i-Tree Canopy Air Pollutant Removal and Monetary Value Model Descriptions

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Abstract

The default values (the multipliers) of air pollutant removal rates (g m^{-2} yr^{-1}) and monetary values ($ m^{-2} yr^{-1}) for a unit tree cover were derived from i-Tree Eco analyses in the conterminous United States in 2010 (Nowak et al. in review). Three analyses were conducted for rural and urban areas in all counties and then aggregated into the county-level; 1) derivation of the total tree cover, evergreen percentage and leaf area index, 2) estimation of air pollutant removals and concentration changes, and 3) valuation of air pollutant removals.

1. Introduction

i-Tree Canopy is designed to allow users to easily and accurately estimate tree and other cover classes (e.g.,grass, building, roads, etc.) within their city or any area they like. This tool randomly lays points (number determined by the user) onto Google Earth imagery and the user then classifies what cover class each point falls upon. The user can define any cover classes that they like and the tool will show estimated percentage for each cover class throughout the interpretation process. Based on the area classified as the tree cover class, the tool provides annual amount of air pollutants removed through dry deposition process by trees and associated monetary values. The air pollutants estimated are six criteria pollutants defined by the U.S. Environmental Protection Agency (EPA); carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter (PM), which includes particulate matter less than 2.5 microns ($PM_{2.5}$) and particulate matter greater than 2.5 and less than 10 microns (PM_{10*}).

The default values (the multipliers) of air pollutant removal rates (g m^{-2} yr^{-1}) and monetary values ($ m^{-2} yr^{-1}) for a unit tree cover were derived from i-Tree Eco analyses in the conterminous United States in 2010 (Nowak et al. in review). Three analyses were conducted; 1) derivation of the total tree cover, evergreen percentage and leaf area index, 2) estimation of air pollutant removals and concentration changes, and 3) valuation of air pollutant removals. These analyses were performed for rural and urban areas in all counties and then aggregated into the county-level values. i-Tree Canopy currently uses the county-level multipliers to estimate annual air pollutant removals and associated monetary values.

This document describes the materials, methods and limitations in the model and processes used to derive the default multipliers.

2. Materials and Methods

2.1. Rural/urban area classification

Urban areas were delimited using 2010 Census data and definitions (U.S. Census Bureau 2013), while rural areas were defined as all land not classified as urban.

2.2. Tree parameters

The tree cover was derived from 2001 National Land Cover Database (NLCD) tree cover maps (USGS 2008) with an adjustment (Nowak and Greenfield 2010). Percent tree cover classified as evergreen was determined for each county based on evergreen, deciduous and mixed forest land covers as classified by the NLCD. Maximum leaf area index (LAI) was derived from the level-4 MODIS/Terra global Leaf Area Index product for the 2007 growing season (USGS 2013). The default values of 4.9 (Nowak et al. 2008) and 3.2 (Schlerf et al. 2005) for urban and rural areas, respectively, were employed for areas with missing or abnormally low LAI.

2.3. Air pollutant removals and concentration changes

Air pollutant removal and concentration change due to dry deposition to trees were estimated on an hourly-basis and then summarized for a year with i-Tree Eco (Nowak et al. 2006; 2013, Hirabayashi et al. 2011; 2012). For each area, the total tree cover, evergreen percentage, LAI, as well as the surface weather, upper air, and air pollutant concentration data at the monitoring station closest to the area's geographic center were used in the analyses. Totally 979 weather stations from the National Climatic Data Center (NCDC 2013), 74 radiosonde stations from the National Oceanic and Atmospheric Administration (NOAA 2013), and 4,116 air pollutant monitoring stations from the U.S. EPA's Air Quality System (US EPA 2013) were employed. The $PM_{2.5}$ concentration was subtracted from the PM_{10} concentration to produce an adjusted PM_{10} concentration denoted as PM_{10*} (2.5- to 10-micron particles) to avoid PM_{10} double counting $PM_{2.5}$ values. The minimum and maximum estimates of removal were based on minimum and maximum deposition velocities from the literature.

2.4. Air pollutant removal valuation

The U.S. EPA's BenMAP was used to estimate the incidence of adverse health effects and associated monetary values resulting from changes in NO_2, O_3, $PM_{2.5}$ and SO_2 concentrations (US EPA 2012). The pollutant removal value for CO and PM_{10*} were CO = \$1,470 t^{-1} and PM_{10*} = \$6,910 t^{-1} for urban and CO = \$27 t^{-1} and PM_{10*} = \$126 t^{-1} for rural areas. Urban values were estimated using national median externality values (Murray et al. 1994) adjusted to 2010 values using the producer price index (U.S. Department of Labor 2012), while rural values were derived from urban values adjusted based on the rural to urban value ratio for all four BenMAP pollutants (NO_2, O_3, $PM_{2.5}$, and SO_2).

For each rural and urban area in counties, calculated total removal amount and monetary value were divided by the area's total tree cover to derive the removal amount and monetary value multipliers, respectively. For the entire county, the multipliers were derived by aggregating rural and urban areas in the county. In i-Tree Canopy, the air pollutant amount annually removed by trees and the associated monetary value can be calculated with the tree cover in the area of interest multiplied by these multipliers based on the county-level values in the United States. For countries outside the United States, county multipliers derived from the Unites States' total removal amount, monetary value and tree cover can be used. Table 1 presents national values for the entire rural and urban areas as well as counties in the conterminous United States.

Table 1 Multipliers derived from the United States' total values

Pollutant	Removal Multiplier (g m^{-2} yr^{-1})			Value Multiplier ($ m^{-2} yr^{-1})		
	Rural	Urban	County	Rural	Urban	County
CO	0.100	0.127	0.101	0.00000268	0.000186	0.00000948
NO_2	0.545	0.700	0.551	0.00000398	0.000337	0.0000163
O3	5.493	5.404	5.490	0.000287	0.0155	0.000850
PM_{10*}	1.851	1.534	1.839	0.000233	0.0106	0.000617
$PM_{2.5}$	0.266	0.276	0.267	0.000578	0.0324	0.00176
SO_2	0.347	0.344	0.347	0.00000101	0.0000507	0.00000285

3. Limitations of modeling approach

3.1. Adverse effects of trees for $PM_{2.5}$

Tree is a temporary retention site for atmospheric particles; $PM_{2.5}$ intercepted by trees due to dry deposition may be resuspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall. In i-Tree Eco, $PM_{2.5}$ is intercepted and accumulated on trees on an hourly-basis with no rain or low wind conditions, typically resulting in decrease in the $PM_{2.5}$ concentration. The $PM_{2.5}$ accumulated on leaves is washed off from leaves to the ground with a rain event. When an hourly high wind event occurs, larger amount of accumulated $PM_{2.5}$ than deposited in that hour may be resuspended to the atmosphere, typically causing increase in the $PM_{2.5}$ concentration. The $PM_{2.5}$ concentration can also be affected by the atmospheric mixing height: when the $PM_{2.5}$ quantity remains the same in atmosphere, higher mixing height leads to lower concentration and vice versa. Because of these atmospheric factors the mean $PM_{2.5}$ concentration may be increased annually or quarterly in areas with low rain and high winds throughout a year. As a result, monetary values for $PM_{2.5}$ removal are computed negative in BenMAP, indicating trees decrease the air quality and thus the incidence of adverse health effects is increased. Tables 2-4 present counties with the negative monetary value multipliers for $PM_{2.5}$

Table 2 County rural areas with negative $value multiplier for $PM_{2.5}$ due to mean annual and/or quarterly concentration increase

State	State FIPS	County	County FIPS	Value Multiplier ($ $m^{-2} yr^{-1}$)
Arizona	04	La Paz	012	-0.000000523
Iowa	19	Buena Vista	021	-0.0000109
Iowa	19	Cherokee	035	-0.0000434
Iowa	19	Crawford	047	-0.0000359
Iowa	19	Ida	093	-0.0000258
Iowa	19	O'Brien	141	-0.0000223
Iowa	19	Sac	161	-0.0000183
Minnesota	27	Stevens	149	-0.00000301
Nevada	32	Clark	003	-0.000000477
Texas	48	Culberson	109	-0.000000128
Texas	48	Pecos	371	-0.000000286
Texas	48	Reeves	389	-0.000000192
Virginia	51	Alleghany	005	-0.0000225
Virginia	51	Bath	017	-0.00000446
Virginia	51	Giles	071	-0.00000210
West Virginia	54	Nicholas	067	-0.00000319

Table 3 County urban areas with negative $value multiplier for $PM_{2.5}$ due to mean annual and/or quarterly concentration increase

State	State FIPS	County	County FIPS	Value Multiplier ($ $m^{-2} yr^{-1}$)
Arizona	04	Apache	001	-0.00208
Arizona	04	La Paz	012	-0.000993
Arizona	04	Mohave	015	-0.000283
Arizona	04	Navajo	017	-0.00196
Arizona	04	Yuma	027	-0.00254
California	06	Imperial	025	-0.00248
Colorado	08	Adams	001	-0.0143
Colorado	08	Bent	011	-0.0217
Colorado	08	Broomfield	014	-0.0108
Colorado	08	El Paso	041	-0.000901
Colorado	08	Huerfano	055	-0.00310
Colorado	08	Las Animas	071	-0.00245
Colorado	08	Logan	075	-0.00255
Colorado	08	Morgan	087	-0.000695
Colorado	08	Otero	089	-0.0161
Colorado	08	Pueblo	101	-0.00280
Colorado	08	Yuma	125	-0.00268
Iowa	19	Buena Vista	021	-0.00564

Iowa	19	Cherokee	035	-0.0111
Iowa	19	Crawford	047	-0.00764
Iowa	19	O'Brien	141	-0.0102
Kansas	20	Finney	055	-0.00457
Kansas	20	Grant	067	-0.0154
Kansas	20	Pawnee	145	-0.000642
Kansas	20	Scott	171	-0.00314
Kansas	20	Seward	175	-0.0126
Kansas	20	Stevens	189	-0.0201
Minnesota	27	Blue Earth	013	-0.00348
Minnesota	27	Le Sueur	079	-0.00233
Minnesota	27	Nicollet	103	-0.00324
Minnesota	27	Waseca	161	-0.00541
Montana	30	Custer	017	-0.000678
New Mexico	35	Bernalillo	001	-0.00327
New Mexico	35	Curry	009	-0.00391
New Mexico	35	Dona Ana	013	-0.00436
New Mexico	35	Eddy	015	-0.00724
New Mexico	35	Grant	017	-0.00664
New Mexico	35	Luna	029	-0.0103
New Mexico	35	Otero	035	-0.00140
New Mexico	35	Quay	037	-0.00773
New Mexico	35	Roosevelt	041	-0.00650
New Mexico	35	Sierra	051	-0.0128
New Mexico	35	Socorro	053	-0.00220
New Mexico	35	Torrance	057	-0.000744
New Mexico	35	Valencia	061	-0.00129
Oklahoma	40	Texas	139	-0.0122
Oklahoma	40	Woodward	153	-0.00725
South Dakota	46	Meade	093	-0.000280
South Dakota	46	Pennington	103	-0.0107
Texas	48	Bailey	017	-0.00363
Texas	48	Carson	065	-0.00303
Texas	48	Castro	069	-0.00349
Texas	48	Childress	075	-0.00175
Texas	48	Coryell	099	-0.00769
Texas	48	Crane	103	-0.00369
Texas	48	Dallam	111	-0.0204
Texas	48	Deaf Smith	117	-0.0126
Texas	48	Ector	135	-0.00202

Texas	48	El Paso	141	-0.00998
Texas	48	Floyd	153	-0.0144
Texas	48	Gray	179	-0.0137
Texas	48	Hale	189	-0.00428
Texas	48	Hansford	195	-0.0117
Texas	48	Hartley	205	-0.0204
Texas	48	Hemphill	211	-0.00775
Texas	48	Hutchinson	233	-0.00911
Texas	48	McCulloch	307	-0.000872
Texas	48	Moore	341	-0.0129
Texas	48	Ochiltree	357	-0.0126
Texas	48	Parmer	369	-0.00820
Texas	48	Pecos	371	-0.0160
Texas	48	Potter	375	-0.0122
Texas	48	Randall	381	-0.0125
Texas	48	Reagan	383	-0.000276
Texas	48	Reeves	389	-0.0213
Texas	48	Swisher	437	-0.00403
Texas	48	Tom Green	451	-0.00162
Texas	48	Ward	475	-0.00431
Texas	48	Willacy	489	-0.00519
Texas	48	Winkler	495	-0.00663
Virginia	51	Covington	580	-0.000904
West Virginia	54	Greenbrier	025	-0.00021
Wisconsin	55	Clark	019	-0.00082
Wisconsin	55	Taylor	119	-0.00049

Table 4 Counties with negative $value multiplier for $PM_{2.5}$ due to mean annual and/or quarterly concentration increase

State	State FIPS	County	County FIPS	Value Multiplier ($\$ m^{-2} yr^{-1}$)
Arizona	04	La Paz	012	-0.00000177
Arizona	04	Navajo	017	-0.00000740
Arizona	04	Yuma	027	-0.0000293
California	06	Imperial	025	-0.0000240
Colorado	08	Adams	001	-0.00194
Colorado	08	Bent	011	-0.0000154
Colorado	08	Broomfield	014	-0.0078
Colorado	08	Logan	075	-0.00000670
Colorado	08	Otero	089	-0.000133
Iowa	19	Buena Vista	021	-0.0000565
Iowa	19	Cherokee	035	-0.000120

Iowa	19	Crawford	047	-0.000147
Iowa	19	Ida	093	-0.0000258
Iowa	19	O'Brien	141	-0.000127
Iowa	19	Sac	161	-0.0000183
Kansas	20	Finney	055	-0.0000110
Kansas	20	Grant	067	-0.00000322
Kansas	20	Seward	175	-0.000108
Minnesota	27	Blue Earth	013	-0.000193
Minnesota	27	Le Sueur	079	-0.0000230
Minnesota	27	Nicollet	103	-0.00000501
Minnesota	27	Waseca	161	-0.0000702
New Mexico	35	Bernalillo	001	-0.000433
New Mexico	35	Curry	009	-0.0000195
New Mexico	35	Dona Ana	013	-0.000137
New Mexico	35	Eddy	015	-0.0000358
New Mexico	35	Luna	029	-0.0000367
New Mexico	35	Sierra	051	-0.0000164
New Mexico	35	Socorro	053	-0.000000132
New Mexico	35	Valencia	061	-0.0000753
Oklahoma	40	Woodward	153	-0.0000308
South Carolina	45	Calhoun	017	-0.00000375
Texas	48	Coryell	099	-0.000125
Texas	48	Crane	103	-0.00000262
Texas	48	Culberson	109	-0.000000128
Texas	48	Deaf Smith	117	-0.0000148
Texas	48	Ector	135	-0.0000781
Texas	48	El Paso	141	-0.00281
Texas	48	Gray	179	-0.0000414
Texas	48	Hale	189	-0.00000629
Texas	48	Hansford	195	-0.00000279
Texas	48	Hemphill	211	-0.0000127
Texas	48	Hutchinson	233	-0.000144
Texas	48	Moore	341	-0.0000123
Texas	48	Ochiltree	357	-0.0000379
Texas	48	Pecos	371	-0.0000177
Texas	48	Potter	375	-0.000120
Texas	48	Randall	381	-0.0000604
Texas	48	Reeves	389	-0.0000410
Texas	48	Tom Green	451	-0.0000122
Texas	48	Ward	475	-0.0000248

Texas	48	Winkler	495	-0.0000192
Virginia	51	Bath	017	-0.00000446
Virginia	51	Covington	580	-0.000898

3.2. BenMAP estimates

Some (0.3%) of BenMAP estimates for counties came out with positive multiplier values (i.e., reduced pollution concentration led to increased health impacts) (Table 5). For these counties and pollutants, the monetary values were estimated based on a linear robust regression between the dollar values per metric ton of pollutant removed and population density for all of the other counties. The regression equations employed for the rural areas are:

NO_2: $y = 0.6264x + 0.108$ ($R^2 = 0.96$)

O_3: $y = 4.0598x + 3.9829$ ($R^2 = 0.91$)

$PM_{2.5}$: $y = 149.405x + 186.4572$ ($R^2 = 0.87$)

SO_2: $y = 0.2203x + 0.0132$ ($R^2 = 0.91$)

,where y is dollars per metric ton and x is population density (people per km^2). The regression equations employed for the urban areas are:

NO_2: $y = 0.5544x + 30.3794$ ($R^2 = 0.65$)

O_3: $y = 3.8897x + 103.4157$ ($R^2 = 0.50$)

$PM_{2.5}$: $y = 148.4872x + 8269.303$ ($R^2 = 0.39$)

SO_2: $y = 0.1493x + 22.21$ ($R^2 = 0.45$)

For the counties and pollutants in Table 5, rural and urban monetary values estimated above were aggregated to derive total values for the county.

Table 5 Counties and air pollutants estimated with linear robust regressions

State	State FIPS	County	County FIPS	Pollutant
Arkansas	05	Columbia	027	NO2
Georgia	13	Jackson	157	NO2
Georgia	13	Walton	297	NO2
South Carolina	45	Calhoun	017	NO2
Washington	53	Mason	045	O3
California	06	Fresno	019	PM2.5
California	06	Lake	033	PM2.5
Iowa	19	Calhoun	025	PM2.5
Iowa	19	Palo Alto	147	PM2.5
Iowa	19	Pocahontas	151	PM2.5
Iowa	19	Shelby	165	PM2.5
Louisiana	22	Orleans	071	PM2.5
Maine	23	Sagadahoc	023	PM2.5

Michigan	26	Iron	071	PM2.5
Michigan	26	Mason	105	PM2.5
Minnesota	27	Clay	027	PM2.5
Mississippi	28	Hancock	045	PM2.5
Montana	30	Dawson	021	PM2.5
Nebraska	31	Cedar	027	PM2.5
Nebraska	31	Rock	149	PM2.5
North Dakota	38	Emmons	029	PM2.5
North Dakota	38	McKenzie	053	PM2.5
South Dakota	46	Campbell	021	PM2.5
South Dakota	46	Clay	027	PM2.5
Texas	48	Brooks	047	PM2.5
Texas	48	Walker	471	PM2.5
Washington	53	Kittitas	037	PM2.5
Washington	53	Wahkiakum	069	PM2.5
Wisconsin	55	Sheboygan	117	PM2.5
Wisconsin	55	Waupaca	135	PM2.5
Arkansas	05	Boone	009	SO2
Arkansas	05	Hot Spring	059	SO2
Arkansas	05	St. Francis	123	SO2
Arkansas	05	White	145	SO2
Arkansas	05	Woodruff	147	SO2
Iowa	19	Dubuque	061	SO2
Kentucky	21	Carlisle	039	SO2
Louisiana	22	Jefferson	051	SO2
Nevada	32	Mineral	021	SO2
North Carolina	37	Iredell	097	SO2
Oklahoma	40	Ottawa	115	SO2
Texas	48	Loving	301	SO2

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