i-Tree Eco Precipitation Interception Model Descriptions

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Version 1.3

January 30, 2013

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1. Introduction

Employing field-surveyed urban forest information, location specific data, weather data, and air pollutant measurements, i-Tree Eco assesses the structure of community trees and quantifies the environmental services that trees provide. With a newly integrated feature, i-Tree Eco version 5 will provide capability to estimate precipitation intercepted by vegetation that can contribute to the reduction of stormwater. This document provides detailed i-Tree Eco precipitation interception model descriptions.

2. Model Descriptions

Precipitation interception model implemented in i-Tree Eco version 5 was developed based on i-Tree Hydro (Wang et al. 2008). In typical sampling i-Tree Eco projects, the area of interest is partially covered by vegetation (trees or shrubs) and the other is impervious or pervious ground cover. The model assumes that precipitation is uniformly distributed over the area, some portion of which falls on the area covered by vegetation and the others fall on the ground area. The precipitation fell on the vegetation is partially intercepted by leaves, and the remainder reaches the ground under the canopy. The precipitation reached on the ground (directly and/or through canopy) is partially intercepted by depressions on the ground and the remainder infiltrates to the ground of pervious cover or run offs over impervious cover. This surface runoff over impervious cover contributes to the flush stormwater. In i-Tree full inventory projects, the area of interest is assumed to be entirely covered by vegetation.

In addition to the actual scenario described above, the hypothetical scenario, in which the same area of interest is not covered by vegetation at all, is considered in the model. Figure 1 illustrates these two scenarios. In both scenarios, hourly precipitation interception processes are first calculated and total annual surface runoff volume is then calculated. In general, the actual scenario produces less surface runoff than the hypothetical scenario due to the effect of vegetation that intercepts, stores, and evaporates rain water. By taking difference in surface runoff between the two scenarios, the effect of vegetation in reducing the surface runoff can be determined as net avoided runoff.

The net avoided runoff is further summarized for individual trees, species in the analysis domain and species in land use types. The monetary value for precipitation interception is equated to net avoided runoff. As such, a US national average dollar value was calculated ($0.008936/gallon) and applied based on 16 studies of costs of stormwater control. See the US Forest Service's Tree Guide series (McPherson et al. 1999; 2000; 2001; 2002; 2003; 2004; 2006a; 2006b; 2006c; 2007; 2010, Peper et al. 1999; 2000, Vargas et al. 2007a; 2007b; 2008). The following subsections describe the detailed processes and calculation of precipitation interception.

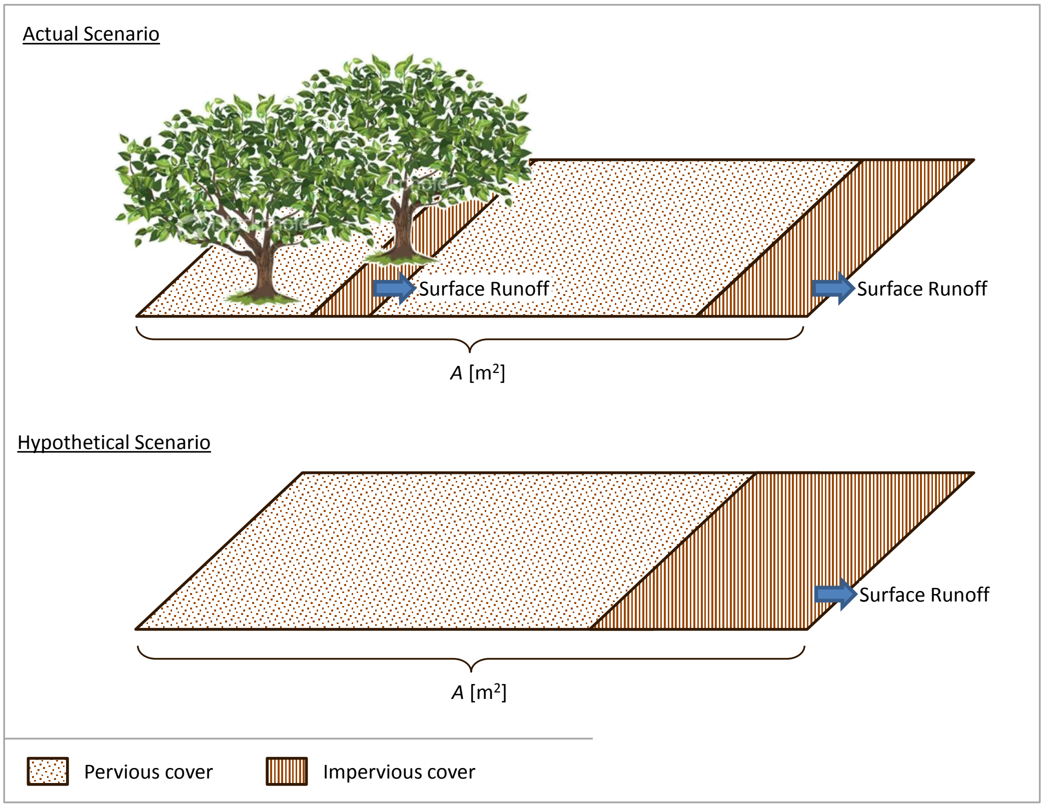

Figure 1 i-Tree Eco version 5 precipitation interception model diagram

2.1. Hourly precipitation interception process for vegetated cover

2.1.1. Process by vegetation

Precipitation interception by vegetation is calculated in three stages: 1st stage starts when a precipitation event starts and ends when the canopy storage capacity is filled, 2nd stage is during the period in which the canopy storage capacity is filled and all subsequent precipitation reaches the ground, and 3rd stage starts when the precipitation stops and intercepted rain starts to dry.

Figure 2 illustrates the 1st stage of the precipitation interception process with vegetation. Precipitation (*P*) [m] is divided into 1) in canopy precipitation (*Pc*) [m] that falls on and touches canopy and 2) through canopy precipitation (*Pt*) [m] that falls through the canopy as free throughfall without contact and reaches the ground. In the 1st stage, *Pc* is intercepted and stored (*Sv*) [m] within vegetation, and part of it evaporates into the air (*Ev*) [m].

At stage 1, vegetation storage at time *t* (Sv_t) [m] is calculated as

$$Sv_t = Sv_{t-1} + Pc_t - Ev_{t-1} \tag{1}$$

If $Sv_t < 0$, 0 is set to Sv_t, whereas if $Sv_t >= Sv_{max}$, Sv_{max} is set to Sv_t and the 1st stage ends. Sv_{max} is calculated as

$$Sv_{max} = S_L LAI \tag{2}$$

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

In canopy precipitation at time *t* (Pc_t) [m] is calculated as

$$Pc_t = P_t - Pt_t \tag{3}$$

Through canopy precipitation at time *t* (Pt_t) [m] is calculated as (Dijk and Bruijnzeel 2001)

$$Pt_t = P_t(1 - c) \tag{4}$$

c is canopy cover fraction that is related to the canopy LAI.

$$c = 1 - e^{-kLAI} \tag{5}$$

k is an extinction coefficient (=0.7 for trees and 0.3 for shrubs) (Wang et al. 2008). At time *t*, amount of the precipitation reaching the ground is equal to Pt_t [m].

Evaporation from vegetation at time *t* (Ev_t) [m] is calculated as

$$Ev_t = \left(\frac{Sv_t}{Sv_{max}}\right)^{2/3} PE_t \tag{6}$$

PE_t [m] is potential evaporation at time t calculated by the weather preprocessor.

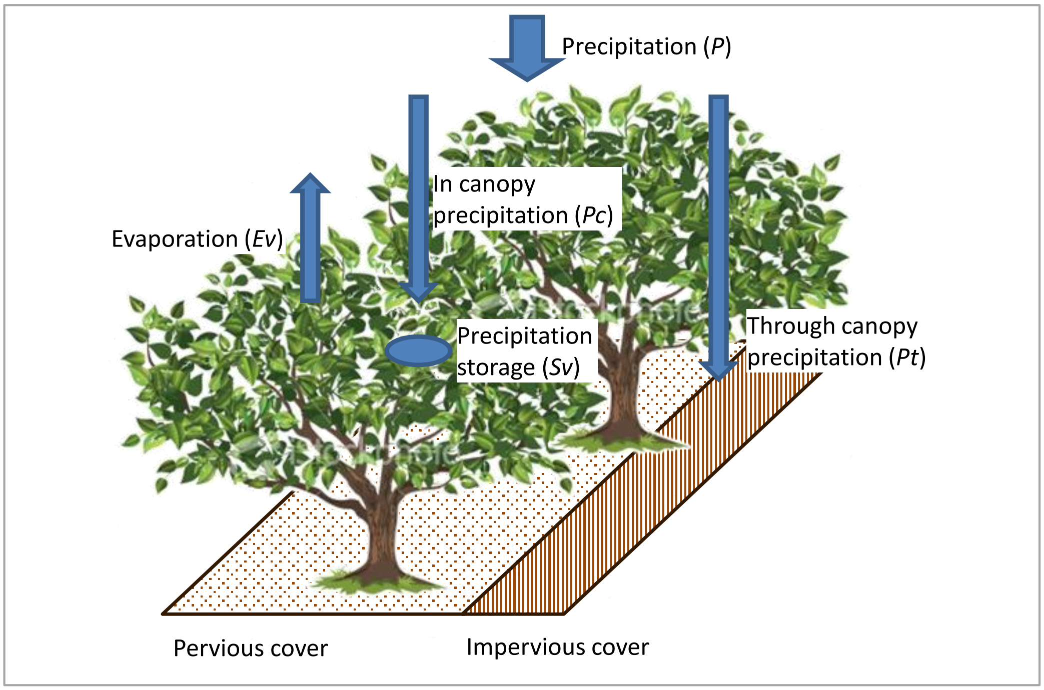

Figure 2 1st stage of the precipitation interception by vegetation, starting when the precipitation (*P*) starts and ending when the canopy storage (*Sv*) reaches Sv_{max}

Figure 3 illustrates the 2nd stage of the precipitation interception process with vegetation. Same as the 1st stage, precipitation (*P*) is divided into *Pc* and *Pt*. In the 2nd stage, though, *Pc* is not stored anymore because the storage capacity is reached and thus drips from canopy (*D*) [m] while evaporation occurs from the storage throughout the stage.

Sv_t is calculated with Eqn. 1, resulting in Sv_{max}. Pc_t, Pt_t and Ev_t are calculated with Eqns. 3, 4 and 6, respectively.

For the first time in the 2nd stage ($Sv_{t-1} < Sv_{max}$), canopy drip at time *t* (*Dt*) [m] is calculated as

$$D_t = Pc_t - (Sv_{max} - Sv_{t-1}) - Ev_t \tag{7}$$

After that *Dt* can be calculated as

$$D_t = Pc_t - Ev_t \tag{8}$$

At time *t*, amount of the precipitation reaching the ground is sum of D_t and Pt_t.

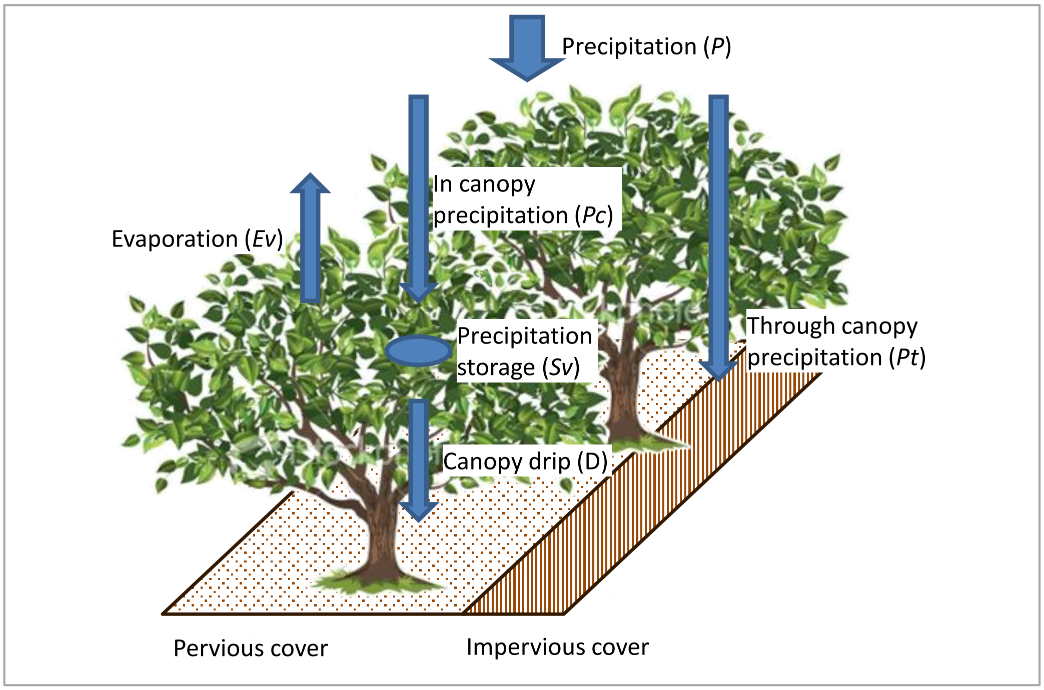

Figure 3 2nd stage of the precipitation interception by vegetation during the canopy storage (*Sv*) is equal to Sv_{max}

In the 3rd stage, as the precipitation stops, only evaporation from vegetation occurs (Figure 4), which can be calculated with Eqn. 6.

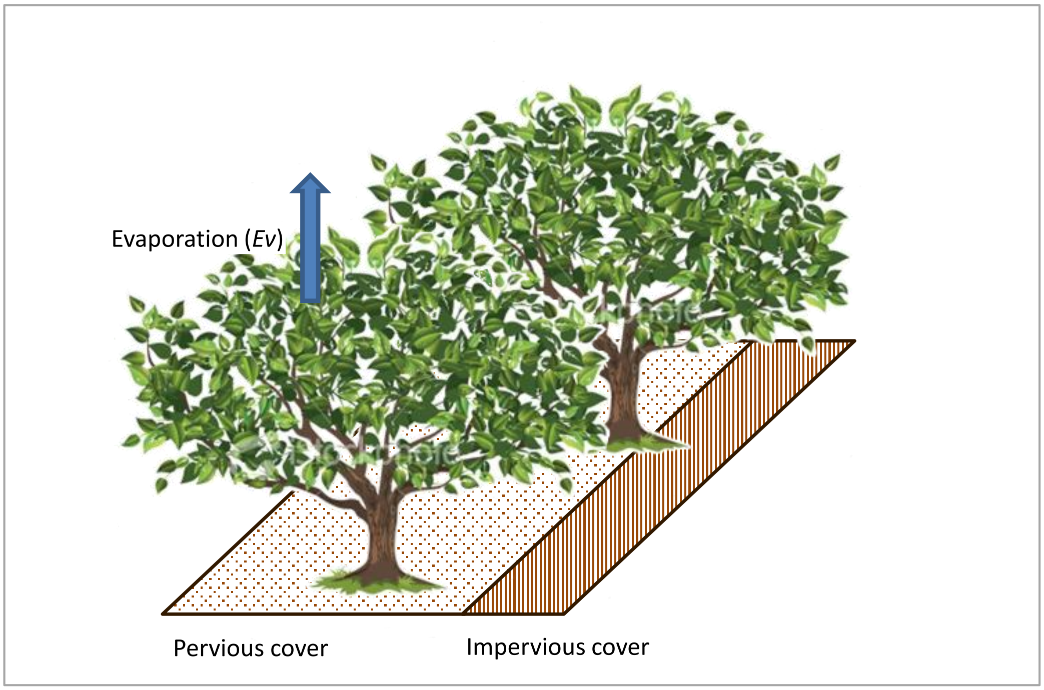

Figure 4 3rd stage of the precipitation interception by vegetation is drying stage, starting when precipitation stops

2.1.2. Process by impervious cover under canopy

With precipitation intercepted by vegetation, the sum of through canopy precipitation at time *t* (Pt_t) [m] and canopy drip at time *t* (D_t) [m] reach the ground. With this amount, same three stages as Section 2.1.1 are employed here.

Figure 5 illustrates the 1st stage of the precipitation interception process by impervious cover. At stage 1, impervious cover depression storage at time *t* (Svi_t) [m] is calculated as

$$Svi_t = Svi_{t-1} + (Pt_t + D_t) - Evi_{t-1} \quad (9)$$

If $Svi_t < 0$, 0 is set to Svi_t, whereas if $Svi_t >= Si_{max}$, Si_{max} is set to Svi_t and the 1st stage ends. Si_{max} is constant (=0.0015m).

Evaporation from impervious cover at time *t* (Evi_t) [m] is calculated as

$$Evi_t = \left(\frac{Svi_t}{Si_{max}}\right) PEg_t \tag{10}$$

PEg_t is potential ground evaporation at time t calculated by the weather preprocessor.

Overland runoff at time t (Rv_t) [m] is calculated as

$$Rv_t = (Pt_t + D_t) - (Si_{max} - Svi_{t-1}) - Evi_t \tag{11}$$

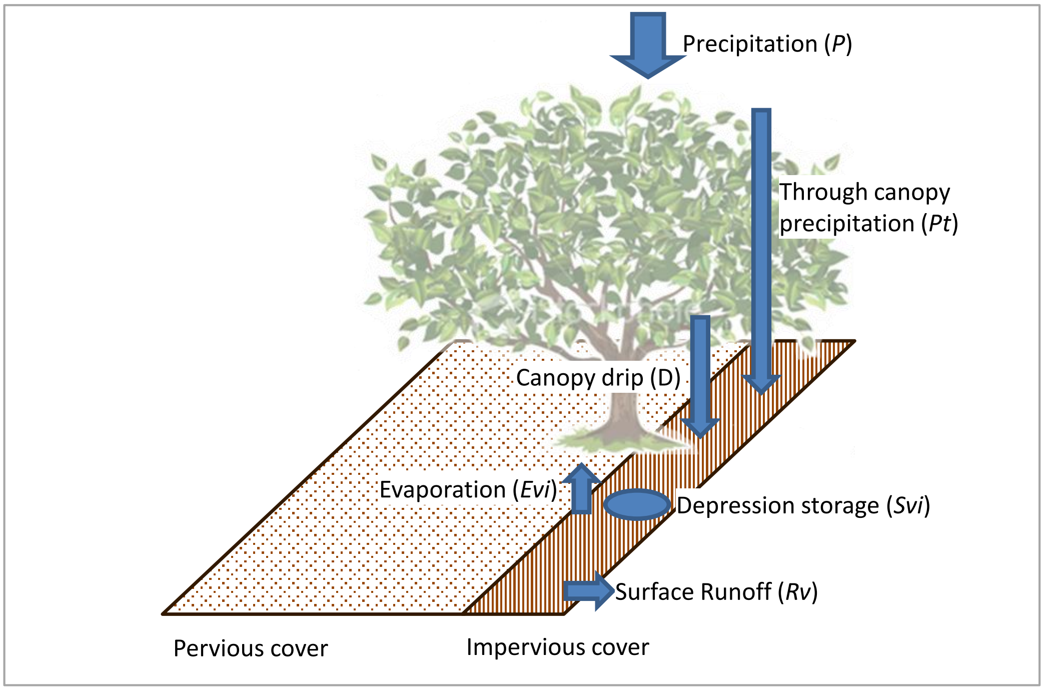

Figure 5 1st stage of the precipitation interception by impervious cover, starting when the precipitation (P) starts and ending when the depression storage of impervious cover (Svi) reaches Si_{max}

At stage 2, impervious cover depression storage at time t (Svi_t) is calculated with Eqn. 9, resulting in Si_{max}. Evaporation (Evi_t) is calculated with Eqn. 10, and runoff at time t (Rv_t) is calculated as

$$Rv_t = (Pt_t + D_t) - Evi_t \tag{12}$$

At stage 3, Evaporation (Evi_t) is calculated with Eqn. 10.

2.1.3. Process by pervious cover under canopy

Based on study by Nowak and Greenfield (2012), it is assumed that 74.5% of the ground-reaching precipitation falls on pervious cover. The same three stages as Sections 2.1.1 are employed here.

Figure 6 illustrates the 1st stage of the precipitation interception process by pervious cover. At stage 1, pervious cover depression storage at time *t* (Svp_t) [m] is calculated as

$$Svp_t = Svp_{t-1} + (Pt_t + D_t) - Evp_{t-1} \tag{13}$$

If $Svp_t < 0$, 0 is set to Svp_t, whereas if $Svp_t >= Sp_{max}$, Sp_{max} is set to Svp_t and 1st stage ends. Sp_{max} is constant (=0.001m).

Evaporation from pervious cover at time *t* (Evp_t) [m] is calculated as

$$Ep_t = \left(\frac{Svp_t}{Sp_{max}}\right) PEg_t \tag{14}$$

PEg_t is potential ground evaporation at time *t* calculated by the weather preprocessor.

Infiltration at time *t* (Iv_t) [m] is calculated as

$$Iv_t = (Pt_t + D_t) - (Sp_{max} - Svp_{t-1}) - Evp_t \tag{15}$$

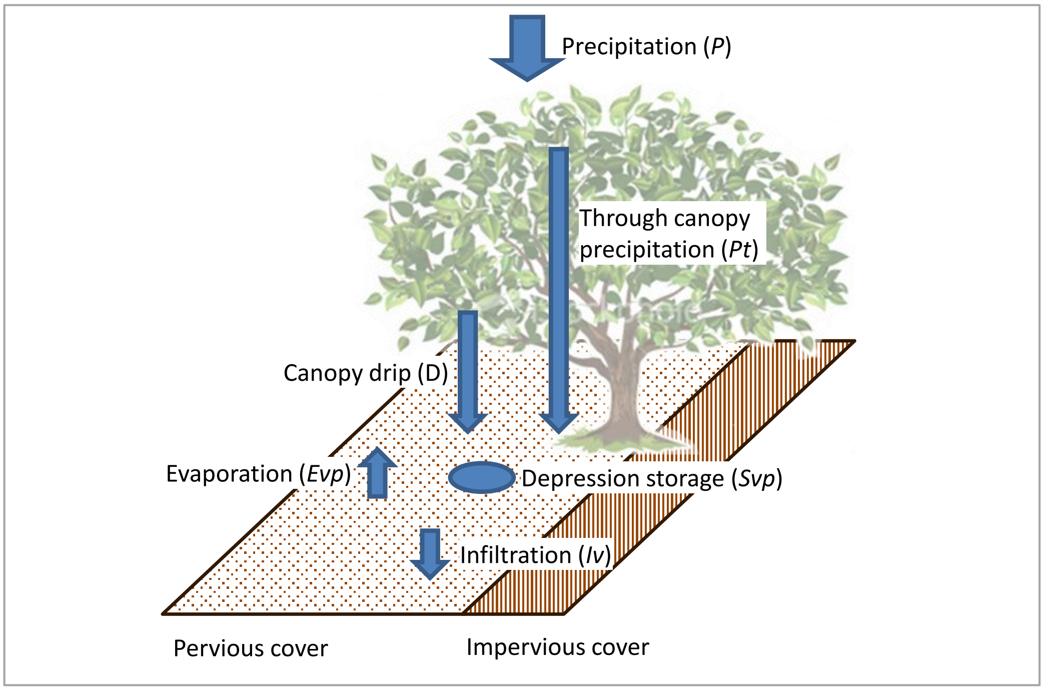

Figure 6 1st stage of the precipitation interception by pervious cover, starting when the precipitation (*P*) starts and ending when the depression storage of pervious cover (*Svp*) reaches Sp_{max}

At stage 2, pervious cover depression storage at time *t* (Svp_t) is calculated with Eqn. 13, resulting in Sp_{max}. Evaporation (Evp_t) is calculated with Eqn. 14, and infiltration at time *t* (Iv_t) is calculated as

$$I_{vt} = (Pt_t + D_t) - Evp_t \tag{16}$$

At stage 3, Evaporation (Evp_t) is calculated with Eqn. 14.

2.2. Hourly precipitation interception processes for ground cover

2.2.1. Process by impervious cover

Without vegetation, the same process as section 2.1.2 and thus Eqns. 9 to 12 can be applied except that all of the precipitation at time *t* (P_t) [m] reaches the ground. Thus, $Pt_t + D_t$ is replaced with P_t.

Figure 7 illustrates the 1st stage of the precipitation interception process by impervious cover. At stage 1, impervious cover depression storage at time t (Sgi_t) [m] is calculated as

$$Sgi_t = Sgi_{t-1} + P_t - Egi_{t-1} \tag{17}$$

If $Sgi_t < 0$, 0 is set to Sgi_t, whereas if $Sgi_t >= Si_{max}$, Si_{max} is set to Sgi_t and the 1st stage ends. Si_{max} is constant (=0.0015m).

Evaporation from impervious cover at time t (Egi_t) [m] is calculated as

$$Egi_t = \left(\frac{Sgi_t}{Si_{max}}\right) PEg_t \tag{18}$$

PEg_t is potential ground evaporation at time t calculated by the weather preprocessor.

Overland runoff at time t (Rg_t) [m] is calculated as

$$R_{gt} = P_t - (Si_{max} - Sgi_{t-1}) - Egi_t \tag{19}$$

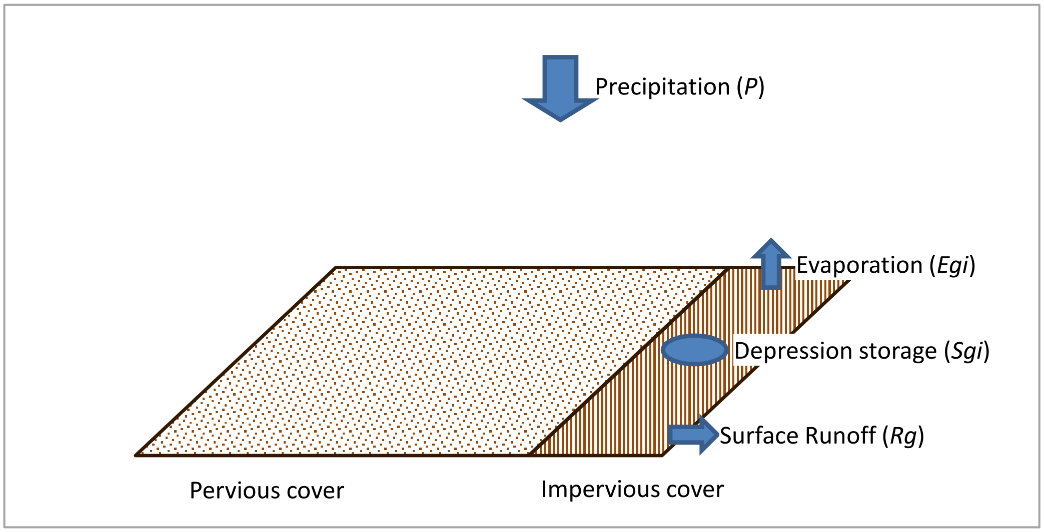

Figure 7 1st stage of the precipitation interception by impervious cover, starting when the precipitation (P) starts and ending when the depression storage of impervious cover (Sgi) reaches Si_{max}

At stage 2, impervious cover depression storage at time t (Sgi_t) is calculated with Eqn. 17, resulting in Si_{max}. Evaporation (Egi_t) is calculated with Eqn. 18, and runoff at time t (Rg_t) is calculated as

$$Rg_t = P_t - Egi_t \tag{20}$$

At stage 3, Evaporation (Egi_t) is calculated with Eqn. 18.

2.2.2. Process by pervious cover

Without vegetation, the same process as section 2.1.3 and thus Eqns. 13 to 16 can be applied except that all of the precipitation at time t (P_t) reaches the ground. Thus, $Pt_t + D_t$ is replaced with P_t.

Figure 8 illustrates the 1st stage of the precipitation interception process by pervious cover. At stage 1, pervious cover depression storage at time t (Sp_t) [m] is calculated as

$$Sgp_t = Sgp_{t-1} + P_t - Egp_{t-1} \tag{21}$$

If $Sgp_t < 0$, 0 is set to Sgp_t, whereas if $Sgp_t >= Sp_{max}$, Sp_{max} is set to Sgp_t and the 1st stage ends. Sp_{max} is constant (=0.001m).

Evaporation from pervious cover at time t (Egp_t) [m] is calculated as

$$Egp_t = \left(\frac{Sgp_t}{Sp_{max}}\right) PEg_t \tag{22}$$

PEg_t is potential ground evaporation at time t calculated by the weather preprocessor.

Infiltration at time t (Ig_t) [m] is calculated as

$$Ig_t = P_t - (Sp_{max} - Sgp_{t-1}) - Egp_t \tag{23}$$

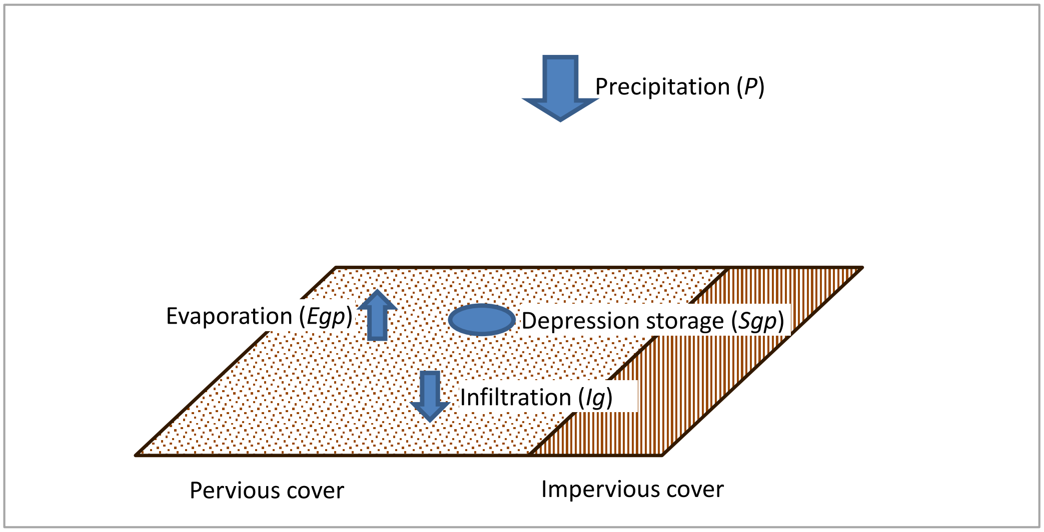

Figure 8 1st stage of the precipitation interception by pervious cover, starting when the precipitation (*P*) starts and ending when the depression storage of pervious cover (*Sgp*) reaches Sp_{max}

At stage 2, pervious cover depression storage at time *t* (Sgp_t) is calculated with Eqn. 21, resulting in Sp_{max}. Evaporation (Egp_t) is calculated with Eqn. 22, and infiltration at time *t* (Ig_t) is calculated as

$$Ig_t = P_t - Egp_t \tag{24}$$

At stage 3, Evaporation (Egp_t) is calculated with Eqn. 22.

2.3. Annual precipitation interception processes

In the Sections 2.1 and 2.2, hourly precipitation interception processes are defined in terms of the depth (m). For annual process, they can be converted to volumes (m^3) by taking areas into consideration. The difference between annual overland surface runoff with vegetation (actual scenario) and without vegetation (hypothetical scenario) across the area of interest is the annual net avoided runoff due to precipitation intercepted by vegetation. Below, the annual volumes are computed for both cases.

Figure 9 presents an example of the actual scenario for sampling i-Tree Eco projects, in which some part of the area is covered by vegetation and the others are not. This whole process involves those for vegetated cover (Section 2.1.1), impervious/pervious ground cover under canopy (Sections 2.1.2 and 2.1.3, respectively) as well as impervious/pervious cover without vegetation (Sections 2.2.1 and 2.2.2, respectively). For i-Tree Eco full inventory projects, as the area of interest is 100% covered by vegetation, the precipitation fell directly on impervious/pervious ground cover (Sections 2.2.1 and 2.2.2) is not considered.

For the elements related to vegetation (i.e. precipitation (*P*) [m], in canopy precipitation (*Pc*) [m], through canopy precipitation (*Pt*) [m], vegetation storage (*Sv*) [m], evaporation from vegetation (*Ev*) [m] and canopy drip (*D*) [m]), the annual volume [m^3] can be derived from the annual sum multiplied by area covered by vegetation (*VA* [m^2]).

Based on the study by Nowak and Greenfield (2002), it is assumed that 25.5% of urban area across the contiguous United States is impervious cover and 74.5% is pervious cover. Applying these percentages to area covered and not covered by canopy (*VA* [m^2] and *GA* [m^2], respectively) provides impervious/pervious area in each area.

In the area covered by vegetation, total runoff from the impervious cover Rv_{total} [m^3] is

$$Rv_{total} = \sum Rv_t \times VA \times 0.255 \quad (25)$$

In the area not covered by canopy, total runoff from the impervious cover Rg_{total} [m^3] is

$$Rg_{total} = \sum Rg_t \times GA \times 0.255 \quad (26)$$

From Eqns. 25 and 26, total runoff from the area Ra_{total} [m^3/yr] is

$$Ra_{total} = Rv_{total} + Rg_{total} \quad (27)$$

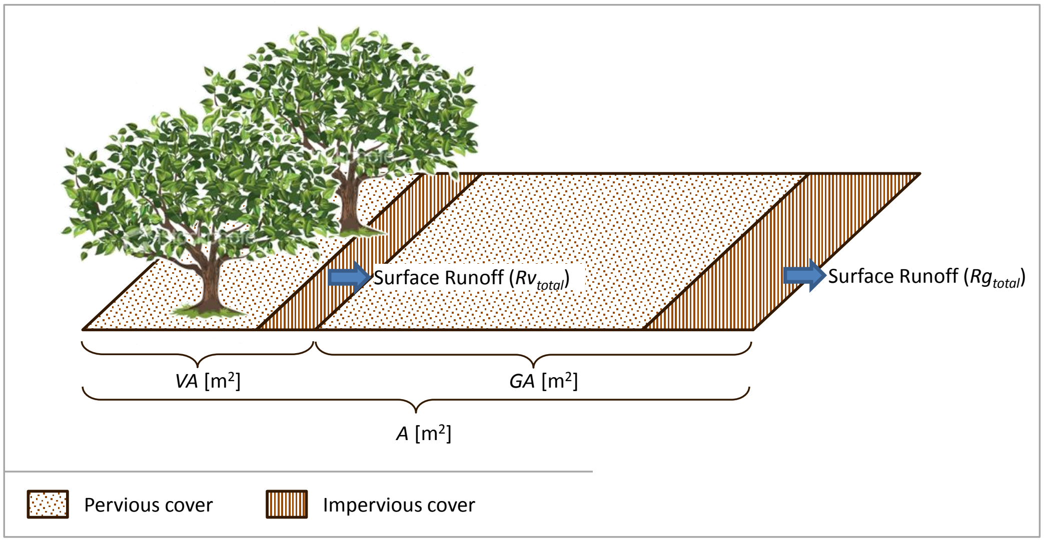

Figure 9 Example of actual scenario

Figure 10 presents an example of the hypothetical scenario, in which there is no vegetation cover in the area. This process only involves those for impervious/pervious cover without vegetation (Sections 2.2.1 and 2.2.2, respectively).

Runoff from impervious cover of the hypothetical ground area Rh_{total} [m^3] is

$$Rh_{total} = \sum Rg_t \times A \times 0.255 \tag{28}$$

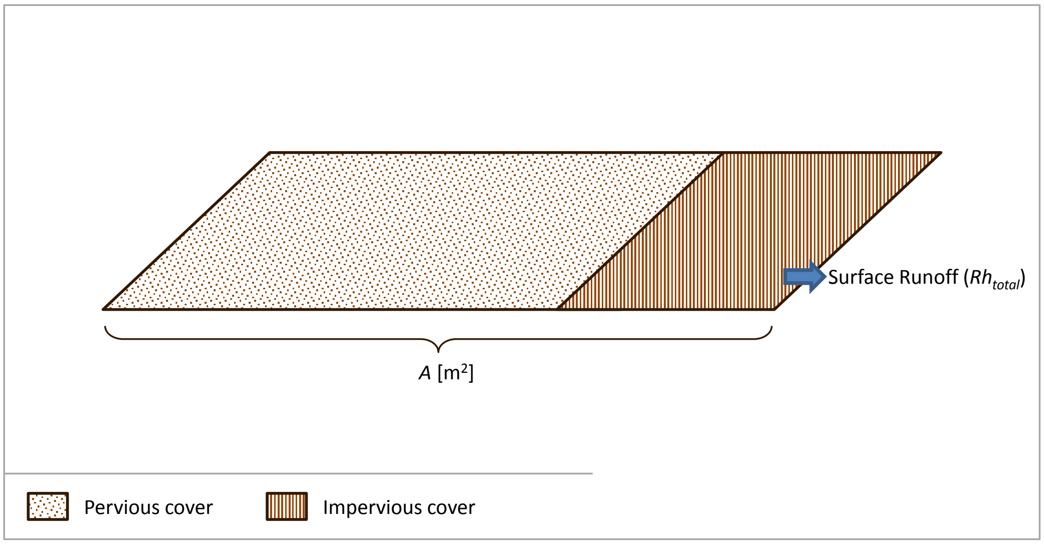

Figure 10 Example of hypothetical scenario

Annual avoided runoff due to precipitation intercepted by vegetation S [m^3] can be calculated as

$$S = Rh_{total} - Ra_{total} \quad (29)$$

3. Project Summary of Precipitation Interceptions

The annual results of precipitation interception by vegetation, S [m^3] are further converted into more detailed summaries such as those per individual trees, per species across an analysis domain and per species in land use types depending on project types (full inventory or sampling project). Figure 1 illustrates the structure of this section, in which sub sections explaining the methodology to calculate more detailed summaries for each project are presented.

	Project	
	Inventory	*Sample*
Individual trees	Section 3.1	N/A
Species in an analysis domain	Section 3.2	Section 3.3
Species in landuse types	N/A	Section 3.4

Figure 11 Structure of Section 3 explaining more detailed summarizing methods

3.1. Individual tree summary for inventory projects

Precipitation interception volume ($S_{i(g,s)}$) for individual tree i of genera g and species s is estimated as

$$S_{i(g,s)} = S \times \frac{LA_{i(g,s)}}{\sum LA_i} \tag{30}$$

S = yearly precipitation interception volume
$LA_{i(g,s)}$ = leaf area for tree i of genera g and species s
$\sum LA_i$ = sum of leaf area for all trees

3.2. Species-based summary in an analysis domain for inventory projects

Precipitation interception volume (S_s) summarized for species s is estimated as

$$S_s = \sum S_{i(g,s)} \tag{31}$$

3.3. Species-based summary in an analysis domain for sample projects

Precipitation interception volume (S_s) summarized for species s is estimated as

$$S_s = S \times \frac{LA_s}{\sum \mathrm{LA}} \tag{32}$$

S	=	yearly precipitation interception volume
LA_s	=	leaf area for species s across a city
$\sum LA$	=	sum of leaf area for all trees across a city

3.4. Species-based summary in landuse types for sample projects

Precipitation interception volume ($S_{l,s}$) summarized for landuse type l and species s is estimated as

$$S_{l,s} = S \times \frac{LA_{l,s}}{\sum \mathrm{LA}} \tag{33}$$

S	=	yearly precipitation interception volume
$LA_{l,s}$	=	leaf area for species s across land use l
$\sum LA$	=	leaf sum of leaf area for all trees across a city

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