Making Urban Trees Count: A Project to Demonstrate the Role of Urban Trees in Achieving Regulatory Compliance for Clean Water

Center for Watershed Protection

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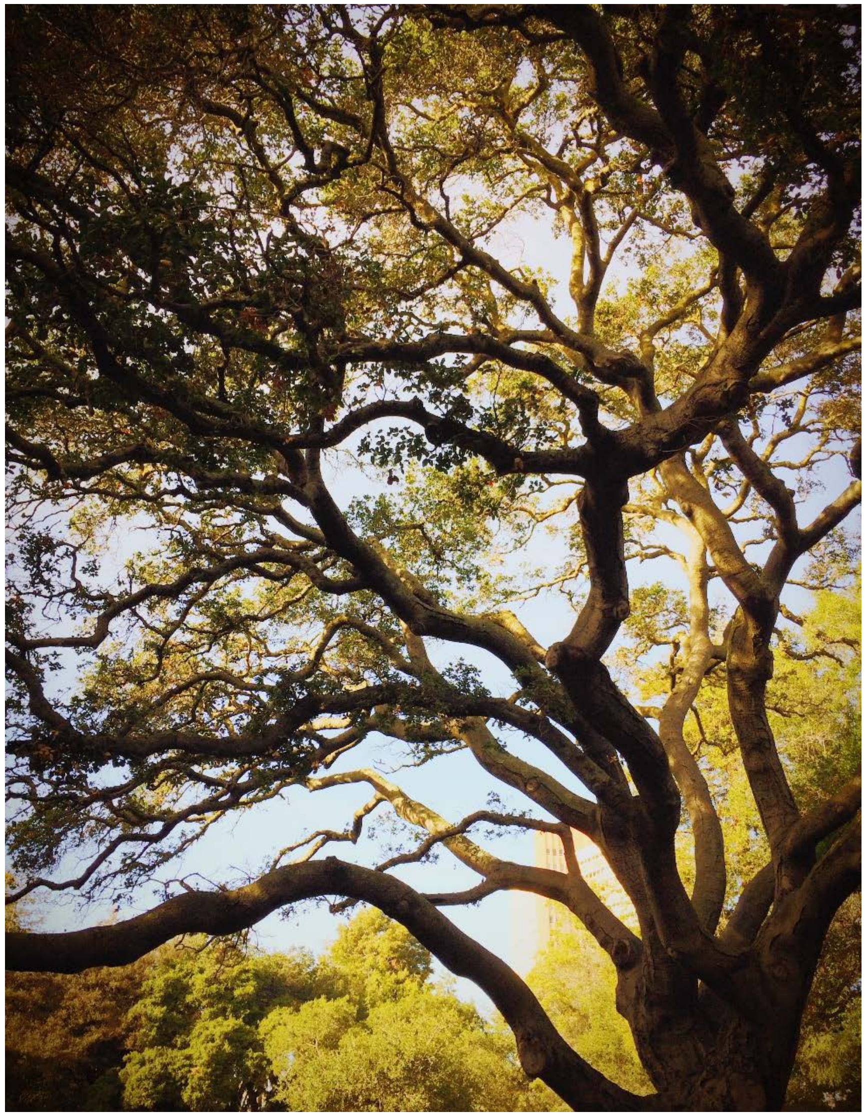

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CREDITING FRAMEWORK PRODUCT #2:

Water Balance Model Documentation

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Relative and Absolute Reductions in Annual Water Yield and Non-Point Source Pollutant Loads of Urban Trees

By Justin Hynicka and Deb Caraco

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Introduction

The use of trees to meet stormwater management requirements is hampered by the uncertainty of how to "credit" trees for runoff and pollutant load reduction in order to compare with other best management practices (BMPs). The Center for Watershed Protection, with a grant from the U.S. Forest Service, undertook a study to develop a science-based crediting system for urban tree planting. A review of the literature and existing crediting systems found that a limited number of studies directly addressed the water quality benefits of urban trees, and the available studies were highly variable in their methods, scale, and results given the many factors (e.g., tree characteristics, storm event and meteorological factors) that affect the amount of runoff or pollutant load reduced by urban trees. Therefore, the project team developed a water balance model to provide an improved method to quantify the effects of urban tree canopy on stormwater runoff reduction and water quality. While the model accounts for all aspects of the water balance to generate water yield, the results are presented only for runoff reduction as described in the documentation. This paper provides the documentation for the water balance model.

The water balance model results were used to develop two tree planting credits: 1) a Pollutant Load Reduction Credit and 2) a Stormwater Performance-Based Credit. These credits provide regulators and stormwater practitioners a means to better integrate and account for the effect of trees for stormwater regulatory compliance. The water balance model provides results for all regions of the U.S., so that the crediting framework may be implemented in any state or locality. The model and crediting methods may be adapted in the future for a variety of scales given the desired application (e.g., city, different tree species, local climate data).

The model results are considered 'optimal,' as the growing conditions for the trees do not account for stresses in the urban environment that may influence tree growth or mortality. However, the results are conservative as the output provided is shown for runoff reduction only and does not account for losses due to leachate, below the shallow groundwater or rooting zone.

Further, the water quality benefits are associated with the amount of runoff reduction and do not account for nutrient processing and fate by the tree species. These assumptions are deemed necessary given the scope of the project, scale of application and available data to parameterize the model. Further, communities or organizations adopting the credit framework and methods may use local data rather than the default values as described in the companion credit documentation.

Methods

Fundamental principles in watershed hydrology were used to estimate mean annual water yield for urban land uses, with and without tree canopy, in eleven broad climate zones across the continental U.S.A. and Hawai‘i. These eleven climate zones are based on the i-Tree Tools' sixteen climate zones, except several smaller neighboring zones were combined in California, the Desert Southwest, and Florida (Figure 1, Table 1).

Table 1. Eleven Climate regions used in the Water-Balance Model.

California Coast and Interior	Midwest	Northeast
Coastal Plain	Pacific Northwest	North
Interior West	South	Tropical
Lower Midwest	Southwest Interior	

Note: AZ, NM, TX were included in the SW Interior to form Southwest Interior. Temperate Interior portions of WA, OR, ID, NV added to Interior West. S. CA and N CA Coast combined with Inland Valley and Inland Empire to form CA Coast and Interior

To estimate water yield, which is the portion of precipitation that ultimately becomes streamflow, we used a general mass balance approach (Eq. 1) to account for atmospheric inputs (In), pathways of water loss or outputs (Out), and change in soil storage (ΔSt). Since Precipitation (P) is assumed to be the only input of water for all scenarios in this study, water yield estimates best reflect well drained sites where the water table is consistently below the plant-rooting zone (~3 ft deep). Pathways of water loss include interception (Int), direct surface runoff (R), gravitational soil water that drains beneath the plant rooting zone (i.e., soil leaching, L), and evapotranspiration (ET). Water yield calculations were performed on a step-wise daily time interval using equations 2 through 7, but with infiltration (I), L, and St equal to zero for impervious surfaces. A conceptual model of these water balance calculations is shown in Figure 2. Data sources and underlying equations for each variable are presented next in the order they appear in these equations.

General Mass Balance:	$In = Out + \Delta St$	**(Eq. 1)**
Interception	Int=f(P,*tree canopy*)	**(Eq. 2)**
Effective Precipitation:	$P_{eff} = P - Int$	**(Eq. 3)**
Runoff, R:	$R = f(P_{eff}, land\ cover, St)$	**(Eq. 4)**
Infiltration, I:	$I = P_{eff} - R$	**(Eq. 5)**
Leaching, L:	$L = I + St_t - St_{max}$	**(Eq. 6)**
Soil Storage, St:	$St_{t+1} = St_t + I = \ -L - ET$	**(Eq. 7)**

Additional Terms in Equations 1-7 include the following:

In = Inputs (in.)

Out = Outputs (in.)

St_t = Soil Storage (in.) at time t

ΔSt = Change in Soil Storage (in.)
ET = Evapotranspiration (in.)

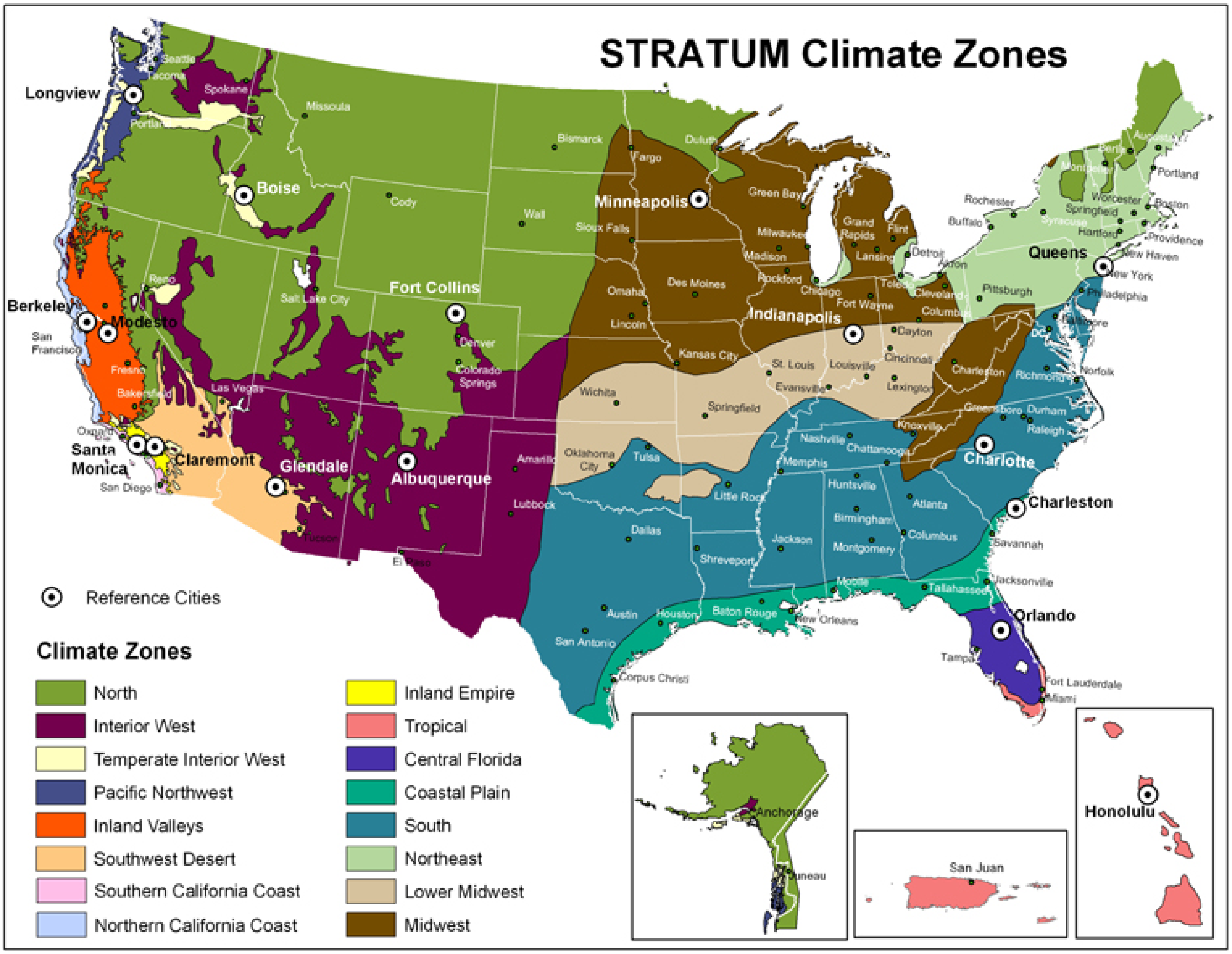

Figure 1. 16 Climate zones used as the basis for classification of 11 climate regions (Modified from source: https://www.itreetools.org/resources/archives.php)

1. Precipitation

To account for variation in precipitation across space and time, we used six years (Jan. 2008 to Dec. 2013) of daily rainfall data (National Climatic Data Center, NCDC, 2016) from two to three locations per climate zone. Locations were chosen to maximize coverage across the continental U.S.A. and within each climate zone, and mean annual precipitation among locations ranged from 6.44 to 67.66 inches per year (Reno, NV and Miami, FL, respectively). Instructions for accessing daily rainfall data for the locations in this study as well as other locations within the NCDC network are included in Appendix A.

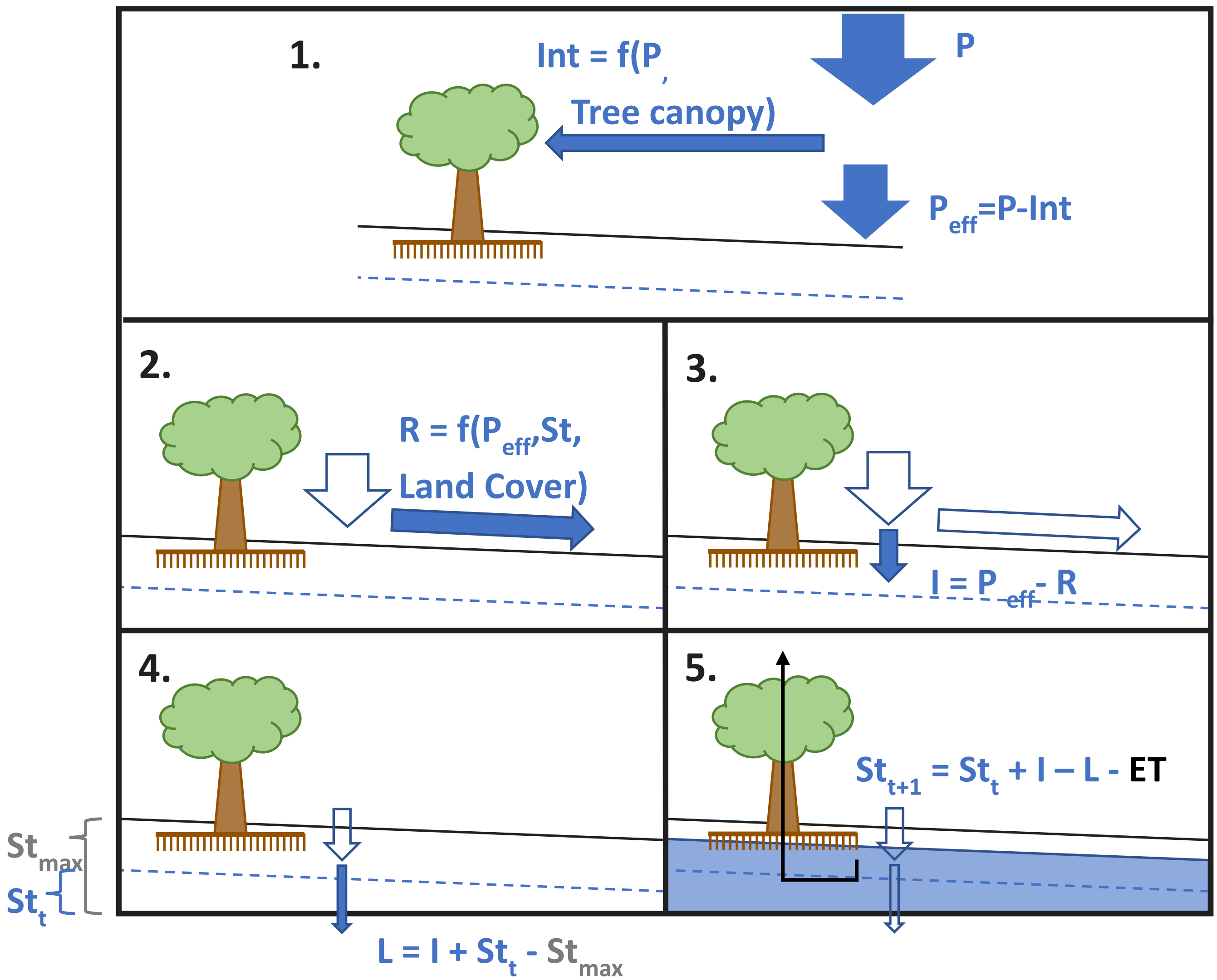

Figure 2. Conceptual model of step-wise calculations used in the water yield model. Box 1 corresponds to equations 2 and 3, and Boxes 2 to 5 correspond to equations 4 to 7, respectively.

2. Effective Precipitation and Tree Physical Properties

Compared to turf grass and impervious surfaces, our reference land cover types, tree foliage and branches intercept precipitation and reduce the amount of water reaching the ground surface. This reduced input of water is known as effective precipitation, and was estimated using the assumption that water will form a 8/1000th" (0.2 mm) thick layer on vegetation surfaces (Dickinson 1984; Eq. 8). This equation accounts for this interception using a tree property known as the "Leaf Area Index" (LAI). This unitless parameter representes the ratio of the one-sided leaf area to ground area beneath a tree canopy.

Interception was only calculated during the growing season, which was represented uniformly as the period between April and October. It is acknowledged this is a simplifying assumption that is not applicable throughout the United States and will be a consideration for future improvements to the model. However, this may be readily adapted in the model code for specific regions and locations.

$$P_{eff} = P - LAI \times 0.2\,mm \times \frac{1\,in}{25.4\,mm} \qquad \textbf{(Eq. 8)}$$

Where:

P_{eff} = Effective Precipitation (in.)

P = Precipitation (in.)

LAI = Leaf Area Index

Trees come in all shapes and sizes and the factors that influence tree species selection for planting are varied (e.g. ascetics, large shade trees, height restrictions dues to utility lines, etc.). To better understand how tree shape and size affect water yield and the non-point source pollution loads carried by water, we modeled water yield for six vegetation types for 31 locations. The six vegetation types include three deciduous broadleaf tree species (large, medium, and small trees), two evergreen coniferous tree species (large and small trees), and managed turf grass which serves as the reference land use. Hawai‘i was the only exception and only had four vegetation types because it does not have any native conifer tree species. We identified native tree species of each size group based on height at maturity, and obtained key tree metrics using a custom version of i-

Tree Forecast (Alexis Ellis and Ari Daniels, personal communication). Tree species selections and their key metrics are summarized in Appendix E and the list of species is included in Appendix F.

The key tree metrics in water yield calculations are leaf area index (LAI), crown height, and crown width. LAI appears in the calculations for both effective precipitation (Eq. 8) and evapotranspiration (see vapor flow resistance in Appendix C). Crown height appears in the calculation for evapotranspiration (see aerodynamic resistance in Appendix C). Crown width is used to covert water flux depths to volumes, and is the factor that most strongly distinguishes small trees from larger trees. For each tree in each location, tree growth was modeled annually for 100 years using i-Tree Forecast with zero mortality, zero crown dieback, full light conditions, and user defined frost free days equal to the mean number of days per year with minimum daily temperature > 5°C (U.S. Forest Service). We used break point regression in the computational program R to identify the year when tree growth (height) stabilized, and extracted the key tree metrics from that year for water yield calculations. Based on this approach, the key tree metrics used for modelling represent a tree near maturity, with optimal growing conditions, and average health.

3. Runoff

For each location and vegetation type, we estimated runoff using the Soil Conservation Service Curve Number Method (Eq. 9; USDA, 1989).

$$R = \frac{(P-A)^2}{(P-A)+S} \qquad \textbf{(Eq. 9)}$$

Where:

R = Runoff (in.)

A = Initial Abstraction (in.)

S = Potential Retention (in.) [1]

[1] Note that the S value in this equation is related to soil storage but is not the same as the soil storage (St) described in the mass balance equations.

The curve number method was originally designed to estimate stormflow following large precipitation events with flood planning as the most obvious application (Garen and Moore 2005). During the development of this method, observations of precipitation and runoff volume at the watershed scale revealed that the ratio of initial abstractions to potential maximum water retention (A/S) was approximately equal to 0.2 (USDA 1989). However, more recent research has demonstrated that this assumption significantly underestimates runoff at smaller scales, and that A/S = 0.05 is a more appropriate assumption for small urban areas (Woodward et al. 2003). Substituting 0.05 S for A in equation 9 yields the following:

$$R = \frac{(P - 0.05 \cdot S)^2}{P + 0.95 \cdot S} \qquad \textbf{(Eq. 10)}$$

In the curve number method, the total maximum water retaining capacity (*S*) is further simplified to a dimensionless 'curve number' factor, *CN*, ranging from 0 to 100 (Eq. 11 and 12). The curve number accounts for the physical attributes of the land surface as well as the hydrologic properties of the underlying soil that affect infiltration. Urban development frequently and negatively impacts soil quality by removing organic rich soil horizons and compacting soil particles with heavy machinery, such that hydrologic soil group C is the most commonly encountered soil type in developed areas. Even so, soils with infiltration rates indicative of higher quality exist in developed areas such as parks, other areas minimally disturbed by development, or remediated soils.

CN Calculation

To evaluate the interactions between location (climate), tree species and soil quality, we estimated runoff at a daily time interval for each hydrologic soil group, A through D. The "base" CN values were taken from USDA Technical Release55, *Urban Hydrology for Small Watersheds* (Table 2). The CNs for the initial conditions (no trees) was based on open space, fair condition values. Reference values for turf grass were used in most regions, but in arid regions (Interior West and Southwest Interior), range curve numbers were used. (Table 2).

Table 2. Base Curve Numbers by Climate and Soil Type/Surface		
Soil/Land Cover Combination	Arid (Southwest Interior and Interior West)	Humid (Other Regions)
HSG A	49	55
HSG B	69	71
HSG C	79	81
HSG D	84	89
Impervious	98	98

These base CN values were first modified to be consistent with the CN calculations reported in Woodward (2003; Equation 11). This equation adjusts the curve number to account for the modified calculation of the S value. The resulting curve numbers will be lower than the standard values in Table 3, particularly at the lower end of the curve number range. The 49 value will be converted to 34, while the 98 curve number will be almost equal to 98.

$$CN_{adj} = \frac{100}{1.879 \times \left(\frac{100}{CN_{base}} - 1\right)^{1.15} + 1} \quad \textbf{(Eq. 11)}$$

To account for the *temporal* effects of stemflow, and improved physical structure of soils by tree roots (Day et al. 2010), base CN values were reduced by 4 units for scenarios with longer-lived large and medium tree species and 2 units for shorter-lived small tree species. The adjustments to the CNs were based on improved land cover conditions as reported in the TR55 documentation for urban areas, along with professional judgement. The factor increase followed, in general, the decrease in CN from fair to good condition. Best professional judgement was used to partition the effect based on the size of tree. To date, research is limited to quantify the relative effects of trees planted and growth on the soil characteristics. For example, Bartens et al. (2008) showed that tree roots increased soil infiltration rates by an average of 63% over unplanted controls and 153% for severely compacted soils. This same study demonstrated that trees can also increase infiltration rates in structural soils, with green ash grown in CU Soil having an infiltration rate 27 times greater than the unplanted CU Soil control sites.CN values for impervious surfaces were not adjusted from the base value of 98.

Finally, we adjusted the curve number based on soil water storage for pervious land uses (See section 4, following for soil storage calculation) using the technique described in the SWAT model documentation (Texas WRI, 2011; available at http://swat.tamu.edu/media/99192/swat2009-theory.pdf). This is accomplished by interpolating between curve numbers based on the soil storage value. Using the following series of calculations.

First, we establish different curve numbers for wilting point (CN1, Soil storage = 0 in our model) and field capacity (CN3, Soil storage = Smax in our model). The adjusted curve numbers calculated above represent average soil moisture conditions (Equations 12 and 13).

$$CN1 = CN - \frac{20 \times (100 - CN)}{100 - CN + e^{[2.533 - 0.0636 \times (100 - CN)]}} \quad \textbf{(Eq. 12)}$$

$$CN3 = CN \times e^{0.0636 \times (100 - CN)} \quad \textbf{(Eq. 13)}$$

For each value of CN, we calculate the Storage parameter, S in Equation 14.

$$S = \frac{1000}{CN} - 10 \quad \textbf{(Eq. 14)}$$

Then we adjust the value of the parameter S, based on the soil storage using two shape parameters (Equations 15-17). In these equation, S1 and S3 correspond to curve numbers CN1 and CN3. The parameter St is soil storage in inches (See next section). Maximum soil storage (St_{max} corresponds to field capacity, which is estimated at 6" of soil storage, while St_{sat} refers to saturated soil conditions, which we set to 9" of soil storage. This saturated condition is used only to set shape parameters, as the soil does not exceed field capacity in the water balance model.

$$S_{adj} = S3 \times \left(1 - \frac{St}{St + e^{[w1 - w2 \times St]}}\right) \quad \textbf{(Eq.15)}$$

$$w1 = ln\left(St_{max} \times \left(\frac{1}{1-\frac{S3}{S1}} - 1\right)\right) + w2 \times St_{max} \quad \textbf{(Eq. 16)}$$

$$w2 = \frac{ln\left(St_{max}\times\left(\frac{1}{1-\frac{S3}{S1}}-1\right)\right)-\ln\left(St_{sat}\times\left(\frac{1}{1-\frac{0.1}{S1}}-1\right)\right)}{St_{sat}-St_{max}} \quad \textbf{(Eq. 17)}$$

In Equations 15-17:

S_{adj}	=	Adjusted Storage Parameter (in.)
S3	=	Storage Parameter at Field Capacity (in.)
S1	=	Storage Parameter at Wilting Point (in.)
St	=	Soil Storage (in.)
St_{max}	=	Soil Storage at field capacity (in.); 6 inches
St_{sat}	=	Soil Storage at Saturation (in.); 9 inches
$w_{1,2}$	=	Unitless Shape Parameters

Runoff Calculation

After the storage factor, S, has been adjusted, runoff in inches (R), is calculated using Equation 18.

$$R = \frac{(P-0.05\times S)^2}{P+0.95\times S} \quad \textbf{(Eq. 18)}$$

For pervious land cover types, all water remaining after interception and runoff is assumed to infiltrate into soil (Eq. 5). Then, if the amount of infiltration exceeds the soil water holding capacity excess water is assumed to leach vertically below the plant rooting zone becoming shallow groundwater (Eq. 6). Otherwise, we assume that no leaching occurs (i.e., if $I_n < St_{max} - St_t$). The maximum water holding capacity (St_{max}) varies with soil texture (lowest in both very sandy and very clayey soils) and ranges from ~1 to 2 inches per foot of soil (Brady and Weil 1996). For all scenarios in this analysis, we used a maximum soil water holding capacity of 2 inches per foot of soil, and a total soil depth of 1 m - the typical rooting depth of trees. This is recognized as a simplifying assumption, and analyses that investigate alternative soil depths, as well as soil capacities are recommended in the future.

The actual volume of soil water (*St*) will vary over time as a function of the initial soil water volume after infiltration and leaching minus the amount of evaporated and transpired water (Eq. 7). Tracking changes in soil water over time also has the advantage of placing an upper limit on ET, and adjusting runoff volumes. We allowed for a 1-year calibration period of soil water by initially setting $St_0 = St_{max}$, and excluding results from the first model year, 2008, from the average annual results.

For impervious surfaces, the small fraction of water remaining after interception and runoff is assumed to evaporate back into the atmosphere from the land surface. Consequently, no infiltration or leaching occurs for this land cover type, and changes in soil water were not tracked.

4. Evapotranspiration

Each day, evapotranspiration (ET) by vegetation returns soil water to the atmosphere, allowing more infiltrated water to be stored in soil the next time it rains (Eq. 7). ET is influenced by both climatic conditions and plant physical characteristics that transfer energy and convert liquid water to water vapor. While several methods have been established to estimate daily potential evapotranspiration (for example, see Vörösmarty and others 1998), we chose to use the Penmen-Monteith equation (**Eq.19**, Monteith 1965; Zotarelli et al. 2010; Allen et al. 1998) given its prevalent use for agricultural crops and widely available data. To calculate PET (in inches) using the Penman-Monteith equation, we combined three datasets including (1) scaled-up, from hourly to daily, solar radiation data (Sengupta et al. 2014; National Renewable Energy Laboratory 2014) for each of the 31 locations from 2008 through 2013. Instructions for accessing seamless solar radiation data are included in Appendix B. Variables, constants, and other sub-equations of Eq. 17 are defined and provided in Appendix C.

Eq. 19:

$$PET = \left(\frac{\Delta R_n + c_p \rho_w D_a / r_a}{\Delta + \gamma \cdot (1 + r_c / r_a)}\right) \cdot \left(\frac{1000 \cdot L_v}{25.4 \cdot \rho_w}\right)$$

The actual Evapotranspiration (ET) is determined based on the Potential Evapotranspiration and the soil storage, so that the ET calculated at each time is equal to the *minimum* between the PET (in inches) and the soil storage (St_t; in inches).

5. Expression of Runoff Reduction Results

Results of the water yield model are provided in Tables 3 to 7. The results represent runoff reduction and do not account for the loss of water from leachate. The results are presented both as relative and absolute values comparing runoff reduction from a tree relative to a reference land use, which in this case is either turf grass with hydrologic soil group A through D or impervious surfaces (Equations 20 and 21, respectively).

The annual average reductions represent a maximum value, or optimum function, as the trees are represented in the model at an estimated maturity based on the "forecast year" from the i-Tree Forecast resultant growth curves. Future applications of these results may apply discount factors to account for 1) stress factors that affect the growth of trees in urban areas and 2) average annual lifespan reported to be between 19-28 years for trees in urban areas (Roman and Scatena, 2011) or 15 years for an urban tree in Baltimore, MD (Nowak et al. 2004).

Eq. 20:

$$\boldsymbol{f = \left(1 - \frac{\sum R_{tree}}{\sum R_{ref}}\right) x\ 100}$$

Where:

f = relative runoff reduction (%)

R_{tree} = Runoff volume in the treed condition (in.)

R_{ref} = Runoff volume in the reference condition (in.)

Eq. 21:

$$\boldsymbol{RR = \left(\sum R_{ref} - \sum R_{tree}\right) x A_{can} x 0.62/N}$$

Where:

RR	=	Average Annual Runoff Reduction (gal.)
A_{can}	=	Area beneath the tree canopy (sf)
N	=	Number of years modeled (5 in this case)
0.62	=	conversion factor (inch-sf to gallons)

Table 2. Relative and absolute runoff reduction for broadleaf large deciduous trees.

Zone	HSG-A		HSG-B		HSG-C		HSG-D		IMP	
	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)
California_Coast_and_Interior	30.0	89	46.9	193	39.0	391	37.1	555	2.3	168
Coastal_Plain	70.6	942	43.0	2491	33.6	3704	29.2	4349	2.9	1503
Interior_West	NA	12	92.3	64	60.8	216	58.7	626	12.0	884
Lower_Midwest	71.2	593	53.1	654	46.7	1212	43.9	1623	5.4	777
Midwest	80.1	604	57.1	856	49.1	1505	46.0	1993	6.4	821
North	33.3	48	68.0	315	61.3	686	58.8	1001	15.6	1239
Northeast	68.1	774	52.0	558	46.2	963	44.1	1268	9.0	779
Pacific_Northwest	42.4	215	30.7	358	27.8	692	27.3	992	5.9	728
South	79.1	2729	58.3	3395	50.4	5338	47.4	6686	9.2	3423
Southwest_Interior	66.7	57	53.0	84	43.5	193	40.5	403	11.4	642
Tropical	66.8	904	38.8	3354	34.1	5142	32.8	6306	3.7	1744

Table 3. Relative and absolute runoff reduction for broadleaf medium deciduous trees.

Zone	HSG-A		HSG-B		HSG-C		HSG-D		IMP	
	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)
California_Coast_and_Interior	40.0	89	55.9	167	48.2	333	45.6	461	4.4	191
Coastal_Plain	86.8	389	61.4	1211	51.4	1900	46.5	2306	10.5	1733
Interior_West	0.0	0	73.5	2	48.0	7	46.2	22	7.3	29
Lower_Midwest	88.8	707	66.6	944	57.7	1724	54.2	2302	8.2	1347
Midwest	90.7	608	73.3	1186	64.5	2129	60.9	2831	9.7	1315
North	20.0	2	58.3	13	45.3	28	46.4	41	8.3	43
Northeast	68.2	1295	52.3	1100	46.7	1895	44.6	2491	9.2	1548
Pacific_Northwest	42.4	216	31.3	354	28.4	686	27.9	984	6.3	760
South	63.8	1339	45.9	1482	39.4	2292	36.8	2849	5.1	1017
Southwest_Interior	66.7	3	49.1	12	36.5	27	36.0	58	7.0	68
Tropical	85.0	2087	62.9	2209	56.6	3505	54.6	4322	9.6	1929

Table 4. Relative and absolute runoff reduction for broadleaf small deciduous trees.

Zone	HSG-A		HSG-B		HSG-C		HSG-D		IMP	
	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)
California_Coast_and_Interior	15.0	4	26.8	10	23.9	22	22.5	32	2.1	17
Coastal_Plain	70.4	246	42.0	651	32.5	951	27.2	1078	4.0	531
Interior_West	33.3	1	42.7	15	48.0	54	42.4	145	9.0	221
Lower_Midwest	34.4	28	24.9	45	21.7	82	20.5	111	3.5	72
Midwest	79.3	174	55.5	280	47.1	488	43.5	636	7.1	305
North	28.9	16	60.8	106	43.4	223	44.9	320	11.1	339
Northeast	42.9	270	30.8	212	27.4	353	26.2	457	5.7	269
Pacific_Northwest	25.7	16	19.6	30	17.6	57	17.2	82	4.8	78
South	46.1	332	33.4	577	28.6	909	26.6	1133	4.2	472
Southwest_Interior	50.0	5	27.3	10	28.8	22	26.5	43	9.6	81
Tropical	60.1	152	38.1	231	33.4	357	32.4	439	4.2	133

Table 5. Relative and absolute runoff reduction for coniferous evergreen large trees.

Zone	HSG-A		HSG-B		HSG-C		HSG-D		IMP	
	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)
California_Coast_and_Interior	40.0	105	58.7	136	50.2	270	48.6	383	5.0	177
Coastal_Plain	83.1	319	56.3	957	46.1	1475	41.0	1765	6.0	868
Interior_West	33.3	11	97.4	23	67.0	77	62.0	213	11.8	307
Lower_Midwest	87.2	728	66.3	743	57.6	1358	54.2	1813	7.6	958
Midwest	97.7	718	82.2	1062	74.2	1948	70.4	2602	11.9	1268
North	33.3	22	68.3	143	62.7	308	60.3	448	16.8	584
Northeast	83.0	1689	64.4	927	57.7	1548	55.1	2011	15.5	1475
Pacific_Northwest	50.1	314	38.8	359	35.9	710	35.3	1021	12.1	1198
South	71.4	1672	52.6	1492	45.5	2353	42.3	2923	6.2	1090
Southwest_Interior	66.7	63	53.9	65	42.7	129	40.6	237	11.6	373
Tropical	93.6	5313	73.8	2522	65.2	3914	61.5	4810	7.4	1402

Table 6. Relative and absolute runoff reduction for coniferous evergreen small trees.

Zone	HSG-A		HSG-B		HSG-C		HSG-D		IMP	
	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)	Rel. (%)	Abs (Gal)
California_Coast_and_Interior	40.0	34	59.8	59	53.0	121	50.2	170	5.7	87
Coastal_Plain	86.2	11	60.8	34	50.3	52	45.4	63	8.7	40
Interior_West	33.3	2	100.0	6	75.4	21	66.9	59	17.7	120
Lower_Midwest	96.3	293	81.1	395	72.5	747	68.6	1007	16.0	909
Midwest	100.0	248	90.2	351	83.5	659	80.1	888	19.7	627
North	33.3	5	69.0	36	64.5	79	62.8	117	22.6	229
Northeast	87.1	712	68.7	359	62.2	635	59.5	843	18.5	827
Pacific_Northwest	46.3	71	35.7	79	33.0	156	32.5	223	9.3	218
South	83.6	625	63.8	753	56.4	1214	53.5	1536	11.7	885
Southwest_Interior	66.7	28	53.9	19	44.7	43	41.6	90	13.6	173
Tropical	95.5	74	77.4	90	69.7	142	65.7	174	10.2	65

Reductions in annual nutrient loading rates can be calculated using these results in one of two ways. The first option is to multiply the relative reduction rates (%) by typical annual loading rates for each base land use condition (Eq. 20). It is important to note, however, that the relative reductions are relative to grass in the same soil group. Consequently, these relative numbers are best used when compared to a base loading rate (lb/ac/year) that is specific to the soil group.

Eq. 20:

$$\boldsymbol{LR = fxLxA_{can}/43{,}560}$$

Where:

LR = Load Reduction (lb/year)

L = Average annual loading rate for the reference condition (lb/ac/year)

Annual load reductions can also be calculated by multiplying the volumetric runoff reductions (gal/year) times a concentration (Eq. 21). For pollutants that are present primarily in the particulate phase, such as phosphorus and suspended solids, typical urban runoff concentrations should be used. However, we recommend using reduced concentrations to depict the effects of tree canopy on soluble pollutants such as nitrogen. This is a conservative assumption that accounts for the fact that runoff reduction achieved by trees could possibly result in greater infiltration of soluble pollutants to the soil surface. Recommended pollutant concentrations are included in Table 8.

Eq. 21:

$$\boldsymbol{LR = RRxCx8.33x10^{-6}}$$

Where:

C = Pollutant concentration in runoff (mg/L)

Table 8. Recommended Pollutant Concentrations to Estimate Annual Load Reduction	
Pollutant	*Concentration (mg/L)*
TN	1.45
TP	0.25
TSS	140
Source: National Stormwater Quality Database, vers 1.1,	

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Appendix A. Instructions for accessing and downloading Local Quality Controlled rainfall data

1. Follow link to National Climatic Data Center: https://www.ncdc.noaa.gov/cdo-web/datasets
2. Expand the ‘Local Climatological Data’ dataset from the list of datasets under the ‘Climate Data Online’ heading, and click the mapping tool.
3. In the Layers tab in the left side bar, ‘Local Climatological Data’ should already be selected such that many orange dots are displayed on the map. If you don’t see dots, navigate to the Layers tab in the left sidebar, click the checkbox to the left of the ‘Local Climatological Data’ layer, and un-check any other layers.
4. Also, click the ‘wrench’ icon to the right of the ‘Hourly Precipitation’ data layer and a toolbox should appear in the upper right corner of the map.
5. Using the list of locations provided by the Center for Watershed Protection, use the ‘search for a location’ tool box in the upper left corner of the map to navigate to that location.
    a. For example, if I enter Baltimore, MD in the search toolbox and zoom out one level in the map I see three weather stations indicated by pink dots.
6. Use the map to find weather stations close to the desired location.
7. In the toolbox, click identify. This allows you to click on a weather station dot, and the information for the station will appear under the ‘Results’ tab in the left sidebar.
8. In the left sidebar under the ‘Results’ tab, click the checkbox next to the weather station name. Then click ‘Add to Cart’ at the bottom of the webpage – this will take you to a new screen.
9. Under the select output format, choose ‘LCD CSV’.
10. Select the data range of interest and click Apply.
11. Click ‘continue’ at the bottom of the page – this will take you to a new screen.
12. Review the data request summary. If everything looks good, enter your e-mail address and click ‘Submit Order’ at the bottom of the page and a link to the download will be sent to your e-mail.

Appendix B. Instructions for accessing and downloading seamless solar radiation for the continental U.S.A and Hawai‘i

1. Follow link to National Solar Radiation Database: https://maps.nrel.gov/nsrdb-viewer
2. In left sidebar click 'Select and Query Data' tab, then 'Data Layer' tab
3. I like to turn on the MTS2 sites by clicking the box for this field under 'NSRDB'. MTS2 sites are weather stations with measured meteorological data from 1991 to 2005, and we will get precipitation data from a subset of these sites later on.
4. In the upper right hand corner of the map there is a search tool that is almost hidden. It looks like the sighting scope on a gun. You can enter the lat-long data from the rainfall stations here and it will navigate you to that point. Then click 'Download Data' tab at top of page.
5. Use the point tool to click near the weather station of interest.
6. The point tool will give you access to both measured data (MTS2 1991 to 2005) and modelled data from 1998 to 2015 (PSM - Physical Solar Model), but we want to download PSM data.
7. Click 'Select All Download Options' first, then 'Select All Attributes'
8. Then select year individually, starting with the most recent through 2005, or some other desired date.
9. Click download data at the bottom of the page and a link to the download will be sent to your e-mail.

Appendix C. Constants, variables and sub-equations in the Penman-Monteith equation

$PET = \left(\frac{\Delta R_n + c_p \rho_w D_a / r_a}{\Delta + \gamma \cdot (1 + r_c/r_a)}\right) \cdot \left(\frac{1000 \cdot L_v}{25.4 \cdot \rho_w}\right)$	Penman-Monteith potential evapotranspiration (inches)
$\Delta = \frac{4098 \cdot eT_{mean}}{(273.3 + (T_{max} + T_{min})/2)^2}$	Rate of change of vapor pressure with temperature T (kPa K^{-1})
$eT_{mean} = \frac{eT_{max} + eT_{min}}{2}$	Mean daily saturated vapor pressure (kPa)
$eT_{max,min} = 0.6108 \cdot exp\left(\frac{17.27 \cdot T}{T + 237.3}\right)$	Saturated vapor pressure at temperature T (kPa)
$R_n = R_s - R_l$	Net radiation (MJ m^{-2} day^{-1})
$R_s = r_{ghi} \cdot (1 - \alpha)$	Net incoming shortwave radiation (MJ m^{-2} day^{-1})
r_{ghi}	Incoming shortwave radiation (MJ m^{-2} day^{-1}, from NSRD)
α	Albedo (unitless)
$R_l =$	Net outgoing long wave radiation (MJ m^{-2} day^{-1})

$$\sigma\left(\frac{(T_{max}+273.16)^4 + (T_{min}+273.16)^4}{2}\right) \cdot \left(0.34 - 0.14\sqrt{e_a}\right) \cdot \left(1.35 \cdot \frac{r_{ghi}}{r_{ghi-cs}} - 0.35\right)$$

$\sigma = 4.903 \times 10^{-9}$	Stefan-Boltzmann constant (MJ K^{-4} m^{-2} day^{-1})
$e_a = \frac{eT_{min}\left(\frac{RH_{max}}{100}\right) + eT_{max}\left(\frac{RH_{min}}{100}\right)}{2}$	Actual vapor pressure (kPa)
$RH_{max,min}$	Relative humidity (unitless, from NSRD)
r_{ghi-cs}	Clear sky shortwave radiation (MJ m^{-2} day^{-1}, from NSRD)
$c_p = 1.013 \times 10^{-3}$	Heat capacity of air (MJ kg^{-1} C^{-1})
$\rho_w = 1 \times 10^3$	Density of water (kg m^{-3})
$D_a = eT_{mean} - e_a$	Vapor pressure deficit in air (kPa)
$r_a =$	Aerodynamic resistance (s m^{-1})

$$\frac{\ln\left(\frac{z_m - d}{z_m}\right)\ln\left(\frac{z_h - d}{z_{oh}}\right)}{k^2 u_z} = \frac{\ln\left(\frac{\frac{1}{3}h}{0.123 \cdot h}\right)\ln\left(\frac{\frac{1}{3}h}{0.0123 \cdot h}\right)}{k^2 u_z}$$

h	Vegetation height (m, from i-Tree Forecast)
$k = 0.41$	von Karmen's constant (unitless)
u_z	Mean daily windspeed (m s^{-1}, from NRSD)
$\gamma = \frac{c_p \cdot P_{mean}}{0.622 \cdot \lambda}$	Psychormetric constant, kPa C^-1
P_{mean}	Mean daily atmospheric pressure (kPa, from NSRD)
$\lambda = 2.448$	Latent heat of vaporization (MJ kg^{-1})
$r_c = \frac{200}{LAI}$	Surface or canopy resistance (s m^{-1})
LAI	Leaf area index (unitless, from i-Tree Forecast)

Appendix D. *Overview of the i-Tree Forecast Modeling Tool*

i-Tree Forecast estimates annual tree canopy coverage amounts and growth based on tree population data for an area of interest. It is a part of the i-Tree suite of models developed by the USFS (Nowak et al. 2013a, b). i-Tree Forecast is an empirical model that was released in Spring 2016 as part of the i-Tree ECO model. The USFS provided simulations of i-Tree Forecast based on Panel input using a pre-release version of the model. Documentation of the model can be found in Nowak et al. (2013a, 2013b) with additional documentation expected to be available when i-Tree ECO is released (i.e., https://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6Guide_UsingForecast.pdf).

The area of tree canopy cover is predicted by the following tree characteristics: species (growth rate, height at maturity), diameter at breast height (DBH), crown light exposure (CLE) and dieback. For the purposes of the simulations defined by the Panel, the growth rate is not affected by dieback as the trees planted were assumed to be in good condition. The tree characteristic data used in i-Tree Forecast is based on data published in the literature and field data from areas throughout the United States[2]. The field and published data provide species-specific information on DBH, tree height, crown height, crown width and other variables to derive equations used in the model. The growth rate and other tree parameters of an individual tree (or group of trees) are dependent on DBH for a species, which functions as the primary independent variable in the i-Tree Forecast model. Figure 1a shows how each size class of tree has a unique set of seven diameter ranges to which base mortality rates are assigned. If a user specifies a different mortality rate, a similar distribution of DBH class is used in i-Tree Forecast. A user-defined mortality rate of 5% was selected by the Panel (see next section for more detailed description), with additional model simulations evaluating a 2.5% mortality. This mortality rate is applied in the initial year (at planting) but will vary in subsequent years based on DBH as shown in Figure 1b below.

[2] List of databases include: http://hort.ufl.edu/; http://plants.usda.gov; http://www.backyardgardener.com/; http://www.ces.ncsu.edu/; http://www.floridata.com; http://www.hort.uconn.edu/plants/; http://www.hortpix.com/index.html; http://en.hortipedia.com/wiki/

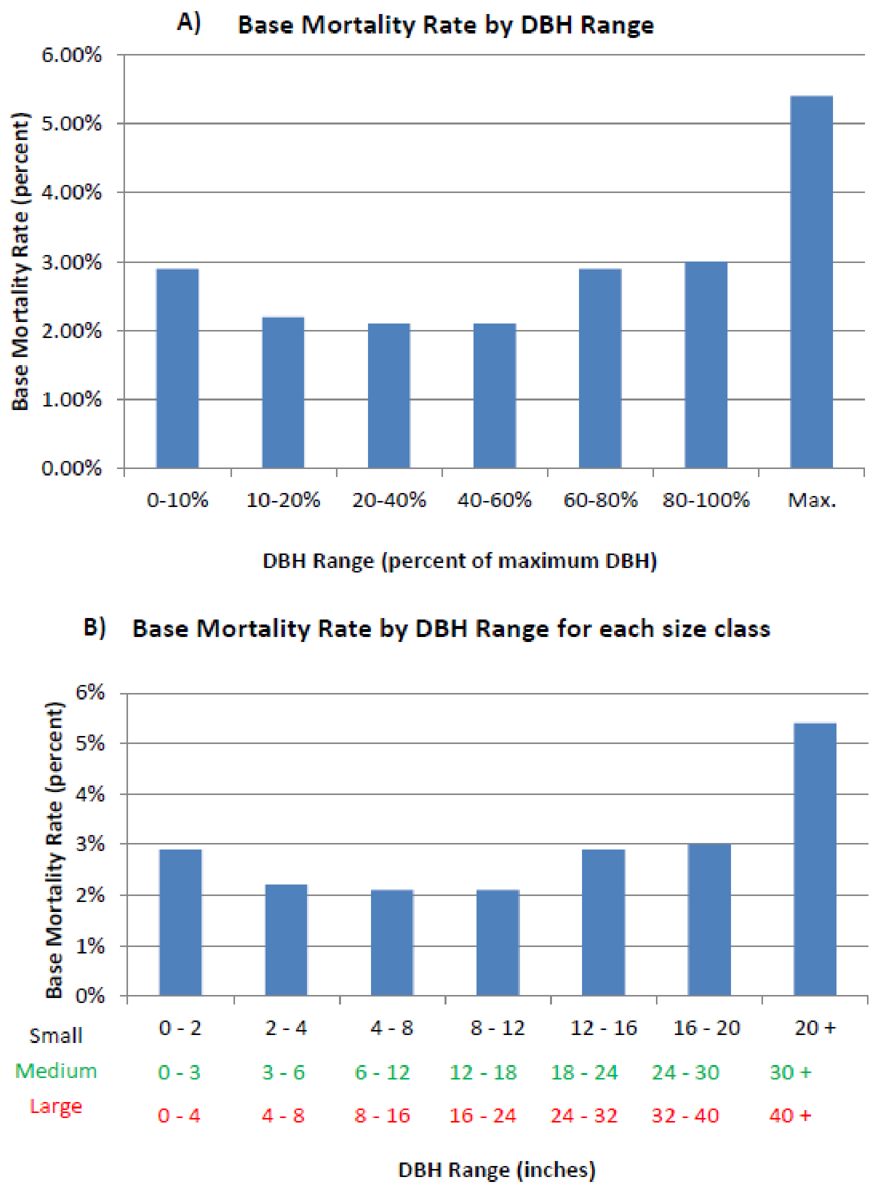

Figure 1. Mortality rate distribution by diameter class with range classified by DBH for the species (A) and for actual DBH classes for small, medium and large tree species (B), (Nowak et al. 2013b)

Appendix E. Tree species and metrics from i-Tree Forecast at selected locations for the 11 climate regions. (All metrics approximate trees at maturity as identified by the Forecast Year).

Table E-1. Tree species and metrics from i-Tree Forecast at selected locations for the 11 climate regions. (All metrics approximate trees at maturity as identified by the Forecast Year).

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
California Coast and Interior	Los Angeles	CA	QULO	BDL	0.17	17	77.9	42.0	49.9	5.1
California Coast and Interior	Los Angeles	CA	LYFL	BDM	0.17	17	50.7	28.2	29.0	10.3
California Coast and Interior	Los Angeles	CA	CH16	BDS	0.17	4	23.0	15.3	12.4	5.8
California Coast and Interior	Los Angeles	CA	SESE	CEL	0.12	16	73.3	29.0	39.5	13.4
California Coast and Interior	Los Angeles	CA	JUCA1	CES	0.12	13	41.9	18.9	32.8	16.0
California Coast and Interior	Los Angeles	CA	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
California Coast and Interior	San Francisco	CA	QULO	BDL	0.17	17	77.7	41.9	49.9	5.1
California Coast and Interior	San Francisco	CA	QUAG	BDM	0.17	29	67.4	34.0	42.8	11.6
California Coast and Interior	San Francisco	CA	CEOC3	BDS	0.17	3	24.2	13.3	12.9	3.2
California Coast and Interior	San Francisco	CA	SESE	CEL	0.12	16	73.3	29.0	39.5	13.4
California Coast and Interior	San Francisco	CA	JUCA1	CES	0.12	14	41.9	18.9	32.8	16.0
California Coast and Interior	San Francisco	CA	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Coastal Plain	Baton Rouge	LA	QUVI	BDL	0.17	37	47.3	55.7	37.9	3.8
Coastal Plain	Baton Rouge	LA	MAGR	BDM	0.17	27	54.8	31.7	47.3	15.3
Coastal Plain	Baton Rouge	LA	COFL	BDS	0.17	21	31.4	28.6	20.5	5.2
Coastal Plain	Baton Rouge	LA	TADI	CEL	0.12	19	73.4	29.1	39.6	8.6
Coastal Plain	Baton Rouge	LA	SERE2	CES	0.12	29	8.5	5.3	14.1	12.3
Coastal Plain	Baton Rouge	LA	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
Coastal Plain	Charleston	SC	QUVI	BDL	0.17	37	47.4	55.9	38.0	3.8
Coastal Plain	Charleston	SC	MAGR	BDM	0.17	27	54.8	31.7	47.3	15.3
Coastal Plain	Charleston	SC	COFL	BDS	0.17	21	31.5	28.7	20.6	5.2
Coastal Plain	Charleston	SC	PIPA	CEL	0.12	21	81.9	31.4	39.2	7.3
Coastal Plain	Charleston	SC	SERE2	CES	0.12	29	8.5	5.3	14.1	12.3
Coastal Plain	Charleston	SC	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Coastal Plain	Corpus Christi	TX	QUVI	BDL	0.17	33	48.0	56.6	38.6	3.8
Coastal Plain	Corpus Christi	TX	MAGR	BDM	0.17	24	54.8	31.7	47.3	15.3
Coastal Plain	Corpus Christi	TX	COFL	BDS	0.17	19	31.7	28.9	20.8	5.2
Coastal Plain	Corpus Christi	TX	TADI	CEL	0.12	16	73.3	29.0	39.5	8.6
Coastal Plain	Corpus Christi	TX	SERE2	CES	0.12	29	8.5	5.3	14.1	12.3
Coastal Plain	Corpus Christi	TX	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Interior West	Boise	ID	ULAM	BDL	0.17	55	84.2	54.2	57.7	6.3
Interior West	Boise	ID	POTR1	BDM	0.17	9	35.8	10.9	18.9	3.6
Interior West	Boise	ID	MATS	BDS	0.17	41	25.4	28.0	18.1	5.4
Interior West	Boise	ID	PICO	CEL	0.12	36	80.7	30.1	38.1	7.6
Interior West	Boise	ID	TABR	CES	0.12	38	37.1	13.8	21.0	9.8
Interior West	Boise	ID	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Interior West	Reno	NV	QUEM	BDL	0.17	52	66.6	33.4	42.2	11.7
Interior West	Reno	NV	CERE	BDM	0.17	23	27.1	14.9	15.6	6.6
Interior West	Reno	NV	CH16	BDS	0.17	11	22.3	14.9	11.9	5.7
Interior West	Reno	NV	PIED	CEL	0.12	45	48.3	16.7	22.5	6.3
Interior West	Reno	NV	JUMO	CES	0.12	44	36.9	16.5	29.1	14.4
Interior West	Reno	NV	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
Interior West	Salt Lake City	UT	ULAM	BDL	0.17	55	84.2	54.2	57.7	6.3
Interior West	Salt Lake City	UT	POTR1	BDM	0.17	9	35.8	10.9	18.9	3.6
Interior West	Salt Lake City	UT	MATS	BDS	0.17	41	27.0	31.0	19.4	5.3
Interior West	Salt Lake City	UT	PICO	CEL	0.12	36	80.7	30.1	38.1	7.6
Interior West	Salt Lake City	UT	JUSC	CES	0.12	29	33.6	14.9	26.3	12.9
Interior West	Salt Lake City	UT	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Lower Midwest	Cincinnati	OH	QUAL	BDL	0.17	50	73.1	33.0	43.2	5.0
Lower Midwest	Cincinnati	OH	ACRU	BDM	0.17	25	70.9	35.3	45.9	7.8
Lower Midwest	Cincinnati	OH	CECA	BDS	0.17	5	22.6	12.5	12.2	3.1
Lower Midwest	Cincinnati	OH	PIVI	CEL	0.12	21	64.8	31.5	30.5	6.0
Lower Midwest	Cincinnati	OH	JUVI	CES	0.12	42	44.7	20.8	35.1	16.6
Lower Midwest	Cincinnati	OH	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Lower Midwest	St Louis	MO	QUAL	BDL	0.17	50	73.1	33.0	43.2	5.0
Lower Midwest	St Louis	MO	ACRU	BDM	0.17	25	71.1	35.4	46.0	7.8
Lower Midwest	St Louis	MO	CECA	BDS	0.17	5	22.6	12.5	12.2	3.1
Lower Midwest	St Louis	MO	PIVI	CEL	0.12	21	65.1	31.6	30.6	6.0
Lower Midwest	St Louis	MO	JUVI	CES	0.12	42	44.7	20.8	35.1	16.6
Lower Midwest	St Louis	MO	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Lower Midwest	Wichita	KS	QUAL	BDL	0.17	50	73.1	33.0	43.2	5.0
Lower Midwest	Wichita	KS	ACRU	BDM	0.17	25	71.1	35.4	46.0	7.8
Lower Midwest	Wichita	KS	CECA	BDS	0.17	6	23.4	12.9	12.5	3.1
Lower Midwest	Wichita	KS	PIST	CEL	0.12	26	77.3	31.1	46.3	9.7
Lower Midwest	Wichita	KS	JUVI	CES	0.12	42	44.7	20.8	35.1	16.6
Lower Midwest	Wichita	KS	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
Midwest	Des Moines	IA	QUAL	BDL	0.17	51	73.9	33.5	43.6	5.0
Midwest	Des Moines	IA	ACRU	BDM	0.17	27	69.8	34.8	45.0	7.7
Midwest	Des Moines	IA	PRPE1	BDS	0.17	17	39.1	19.5	21.2	5.5
Midwest	Des Moines	IA	PIST	CEL	0.12	29	75.9	30.6	45.8	9.7
Midwest	Des Moines	IA	THOC	CES	0.12	64	46.6	17.0	33.7	18.0
Midwest	Des Moines	IA	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Midwest	Lansing	MI	QUAL	BDL	0.17	51	73.9	33.5	43.6	5.0
Midwest	Lansing	MI	ACRU	BDM	0.17	30	69.4	34.6	44.7	7.7
Midwest	Lansing	MI	PRPE1	BDS	0.17	18	39.1	19.5	21.2	5.5
Midwest	Lansing	MI	PIST	CEL	0.12	34	76.2	30.7	45.9	9.7
Midwest	Lansing	MI	THOC	CES	0.12	62	45.1	16.6	32.7	17.4
Midwest	Lansing	MI	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Midwest	Minneapolis	MN	QUAL	BDL	0.17	52	74.3	33.8	43.9	4.9
Midwest	Minneapolis	MN	ACRU	BDM	0.17	30	68.9	34.4	44.4	7.7
Midwest	Minneapolis	MN	PRPE1	BDS	0.17	21	39.4	19.7	21.3	5.5
Midwest	Minneapolis	MN	PIST	CEL	0.12	34	76.2	30.7	45.9	9.7
Midwest	Minneapolis	MN	THOC	CES	0.12	61	44.4	16.5	32.3	17.1
Midwest	Minneapolis	MN	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
North	Bismarck	ND	ACSA1	BDL	0.17	42	67.2	44.2	54.3	7.0
North	Bismarck	ND	POTR1	BDM	0.17	9	35.8	10.9	18.9	3.6
North	Bismarck	ND	MATS	BDS	0.17	40	25.2	27.7	18.0	5.4
North	Bismarck	ND	PICO	CEL	0.12	36	80.7	30.1	38.1	7.6
North	Bismarck	ND	JUSC	CES	0.12	40	33.6	14.9	26.3	12.9
North	Bismarck	ND	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
North	Cheyenne	WY	ULAM	BDL	0.17	63	82.2	53.0	56.2	6.2
North	Cheyenne	WY	POTR1	BDM	0.17	10	34.0	10.6	18.5	3.6
North	Cheyenne	WY	MATS	BDS	0.17	40	25.2	27.7	18.0	5.4
North	Cheyenne	WY	PIPO	CEL	0.12	48	77.7	27.9	36.2	8.1
North	Cheyenne	WY	JUSC	CES	0.12	39	33.1	14.7	25.8	12.7
North	Cheyenne	WY	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
North	Missoula	MT	ULAM	BDL	0.17	31	44.5	25.1	27.8	8.6
North	Missoula	MT	POTR1	BDM	0.17	17	34.4	10.7	18.6	3.6
North	Missoula	MT	MATS	BDS	0.17	27	19.0	17.5	13.4	4.4
North	Missoula	MT	PICO	CEL	0.12	50	69.5	23.9	31.8	8.2
North	Missoula	MT	TABR	CES	0.12	69	37.5	14.0	21.2	9.9
North	Missoula	MT	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Northeast	Pittsburgh	PA	QURU	BDL	0.17	21	54.0	24.9	33.6	7.6
Northeast	Pittsburgh	PA	ACRU	BDM	0.17	27	69.8	34.8	45.0	7.7
Northeast	Pittsburgh	PA	CECA	BDS	0.17	6	22.6	12.5	12.2	3.1
Northeast	Pittsburgh	PA	TSCA	CEL	0.12	50	56.9	25.2	38.2	15.6
Northeast	Pittsburgh	PA	JUVI	CES	0.12	40	43.5	20.0	34.2	16.5
Northeast	Pittsburgh	PA	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Northeast	Portland	ME	QURU	BDL	0.17	21	54.3	25.1	33.7	7.5
Northeast	Portland	ME	ACRU	BDM	0.17	27	70.0	34.9	45.2	7.8
Northeast	Portland	ME	PRPE1	BDS	0.17	17	39.1	19.5	21.2	5.5
Northeast	Portland	ME	PIST	CEL	0.12	29	75.9	30.6	45.8	9.7
Northeast	Portland	ME	THOC	CES	0.12	64	46.6	17.0	33.7	18.0
Northeast	Portland	ME	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
Northeast	Syracuse	NY	QURU	BDL	0.17	21	54.0	24.9	33.6	7.6
Northeast	Syracuse	NY	ACRU	BDM	0.17	27	69.6	34.7	44.9	7.7
Northeast	Syracuse	NY	PRPE1	BDS	0.17	18	39.4	19.7	21.3	5.5
Northeast	Syracuse	NY	TSCA	CEL	0.12	50	56.9	25.2	38.2	15.6
Northeast	Syracuse	NY	THOC	CES	0.12	64	46.3	16.9	33.6	18.0
Northeast	Syracuse	NY	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Pacific Northwest	Eugene	OR	QUGA2	BDL	0.17	50	64.8	32.2	41.0	5.8
Pacific Northwest	Eugene	OR	FRLA	BDM	0.17	30	65.2	31.7	36.1	6.3
Pacific Northwest	Eugene	OR	ACCI	BDS	0.17	4	22.4	11.5	12.9	4.7
Pacific Northwest	Eugene	OR	PSME	CEL	0.12	41	75.0	28.7	39.8	13.7
Pacific Northwest	Eugene	OR	TABR	CES	0.12	27	37.5	14.0	21.2	9.9
Pacific Northwest	Eugene	OR	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Pacific Northwest	Seattle	WA	QUGA2	BDL	0.17	50	64.8	32.2	41.0	5.8
Pacific Northwest	Seattle	WA	FRLA	BDM	0.17	30	65.2	31.7	36.1	6.3
Pacific Northwest	Seattle	WA	ACCI	BDS	0.17	5	22.9	11.7	13.2	4.7
Pacific Northwest	Seattle	WA	PSME	CEL	0.12	41	75.0	28.7	39.8	13.7
Pacific Northwest	Seattle	WA	TABR	CES	0.12	27	37.5	14.0	21.2	9.9
Pacific Northwest	Seattle	WA	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
South	Chattanooga	TN	PLOC	BDL	0.17	36	96.5	47.7	69.0	12.7
South	Chattanooga	TN	QUMU	BDM	0.17	29	68.3	34.5	43.4	5.7
South	Chattanooga	TN	COFL	BDS	0.17	26	31.3	28.4	20.4	5.2
South	Chattanooga	TN	PIEC	CEL	0.12	25	81.5	30.9	38.8	7.4
South	Chattanooga	TN	JUVI	CES	0.12	34	45.5	21.3	35.7	16.8
South	Chattanooga	TN	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
South	Dallas	TX	PLOC	BDL	0.17	33	97.7	48.3	70.1	12.8
South	Dallas	TX	QUMU	BDM	0.17	26	69.5	35.4	44.2	5.6
South	Dallas	TX	CODR	BDS	0.17	27	32.4	31.6	22.6	5.2
South	Dallas	TX	PITA	CEL	0.12	30	79.8	39.0	46.8	6.7
South	Dallas	TX	JUVI	CES	0.12	36	47.3	22.5	37.0	16.8
South	Dallas	TX	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
South	Washington	DC	PLOC	BDL	0.17	35	94.8	46.8	67.5	12.6
South	Washington	DC	ACRU	BDM	0.17	23	71.4	35.5	46.2	7.8
South	Washington	DC	PRYE	BDS	0.17	15	39.7	19.8	21.5	5.5
South	Washington	DC	PIST	CEL	0.12	23	77.0	31.0	46.2	9.7
South	Washington	DC	JUVI	CES	0.12	33	44.7	20.8	35.1	16.6
South	Washington	DC	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Southwest Interior	Albuquerque	NM	QUMA1	BDL	0.17	50	65.2	32.5	41.3	5.8
Southwest Interior	Albuquerque	NM	SACANE	BDM	0.17	25	16.0	15.6	12.7	3.2
Southwest Interior	Albuquerque	NM	CH16	BDS	0.17	8	22.7	15.1	12.2	5.8
Southwest Interior	Albuquerque	NM	PICO	CEL	0.12	31	80.8	30.2	38.2	7.6
Southwest Interior	Albuquerque	NM	PIED	CES	0.12	35	51.3	17.6	23.8	6.7
Southwest Interior	Albuquerque	NM	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Southwest Interior	Flagstaff	AZ	QUEM	BDL	0.17	46	72.1	37.3	46.0	11.2
Southwest Interior	Flagstaff	AZ	CERE	BDM	0.17	17	27.1	14.9	15.6	6.6
Southwest Interior	Flagstaff	AZ	CH16	BDS	0.17	8	22.3	14.9	11.9	5.7
Southwest Interior	Flagstaff	AZ	PIED	CEL	0.12	34	50.6	17.4	23.5	6.6
Southwest Interior	Flagstaff	AZ	JUMO	CES	0.12	33	37.7	16.9	29.7	14.6
Southwest Interior	Flagstaff	AZ	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Zone	City	State	SppCode	TreeType	Albedo	ForecastYear (age of tree)	Height (ft)	Crown Width (ft)	Crown Height (ft)	Leaf Areal Index
Southwest Interior	Lubbock	TX	QUMA1	BDL	0.17	48	73.5	38.3	47.0	5.4
Southwest Interior	Lubbock	TX	SACANE	BDM	0.17	19	16.0	15.4	12.6	3.2
Southwest Interior	Lubbock	TX	CH16	BDS	0.17	6	22.7	15.1	12.2	5.8
Southwest Interior	Lubbock	TX	PITA	CEL	0.12	34	79.8	39.6	47.4	6.6
Southwest Interior	Lubbock	TX	PIED	CES	0.12	28	52.1	17.9	24.1	6.8
Southwest Interior	Lubbock	TX	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Tropical	Honolulu	HI	ACKO	BDL	0.17	27	81.0	36.4	44.4	5.8
Tropical	Honolulu	HI	ACKO2	BDM	0.17	9	44.8	23.6	24.5	5.2
Tropical	Honolulu	HI	SAEL2	BDS	0.17	4	18.4	9.1	8.8	5.3
Tropical	Honolulu	HI	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Tropical	Miami	FL	QUVI	BDL	0.17	33	48.0	56.7	38.6	3.8
Tropical	Miami	FL	MAGR	BDM	0.17	22	55.2	31.9	47.7	15.3
Tropical	Miami	FL	LAIN	BDS	0.17	22	19.3	14.2	16.3	4.8
Tropical	Miami	FL	TADI	CEL	0.12	16	73.3	29.0	39.5	8.6
Tropical	Miami	FL	SERE2	CES	0.12	29	8.5	5.3	14.1	12.3
Tropical	Miami	FL	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9
Tropical	Tampa	FL	QUVI	BDL	0.17	33	48.0	56.7	38.6	3.8
Tropical	Tampa	FL	MAGR	BDM	0.17	22	55.2	31.9	47.7	15.3
Tropical	Tampa	FL	LAIN	BDS	0.17	22	19.3	14.2	16.3	4.8
Tropical	Tampa	FL	TADI	CEL	0.12	16	73.3	29.0	39.5	8.6
Tropical	Tampa	FL	SERE2	CES	0.12	29	8.5	5.3	14.1	12.3
Tropical	Tampa	FL	GRASS	GRA	0.25	1	0.1	NA	0.1	2.9

Appendix F: List of Tree Species

SpeciesCode	ScientificName	CommonName	Tree Type[1]
ACCI	Acer circinatum	Vine maple	BDS
ACKO	Acacia koa	Koa	BEL
ACRU	Acer rubrum	Red maple	BDM
ACSA1	Acer saccharinum	Silver maple	BDL
CECA	Cercis canadensis	Eastern redbud	BDS
CEOC3	Cercis occidentalis	Western redbud	BDS
CERE	Celtis reticulata	Western hackberry	BDM
COFL	Cornus florida	Flowering dogwood	BDS
FRLA	Fraxinus latifolia	Oregon ash	BDM
JUCA1	Juniperus californica	California juniper	CEM
JUMO	Juniperus monosperma	One seed juniper	CES
JUSC	Juniperus scopulorum	Rocky mountain juniper	CES
JUVI	Juniperus virginiana	Eastern red cedar	CES
LAIN	Lagerstroemia indica	Crapemyrtle	BDS
LYFL	Lyonothamnus floribundus	Lyontree	BDL
MAGR	Magnolia grandiflora	Southern magnolia	BDM
MATS	Malus tschonoskii	Crabapple	BDS
PICO	Pinus contorta	Lodgepole pine	CEL
PIEC	Pinus echinata	Shortleaf pine	CEL
PIED	Pinus edulis	Pinyon pine	CEL
PIPA	Pinus palustris	Longleaf pine	CEL
PIPO	Pinus ponderosa	Ponderosa pine	CEL
PIST	Pinus strobus	Eastern white pine	CEL
PITA	Pinus taeda	Loblolly pine	CEL
PIVI	Pinus virginiana	Virginia pine	CEL
PLOC	Platanus occidentalis	American sycamore	BDL
POTR1	Populus tremuloides	Quaking aspen	BDM
PRPE1	Prunus pensylvanica	Pin cherry	BDS
PRYE	Prunus yedoensis	Yoshino flowering cherry	BDS
PSME	Pseudotsuga menziesii	Douglas fir	CEL
QULO	Quercus lobata	California white oak	BDL
QUMA1	Quercus macrocarpa	Bur oak	BDL
QURU	Quercus rubra	Northern red oak	BDL
QUVI	Quercus virginiana	Live oak	BDL
SACANE	Sambucus caerulea var neomexicana	Neomexican blue elderberry	BDS
SERE2	Serenoa repens	Saw palmetto	CES

SpeciesCode	ScientificName	CommonName	Tree Type[1]
SESE	Sequoia sempervirens	Coast redwood	CEL
TABR	Taxus brevifolia	Pacific yew	CES
TADI	Taxodium distichum	Baldcypress	CEL
THOC	Thuja occidentalis	Northern white cedar	CES
ULAMLI	Ulmus american 'Liberty'	Liberty elm	BDL
[1]GRA is turfgrass; BDL = broadleaf large; BDM = broadleaf medium; BDS = broadleaf small; CEL = coniferous evergreen large; CES = coniferous evergreen small			