values ranging from 1.9 to 208 kg C yr^{-1} with an average of 95 kg C yr^{-1}. Figure 5.10 below displays the number of trees per household, and the distribution of C sequestered from the lawn management component of each household.

Figure 5.10: Carbon Sequestration of Households (Lawn Management)

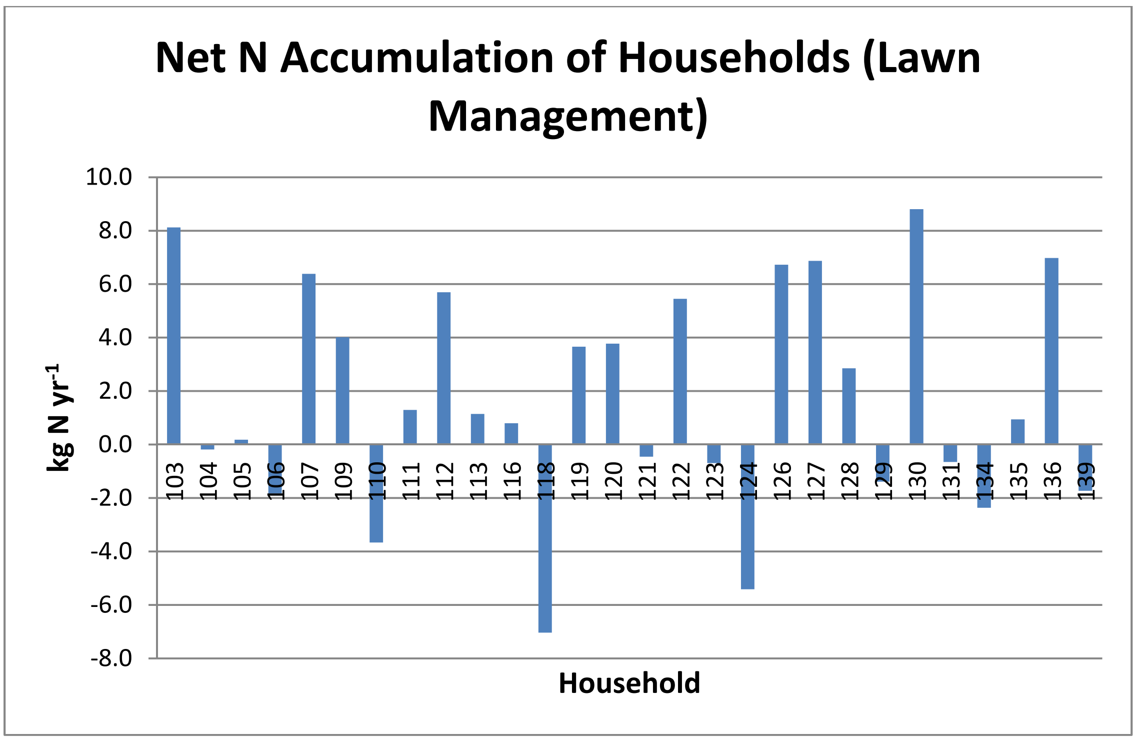


5.4.2 Nitrogen

Inputs of N to the lawn system include atmospheric deposition, composted food waste, dog feces, and fertilizer. All N in dog food was assumed to be excreted, and all dog waste was assumed to be directly inputted to the lawn. As described above (Table 3.2, Chapter 3.7), households were placed into one of five lawn management categories based on the survey responses, from which N fertilization rates were assumed from Milesi et al. (2005). Outputs of N from the lawn system included N in lawn runoff and export of grass clippings and leaves from trees (if removed from site). Mulched or composted grass clippings or leaves were assumed to be returned to the homeowner's yard.

Depending on each household's management of their lawn, opportunities exist to sequester N within the soil and woody biomass of onsite trees/vegetation. Of the 28 surveyed households, 17 had a net accumulation of N due to lawn management practices with values ranging from 0.2 kg N yr^{-1} to 8.8 kg N yr^{-1}. For the 11 households which had a net loss of N, values ranged from -0.2 kg N yr^{-1} to 7.0 kg N yr^{-1}. Net N accumulation rates for all surveyed households are displayed in Figure 5.11, below.

Figure 5.11: Net N Accumulation of Households (Lawn Management)

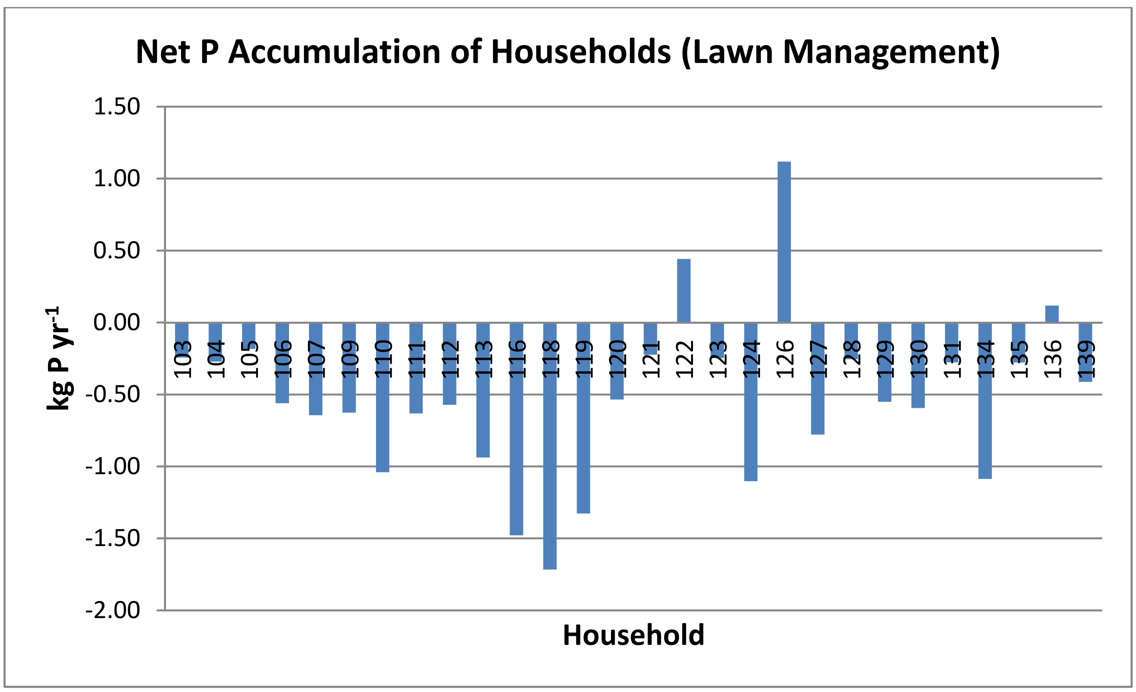


5.4.3 Phosphorus

Inputs of P to the lawn system include atmospheric deposition, composted food waste, and dog feces. Although P is also commonly added to lawns via fertilization, no inputs of P due to fertilization were assumed, as the state of Minnesota banned use of P in fertilizers for urban lawns (Minnesota Statutes 2005). Outputs of P from the lawn system included P in lawn runoff and export of grass clippings and leaves from trees (if removed from site). Mulched or composted grass clippings or leaves were assumed to be returned to the homeowner's yard.

Depending on each household's management of their lawn, opportunities exist to sequester P within the soil and woody biomass of onsite trees/vegetation. Of the 28 surveyed households, 3 had a net accumulation of P, with the remainder experiencing a net loss of P. In general, quantities of P accumulated or lost were relatively minor (ranging from 1.1 kg P yr^{-1} to -1.7 kg P yr^{-1}, respectively).

Figure 5.12: Net P Accumulation of Households (Lawn Management)



Approximately 89% of all households experienced a net loss of P form the lawn component of their property. Although the quantities lost are relatively small (maximum of 1.7 kg P yr^{-1}), over an extended period of time, urban lawns may become depleted of P, which could lead to problems with establishing a healthy cover of grass and other vegetation. In the long term, this may result in an increased potential for soil erosion, which could further deplete the soil of essential nutrients.

5.5 *Food and Wastewater*

As described in Chapter 3.3, caloric consumption and composition of food was assumed based on national average consumption data for the white race from the USDA Continuing Survey of Foods (2005). Consumption of proteins, fats, carbohydrates, fiber, and total calories were estimated from Table 5.10 below.

Table 5.10: Food Consumption – National Averages

	Protein g day^{-1}		Fat g day^{-1}		Carbohydrates g day^{-1}		Fiber		Phosphorus mg/day		Calories	
Age group	M	F	M	F	M	F	M	F	M	F	M	F
<5	49	49	51	51	192	192	9	9	959	959	1,402	1,402
6 to 11	71	62	75	66	283	252	14	12	1,310	1,310	2,061	1,825
12 to 19	99	64	104	67	374	264	18	13	1,705	1,705	2,815	1,894
20-39	103	65	103	64	335	230	19	14	1,618	1,618	2,752	1,769
40-59	93	63	91	62	288	210	19	14	1,456	1,456	2,388	1,653
>60	79	59	75	53	246	187	19	15	1,285	1,285	1,986	1,446

M = male, F = female

Estimates of P from food consumption were assumed directly from the data in Table 5.10. N was assumed to be 16% of protein, and C consumption was estimated based on the conversion factors in Table 5.11, below.

Table 5.11: Carbon Conversion Factors - Foods

Food type	Carbon Conversion Factor*
Protein	0.50
Carbohydrates	0.425
Fats	0.765
Fiber	0.485

*Conversion factors from Klass 2004

The vast majority (approximately 93%) of C_{org} consumed as food is respired as CO_2, with the remainder (primarily from fiber) excreted in human feces and urine (thus becoming an output from the wastewater system). All consumed N and P were assumed to be excreted into wastewater. Additional outputs to wastewater come from several uncharacterized wastes, including detergents, soaps, household chemicals, and dirt brought into the house and washed down drains, etc. Per capita averages for C, N, and P in uncharacterized sources in wastewater are described in Baker et al., 2007. Components of the household wastewater stream are summarized below in Table 5.12.

Table 5.12: Components of Household Wastewater Stream

Element*	Human Excretion	Garbage Disposal (if present)	Uncharacterized Inputs**
Carbon	13	22	28
Nitrogen	13	1.2	-0.5
Phosphorus	1.6	0.14	0.4

*All values listed in g capita^{-1} day^{-1} (Baker et al. 2007)
**Includes detergents, soaps, household chemicals, dirt brought into the house and washed down drains

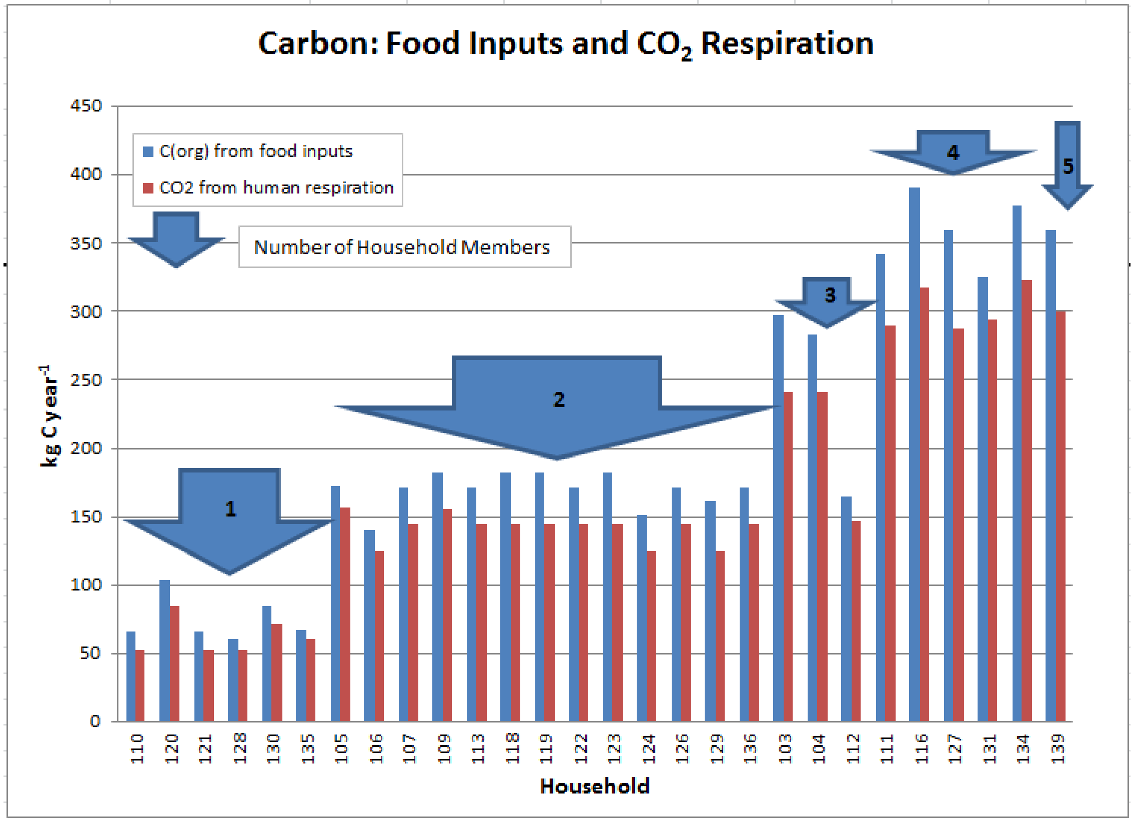
5.5.1 Carbon

C_{org} inputs from food were based on the national average values and the ages and genders of household residents shown in Table 5.10 above. Similarly, CO_2 generated from respiration and C_{org} in the form of feces in wastewater were based on these national averages, and are outputs from the household system. As described previously, composted food waste was considered as an input into the lawn management system. Of the 28 households, 8 compost their food waste. For households with garbage disposals (22), food waste was assumed to be exported out of the household in wastewater.

As C associated with food inputs in this study is based on a national per capita averages (stratified by gender and age), for purposes of this study, individual household decisions do not influence greatly influence the overall inputs or outputs of C from the household system, as all inputs become outputs (either in wastewater, respired CO_2 or as an input to the lawn system). The respective ages and genders of the household residents determined the overall inputs of food and outputs of wastewater. In addition to consumed food, an additional 0.11 kg (wet weight) capita-1 day-1 was assumed as food waste, based on Twin Cities landfill data from Beck, Inc. (1999). Food waste was assumed to be exported from the household either to landfills, to wastewater (for families with garbage disposals), or was considered an input to the lawn system if the household composted their food waste.

Figure 5.13 below summarizes total C inputs related to food and outputs of CO_2 from human respiration. Depending on the households' survey responses, C inputs not respired as CO_2 were assumed to either enter the wastewater system (as human feces or through garbage disposals) or be exported to landfills.

Figure 5.13: Carbon: Food Inputs and CO_2 Respiration



5.5.2 Nitrogen and Phosphorus

Similar to C described above in Chapter 5.5.1, N and P inputs from food were based on the national average values and the ages and genders of household residents shown in Table 5.10 above. All N and P consumed in food were assumed to be excreted in wastewater. As noted above, additional outputs in wastewater were assumed from uncharacterized sources (see Table 5.12).

For households with the same number of residents, slight variability was noted in overall flux of N and P depending on the ages and gender (and thus, total food consumed) of the household residents. Table 5.13 below provides a summary of the distribution of N and P related to food and wastewater.

Table 5.13: Nitrogen and Phosphorus Fluxes: Food and Wastewater					
	Number of Household Members				
	1 (n=6)	2 (n=13)	3 (n=3)	4 (n=5)	5 (n=1)
N inputs (food)					
Minimum	3.6	8.4	9.6	18.8	20.0
Maximum	6.2	10.6	17.4	21.6	20.0
Mean	4.4	9.9	14.5	20.0	20.0
Standard Deviation	1.0	0.6	4.3	1.2	NA
N outputs (wastewater)					
Minimum	3.3	7.7	8.7	17.7	19.0
Maximum	5.7	9.8	15.9	20.1	19.0
Mean	4.1	9.3	13.5	18.7	19.0
Standard Deviation	1.0	0.6	4.2	1.1	NA
P inputs (food)					
Minimum	0.49	0.97	0.98	1.91	2.29
Maximum	0.60	1.20	1.86	2.58	2.29
Mean	0.53	1.13	1.53	2.28	2.29
Standard Deviation	0.04	0.07	1.76	0.24	NA
P outputs (wastewater)					
Minimum	0.62	1.23	1.36	2.43	2.29
Maximum	0.71	1.45	2.19	3.02	2.29
Mean	0.66	1.39	1.91	2.79	2.29
Standard Deviation	0.03	0.07	0.48	0.22	NA
* All values in kg yr^{-1}					

5.6 Miscellaneous

5.6.1 Pets

As described in Chapter 3.3.2, for purposes of this study, only dogs were factored into the HFC. Total dog food consumption was estimated based on the weight of the dog, and C, N, and P in dog food were estimated as detailed in Chapter 3.3.2 and Baker et al. (2007). All N and P consumed in dog food were assumed to be excreted, while waste C is essentially dietary fiber. All dog waste was assumed to be an input into the lawn management system, although it is likely some of the solid waste was collected by the homeowner's and disposed of in the trash.

21 of the 28 households did not own a dog at the time of survey. Of the remaining 7 households, 6 owned one dog, while 1 household owned two dogs. As nutrient flux related to dogs is directly related to the weight of the dog(s), households with smaller dogs showed a smaller flux relative to households with larger dogs. C, N, and P fluxes related for the 7 households with dogs are shown on Table 5.14 below.

Table 5.14: C, N, and P Flux - Pets

Household #	Number of Dogs	Total Weight (kg)	C inputs (kg)	Excreted C (kg yr^{-1})*	N Flux (kg yr^{-1})	P Flux (kg yr^{-1})
103	1	3.6	13	0.3	1.2	0.2
123	1	9.1	26	0.5	2.3	0.5
130	1	11.4	31	0.6	2.8	0.6
122	1	15	38	0.8	3.4	0.7
126	1	39.5	78	1.6	7.1	1.5
136	1	43.6	84	1.8	7.6	1.6
119	2	50	93	2.0	8.4	1.8

* C which is not excreted is assumed to be metabolized (i.e., respired as CO_2)

5.6.2 Paper and Plastic

Inputs of paper and plastic to the household were assumed to be outputted to landfills or recycled, based on estimates from Beck, Inc. (1999) and recycling rates from the Minneapolis recycling program. Average residential recycling rates for paper and plastic are 31% and 23%, respectively. Average consumption rates of residential paper and plastic are provided in Table 5.15, below.

Table 5.15: Paper and Plastic: Average Household Consumption		
	Paper (kg capita^{-1} year^{-1})	**Plastic (kg capita^{-1} year^{-1})**
Entering Landfill	110	33
Recycled	50	10
Total Entering Household	160	43

Elemental compositions of paper and plastic were assumed from Tchobanoglous et al. (1993). Paper was assumed to contain 43% C and 0.3% N with no P. Plastic was assumed to contain 60% C, and no N and P. Because per capita averages were used to estimate household fluxes for paper and plastic, overall nutrient flux due to paper and plastic consumption was directly correlated with the number of household residents, as shown in Table 5.16 below.

Table 5.16: Carbon and Nitrogen Flux: Paper and Plastic				
Number of Household Members	**C flux (kg year^{-1})**		**N flux (kg year^{-1})**	
	Paper	**Plastic**	**Paper**	**Plastic**
1	68.8	21.6	0.15	0
2	137.6	43.2	0.30	0
3	206.4	64.8	0.45	0
4	275.2	86.4	0.60	0
5	344.0	108.0	0.75	0

5.7 Overall Household Nutrient Flux

In terms of overall fluxes of C, N, and P, significant variability exists among the 28 households. Calculated ratios of nutrient inputs between the highest and lowest consuming households were 2.8:1 for C, 3.72 for N, and 2.90 for P. When calculated on a per capita basis the variability was more pronounced, with the corresponding ratios being 4.67:1 for C, 6.43:1 for N, and 4.70 for P.

As the majority of nutrient inputs to the household are consumed and exported from the household, the corresponding ratios for nutrient outputs are similar; however, exhibit slight differences depending on the amount of nutrient sequestration or depletion (largely from the lawn management component). The calculated ratios of nutrient outputs between the highest and lowest consuming households were 2.88:1 for C, 3.15 for N, and 3.35 for P. A summary of overview nutrient flux variability is provided in Table 5.17 below.

Table 5.17: Overall Nutrient Flux - Summary

	Carbon				**Nitrogen**				**Phosphorus**			
	In	Out	Seq[2]	Per Capita	In	Out	Seq	Per Capita	In	Out	Seq	Per Capita
Min[1]	3,920	3,859	2	1,459	11.73	12.68	-7.03	3.98	1.11	1.35	-1.72	0.37
Max[1]	11,282	11,096	208	6,806	43.57	39.91	8.80	25.58	3.21	4.54	1.12	1.74
Mean[1]	7,176	7,081	95	3,532	25.30	23.58	1.73	13.00	1.65	2.18	-0.53	0.83
St Dev	2,135	2,105	60	1,409	8.58	8.23	4.16	6.68	0.55	0.68	0.57	0.39
Hi:Low	2:87:1	2.87:1	111	4.67	3.72	3.15	NA	6.43	2.90	3.36	NA	4.70

[1] Values in kg $year^{-1}$
[2] Seq = Sequestered

The following sections of this Chapter detail the variability for each element, and analyze some of the primary household decisions influencing this variability.

5.7.1 Carbon Variability

As shown in Table 5.17 above, wide variability exists in C flux among the surveyed households as well as on a per capita basis. This distribution is shown in further detail in Figures 5.14 and 5.15 below.

Figure 5.14: Annual Household C Flux - Distribution

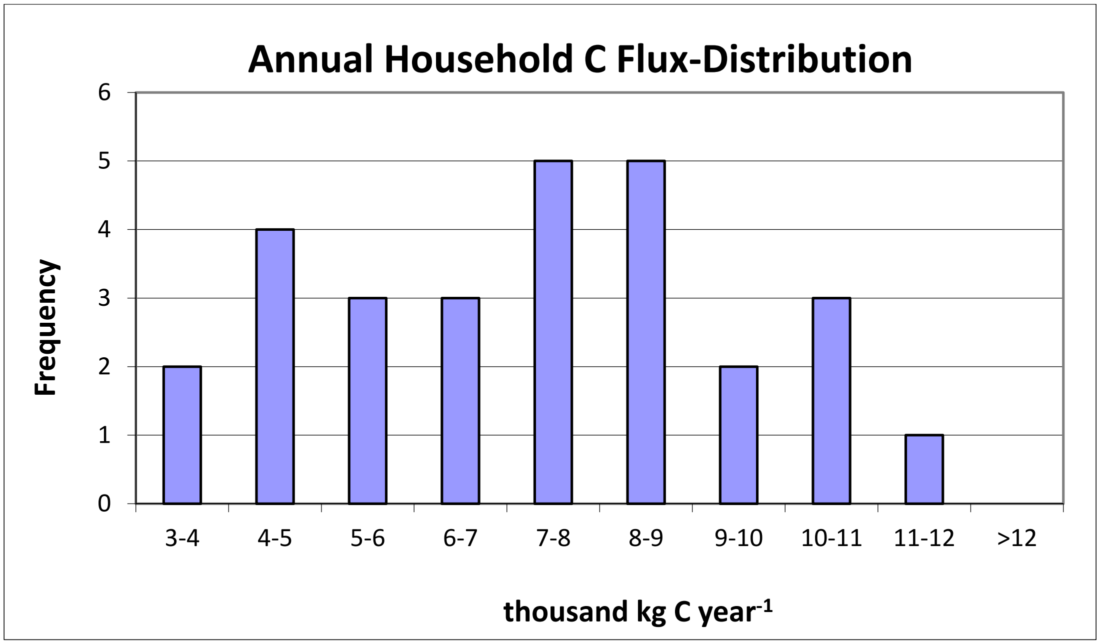
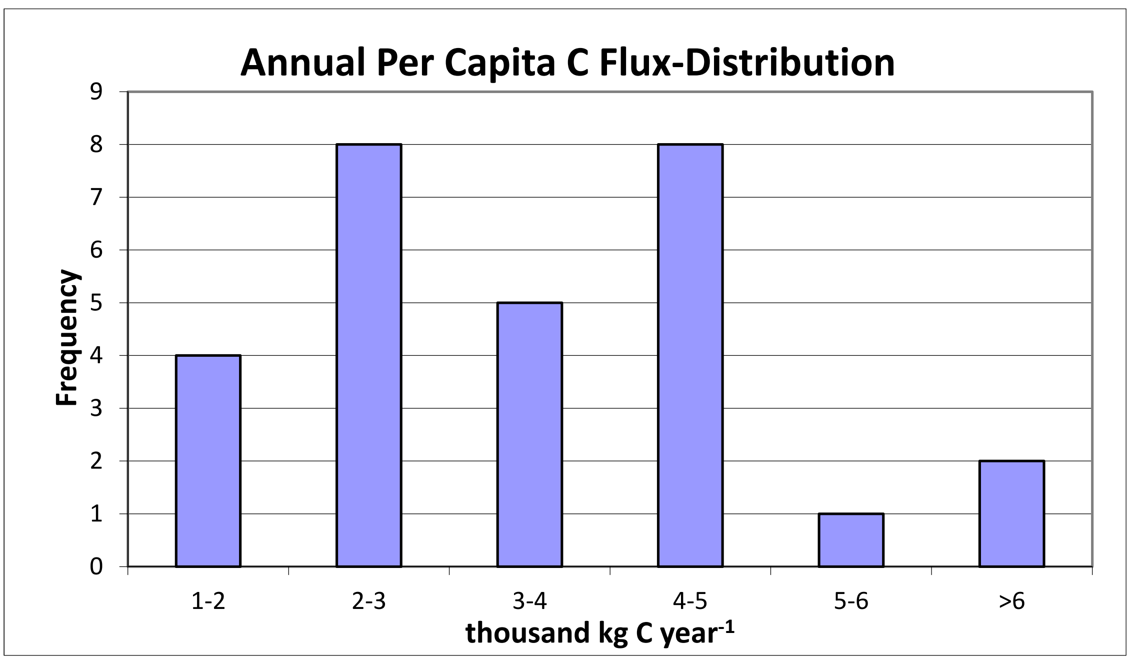


Figure 5.15: Annual Per Capita C Flux - Distribution

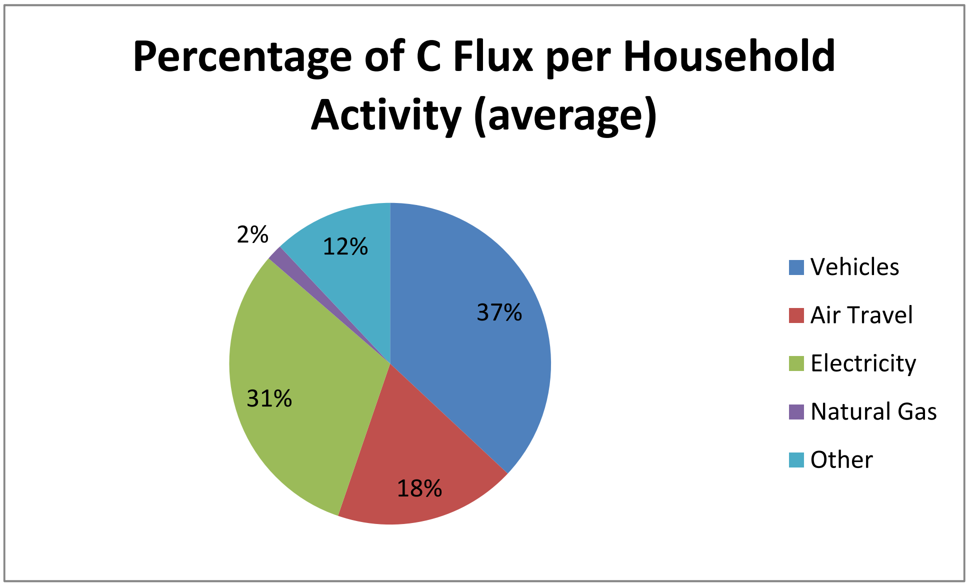


The overwhelming majority of C flux in households is due to the combustion of C_{org} from fossil fuels associated with transportation (vehicle and air travel) and use of household energy sources (electricity and natural gas), which is in turn emitted as CO_2 gas (and to a much lesser extent CO). Despite the variability among transportation and energy usage among the households, the percentage of total C flux for all households due to these factors compared to overall C flux are relatively similar, ranging from 80% to 94% (see Table 5.18).

Table 5.18: Carbon Flux Relative to Household Transportation and Energy						
	Total C flux (kg yr^{-1})					Total C flux
Household	Vehicles	Air Travel	Electricity	Natural Gas	% of Total C	
103	3,134	424	3,758	1,696	91	9,900
104	1,532	131	1,757	1,624	87	5,768
105	814	466	1,180	1,548	90	4,443
106	1,687	546	1,315	1,624	90	5,763
107	1,608	889	994	1,557	88	5,725
109	609	1,022	2,077	1,318	88	5,690
110	1,344	1,939	678	1,335	89	5,935
111	2,856	2,376	3,255	1,081	89	10,714
112	3,482	340	1,971	1,841	90	8,491
113	2,000	2,847	1,309	1,279	88	8,435
116	2,353	688	1,487	2,442	84	8,310
118	2,018	1,575	875	1,597	86	7,048
119	2,699	1,126	1,587	1,941	80	9,204
120	2,297	847	1,251	1,548	88	6,762
121	1,117	0	1,210	1,343	94	3,918
122	3,362	2,300	1,060	3,148	87	11,302
123	3,608	425	1,265	1,793	86	8,288
124	1,987	2,401	1,636	2,500	89	9,584
126	1,721	885	1,879	1,930	90	7,144
127	2,768	860	3,488	1,932	86	10,488
128	739	1,196	1,194	1,112	91	4,682
129	371	0	1,316	1,657	85	3,920
130	0	567	2,499	946	86	4,654
131	1,181	1,119	1,729	1,590	85	6,615
134	3,047	930	1,176	1,747	86	8,014
135	770	416	1,626	1,385	93	4,489
136	4,465	406	1,544	1,894	90	9,277
139	2,177	883	1,849	1,505	86	7,478
Min	*0*	*0*	*678*	*946*	*80*	*3,918*
Max	*4,46,5*	*2,847*	*3,758*	*3,148*	*94*	*11,302*
Mean	*1,991*	*986*	*1,675*	*88*	*88*	*7,216*
Standard Deviation	*1,100*	*761*	*754*	*456*	*2.9*	*2174*

With the exception of a small amount of CO emissions from automotive travel (approximately 4-6% of total C), all of the C values listed in Table 5.18 above were assumed to be emitting as CO_2. A summary pie chart of CO_2 related to household activities is provided as Figure 5.16, below.

Figure 5.16: Percentage of C Flux per Household Activity (average)



The C fluxes described in Table 5.18 above are related to several high-level household decisions, size of home, number of household residents, discretionary travel, etc. The remaining fluxes of C related were relatively minor in terms of mass quantity, and were either calculated based on per capita averages (paper/plastic consumption, food, and uncharacterized sources), or were directly estimated from consumption data (miscellaneous energy, pets) and lawn/tree management.

Variability relating to these household components are described in the preceding sections, and detailed data tables and graphs displaying the inputs and outputs (and forms) of C for each household were generated. Household decisions and socioeconomic factors influencing overall C flux are explored in Chapter 5.8.

5.7.2 *Nitrogen Variability*

As shown in Table 5.17 above, wide variability exists in N flux among the surveyed households as well as on a per capita basis. This distribution is shown in further detail in Figures 5.17 and 5.18 below.

Figure 5.17: Annual Household N Flux - Distribution

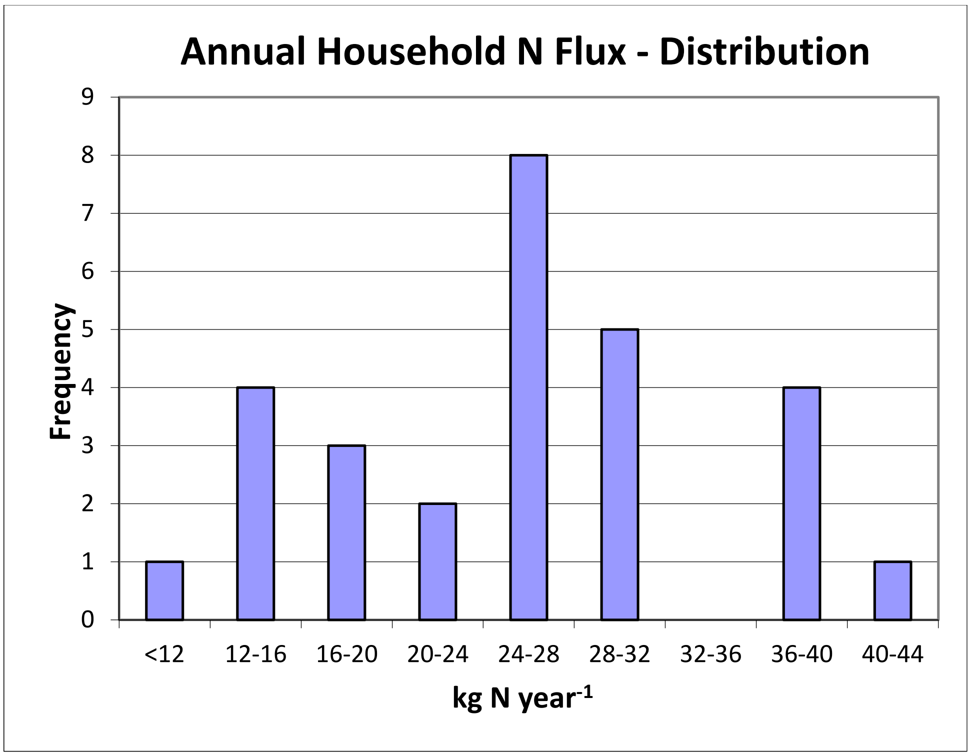
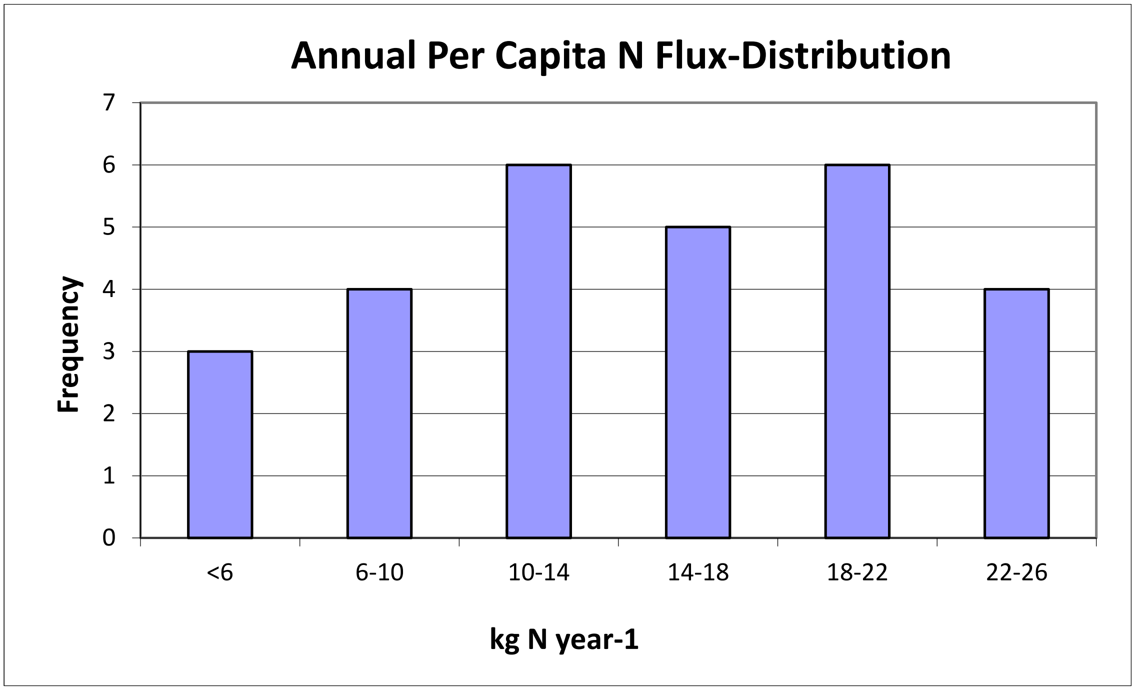


Figure 5.18: Annual Per Capita N Flux - Distribution



The three largest components of N flux are related to vehicles and air travel (converting atmospheric N_2 to NO_x) and from consumption of food (input of N_{org} outputted to wastewater as N_{org}). These three components accounted for at least 75% of all N flux in 22 of the 28 households. In the remaining 6 households, significant N inputs were noted for lawn management (primarily through the use of fertilizer) and/or pet food. Table 5.19 below displays a summary of N fluxes related to vehicles, air travel and food consumption.

Table 5.19: Nitrogen Flux Relative to Household Transportation and Food Consumption					
	Total N flux (ky yr^{-1})			% of Total N	Total N flux
Household	Vehicles	Air Travel	Food		
103	8.4	2.5	17.4	76	37.4
104	4.4	0.4	16.5	97	22.0
105	2.3	1.4	10.0	94	14.5
106	5.2	1.7	8.4	94	16.3
107	4.6	2.7	10.0	67	25.7
109	2.1	7.1	10.1	75	25.9
110	4.0	10.8	3.9	94	19.9
111	8.6	13.7	18.8	91	45.2
112	8.7	1.0	9.6	72	26.8
113	5.1	18.1	10.0	86	38.7
116	6.0	2.1	21.6	75	39.5
118	6.7	10.4	10.6	93	29.7
119	7.4	3.5	10.6	48	44.6
120	5.5	5.2	6.2	76	22.3
121	3.3	0.0	3.9	94	7.7
122	10.0	13.9	10.0	84	40.3
123	9.8	1.3	10.6	87	24.8
124	5.2	14.6	9.0	94	30.6
126	4.6	2.7	10.0	66	26.3
127	7.5	2.6	19.8	77	38.7
128	2.5	7.5	3.6	79	17.3
129	1.3	0.0	9.5	92	11.7
130	0.0	3.9	5.1	41	22.1
131	3.8	3.4	19.0	98	26.7
134	8.8	2.9	20.9	88	37.1
135	2.8	1.3	3.8	78	10.1
136	10.7	1.2	10.0	57	38.5
139	6.3	2.7	20.0	98	29.5
min	0.0	0.0	3.6	41	7.7
max	10.7	18.1	21.6	98	45.2
mean	5.6	5.0	11.4	81	27.5
standard dev	2.8	5.1	5.6	15.1	10.5

With the exception of food consumption which was based on per capita (broken up by gender and age), the N fluxes described in Table 5.19 are highly related to the amount and type of household transportation. As noted above, a small number of the households also had significant N inputs through lawn management practices (particularly fertilization) and/or through pet food (quantity related to the weight of dog).

Variability relating to these household components are described in the preceding sections, and detailed data tables and graphs displaying the inputs and outputs (and forms) of N for each household were generated. Household decisions and socioeconomic factors influencing overall N flux are explored in Chapter 5.8.

5.7.3 Phosphorus Variability

As shown in Table 5.17 above, wide variability exists in P flux among the surveyed households as well as on a per capita basis. This distribution is shown in further detail in Figures 5.19 and 5.20 below.

Figure 5.19: Annual Household P Flux - Distribution

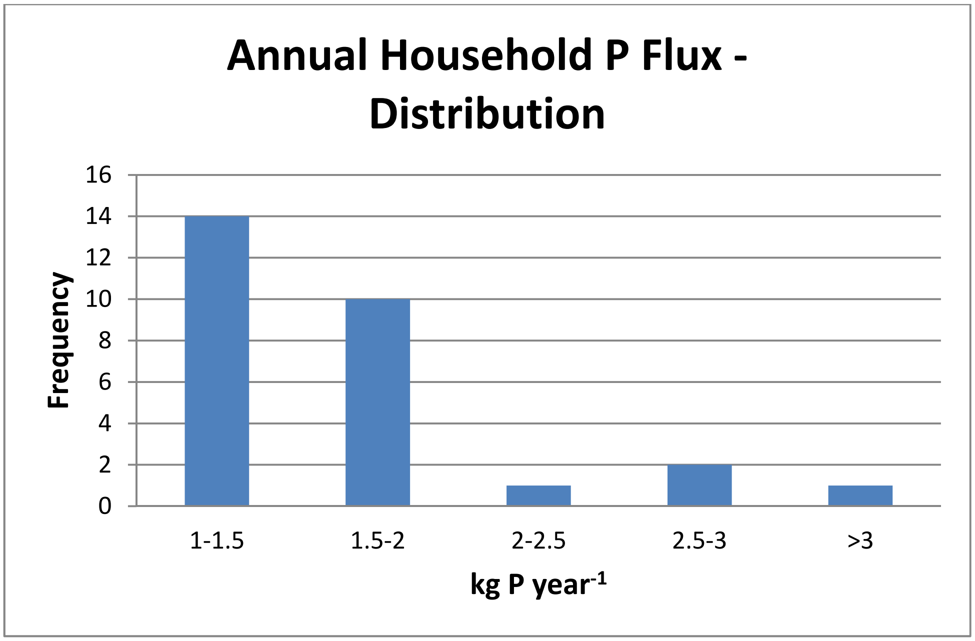
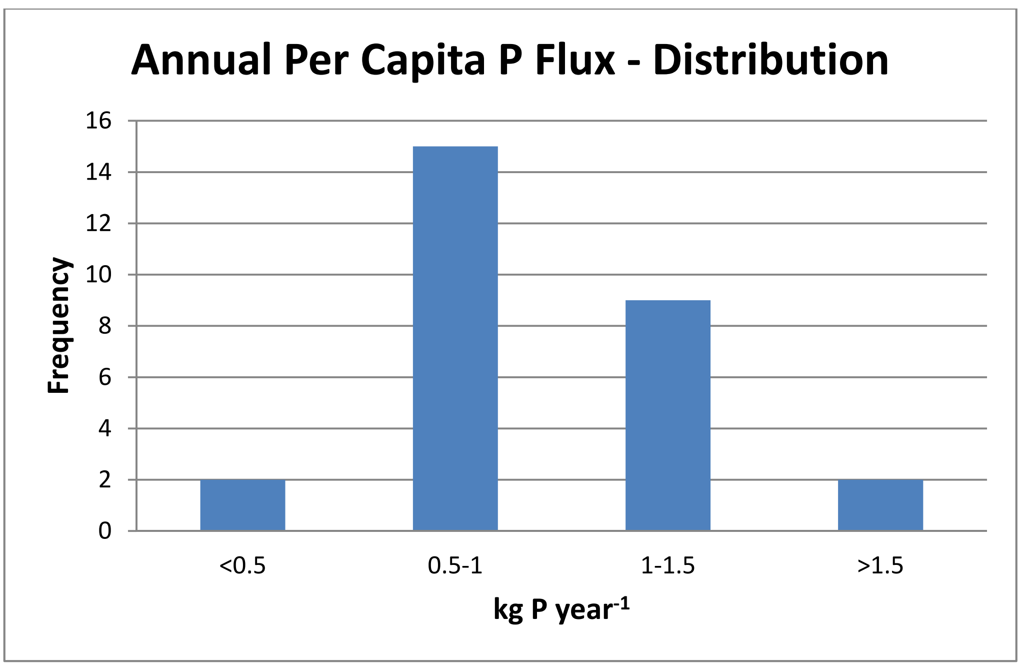


Figure 5.20: Annual Per Capita P Flux - Distribution



Unlike C and N which have large fluxes related to transportation and household energy, no flux of P was assumed for these components. Compared to C and N, on a mass basis, overall P flux was significantly lower, ranging from 0.49 to 2.58 kg yr^{-1}, and averaging 1.29 kg yr^{-1}. The three primary components contributing to P inputs into the household system were food, pets, and uncharacterized sources (detergents, soaps, etc.). P from human food and uncharacterized sources became an output from the household in wastewater, while pet P was assumed to be excreted on the homeowner's yard, becoming an input to the lawn system. For all households, the percent contribution of overall P based on these three components was greater than 91%. Sequestration (or depletion) of P from the household largely depended on the household's management of their lawn system (e.g., clippings/leaves removed vs. left in place). P inputs are summarized in Table 5.20, below.

Table 5.20: Phosphorus Flux: Food, Pets and Uncharacterized Sources					
	Total P flux (ky yr^{-1})			% of Total P	Total P flux
Household	Food	Uncharacterized Sources	Pets		
103	1.86	0.44	0.25	100	2.56
104	1.76	0.44	0.00	100	2.21
105	1.16	0.29	0.00	99	1.46
106	0.87	0.29	0.00	91	1.28
107	1.14	0.29	0.00	99	1.44
109	1.16	0.29	0.00	99	1.47
110	0.51	0.15	0.00	99	0.67
111	2.31	0.58	0.00	100	2.90
112	0.98	0.44	0.00	100	1.42
113	1.14	0.29	0.00	99	1.44
116	2.58	0.58	0.00	99	3.18
118	1.20	0.29	0.00	97	1.53
119	1.20	0.29	1.80	99	3.33
120	0.60	0.15	0.00	99	0.76
121	0.51	0.15	0.00	100	0.66
122	1.14	0.29	0.73	100	2.16
123	1.20	0.29	0.50	100	2.00
124	1.01	0.29	0.00	99	1.31
126	1.14	0.29	1.51	100	2.94
127	2.30	0.58	0.00	99	2.90
128	0.49	0.15	0.00	100	0.64
129	1.08	0.29	0.00	99	1.38
130	0.51	0.15	0.59	98	1.27
131	1.91	0.58	0.00	99	2.51
134	2.31	0.58	0.00	100	2.90
135	0.55	0.15	0.00	100	0.70
136	1.14	0.29	1.62	100	3.06
139	2.29	0.73	0.00	100	3.03
min	0.49	0.15	0.00	91	0.64
max	2.58	0.73	1.80	100	3.33
mean	1.29	0.34	0.25	99	1.90
standard dev	0.63	0.16	0.53	1.752747728	0.89

Variability relating to these household components are described in the preceding sections, and detailed data tables and graphs displaying the inputs and outputs (and forms) of P for all households were generated. Household decisions and socioeconomic factors influencing overall P flux are explored in Chapter 5.8.

5.8 Household Decisions and Factors Influencing Nutrient Fluxes

Nearly every choice households make influences their consumption, which in turn may influence nutrient fluxes. Everyday decisions such as commuting to work/school, setting a thermostat, or even turning on a light lead to consumption of natural resources, and contribute to the nutrient fluxes described throughout this thesis.

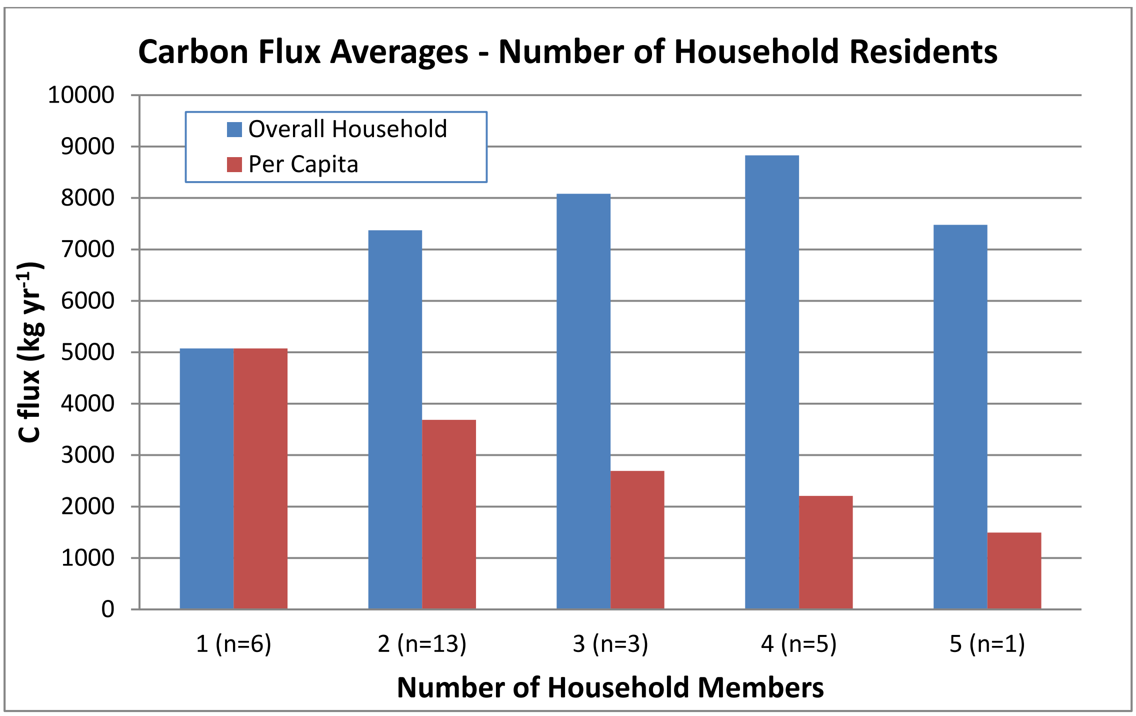
There are however, certain large scale household decisions made less frequently that have a profound impact on overall consumption trends, and thus nutrient flux. These include the size of the household (number of members), transportation decisions, and general housing and lawn characteristics. An overview of the importance of these decisions is provided in the sections below, as well as some examples from the data analyzed in this study. Several of these high-level household decisions may be influenced by certain socioeconomic factors, which are also discussed below.

5.8.1 Size of Household

One of the most fundamental decisions of any household is how many people occupy the residence. Of the 28 households, only 6 were occupied by a single person. The remaining households had between 2 and 5 occupants, with several of the households having children. In general, families with more members tend to have larger homes, travel more frequently, and consume more resources to support day-to-day living activities. Additionally, as several of the factors in this study utilized per capita data, the number of household residents resulted in a direct increase in nutrient fluxes for several of the household components analyzed in this thesis.

In this study, C flux generally increased with an increase in household members; although the one 5-member household (2 adults, 3 small children) did have a lower flux of C than the average 4-person household (see Figure 5.21, below). It is anticipated that this anomaly is due to the small sample size. Additionally, although the overall C flux generally increases with an increase in household size, a dramatic decrease in per capita C flux was noted as household size increased, suggesting certain efficiencies were realized through the shared used of household resources (e.g., energy, transportation, etc.).

Figure 5.21: Carbon Flux Averages – Number of Household Residents



Similar trends were noted for N and P flux with overall household inputs generally increasing with an increase in household size. Also similar to C, a dramatic reduction in per capita N flux was observed with an increase in household size. Per capita fluxes of P also generally declined with an increase in household members, but to a much lesser degree than C and N, as the majority of P inputs were based on per capita averages (see Figures 5.22 and 5.23, below).

Figure 5.22: Nitrogen Flux Averages – Number of Household Residents

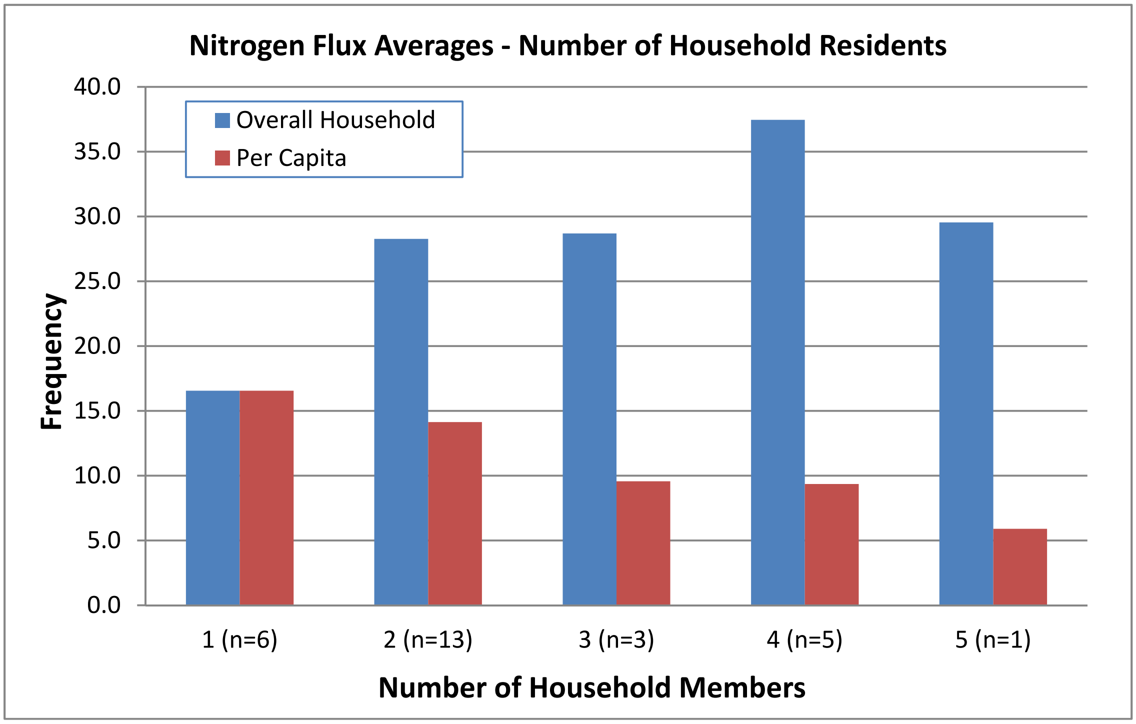
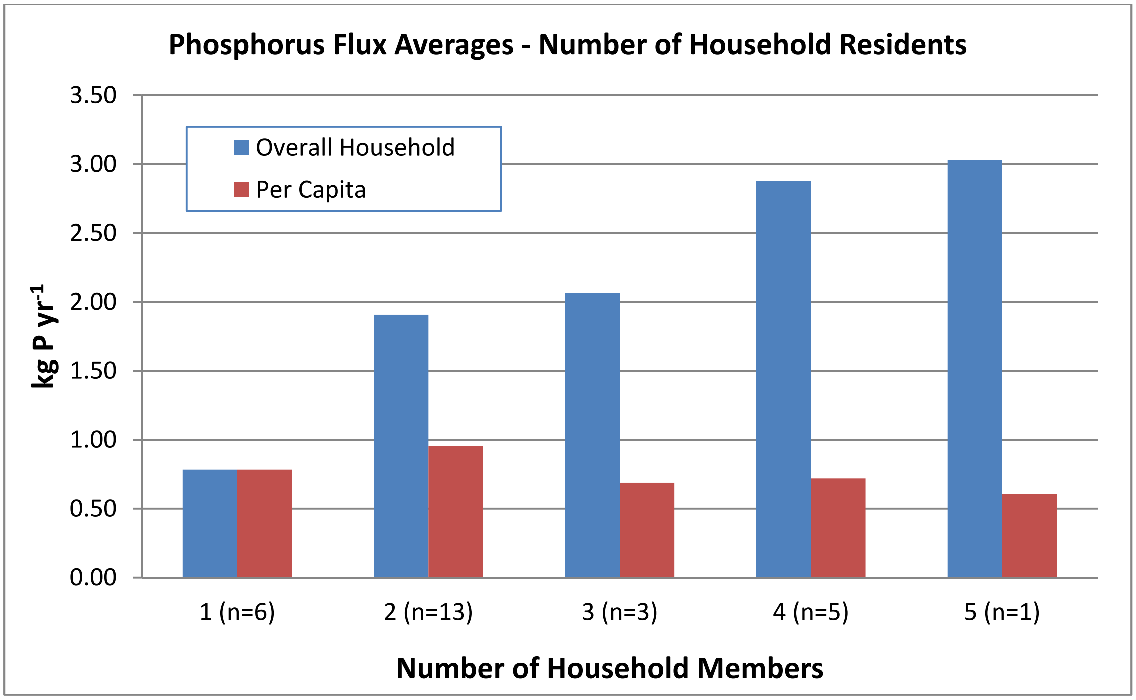


Figure 5.23: Phosphorus Flux Averages – Number of Household Residents



5.8.2 Transportation Decisions

5.8.2.1 Automobiles

As shown in this study, automobile use comprises a substantial percentage of overall household C and N flux, on average 28% and 20%, respectively. With the exception of one household which did not own a car, all households used one or more vehicles during the previous 12-month period. C and N flux from automobile use is directly related to gallons of gasoline consumed, which is a factor of miles driven and the fuel economy (mpg) of household vehicles (N flux was calculated on a per mile basis). As noted above in Table 5.2 (Chapter 5.2.1), fuel economy for vehicles ranged considerably, from 14.8 mpg to 31.7 mpg.

Given the same number of miles driven, an increase in fuel economy will lead to a corresponding decrease in C flux. Since fuel economy has such a large influence on C flux, households which choose to purchase vehicles with higher fuel economy can significantly reduce their overall CO_2 emissions. With respect to NO_x, light trucks/SUVs emit approximately 28% more NO_x per mile driven than passenger cars.

As the choice of household vehicle can have such a large impact on overall nutrient flux (particularly C), this represents one area where high consuming households could easily make a switch to a higher fuel efficiency vehicle and witness large reductions in overall CO_2, without a significant loss of quality of life. However, cars with higher fuel efficiency tend to be lighter and smaller (and are generally viewed as "less safe"), which may not be ideal vehicles for certain households, particularly those with children and/or household with multiple residents. Additionally, while many fuel efficient vehicles are relatively cheap, cars with exceptionally high fuel economy rates (i.e., hybrids) may be too expensive for some households to afford, even if they would like to purchase one.

The amount of miles driven per year is related to numerous factors, with a large percentage assumed from commuting to and from work or school. The majority (68%) of the adult members of the households work outside or the house and commute to work alone in a car. As such, the distance from residence to workplace can have a large influence on overall miles driven per year. According to Metropolitan Council, the average Twin Cities commute is approximately 9 miles one-way. Assuming 240 work days per year, the average commuter driving alone would drive 4,800 miles annually. Households may choose to reduce total commuting miles driven by utilizing mass transit, bicycles, carpooling, or telecommuting. Additional driving miles are related to running errands, as well as travelling to visit friends/families or for vacations. Depending on the location of the residence with respect to shopping/grocery centers, there may be wide variability in the amount of miles driven for running errands.

5.8.2.2 Air Travel

As described previously, air travel reported in this study was assumed to be for personal purposes, and is assumed to be a completely discretionary activity associated with vacationing or visiting friends/family. All but two of the households recorded some air travel in the 12 months prior to the survey. As C and N flux associated with air travel was estimated on a passenger mile basis (and whether the flight was domestic or international), overall fluxes were directly related to total miles flown. Households choosing to reduce or limit their flights (or choose destinations closer to home for vacations) will see a corresponding reduction in C and N fluxes associated with air travel. Socioeconomic factors also may play an impact on the magnitude of a households' air travel, as described in Chapter 5.8.4, below.

5.8.3 Housing Characteristics and Lawn Management

General household characteristics including total square footage and age of home had a large effect on nutrient flux, particularly with respect to C. Larger homes tend to require higher rates of natural gas usage to heat a larger area, and also increased electricity usage due to more appliances and electrical equipment. With respect to finished square footage of home, both natural gas and electricity were shown to increase with increased home size, as shown in Figures 5.24 and 5.25 below.

Figure 5.24: Finished Square Footage and Natural Gas Usage

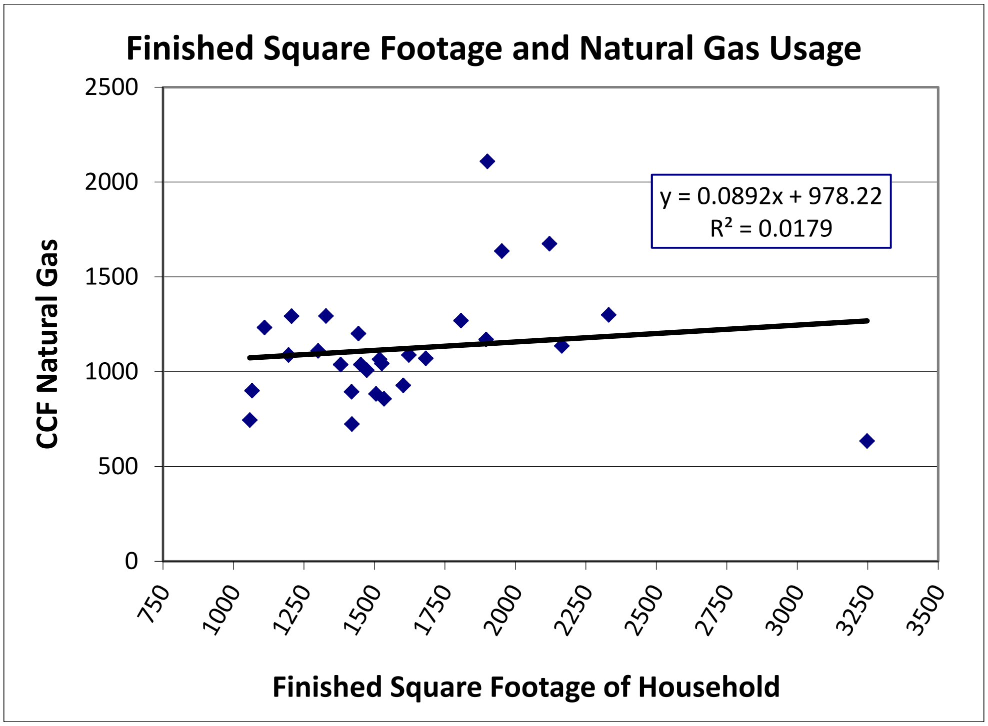
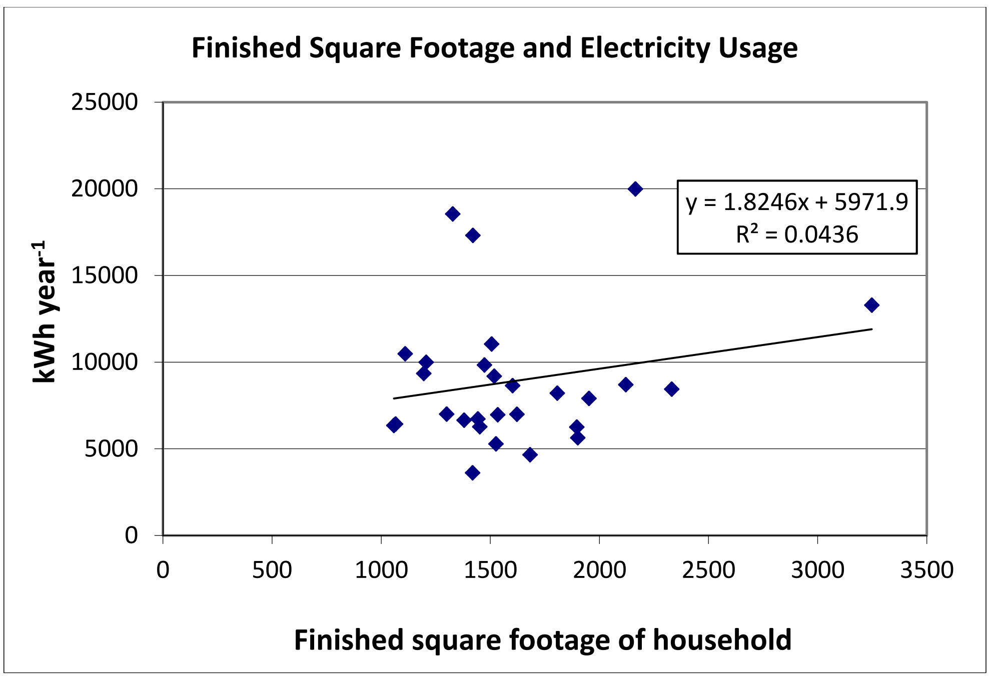
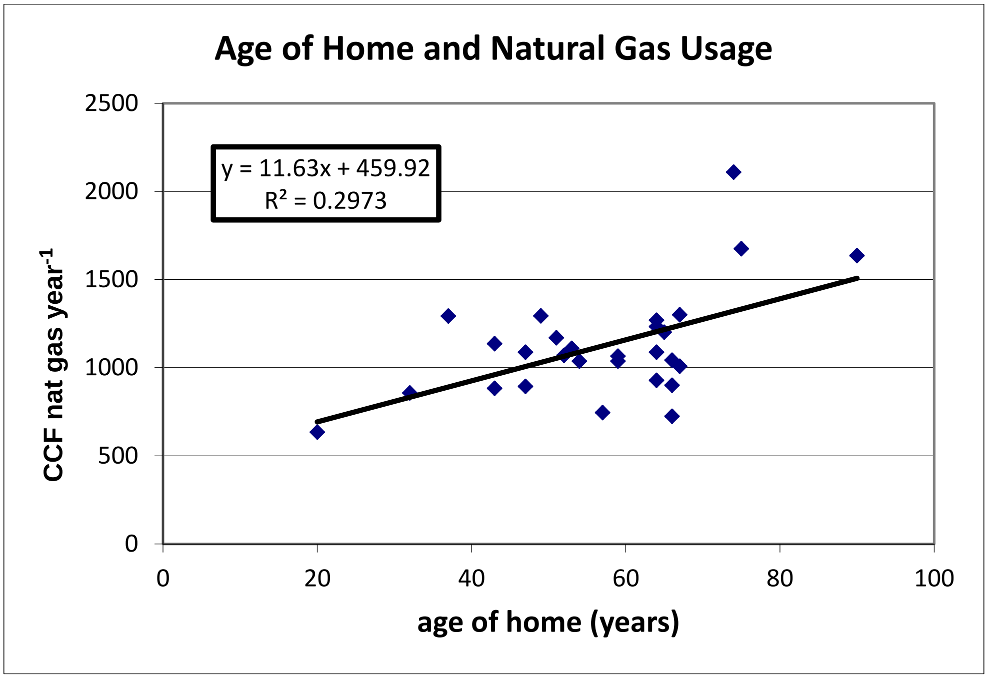


Figure 5.25: Finished Square Footage and Electricity Usage



Age of the home also was shown to have a large impact on household energy usage, particularly with respect to natural gas usage. This is largely due to the fact the older homes are typically less well insulated, and may lose significant amounts of heat through cracks, walls, and/or old windows. The majority of the homes in this survey were between 40-70 years old. The three oldest homes (74, 90, and 90 years old) exhibited the three highest natural gas usages among all 28 surveyed households. The newest home (20 year old) exhibited the lowest natural gas usage among all households.

Figure 5.26: Age of Home and Natural Gas Usage



As described above in Chapter 5.4, lawn management and size can have a large role in nutrient flux, and is one of the few components of the household which provides opportunities to sequester (or lose) C, N, and P in soil and/or plant biomass. In addition to specific household decisions related to lawn management (fertilization, management of yard waste/clippings, etc.) certain biological components of the yard including acreage of lawn and the amount, condition, and species of trees on each homeowners' lot play a significant role in overall nutrient flux, as well as opportunities for sequestration.

5.8.4 Socioeconomic Factors/Constraints

Nearly all of the household components (with the exception of those based on per capita averages) outlined throughout this thesis may be limited (or enhanced) by various socioeconomic factors.

Household income is probably the most important of these socioeconomic considerations, as the amount of household consumption may be limited by what the household can afford to purchase, whether it be how large of a house the household can afford (larger homes are typically more expensive), discretionary air travel, gasoline for automotive travel, or excessively high rates of household energy. In a similar vein, households with higher incomes have more options/choices with respect to consumption. They may be able to afford larger homes, higher utility bills, and take more trips (whether via car or airplane). Through conscious choice, they may also have the ability to reduce their overall nutrient flux by purchasing higher efficiency appliances, newer, better insulated homes, and more expensive high fuel economy cars.

Four of the households in the survey refrained from providing income data. For the remaining 24 households, strong correlations between increased income and C and N flux (and to a lesser extent P) were observed. On average, households in the highest income bracket (\$150,000 - \$200,000 annual income) consumed 58% more C, 93% more N, and 62% more P than households in the lowest income bracket (< \$30,000 annual income). Figures 5.27, 5.28, and 5.29 shows the relationship between annual household income and C, N, and P flux, respectively.

Figure 5.27: Household C Flux and Income (ave)

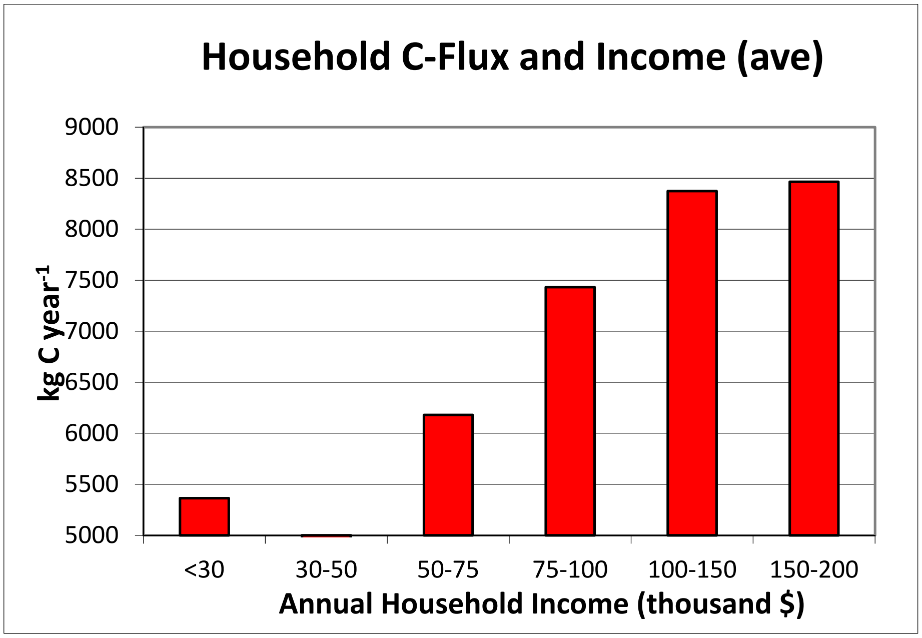


Figure 5.28: Household N Flux and Income (ave)

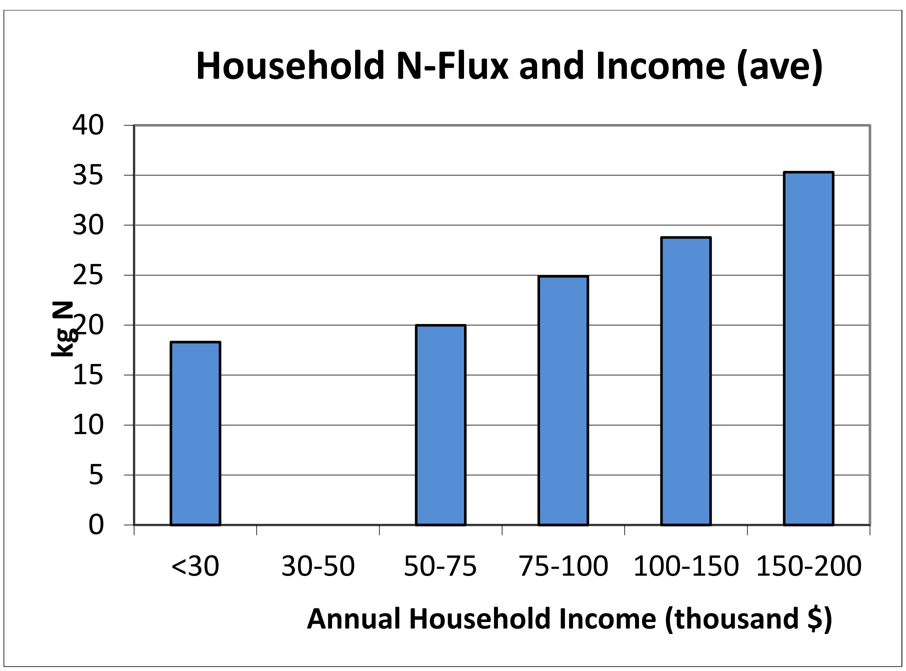
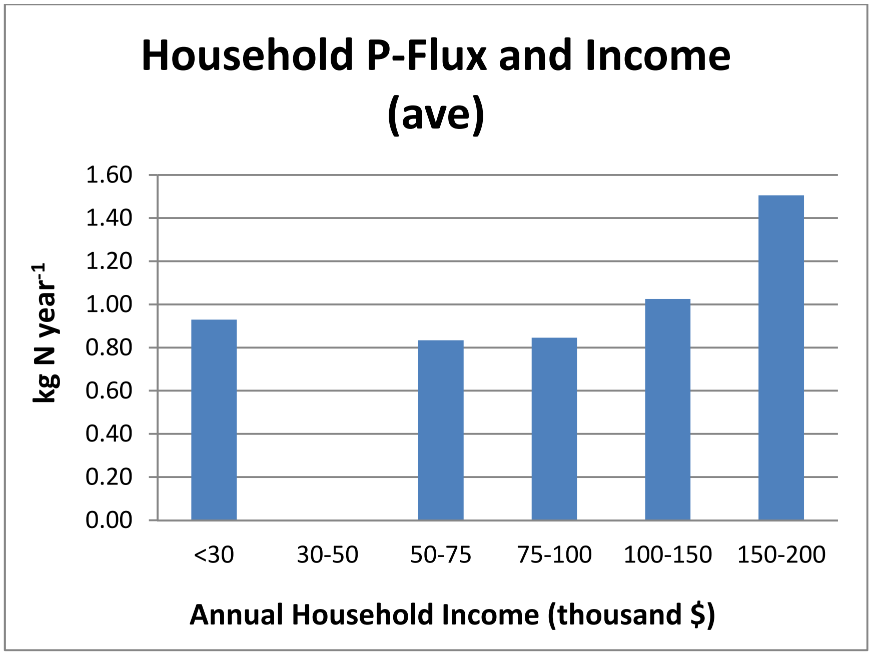


Figure 5.29: Household P Flux and Income (ave)



Household income is largely a component of the education level and employment status of the adult household members. Persons with higher education backgrounds are assumed to have a higher likelihood of being fully employed, as well as make higher salaries. Thus, these social characteristics can be indirectly linked to the data shown in Figures 5.27, 5.28, and 5.29, above.

Another important socioeconomic factor is employment status, which is touched on briefly above. Unemployment can stress household incomes and lead to subsequent reductions in consumption levels, particularly related to travel (no daily commuting). Household energy usage may actually increase for unemployed persons as they are likely spending more time in their homes, thus using more electricity. Households that are comprised of retired individuals generally show less consumption and nutrient flux; however, may have more free time for discretionary travel.

6. DISCUSSION AND CONLCUSIONS

According to Merriam Webster dictionary, a household is defined by "those who dwell under the same roof and compose a family; or, a social unit composed of those living together in the same dwelling." Several factors influence overall household consumption. Some of these factors are difficult to control (climate, source(s) of electricity generation, etc.), or may be limited by societal forces (income, size of family, employment status, etc.). Decisions that households make relatively infrequently (e.g., purchase of home, choice of automobile, number of children) tend to have the highest influence on consumption and nutrient flux. However, the cumulative effects of day-to-day activities (e.g., commuting decisions, consciously reducing household energy consumption) can also have a substantial impact on overall nutrient flux.

Overall nutrient fluxes were consistently higher for households with a larger number of residents. Household with more members generally require a larger home, higher transportation needs, and greater energy demands than households with fewer members. However, when compared on a per capita basis, fluxes tend to be lower for households with more members than fewer. This is thought to occur due to certain efficiencies achieved through sharing of common household resources (e.g., household energy, increased opportunities for carpooling, etc.). Although an increase of household members was shown to increase overall household nutrient flux, on a broader more regional scale, as the number of household members (particularly adult) increase, it reduces the overall number of households in a given geographic area or city, and due to the reduction in per capita consumption, would lead to less overall consumption on a regional level.

Various socioeconomic factors were shown to have a strong influence on overall household consumption and nutrient flux, with annual income appearing to be the most important. On average, households with higher income levels were shown to have substantially higher fluxes of C, N, and P. Households with relatively high income may have a wide variety of choice when it comes to where they live, how large their house is, distance of commute to work, the number and types of vehicle(s) they purchase, and the frequency (and destination) of vacations. High income households also have more choices and opportunities to reduce nutrient flux through purchasing higher efficiency appliances, high fuel economy vehicles, and improving home insulation. Households with lower income levels may desire to be consuming at a higher level (larger house, more air travel, etc.); however, but may be financially limited. Lower income households may also consciously desire to reduce their consumption (through the purchase of higher efficiency appliances, vehicles, improved insulation at the home, etc.), but again may be financially limited in their choices.

Several societal, political, and economic factors which individual households have minimal/no control also have major influences on household nutrient flux. For example, an individual household does not control the percent composition of fuels used in electricity generation (at the time of survey, primarily derived from coal, see Figure 3.1), and the corresponding emissions resulting from generation of electricity. Similarly, while individual households make direct choices regarding choice of personal automotive use, large scale societal trends and demands can lead to significant changes in overall nutrient fluxes, through increased federal fuel economy standards. Over the long term, public demand can result in corresponding changes, either directly through political mandates for alterative/renewable sources of energy (wind, solar, biomass, geothermal, etc.) or financial incentives (i.e., tax deductions) for purchased more fuel efficient vehicles, household appliances, etc.

National and global economics also play an important role in changing long-term trends which can have significant impacts on household consumption. As traditional sources of energy become more limited and prices increase, demand may decrease, and alternate sources gradually become more viable. In the last several years, this has become evident with automotive gasoline, which has witnessed a substantial increase in price, largely due to increased global demand, particularly in developing nations. Several car companies are now mass producing hybrid-electric vehicles which get over 40 mpg (note: highest mpg vehicle in this study was 31.7). Alternative renewable fuel sources (ethanol, biodiesel) for vehicles are also becoming more prominent. More recently, electric cars which do not have any emission are starting to come to market. Indirect emissions from electric cars could be traced back to the composition of the electricity generated, which as stated above, can also shift over time due to society and/or political pressure.

On a local level, the role of urban/suburban planning and decision regarding land use, zoning, and local/regional transportation from municipal, county, or metropolitan agencies can have a significant influence on household consumption, particularly related to automotive use. Reductions in automotive travel can be encouraged locally through expanding alternative transportation options, such as mass transit or promoting bicycle use through designated bike lanes. Reduced emissions from cars/trucks can also be achieved through thoughtful transportation design (timing stoplights, reducing traffic congestion, etc.).

Although socioeconomic and political factors can influence consumption and promote certain behaviors, ultimately it is the individual choices made on the household level which have the most direct and immediate impact on nutrient flux. As shown throughout this thesis, these choices and behaviors lead to a wide variability in the overall household and per capita fluxes of C, N, and P, each of which have environmental consequences locally, regionally, and globally.

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APPENDIX A

Falcon Heights, MN - Urban Nutrient Cycling Household Study Questionnaire

Urban Nutrient Cycling
Household Study

Interviewer Name(s): ______________________________

Interviewee Name(s): ______________________________

Date & Time: ______________________________

General Comments: ______________________________

____

____

____

____

Biogeochemical Household Study

Section 1: To be completed by interviewer

Introduction:

Hello. Thank you for agreeing to participate in our study. The information you provide will help us estimate the types and amounts of nutrients going into and coming out of the "average" home in Falcon Heights. This information will be used to design a larger, nation-wide study focusing on how carbon, nitrogen, and phosphorus move through the urban ecosystem.

I will ask you a variety of questions having to do with your household, such as questions about: the layout of your home, the types of cars your family drives, your family's electricity use, lawn care and landscaping, and waste disposal.

You can decline to answer any question or ask to clarify a question at any time. Do you have any questions before we start?

A: General Household Characteristics

We would like to ask you a few questions about some general aspects of your house.

Q1. What year did you move into your house? ____________________

Q2. Have you built any additions to your house?

- ❑ Yes
- ❑ No (SKIP to question 3)

Q2a. How many square feet did you add? _____________ sq ft.

Q2b. When was the remodeling done? __________________

Q2c. How many dumpsters of material (ie. lumber, etc.) were removed?

____________ number of dumpsters

____________ size of dumpsters

Q3. Have you ever replaced your roof?

- ❑ Yes
- ❑ No (SKIP to question 4)

Q3a. When was the roof replaced? __________________

Q4. What percent of the house is carpeted with wall to wall carpeting? ____________ %

Room Type	**Do you have this room (Y/N)?**	**Is the room carpeted?**
Living room	**Y or N**	**Y or N**
Dining room	**Y or N**	**Y or N**
Kitchen	**Y or N**	**Y or N**
Family/TV room	**Y or N**	**Y or N**
Bedroom 1	**Y or N**	**Y or N**
Bedroom 2	**Y or N**	**Y or N**
Bedroom 3	**Y or N**	**Y or N**
Bedroom 4	**Y or N**	**Y or N**
Basement	**Y or N**	**Y or N**
Attic	**Y or N**	**Y or N**
Other __________	**Y or N**	**Y or N**
Other __________	**Y or N**	**Y or N**

Q5. Do you have a garbage disposal?

- ❑ Yes
- ❑ No (SKIP to question 6)

Q5a. Do you use your garbage disposal, and, if so, for how much food waste?

- ❑ Do not use garbage disposal
- ❑ Minimal amount of food waste (food sauces stuck to plates)
- ❑ Some food waste (plate scraps, etc.)
- ❑ Most food waste

Q6. Do you have fireplaces or wood-burning stoves in your home?

- ❑ Yes
- ❑ No (SKIP to question 7)

Q6a. How many fireplaces and/or wood-burning stoves does your home have?

Wood-burning fireplaces _______
Wood-burning stoves _______
Gas fireplaces _______

Q6b. During an average winter month (2004), how many times did you have a fire in the fireplace or wood-burning stove?

Fireplace _______
Wood-burning stove _________

Q6c. How many cords of firewood did you use in 2004? (A "cord" is a way of measuring wood. One cord is equal to a stack of wood 4ft x 4ft x 8ft.)

_______ cords

Q7. Do you have a propane or charcoal grill?

- ❑ Charcoal grill
- ❑ Propane grill
- ❑ No (SKIP to question 8)

Q7a. On average, how many times do you grill per month?

________________ during the summer

________________ during the non-summer months (rest of year)

Q7b. For propane tanks, how many canisters did you use in 2004?

____________ tanks

Q7c. For charcoal grills, how many bags of charcoal did you use in 2004? What size (lbs)?

____________ # of bags

____________ size of bags

Q8. I would like to ask about appliances in your house.

Appliance	**How many you have**	**Age(s)/ Year it was purchased**	**Gas or Electric (G or E)**
Refrigerator 1			----------------------
2			----------------------
Freezer			----------------------
Stove			**G or E**
Microwave			----------------------
Washer			----------------------
Dryer			**G or E**
Dehumidifier 1			----------------------
2			----------------------
Humidifier			----------------------
Computer/ laptop			----------------------
TV			----------------------

B: Family Characteristics and Household Life

In this section of the interview, we would like to ask you some questions about the family members living in your house and their daily habits.

General

Q9. Now I'm going to ask you a few questions about each family member.

Code	Family Member Name	Age	Gender	Work schedule: full time outside home, part time outside home, full time at home, or part time at home	Comments:
A 1			M or F		
A 2			M or F		
A 3			M or F		
C 1			M or F		
C 2			M or F		
C 3			M or F		
C 4			M or F		

Q10. Do the children live in the house full time?

- ❑ Yes (SKIP to question 11)
- ❑ No

Q10a. During an average week, how many days do the children live in the house?

_______________ days

Q11. Do you have a second home or cabin?

- ❑ Yes
- ❑ No (SKIP to question 12)

Q11a. On average, how much time does your family spend in this second residence?

Units	Total # of days calculation
________________ days per year	__________________ # of days
________________ weeks per year	
________________ weekends per year	

Food and Eating

Q12. How would you describe your family's diet? Meat includes beef, pork, and poultry. Vegetarian items include beans and bean products.

- ❑Primarily meat eaters (meat at almost every meal)
- ❑Moderate meat eaters (most meals have meat and some meals are vegetarian)
- ❑Moderate vegetarian (most meals are vegetarian and some meals have meat)
- ❑Primarily vegetarian (meat eaten very rarely or not at all)

Q13. Now we're going to talk about how often your family eats out. On average, how often does each family member eat out (meal not prepared at home) per week?

Code	**Family Member Name**	**# of times per Week during school year**			**# of times per week during summer**		
		Breakfast	**Lunch**	**Dinner**	**Breakfast**	**Lunch**	**Dinner**
A1							
A2							
A3							
C1							
C2							
C3							
C4							

Clothing

Q14. On average, how many relatively full shopping bags (i.e., Marshall Fields bag) of clothing do you bring into the house per month?

_________________ # of bags

Pets

Q15. Does your family have a pet or pets?

- ❑Yes
- ❑No (SKIP to question 16)

Q15a. Can you tell me a little bit about the pets your family owns?

Family Pet	**Size (lbs)**	**Indoor or outdoor (for cats)**	**Where dog urinates & defecates (majority of the time)**
Dog 1		---------------	**Yard or Walk**
Dog 2		---------------	**Yard or Walk**
Cat 1		**I or O**	-------------------
Cat 2		**I or O**	-------------------

Q15b. Do you have a dog pen?

- ❑ Yes
- ❑ No

<u>Travel</u>

Q16. I would like to ask you about your family's air travel for 2004. I would like to know about trips you've already taken and trips you are planning to take.

Code	**Family Member Name**	**Destination (state or country)**	**Roundtrip or one-way**
A1			**RT or OW**
			RT or OW
			RT or OW
A2			**RT or OW**
			RT or OW
			RT or OW
A3			**RT or OW**
			RT or OW
			RT or OW
C1			**RT or OW**
			RT or OW
			RT or OW
C2			**RT or OW**
			RT or OW
			RT or OW
C3			**RT or OW**
			RT or OW
			RT or OW
C4			**RT or OW**
			RT or OW
			RT or OW
			RT or OW

Q17. How does each family member commute to work or school?

For each person can you tell me:

1. **What types of transportation they use?**
2. **How far they travel (one-way distance)?**
3. **How many days a week they travel this distance?**

Mode:	**Code:**
Drive	**1**
Carpool	**2**
Bus	**3**
Bike	**4**
Walk	**5**
Other	**6**

Code	Name	Job/ School location	Distance	# of days per week	Mode
A1					
A2					
A3					
C1					
C2					
C3					
C4					

Q18. On the weekends—does your family travel more or less than during the week? Why?

Code	Family Member Name	Amount of weekend travel & reason
A 1		
A 2		
A 3		
C 1		
C 2		
C 3		
C 4		

Q19. In 2004 how many weekend trips did your family take (# of trips over 50 miles; # of trips over 100 miles)?

____________ # of trips over 50 miles (about from Minneapolis to St. Cloud)

____________ # of trips over 100 miles (about from Minneapolis to Brainerd)

Q20. What kind of vehicles does your family own?

Vehicle (make & model)	Year	# of cylinders (4,6,8)	Year vehicle was purchased	# of miles on vehicle when purchased

Q21. For family members that drive to work or school, what vehicle do they use?

Code	Family Member Name	Vehicle
A1		
A2		
A3		
C1		
C2		
C3		
C4		

C: Household Waste

The following questions focus on the waste your household produces and how you dispose of it.

Q22. Do you have weekly garbage pick-up?

- ❑ Yes (SKIP to question 23)
- ❑ No

Q22a. How do you dispose of your garbage?

____

____

Q23. How many tall (13 gallon) plastic bags of household waste do you produce each week on average?

__________ thirteen-gallon plastic trash bags

Q24. Do you compost food waste?

- ❑ Yes
- ❑ No (SKIP to question 25)

Q24a. Do you compost food waste on-site (on your property) or off-site?

- ❑ On-site
- ❑ Off-site

Go to 24b.

Q24b. How much food waste do you compost?

- ❑ Some food waste
- ❑ Most food waste
- ❑ All food waste

D: Recycling

Q25. For each category listed below, please indicate how many full bags (paper bags) you recycle every two weeks?

Recyclable Items	# of bags recycled every two weeks
Paper products (newspaper, magazines, mixed mail, office paper, cereal & cracker boxes)	
Aluminum cans	
Glass	
Plastic bottles	
Corrugated cardboard	

Q26. What do you do with corrugated cardboard?

- ❑ Recycle it
- ❑ Throw it away
- ❑ Burn it in fireplace
- ❑ Other ____

Q27. How many newspapers does your household get each week?

_________ daily newspapers (M-F)

_________ weekend newspapers (Sat/Sun)

Q28. How many weekly magazines and journals do you get? ___________ mag. & journals

Q29. How many monthly magazines and journals do you get? _____________ mag & journals

Q30. We would like to know what you do with old clothing. Which methods do you use and what percentage of clothing is disposed of?

Method	Percent
Give it to charity (i.e. Goodwill)	________ %
Throw it away	________ %
Give it to family members	________ %
Recycle it (through city's recycling service)	________ %
Sell it (ie. garage sale or consignment shop)	________ %
Other ______________________	________ %

E: Energy Consumption

We would like to ask you some questions about your family's use of energy. We have a few questions about electricity and gas.

Q31. Is your home air conditioned?

- ❑ Yes
- ❑ No (SKIP to question 32)

Q31a. Do you have central air or window units (if window units, how many do you have?)

- ❑ Central air
- ❑ Window units; __________ Number of window units
- ❑ Other ____

Q31b. On average, what temperature do you set your thermostat in the summer?

____________ ºF

- ❑ Don't use it

Gas

Q32. What type of heating system do you have?

- ❑ Gas
- ❑ Electric
- ❑ Oil
- ❑ Wood
- ❑ Other _____________________

Q33. At what temperature do you normally set your thermostat in the winter?

Winter setting _____ ºF

Q34. Do you have a programmable thermostat?

- ❑ Yes
- ❑ No

Q34a. What do you set it at? During the day/night, week, and weekend?

____

____

____

Energy Conservation

Q35. Have you done any household modifications to conserve energy?

Modification/ Action	Yes	No	Not Applicable	Did you do this? Yes	No
Is your water heater insulated?	❑	❑	❑	❑	❑
Are your hot water pipes insulated?	❑	❑	❑	❑	❑
Do you replace your furnace filters regularly?	❑	❑	❑	❑	❑
Do you have energy efficient windows?	❑	❑	❑	❑	❑
Have you sealed leaky windows and doorways?	❑	❑	❑	❑	❑
Have you added wall insulation?	❑	❑	❑	❑	❑
Have you added roof insulation?	❑	❑	❑	❑	❑
Have you replaced your air conditioner with a higher efficiency model?	❑	❑	❑	❑	❑
Have you replaced your heater with higher efficiency model?	❑	❑	❑	❑	❑
Have you put in landscaping for house cooling and/or heating?	❑	❑	❑	❑	❑

Other modifications: ____

____

Electricity & Gas Bills

Q36. Interviewer: Ask homeowner if they would be willing to sign the consent form for electricity and gas use.

F: Lawn Care & Landscaping

Now we would like to ask you a few questions about your lawn and how you take care of it.

Q37. Have you re-sod your lawn?

- ❑ Yes
- ❑ No (SKIP to question 38)

Q37a. What year did you re-sod your lawn? __________

Q38. Do you test your soil?

- ❑ Yes
- ❑ No (SKIP to question 39)

Q38a. How do you use the information? _________________________

Q39. Do you fertilize your lawn?

- ❑ Yes
- ❑ No (SKIP to question 40)

Q39a. Do you use a lawn care company to apply fertilizer to your lawn?

- ❑ Yes; What is the company's name? ________________________ (SKIP to 40)
- ❑ No

Q39b. When you fertilize, how do you know how much to apply?

- ❑ Based on soil test results
- ❑ Instructions on back of bag
- ❑ No criteria used
- ❑ Other ____

Q39c. During the 2004 growing season, how many times did you fertilize your lawn?

_______ times

Q39d. How much (number of bags) fertilizer do you use per year? _________ bags

Q40. Do you fertilize your garden?

- ❑ Yes
- ❑ No (SKIP to question 41)

Q40a. Do you use a company to apply fertilizer to your garden?

- ❑ Yes; What is the company's name? __________________________ (SKIP to 41)
- ❑ No

Q40b. When you fertilize your garden, how do you know how much to apply?

- ❑ Based on soil test results
- ❑ Based on vegetation type
- ❑ Instructions on back of bag

- ❑ No criteria used

Q40c. During the 2004 growing season, how many times did you fertilize your garden?
_______ times

Q40d. How much (number of bags) fertilizer did you use in 2004? _________ bags

Q41. Do you apply pesticides or herbicides to control insects and/or weeds to your lawn?

- ❑ Yes
- ❑ No (SKIP to question 42)

Q41a. Who applies the pesticides or herbicides to your lawn?

- ❑ You apply them
- ❑ A company applies them. Company name _________________
- ❑ Other ______________________

Q41b. Do you apply pesticides or herbicides as a preventative measure or to target a specific problem?

- ❑ Preventative measure
- ❑ Specific problem. What is the problem? ______________________________
____

Go to question 41c.

Q41c. How often do you apply pesticides or herbicides to your lawn?

_________________ times per week

_________________ times per month

Q41d. Do you have safety concerns regarding the application of pesticides?

- ❑ No (SKIP to question 42)
- ❑ Yes; What are your concerns? ___________________________________
____

Q42. Do you apply pesticides or herbicides to control insects and/or weeds to your garden?

- ❑ Yes
- ❑ No (SKIP to question 43)

Q42a. Who applies the pesticides or herbicides to your garden?

- ❑ You apply them
- ❑ A company applies them. Company name _________________
- ❑ Other ______________________

Q42b. Do you apply pesticides or herbicides as a preventative measure or to target a specific problem?

- ❑ Preventative measure
- ❑ Specific problem. What is the problem? ______________________________
  ____

Q42c. How often do you apply pesticides or herbicides to your garden?

_________________ times per week

_________________ times per month

Q42d. Do you have safety concerns regarding the application of pesticides?

- ❑ No (SKIP to question 43)
- ❑ Yes; What are your concerns? ___________________________________
  ____

Q43. During an average year, how many cubic feet (cubic yards, # of wheelbarrows) of mulch do you add to your yard (ie. landscaping, around trees, etc.)?

________ (Circle unit: # of bags, cubic feet, cubic yards, # of wheelbarrows)

Q44. Do you water your lawn and how do you do it?

- ❑ Yes
- ❑ No (SKIP to question 45)

Q44a. Watering technique	**Number of times per week**	**Length of time you water each time you water**
Sprinkler system		
Moveable sprinklers		
Spraying water by hand (using garden hose)		

Q45. Do you water your garden and how do you do it?

- ❑ Yes
- ❑ No (SKIP to question 46)

Q45a. Watering technique	**Number of times per week**	**Length of time you water each time you water**
Sprinkler system		
Moveable sprinklers		
Spraying water by hand (using garden hose)		

Q46. What type of lawn mower do you have? (Do you put an oil & gas mixture into the gas tank? If so, it is a 2 stroke engine. If you put only gas in, it is a four stroke.)

- ❑ 4 stroke engine (gas)
- ❑ 2 stroke engine (oil and gas mixture)
- ❑ Electric motor
- ❑ Other ______________________________________

Q47. During an average month (of 2004), how many times did you mow?

___________ times

Q48. What type of lawn equipment do you have?

Lawn equipment	Gas or Electric	How much did you use this item in 2004? (infrequently 0-10 times; moderately 11-20; frequently 20 or more times)
Leaf blower	**G or E**	**Infreq or Mod or Freq**
Chain saw	**G or E**	**Infreq or Mod or Freq**
Weed wacker	**G or E**	**Infreq or Mod or Freq**
Hedge trimmers	**G or E**	**Infreq or Mod or Freq**
Snow blower	**G or E**	**Infreq or Mod or Freq**

Q49. How do you dispose of lawn clippings?

- ❑ Leave clippings on lawn
- ❑ Dispose of with regular household garbage
- ❑ Yard waste removal company removes it
- ❑ Household (on your property) compost pile
- ❑ Off-site (not on your property) compost area
- ❑ Other ____

Q50. How do you dispose of leaves and herbaceous (non-woody) garden waste?

- ❑ Rake leaves into street
- ❑ Dispose of with regular household garbage
- ❑ Yard waste removal company removes it
- ❑ Household (on your property) compost pile
- ❑ Off-site (not on your property) compost area
- ❑ Other ____

Q51. How do you dispose of branches?

- ❑ Dispose of with regular household garbage
- ❑ Yard waste removal company removes it
- ❑ Household (on your property) compost pile
- ❑ Off-site (not on your property) compost area
- ❑ Other ____

Q52. What type of tree leaf (tree species—oak, elm, maple) makes up most of your leaf yard waste?

_________________ (tree species)

Q53. What percentage of the leaves you remove from your yard comes from trees in your yard? What percentage comes from neighbors' trees?

________ % from trees in your yard

________ % from neighbors' trees

Q54. How many bags (30 gallon bag) of yard waste did you dispose of in 2004?

Yard waste type	# of bags disposed of each month	Other estimates (cubic feet, pickup truck loads, etc)
Lawn clippings		
Leaves		
Branches		

Q55. How many waste cans has your provider given you and what are their sizes? *(See picture below. From left to right 32 gal, 64 gal, and 96 gal).*

Waste cans	Size (in gallons)	Size (in cubic feet)
Waste can 1		
Waste can 2		
Waste can 3		

Q56. How many miles are currently on each vehicle? Can we call back in 6 months and get another odometer reading?

*(Interviewer: Check odometer on each vehicle ***IMPORTANT***)*

Vehicle (make & model)	# of miles currently on vehicle

Q57. What type and brand of fertilizer do you use for your lawn? (Get the N-P-K ratio; ie. 40-10-5)

____

____

(type—full title of fertilizer; size of bag)

Q58. What type and brand of fertilizer do you use for your garden? (Get the N-P-K ratio; ie. 40-10-5)

____

____

(type—full title of fertilizer; size of bag)

Date: ______________________________

To: Xcel Energy

Attention: Ben

Correspondence Team

3115 Center Point Dr.

Roseville, MN 55113

Account #: ______________________________

As a customer with your company, I (we) hereby authorize and request that a report detailing my (our) energy use history (kwh and therms) with your company be forwarded to the Kristen Nelson and Michelle Payton, researchers at the University of Minnesota.

Please include the number of kilowatt hours and therms used each month from August 2003 to July 2004.

Please be advised, this letter serves as my (our) authorization for the release of my (our) energy use history information with your company. Thank you for your cooperation in this matter.

____

Signature

____

Name (Please print)

____

____

Address

____

Telephone

Section 2: About your actions

About Your Actions

Household decisions impact nutrient cycles in a variety of ways. The choices we make influence what goes into the cycle and what comes out. In this part of the survey, we would like to ask you a few questions about your actions. There are no “right” or “wrong” actions. We are only interested in understanding the relationship between household choices and nutrient cycles.

A: Driving

Q1. What are you trying to impact with the current amount you drive your car? Why? What are the advantages and disadvantages?

Q2. How knowledgeable do you think you are about how the current amount you drive impacts nutrient cycling? Why?

Q3. How does what others (family & friends) think influence your decisions about how much you drive?

Q4. How much do you feel you can control the amount you drive? Why? If you could make a change what would it be?

B: Your current consumption of beef, pork, and poultry

Q1. What are you trying to impact with your consumption of meat (beef, pork, and poultry)? What are the advantages and disadvantages?

Q2. How knowledgeable do you think you are about how your consumption of meat (beef, pork, and poultry) impacts nutrient cycling? Why?

Q3. How does what others (family & friends) think influence your decisions about your consumption of meat (beef, pork, and poultry)?

Q4. How much do you feel you can control your consumption of meat (beef, pork, and poultry)? Why? If you could make a change what would it be?

C: Your current use of electricity and gas

Q1. What are you trying to impact with your current use of electricity and gas to heat and cool your home? What are the advantages and disadvantages?

Q2. How knowledgeable do you think you are about how your current use of electricity and gas to heat and cool your home impacts nutrient cycling? Why?

Q3. How does what others (family & friends) think influence your decisions about your current use of electricity and gas to heat and cool your home?

Q4. How much do you feel you can control your current use of electricity and gas to heat and cool your home? Why? If you could make a change what would it be?

D: Your current use of fertilizer

Q1. What are you trying to impact with your current use of fertilizer? (What are the advantages and disadvantages?)

Q2. How knowledgeable do you think you are about how your current use of fertilizer impacts nutrient cycling? Why?

Q3. How does what others (family & friends) think influence your decisions about your current use of fertilizer?

Q4. How much do you feel you can control your current use of fertilizer? Why? If you could make a change what would it be?

E: The current amount of trash you produce

Q1. What are you trying to impact with the current amount of trash you produce? What are the advantages and disadvantages?

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Q2. How knowledgeable do you think you are about how the current amount of trash you produce impacts nutrient cycling? Why?

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Q3. How does what others (family & friends) think influence your decisions about the current amount of trash you produce?

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Q4. How much do you feel you can control the current amount of trash you produce? Why? If you could make a change what would it be?

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Section 3: About You

We would like to ask a few more questions about your background.

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We would like to ask a few more questions about your background.

Q17. What is your gender? *Please check one.*

- ❑ Male
- ❑ Female

Q18. What is your current age? _______

Q19. Do you consider yourself: *Please check all that apply.*

- ❑ White
- ❑ Hispanic
- ❑ African American
- ❑ Asian or Pacific Islander
- ❑ Native American
- ❑ Alaskan Native
- ❑ Other ___________________

Q20. For each adult family member, what is their highest level of education?
Please check one response for each family member.

Education	A few years of high school	High school degree	2 yr degree	4 yr degree	Graduate degree
Adult 1	❑	❑	❑	❑	❑
Adult 2	❑	❑	❑	❑	❑
Adult 3	❑	❑	❑	❑	❑
Adult 4	❑	❑	❑	❑	❑

Q21. What is the work status of each adult in the household? *Please check one response for each adult.*

	Working (office at home)	Working (office outside home)	Unemployed	Retired	Working as Homemaker	Student
Adult 1	❑	❑	❑	❑	❑	❑
Adult 2	❑	❑	❑	❑	❑	❑
Adult 3	❑	❑	❑	❑	❑	❑
Adult 4	❑	❑	❑	❑	❑	❑

Q22. What is the approximate value of your house? *Please check one.*

- ❑ Under $100,000
- ❑ $100,000 to $200,000
- ❑ $200,001 to $300,000
- ❑ $300,001 to $400,000
- ❑ $401,000 to $500,000
- ❑ Over $500,000

Q23. If you added together the yearly incomes, before taxes, of all the members of your household for last year, would it total: *Please check one.*

- ❑ Less than $30,000
- ❑ $30,000 to $49,999
- ❑ $50,000 to $74,999
- ❑ $75,000 to $99,999
- ❑ $100,000 to $149,999
- ❑ $150,000 to $199,999
- ❑ $200,000 to $249,999
- ❑ $250,000 to $299,999
- ❑ More than $300,000