i-Tree Streets/Design/Eco Rainfall Interception Model Comparisons

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Abstract

i-Tree Streets/Design and Eco estimate annual rainfall interception by urban forest based on different physics-based water balance models. Streets/Design is based on Xiao et al. (1998), while Eco is based on Wang et al. (2008) and improved by Hirabayashi (2013). In Xiao et al. (1998), annual rainfall interception percentage against the gross precipitation in Sacramento County, CA was estimated 1.0 % for the entire area and 11.1 % for the canopy-covered area. Applying Wang et al.'s model without Hirabayashi's model to the same study area resulted in 0.6 % and 8.6 %, respectively. The results didn't exactly match, but considering the differences in the two models' parameterizations, it can be concluded that they were relatively in a good agreement. Although these results seem feasible to represent annual rainfall interception by urban forest, they may be too large if these results are interpreted as annual avoided runoff due to trees. Even if these trees were all removed, rainfall otherwise intercepted by trees may infiltrate into the ground or be stored on ground depressions and thus not all of the rainfall would runoff. To represent the annual avoided runoff, the effects by trees need to be isolated from Xiao et al.'s or Wang et al.'s results. Hirabayashi (2013) developed tree effect isolation method incorporating into Wang et al.'s model in i-Tree Eco. With this improvement, the annual avoided runoff for Sacramento County, CA was estimated 0.14 % for the entire area, about one seventh of Xiao et al. 's annual rainfall interception (1.0 %).

1. Introduction

Three i-Tree version 5 tools (i.e. Streets, Design and Eco) provide annual estimate of rainfall interception by urban trees. Developed based on Xiao et al. (1998)'s model, i-Tree Streets/Design report annual rainwater volume intercepted by trees that can infer the runoff avoided annually. With a water balance approach, their model computes canopy interception as the sum of canopy surface water storage and evaporation, which equates the loss of rainwater to the ground through canopy and trunk from the gross precipitation. Their model is physically plausible as an estimate of rainfall interception; however, it may overestimate if the rainfall interception is used to represent avoided

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runoff. Not all of the rainwater intercepted by trees would runoff if there were no trees at all since the rainwater reached the ground may be intercepted by ground depression and/or infiltrate into the ground. To estimate runoff avoided solely by the effect of trees, those effects by ground cover need to be subtracted.

i-Tree Eco was developed based on the model by Wang et al. (2008), which employed the similar physics-based approach as Xiao et al. (1998)'s to estimate rainwater interception by canopy. To isolate trees' effect on annual avoided runoff, the model was improved by taking into account the interception by trees and ground cover depressions, infiltration into pervious cover as well as runoff on impervious cover (Hirabayashi 2013).

Applying their model, Xiao et al. (1998) estimated annual rainfall interception at the urban forest canopy level as well as the landscape level in four sectors (i.e. City, Suburban, Rural, and the entire county) in Sacramento County, CA. In this document, i-Tree Eco was also applied at the same levels in the same four sectors with and without tree effect isolation model to compare the estimates produced by the two models.

2. Methods

2.1. Xiao et al. (1998)'s rainfall interception model

Gross precipitation is either intercepted by canopy leaves, branches, and trunk, or it falls directly to the ground without hitting the tree. Intercepted water is stored temporarily on canopy leaf and bark surfaces, eventually drips from leaf surfaces, and flows down tree stem surfaces to the ground, or it evaporates. Interception accounts for the sum of canopy surface water storage and evaporation. The total water balance on a canopy surface in terms of water depth can be expressed by the following equation:

$$I = C + E = P - TH - F - D \quad (1)$$

where I is the interception by trees, C is the canopy surface water storage, which includes water storage on leaf and trunk surfaces; E is evaporation from canopy surfaces, which includes evaporation from leaf, branches and trunk surfaces; P is gross precipitation; TH is free throughfall (precipitation directly passing through the canopy); F is stem flow; and D is water drip from leaves and branches.

Details to computer each term in Eqn. 1 were not revealed in Xiao et al. (1998).

2.2. Wang et al. (2008)'s rainfall interception model

The rainfall interception is similarly estimated as Xiao et al. (1998) but in a simplified way (i.e. *C*, *E* and *D* only include components by leaf only and *F* is omitted):

$$I = C' + E' = P - TH - D' \tag{2}$$

where *C'* is the leaf water storage; *E'* is evaporation from leaves; and *D'* is water drip from leaves. The maximum capacity of C' is define as:

$$C'_{max} = S_L LAI \tag{3}$$

S_L is specific leaf storage of water (=0.0002 m).

2.3. Hirabayashi (2013)'s tree effect isolation model

In this improvement incorporated in i-Tree Eco, an actual scenario and hypothetical scenario are considered to estimate annual avoided runoff solely provided by trees' rainfall interception (Fig. 1). In both cases, it is assumed that 74.5% of the urban area (regardless of under canopy or not) is pervious and 25.5 % is impervious cover (Nowak and Greenfield 2012). In the actual scenario, rain fall interception is estimated with Eqn. 2, and in the hypothetical scenario the water balance in terms of water depth can be expressed as:

$$P = In + S + R + E \tag{4}$$

where *In* is infiltration to the pervious cover, *S* is depression storage on both pervious and impervious covers, *R* is surface runoff from impervious cover, and *E* is evaporation. For pervious and impervious cover, the maximum depression storage is defined 0.001 (m) and 0.0015 (m), respectively.

To account for the infiltration and ground depression storage in pervious and impervious cover, depth of water balance is converted to volume by multiplying area. Infiltration depth is converted to volume by multiplying the area covered by canopy, *VA* (m^2) and 74.5%. Depression storage depth for pervious/impervious cover is converted to volume by multiplying *VA* (m^2) and 74.5%/25.5%, respectively. The rainfall interception depth *I* is converted to volume by multiplying *VA* (m^2). With these conversions, annual avoided runoff volume can be calculated as:

$$R_{avoided} = I - In - S \quad (5)$$

where *I*, *In* and *S* are in volume (m^3).

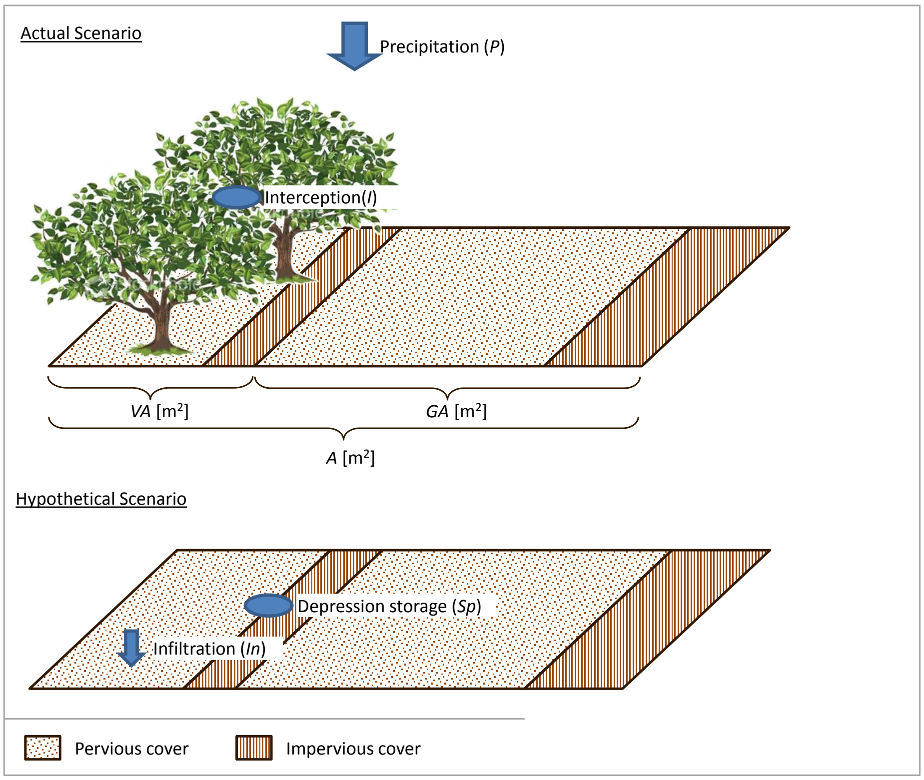

Figure 1 i-Tree Eco version 5 precipitation interception model diagram

3. Results and Discussions

3.1. Comparison of annual rainfall interceptions without tree effect isolation

Table 1 taken from Xiao et al. (1998)'s Table 1 presents their urban forest information. Note that LAI and Evergreen percentages were calculated with Eqns. 4 and 5 below and added to the table for use by i-Tree Eco application.

$$LAI = \frac{\sum(Leaf\ area)}{Area \times Canopy\ (\%)} \quad (4)$$

$$Evergreen = \frac{BE + Conifer + Palm}{\sum(Leaf\ area)} \times 100 \quad (5)$$

Table 1 Leaf area and canopy cover distribution from Xiao et al. (1998)

Sector	Area (km^2)	Canopy	Leaf area (km^2)				LAI	Ever-green
			BE[a]	BD[b]	Conifer	Palm		
City	236.0	13.0%	15.7	126.2	118.5	8.4	8.76	53.1%
Suburban	371.4	15.4%	239.4	182.7	182.9	7.9	10.72	70.2%
Rural	1,970.9	5.2%	358.3	92.5	92.8	0.0	5.30	83.0%
County	2,578.3	7.4%	613.4	401.4	394.2	16.3	7.47	71.8%

[a]Broadleaf evergreen
[b]Broadleaf deciduous

Table 2 taken from Xiao et al. (1998)'s Table 2a presents their annual rainfall intercept estimate using weather data in 1992. Rainfall interception was estimated over three sectors in the county as well as the entire county based on Eqn. 1. Note that these estimates were made at the urban forest canopy level, meaning that only the ground area covered by canopy (Table 1) was considered.

Table 2 Annual rainfall interception at urban forest canopy level from Xiao et al. (1998)

Sector	P (mm)	I (mm)	TH (mm)	D (mm)	F (mm)
City	393.2	23.4	266.3	101.0	2.5
Suburban	433.2	56.3	186.5	238.0	2.7
Rural	415.5	55.4	121.2	236.3	2.6
County	414.1	45.9	186.3	179.3	2.6

Table 3 presents the estimate produced by i-Tree Eco using Area, Canopy (%), LAI and Evergreen listed in Table 1 and hourly weather data measured at the NCDC weather station (USAF:724833, WBAN:23206) in 2010. Due to the model parameterization, values in *TH* include *D'*.

Table 3 Annual rainfall interception at the urban forest canopy level from i-Tree Eco

Sector	P (mm)	I (mm)	TH (mm)	D' (mm)
City	246.6	22.9	223.7	-
Suburban	246.6	25.9	220.7	-
Rural	246.6	17.3	229.3	-
County	246.6	21.2	225.4	-

Based on *P* and *I* in Tables 2 and 3, percentage of rainfall intercepted by trees at the urban forest canopy level for Xiao el al. (1998)'s and i-Tree Eco's model was calculated as shown in Table 4.

Table 4 Annual rainfall interception by percentage from Xiao et al. (1998) and i-Tree Eco

Sector	Xiao et al. (1998)		i-Tree Eco	
	Landscape level	Urban forest canopy level	Landscape level	Urban forest canopy level
City	1.8	6.0	1.2	9.3
Suburban	2.6	13.0	1.6	10.5
Rural	0.6	13.3	0.4	7.0
County	1.0	11.1	0.6	8.6

Landscape level result for Xiao et al. (1998) was taken from their Table 2b (each component in Eqn. 1 at the landscape level was not presented), while for i-Tree Eco was calculated based on precipitation and interception shown in Table 5. Note that, in i-Tree Eco, depth of water balance components (i.e. precipitation, infiltration, interception, and runoff) was converted to volume by multiplying area to take canopy cover, impervious/pervious ground cover within area of interest into consideration. As shown in Table 4, the rainfall interception percentages against the gross precipitation estimated by i-Tree Eco were slightly smaller than those by Xiao et al. (1998)'s model across all sectors (except for City at the urban forest canopy level). This may be due to the omission of other components than leaves (i.e. barks, branches and trunk) in Eqn. 2. As the computation of each component in Eqn. 1 was not discussed in Xiao et al. (1998), it is difficult to identify the true reason to create the differences in the two models' results, but assuming the different parameterization in the two models, the results obtained here are rather comparable and relatively in a good agreement.

Table 5 Annual rainfall interception at landscape level from i-Tree Eco

Sector	P (m^3)	I (m^3)
City	58,205,624	701,787
Suburban	91,599,867	1,480,630
Rural	48,6090,950	1,775,257
County	63,5896,442	4,053,570

3.2. Comparison of annual avoided runoff with tree effect isolation

When comparing the two models in terms of rainfall interception by trees, they revealed a relatively good agreement. However, the final result reported by i-Tree Eco is annual avoided runoff by trees in which tree effects are isolated, while that reported by i-Tree Streets/Design is the annual rainfall intercepted by trees in which tree effects are not isolated. Therefore, the final results from i-Tree Eco and Streets/Design may have a relatively large difference.

Table 6 presents the results estimated by i-Tree Eco for Sacramento County. In the City sector, for instance, interception (710,787 m^3) was adjusted by subtracting infiltration (457,797 m^3) and ground intercept (92,719 m^3), resulted in avoided runoff (151,280 m^3). Comparing Xiao et al. (1995)'s landscape level percentage in Table 4 and avoided runoff (%) in Table 6, Xiao et al. (1995)'s model estimated averagely seven times larger than i-Tree Eco's.

Table 6 Annual avoided runoff from i-Tree Eco

Sector	Interception (m^3)	Infiltration (m3)	Ground intercept (m3)	Avoided runoff (m^3)	Avoided runoff (%)
City	701,787	457,797	92,710	151,280	0.26
Suburban	1,480,630	981,257	323,398	323,398	0.35
Rural	1,775,257	1,185,376	201,531	388,350	0.08
County	4,053,570	2,653,245	522,299	878,026	0.14

4. Conclusions

i-Tree Streets/Design estimates annual rainfall interception by trees based on Xiao et al. (1998)'s model, while i-Tree Eco estimates the same annual tree effect based on Wang et al. (2008)'s model and adjusts it to represent annual avoided runoff based on Hirabayashi (2013)'s model. Employing urban forest information for Sacramento County, CA used in Xiao et al. (1998), this document compared the annual rainfall interception estimated by Xiao et al. (1998) and 1) annual rainfall interception estimated by i-Tree Eco without tree effect isolation, and 2) annual avoided runoff estimated by i-Tree Eco with tree effect isolation. Without tree effect isolation model, the results produced by the two models showed a relatively good agreement, though these results may overestimate annual runoff avoided solely provided by trees. With tree effect isolation model, i-Tree

Eco results became smaller than those without the isolation model. It is necessary, in the future, to validate the results estimated with the tree effect isolation model. However, for the time being, it may be concluded that i-Tree Eco's estimate with tree effect isolation on annual avoided runoff is more realistic as it accounts for more detailed water balance in the canopy covered area.

References

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