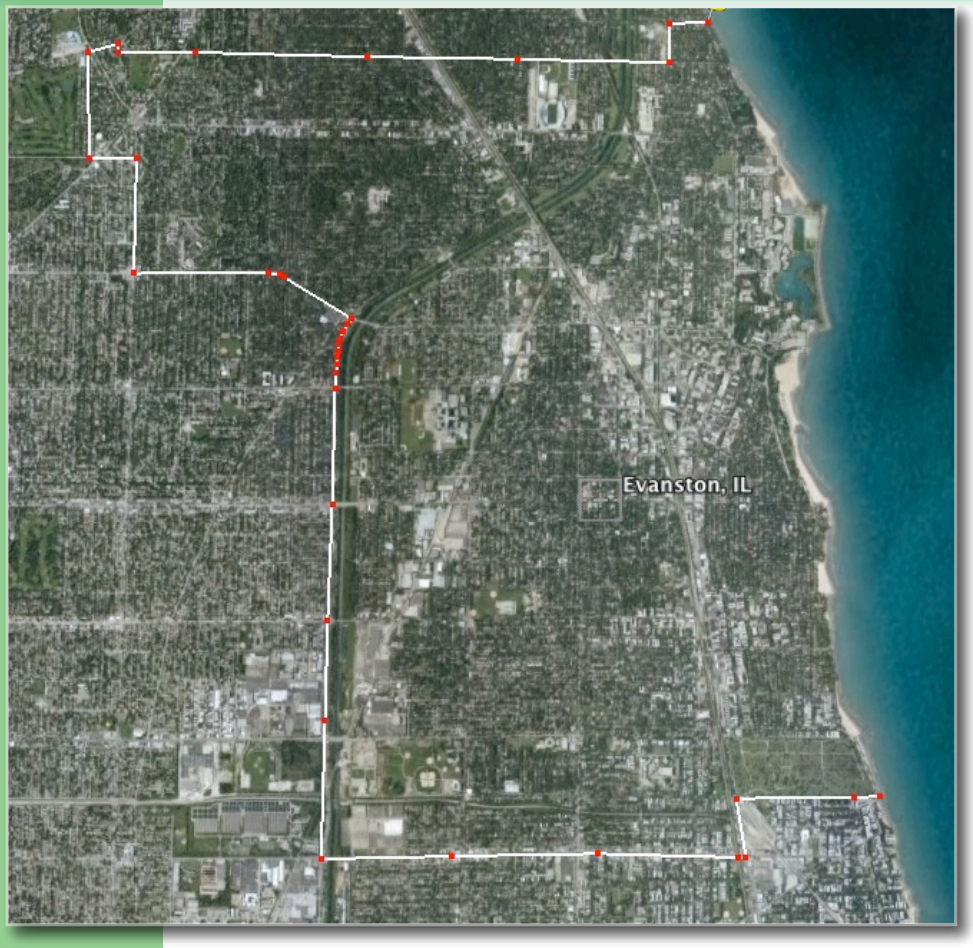
Carbon Sequestration and Air Quality Regulation by Evanston's Trees



Christina Bernardo & Dr. Neal Blair, Faculty Advisor

Dept. of Civil and Environmental Engineering, Northwestern University

Executive Summary

The city of Evanston has set a goal to reduce its carbon dioxide emissions by 13% by the year 2012. The Evanston Climate Action Plan has been formed as a means to reach this goal, analyzing the city's carbons emission sources and suggesting possible actions for emission reductions. In order to fully understand Evanston's carbon budget and take further action towards ECAP's reduction goals, we are investigating the role of trees in the city's carbon cycle. Geographic Information Systems software was used to calculate the tree cover area of Evanston. We also obtained data from various other cities to determine the relationship between the amount of carbon sequestered by trees, or stored for a period of time, and the tree cover area of the city. We then compared Evanston's tree cover area to this model to determine the amount of carbon sequestered by the city's trees. These projections were then compared to Evanston's total carbon dioxide emissions to quantify the proportion of CO_2 emissions stored in the city's trees. We also looked into other data available from other cities regarding pollution uptake by trees to report on the overall effect of tree on the content of Evanston's air.

Our best estimate is that Evanston's trees sequester approximately 1700-2400 tons of carbon per year, although incorporating the greatest degree of uncertainty gives an upper bound on our projection at 7300 tons per year. This means that the trees are storing about 0.2% (with an upper bound of .6%) of the carbon dioxide emitted by the city. These figures are important to understanding Evanston's carbon budget and how the city should handle issues related to carbon management. Additionally, the city's trees are projected to take up over 100 tons of other atmospheric pollutants each year, saving the city around $500,000 by preventing damaging pollution effects. Evanston's trees are a part of the natural carbon cycle and have an effect on the composition of the city's air.

Introduction

The city of Evanston has set a goal to reduce its carbon dioxide emissions by 13% by the year 2012. The Evanston Climate Action Plan[1] has been developed as a means to reach this goal, analyzing the city's carbons emission sources and suggesting possible actions for emission reductions. This report investigates the capacity of Evanston's trees towards reducing the amount of CO_2 in the atmosphere. Trees and other flora sequester carbon by converting carbon dioxide in the atmosphere to vegetative growth. A tree takes in CO_2 and converts it to sugars through photosynthesis. These sugars then provide energy and biomass for new growth of the tree. The tree will store this carbon throughout its lifetime in various compounds that make up its trunk and branches.

In order to fully understand Evanston's carbon budget and take further action towards ECAP's reduction goals, we are investigating the role of trees in the city's carbon cycle. In this project, we aim to achieve a better understanding the relative effects of both the trees' sequestration and the city's emissions on the atmospheric CO_2 levels. We are using previous studies to extrapolate the amount of carbon dioxide Evanston's trees are storing and look into how this may be useful to the city's carbon management goals and policies.

Objectives

The aim of this project is to quantify the carbon sequestered by trees in Evanston. The results have been prepared with intended application to the Evanston Climate Action Plan, to lend insight and counsel on practices and policies regarding trees in Evanston. The ultimate objective of this project is to estimate the amount of carbon dioxide sequestered each year by the trees in Evanston, and to compare this number to the current carbon emissions. Thus we will assess the value of Evanston's trees to the removal of carbon from the air.

Approach

The US Department of Agriculture's Urban Forest Effect Model (UFORE) contains information on local tree populations and their benefits to the surrounding areas for various North American cities. We have used a compilation of data from various UFORE reports to determine the relationship between the amount of carbon sequestered by a city's trees and its land area covered by trees. The resulting model was refined to exclude cities such as New York, NY and San Francisco, CA that exhibited a "big city effect", having unusually small carbon sequestration values for the associated tree cover. This effect can be explained by the smaller diameter and poorer health of trees in a big city[2]. This is in turn explained by the fact that trees in urban centers are exposed to high concentrations of air and ground water pollutants. Also, large cities often exhibit a heat island effect, increasing temperatures in the cities and disrupting the biological processes of the trees.

Within this refined data set, the quality of the relationship between tree area and carbon sequestration was studied by taking various subsets of cities with similar climatic or geographic conditions. To do this, we used limited data sets, including only those cities within a certain range of selected parameters of Evanston. The climatic and geographic parameters used to restrict the data were mean annual temperature, latitude, and mean annual precipitation. The reasoning was that trees in similar climates (characterized by latitude, precipitation patterns, and temperature) would have similar rates of photosynthesis and sequester a similar amount of carbon. The regressions produced by these restricted sets of data confirmed this reasoning, as they showed a stronger relationship between tree cover and carbon sequestered.

The average tree cover of Evanston was found using forest canopy data from the US Geological Survey's National Map Seamless Server (NMSS) database. Northwestern University Geographic Data in Education Initiative's My World Geographic Information System (GIS) software was used to analyze this data for the Evanston area and calculate the average percent tree cover and total area of Evanston. This was used to calculate the city's tree cover area. We then compared Evanston's tree cover to the UFORE models to estimate the amount of carbon sequestered by trees in Evanston.

Method

UFORE analysis data was compiled from 12 North American cities (Boston, MA; Calgary, AB; Jersey City, NJ; Minneapolis, MN; New York, NY; Oakville, ON; Philadelphia, PA; San Francisco, CA; Syracuse, NY; Toronto, ON; Washington, DC; Woodbridge, NJ). The data were analyzed to determine the relationship between the tree cover of the city and the amount of carbon sequestered by the trees each year (See Appendix A for a complete table of UFORE data).

The percent tree cover and area enclosed by each city were used to calculate the tree cover of each city in hectares. This data was then plotted against annual carbon sequestration to determine the relationship between the two factors. This process was then repeated for limited sets of cities; the carbon sequestration versus tree area relationship was calculated for:

- Cities within 5˚ Latitude of Evanston
- Cities within 5˚F mean annual temperature of Evanston
- Cities within 10 inches of Evanston's mean annual precipitation.

Each of these parameter ranges was approximately one standard deviation of the respective climatic factors of all the cities' data. Of these limited data sets, the regression that included only cities within 5˚F of Evanston's mean annual temperature showed the best correlation, therefore the corresponding regression model was used to make carbon sequestration projections for Evanston.

Evanston's tree cover area was calculated using My World GIS software. Forest canopy data was extracted from the US Environmental Protection Agency's Multi-Resolution Land Characteristics Consortium (MRLCC) database, through the NMSS, and converted by ArcGIS, a more advanced GIS program, to ASCII format to be compatible with My World. Evanston's city border was also loaded into My World and together the layers were used to determine the average percentage tree cover in Evanston.

These data were then used to calculate the total tree cover area of Evanston. Then the annual carbon sequestration by Evanston's trees was projected using the various regression models we created. These values were then compared to the overall carbon emissions of Evanston and the ECAP carbon emissions reduction goal.

Additionally, regressions were made to model the amount of pollution that trees uptake each year, and the monetary equivalent of this service. These calculations were done similarly to those for carbon sequestration, using UFORE data from various cities to create projections for Evanston.

Results

A. Tree Cover Area

The My World GIS program used layers of data from the NMSS's MRLCC database to calculate the percent of the area within Evanston that is covered by trees. The software was also used to determine the exact area of Evanston. A simple calculation was then carried out to determine the area of Evanston covered by tree canopy. The image produced by the layers of tree canopy cover and the Evanston border is shown below.

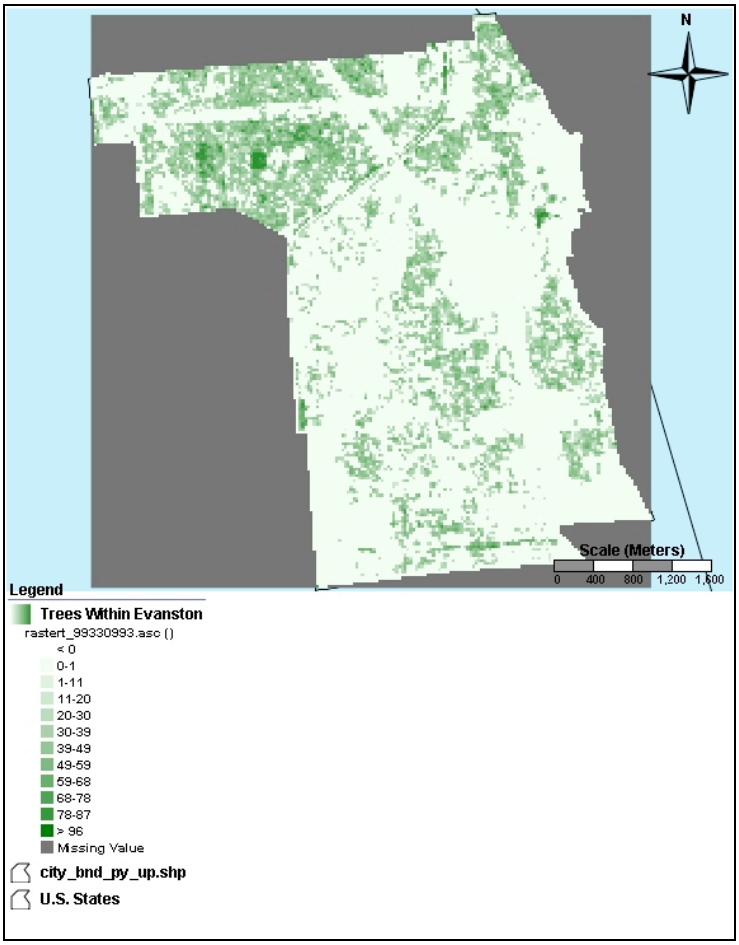


Figure 1: Percent tree cover within Evanston's border.

The numerical results are displayed in the table below.

Table 1: Evanston's tree cover information from NMSS data

Percent tree cover	Evanston Total area (m^2)	Tree cover area (hectares)
14.06 %	20,695,438	290.92

B. Carbon Sequestration

The regressions created by plotting Annual Carbon Sequestration versus Tree Cover for selected data sets are shown below. Each regression has red lines indicating the uncertainties in the data; we can be 95% confident that the true regression (with no error due to natural variations in the data) should fall between the red lines. The vertical green lines show the show the range of Evanston's estimate based on the tree cover and the uncertainties calculated for each data set.

First, the regression including data from all the cities except those with the largest population (determined to show a big city effect) is given below.

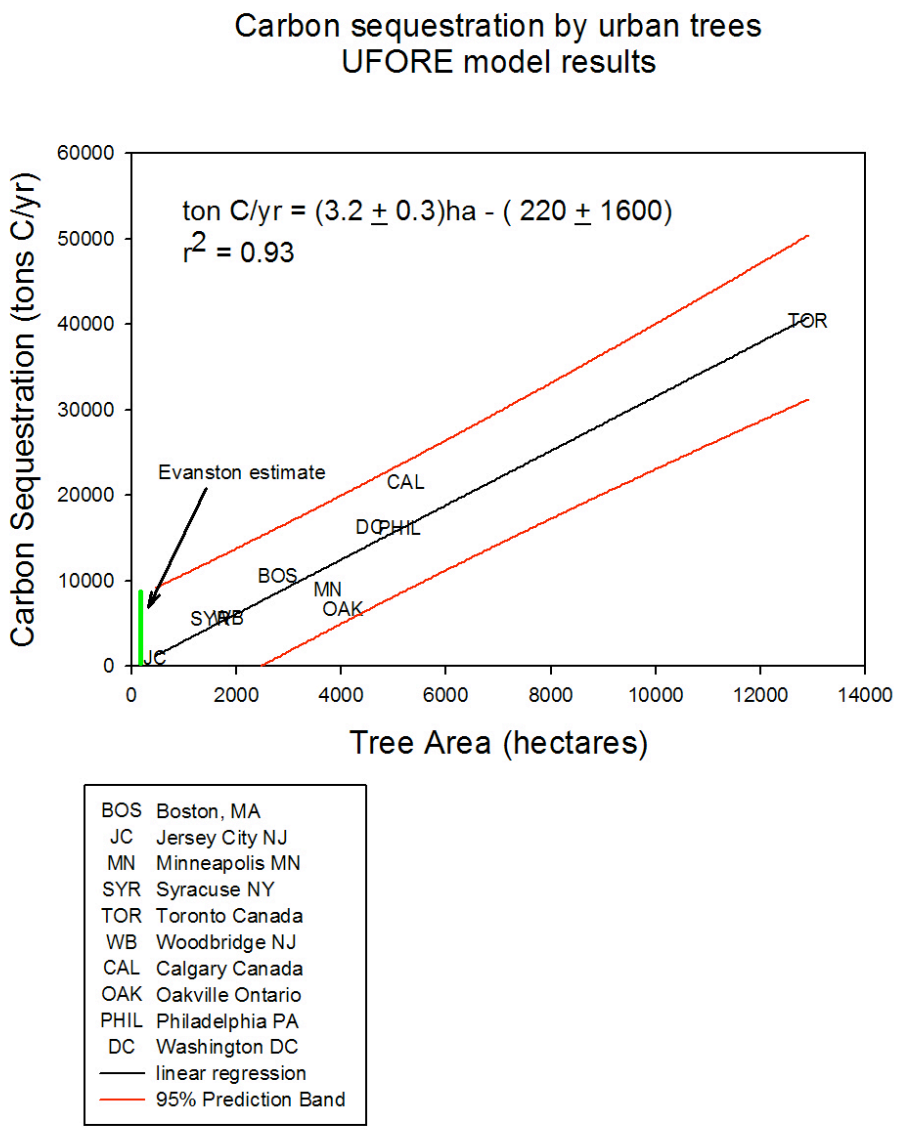


Figure 2: Carbon sequestration vs. tree area, from UFORE reports for all cities (omitting those that exhibited a big-city effect)

Below is a regression including only the data from those cities within 5˚F of Evanston's mean annual temperature. The mean annual temperature factor was determined to provide the strongest correlation with carbon sequestration (see Appendix B for models produced by other subsets of cities).

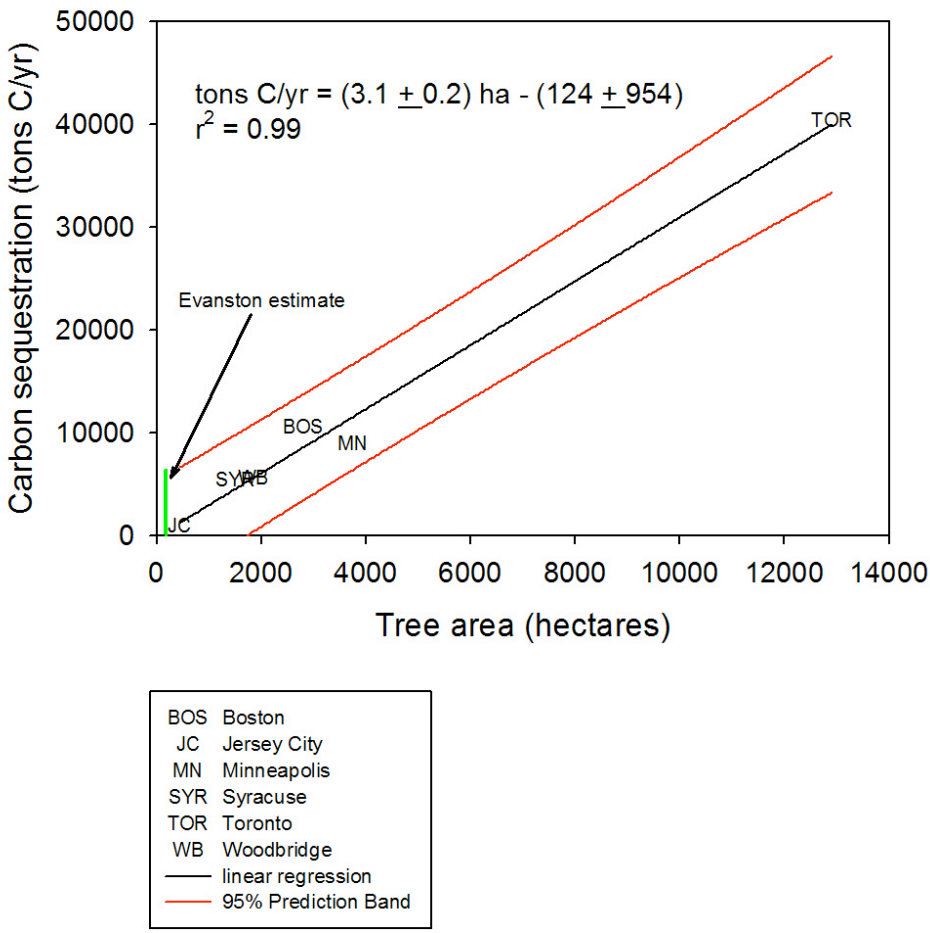


Figure 3: Carbon sequestration vs. tree area, using UFORE data from only cities within 5˚F of Evanston's mean annual temperature

The following table describes the regressions derived from each of the models created for carbon sequestration as a function of tree cover area.

Table 2: Parameters of the models for carbon sequestration as a function of tree cover area

	Slope (tons of carbon sequestered/ hectare tree cover)	Intercept (tons of carbon sequestered)	R^2 (measure of quality of model fit to data points)	Evanston's Projected Carbon Seq (tons/year)	Percent of ECAP's reduction goal	Percent of total carbon emissions sequestered
All Cities (excluding "big" cities)	3.2 ± 0.3	-220 ± 1600	0.93	2223.7 – 2398.2	**1.4 - 1.6%**	**0.20 – 0.21%**
Within 5° Mean Annual Temperature	3.1 ± 0.2	-124 ± 954	0.99	1673.7 – 1790.0	**1.1 – 1.2%**	**0.15 - 0.16%**

From the ECAP report, the carbon emissions reduction goal is 154,438 tons and the total annual carbon emissions is 1,125,954 tons of CO_2.

The regressions used to calculate carbon sequestration follow the model shown below:

C = Carbon Sequestration (short tons/year)
T = land area covered by trees (hectares)
a = slope (tons of carbon sequestered/hectare tree cover)
b = intercept (tons of carbon sequestered)

$$C = a * T + b$$

The figures in the above table use the uncertainty values of a 95% confidence level. However, we can also make projections using a 95% prediction level. While it is likely that the actual values of Evanston's carbon sequestration fall within the 95% confidence interval, the 95% prediction interval gives an additional estimate incorporating a greater degree of uncertainty. As Evanston's tree cover area is smaller than that of the cities used to construct our models, a higher uncertainty may be appropriate and the results using the upper bounds of the 95% prediction interval are shown below.

Table 3: Projections using a 95% prediction level, incorporating greater uncertainties into the calculations

Evanston's Projected Carbon Seq (tons/year)	Percent of ECAP's reduction goal	Percent of total carbon emissions sequestered
7300	**4.7%**	**.6%**

C. Pollution Uptake

The graph below shows the relationship between the tons of pollutants removed by trees per year as a function of hectares of tree cover.

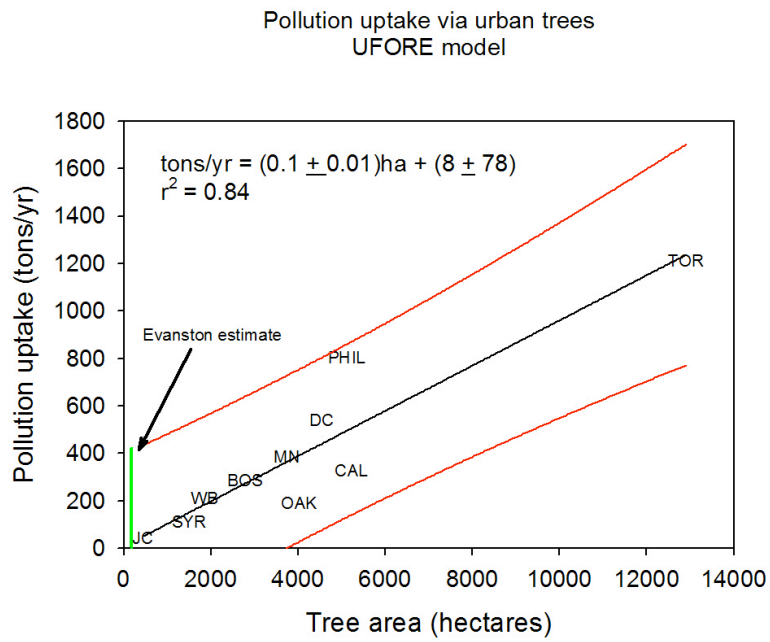


Figure 4: Pollution uptake as a function of tree cover area, from UFORE data

Assuming that the city's pollution emissions are on scale with the other cities studied, Evanston's trees reduce the level of pollutants in the air by 112.2--118.0 tons annually. However, it is difficult to conclusively discuss the significance of these numbers, as Evanston's total pollution emissions are unknown. Using the greater uncertainty of the 95% prediction level, as shown by the vertical green bar in the graph above, the pollution uptake may be as high as 425 tons per year.

We also modeled the monetary value of the pollution uptake by trees, as shown below.

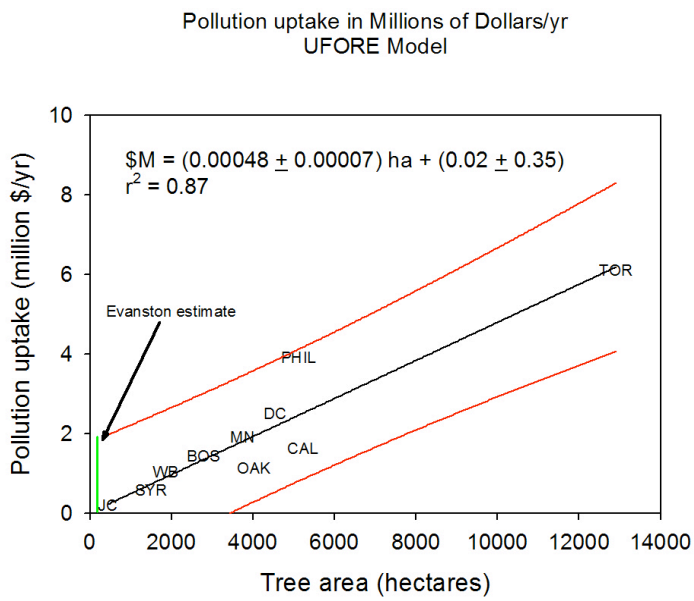


Figure 5: Monetary value of pollution uptake vs. tree cover from UFORE data

Based on this model, the pollution uptake by Evanston's trees saves the equivalent of $489,000 - $530,000 each year (or, with a 95% prediction level, as much as $1,900,000 per year). The pollutants taken into account by the UFORE model are ozone (O_3), particulate matter less than 10 microns, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). The monetary values are based on the median externality value for each pollutant in the US [3]. The externality values represent the money saved by the prevention of harmful effects of pollution, such as the costs of replacing materials degraded by acidic precipitation.

Discussion

Based on the UFORE figures for carbon sequestration and tree cover area, Evanston's tree population sequesters a small portion of the carbon dioxide emitted by the city. Our best estimation is that the trees sequester about 0.2% of the CO_2 emitted by Evanston's businesses, industries, and residences. Even using a greater degree of uncertainty in our calculations, the upper bound on the carbon emissions stored by Evanston's trees is 0.6%. The UFORE data also shows that Evanston's trees uptake an estimated 112—118 tons of air pollutants each year (or approximately 7300 tons using the greater uncertainty of a 95% prediction level). All of these projections are based on the assumption that Evanston fits the pattern of the rest of the cities surveyed by UFORE and there is a degree of uncertainty with any such projection. Evanston is significantly smaller than the other cities surveyed, and we cannot state any of these figures conclusively without carrying out a full-scale UFORE report for Evanston. However, based on the predictions offered by the trends in previous UFORE reports, Evanston's trees sequester 0.2--0.6% of the carbon dioxide that the city emits.

Conclusion

The tree population of Evanston takes up a small fraction of the CO_2 emitted in the city. Based on our the relationship between tree cover area and carbon sequestration in other cities, Evanston's trees taken up at most 0.6% of the carbon dioxide emitted. This figure should be taken into account in matters regarding Evanston's carbon management strategies. It is important to realize that, in the city's CO_2 budget, the trees are only able to store a small portion of the atmospheric carbon. We cannot project what proportion of other airborne pollutants the trees take up as we do not know the total emissions, but we can estimate that Evanston's trees save the city approximately $500,000 a year by preventing damage caused by atmospheric pollutants. Using the UFORE model, we have been able to get an idea of the quantitative impact of trees on Evanston's air.

References

1. "Evanston Climate Action Plan." Nov 2008. City of Evanston & Network for Evanston's Future. <www.cityofevanston.org/global/green/documents/ECAP.pdf>.

2. Hoehn, Robert. "Re: UFORE Big City Effect." Email to Chrissy Bernardo. 2 Mar. 2009.

3. Schlesinger, William. Biogeochemistry : An Analysis of Global Change. 2. San Diego: Academic Press, 1997.

4. Murray, F.J.; Marsh, L.; Bradford, P.A. 1994. New York State energy plan, vol. II: issue reports. Albany, NY: New York State Energy Office.

Acknowledgements

We would like to thank Colleen Buzby, Research Analyst for Northwestern University's School of Education and Social Policy, for her contribution to the GIS research involved with this project. She facilitated our use of My World and ArcGIS software and pointed us to the National Seamless Map Server and National Land Cover Data for the tree cover information our project required.

We would also like to thank Robert Hoehn, Forester for the USDA Forest Service, for his feedback on the causes of the big city effect we found in the UFORE data.

Appendix A: Compilation of UFORE data

The key data taken from the various UFORE reports studied are listed in the table below.

City	Land Area (ha)	Tree Area (%)	Tree Area (ha)	Tree Density (trees per ha)	Carbon Sequestration (tons/year)	Carbon Sequestration (million $/year)	Pollution Uptake (tons/year)	Pollution Uptake (million $/year)
Boston, MA	12540	22.3	2796	94.3	10500	--	284	1.426
Calgary, Canada	72650	7.2	5231	163.6	21400	--	326	1.611
Jersey City, NJ	3860	11.5	444	35.2	890	--	41	0.196
Minneapolis, MN	14220	26.4	3754	69	8900	0.164	384	1.9
Oakville, Ontario	13851	29.1	4031	193	6614	0.141	190	1.12
Philadelphia, PA	32614	15.7	5120	64	16100	0.297	802	3.9
Syracuse, NY	6500	23.1	1502	134.8	5420	--	109	0.568
Toronto, Canada	63000	20.5	12915	119.7	40300	--	1212	6.105
Washington, DC	15900	28.6	4547	121.3	16200	0.299	540	2.5
Woodbridge, NJ	6268	29.5	1849	157.3	5560	--	210	1.037
Evanston								
New York, NY	121440	20.9	25380	42.9	42300	--	1677	8.07
San Francisco, CA	60070	11.9	7148	11.1	5200	0.095	260	1.3

City	Energy Savings (million $/year)	Latitude (°N)	Mean Annual Temperature (°F)	Mean Annual Precipitation (in.)
Boston, MA	--	42.35	51.6	43
Calgary, Canada	--	51.03	39.4	16
Jersey City, NJ	--	40.73	52.6	46
Minneapolis, MN	0.216	44.98	45.4	29
Oakville, Ontario	0.84	43.45	55.5	40
Philadelphia, PA	1.18	39.95	55.3	42
Syracuse, NY	--	43.05	47.4	40
Toronto, Canada	--	43.65	45.7	33
Washington, DC	2.65	38.88	57.5	39
Woodbridge, NJ	--	40.55	52.1	51
Evanston		42.03	48.7	37
New York, NY	--	40.72	52.6	46
San Francisco, CA	--	37.77	58.3	22
Standard Deviation		3.443079371	5.641758985	9.848293704

Appendix B: Additional Figures and Statistics

Evanston total Metric Tons CO_2 Equivalent ($MTCO_2E$) emissions per year (using baseline of 2005, backcasted to 1990 to meet Kyoto protocol):

1,021,448

Evanston Climate Action Plan's annual CO_2 emission reduction goal:

140,104 $MTCO_2E$

Evanston tree cover percentage (from analysis): **14.06 %**

Evanston area (from NSSM city boundary data): 20,695,438 m^2

Evanston tree cover area (calculated): 2,909,219.806 m^2 = **290.9 hectares**

Graph of energy savings as a function of tree cover:

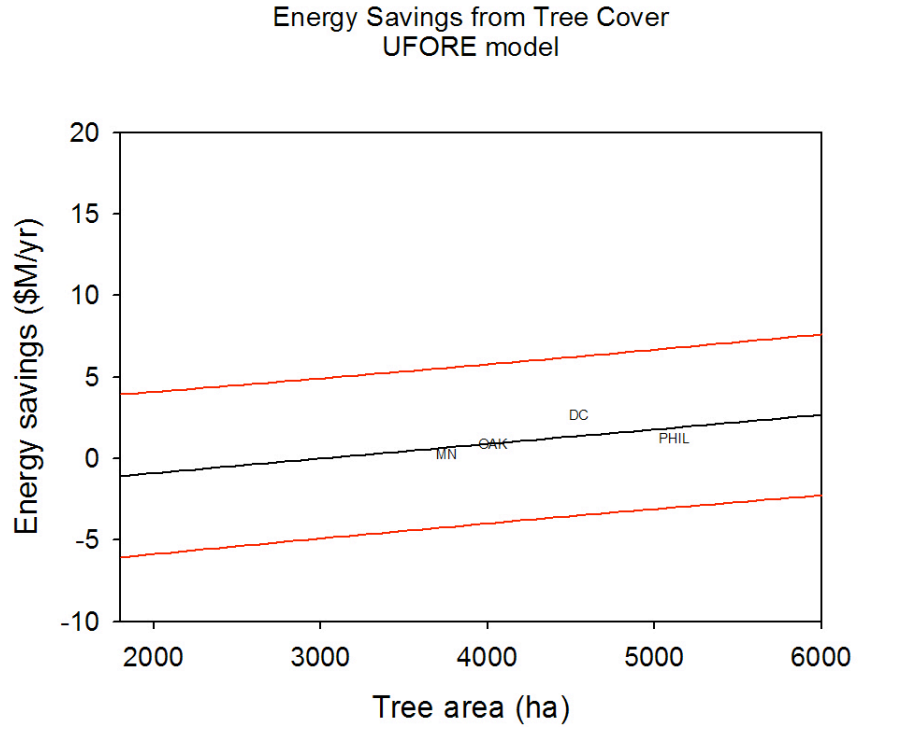


Figure 6: Energy savings as a function of tree cover area, for the UFORE cities with this information available

This model was not used to extrapolate on Evanston's energy savings because no meaningful correlation could be taken from such limited data. The energy savings were calculated based on very specific data taken in each city surveyed, including distance between trees and buildings, percent

The cities used for the carbon sequestration models were also filtered by mean annual precipitation and degrees of latitude as indices of climate and therefore tree characteristics. The clearest correlation in carbon sequestration data was found in cities close to Evanston's mean annual temperature, as reflected in the Results section of the report. Below are shown two additional models that did not provide as accurate regressions, as they showed lower correlation.

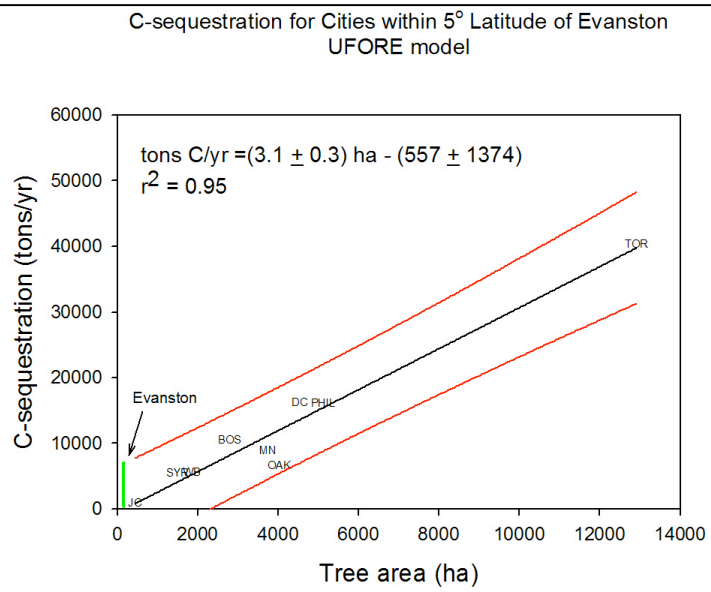


Figure 7: Carbon sequestration as a function of tree cover, using UFORE data of cities within 5˚ of Evanston's latitude

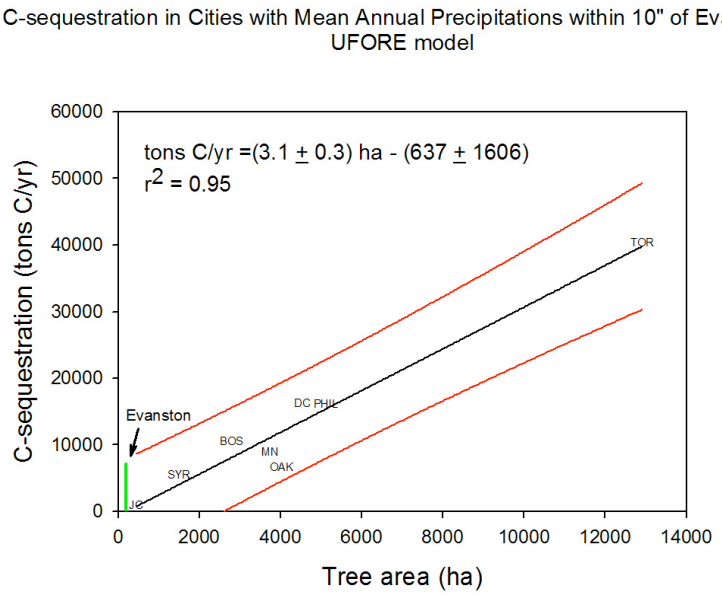


Figure 8: Carbon sequestration as a function of tree cover, using UFORE data from all cities within 10" of Evanston's mean annual precipitation