Surface Storage of Rainfall in Tree Crowns:
Not All Trees Are Equal

By E. Gregory McPherson, Qingfu Xiao, Natalie S. van Doorn, Paula J. Peper, and Erika Teach

Urban forests can be an elegant strategy for managing stormwater (Xiao et al. 1998). The soil that supports tree growth acts like a reservoir that reduces runoff. The tree crown intercepts rainfall on leaves and stems, and the rainfall's evaporation reduces water reaching the ground below. The amount of rainfall intercepted by a tree depends on the amount of precipitation, its intensity and duration, as well as meteorological factors, such as temperature, humidity, and wind (Xiao et al. 2000a). Although arborists have little control over rainfall patterns and meteorology, they can select species to maximize effectiveness based on leaf and stem characteristics that influence surface storage, as well as size. Surface storage capacity, defined as the depth of water temporarily stored on leaf and stem surfaces, can influence the amount of rainfall intercepted. Until now, surface storage capacities have been studied only for forest trees. Based on forest research, green infrastructure accounting tools have assumed a storage depth of one millimeter, regardless of species.

We used a rainfall simulator and branch cuttings of 20 tree species in Davis, California., U.S., to measure the depth of surface water storage under a variety of rainfall conditions (Xiao and McPherson 2016). Deciduous species were measured with leaves-on and leaves-off because rain falls primarily during winter in California.

Mean storage capacities varied threefold across species when all surfaces were considered. Blue spruce (*Picea pungens*) held the most rainwater (1.81 mm) due to the many narrow spaces formed by rigid needles, buds, and stems. Canary island pine (*Pinus canariensis*) had the lowest storage capacity for conifers (0.99 mm), because water flowed readily down its long flexible needles (Figure 1a). Overall, Bradford pear (*Pyrus calleryana* 'Bradford') had the lowest storage value (0.51 mm), due to its smooth leaf and stem surfaces (Figure 1b). The deciduous Chinese pistache (*Pistacia chinensis*) had high storage values (1.17 mm) because its rigid leaflets and rough stems slowed water flow across its surfaces. Among the broadleaf evergreens, holly oak (*Quercus ilex*) stored the most water (0.82 mm), due to its rigid, rough leaf and stem surfaces (Figure 1c). The smoother surfaces of the blue gum (*Eucalyptus globulus*) resulted in the least storage for this tree type (0.70 mm).

For deciduous species, mean storage depths were four times greater for leaves (0.97 mm) than stems (0.25 mm). Accordingly, broadleaf evergreens and conifers will outperform deciduous species during winter rainfall events, assuming equal amounts of leaf and stem surfaces. In reality, a tree's actual amount of leaf and stem surface areas change as it grows, and vary by species, site, and management practices. Growing conditions, irrigation regimes, and pruning intervals influence the amount of surface area available to intercept rainfall. Combining species-specific surface storage values with tree growth provides a more complete picture of potential interception.

The U.S. Forest Service's recently published technical manual (McPherson et al. 2016) and Urban Tree Database (UTD) (USDA 2016) provide growth equations for 171 distinct species across 16 U.S. climate zones from measurements on over 14,000 city trees. Although tree growth is a result of complex process, these growth equations capture changes in tree size in surprisingly simple and accurate ways. We used UTD growth equations that predicted dbh from age and leaf area from dbh for the 20 species. The surface storage capacity for leaf-on and leaf-off conditions was multiplied by its leaf- and stem-surface areas to estimate potential interception at five-year intervals for 40 years after planting. Based on previous research, we assumed a stem to leaf area ratio of 0.425 (Xiao et al. 2000b). Potential interception is the tree's maximum surface storage capacity, as might occur during a long and gentle rainfall event.

Chinese pistache and sweetgum (*Liquidambar styraciflua*) are estimated to store the most rainwater during the first 10 years because of relatively rapid growth, large amounts of leaf area (140 m^2), and high leaf storage depth values (1.51 and 1.16 mm, respectively) (see *Five-Year Intervals*). Honeylocust (*Gleditsia triacanthos*), Raywood ash (*Fraxinus angustifolia* 'Raywood'), and crapemyrtle (*Lagerstroemia indica*) store the least amount of rainwater after 10 years due to relatively little leaf area (15 to 35 m^2) and low storage depth values (0.59 to 0.75 mm). After 20 years, the Japanese zelkova (*Zelkova serrata*) replaces pistache as top performer, and the blue spruce, London planetree (*Platanus acerifolia.*), evergreen ash (*Fraxinus uhdei*), and valley oak (*Quercus lobata*) gain prominence. These species are large-stature trees that begin to outgrow the smaller-statured species after 20 years. During the remaining 20 years, these top performing species are joined by the large growing redwood (*Sequoia sempervirens*), Canary Island pine, and Italian stone pine (*Pinus pinea*).

After deciduous trees lose their leaves in autumn, potential interception after 40 years was calculated to range from 6% to 17% of amounts during the leaf-on period. Without their leaves, zelkova and sweetgum had capacity to store more rainfall than other species (0.1 m^3), but still only 7% and 12% of the amount each stored with foliage, respectively. The bare branches of ginkgo (*Ginkgo biloba*) and Raywood ash stored the least rainfall (0.02 m^3).

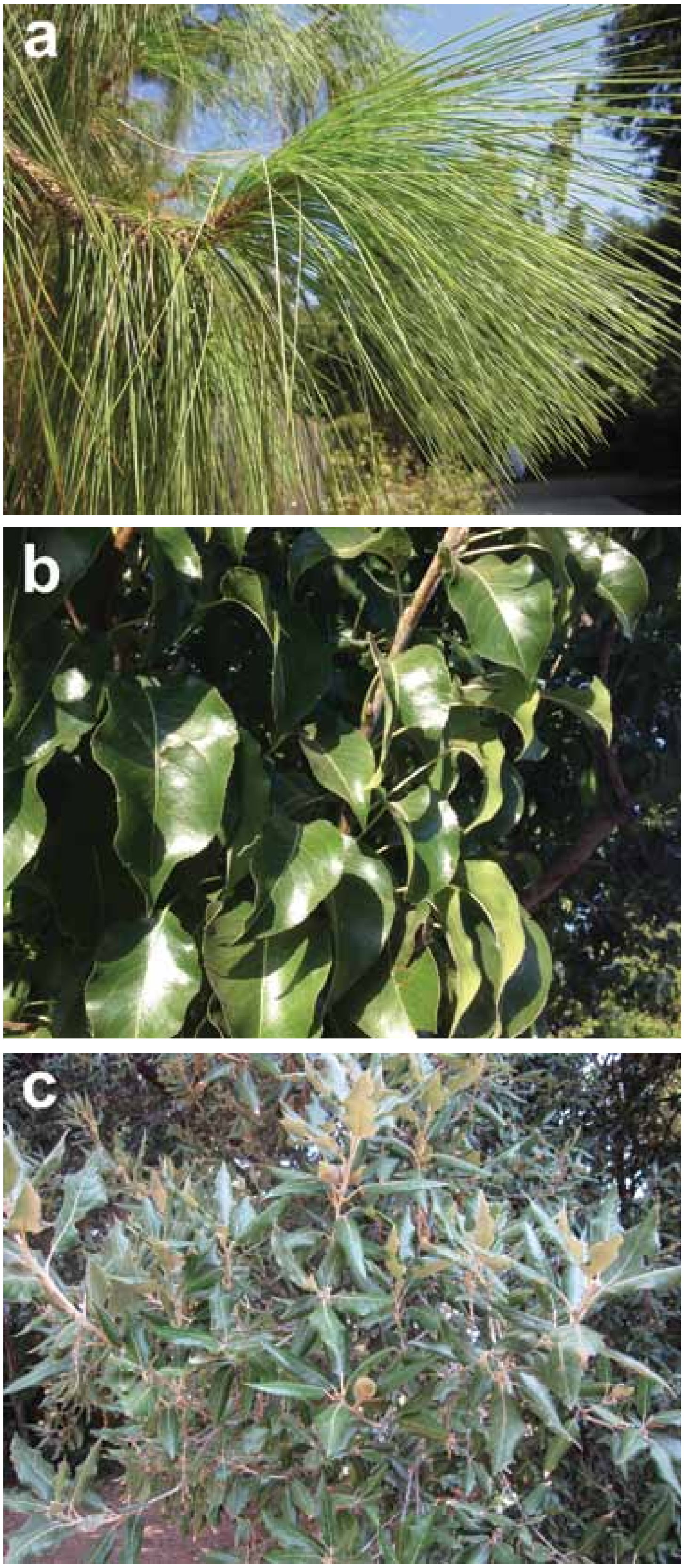
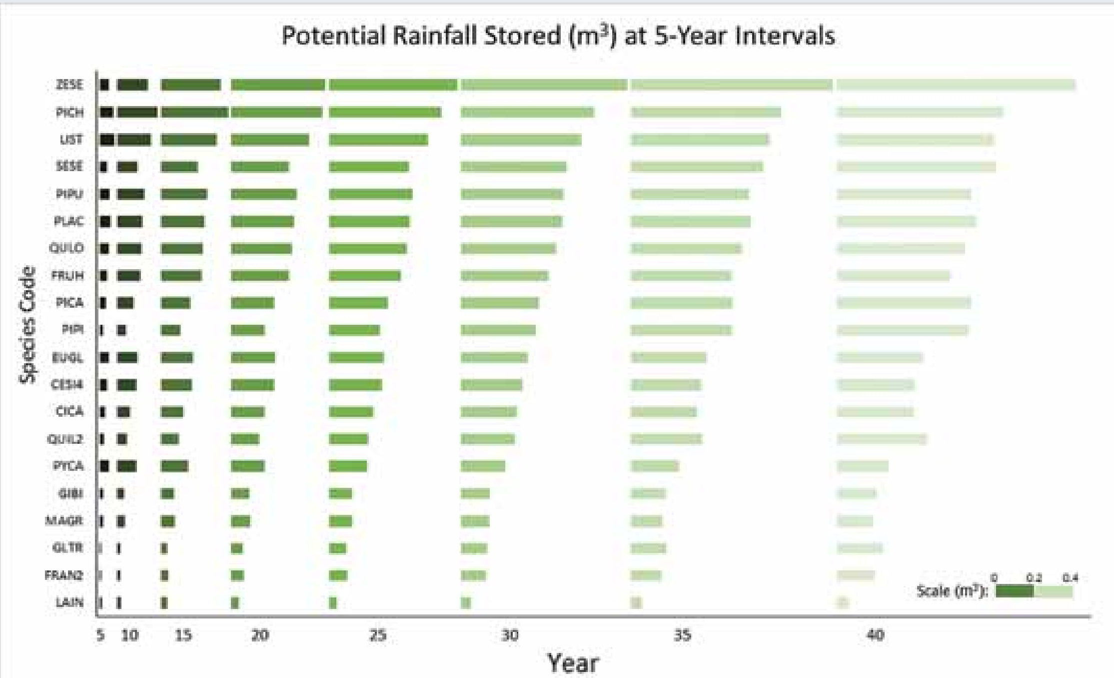


Figure 1. Three of the species analyzed in the study: a) Canary Island pine, b) Bradford pear, and c) holly oak. The tree's leaf and stem complexity, rigidity, and surface roughness affects its surface-storage potential.

Five-Year Intervals

The surface storage potential at five-year intervals after planting for 40 years (cubic meter per tree, 264 gallons per cubic meter). The table below gives the code, scientific, and common name for each species.

Sp. code	Scientific name	Common name
ZESE	*Zelkova serrata*	Japanese zelkova
PICH	*Pistacia chinensis*	Chinese pistache
SESE	*Sequoia sempervirens*	coast redwood
LIST	*Liquidambar styraciflua*	sweetgum
PLAC	*Platanus × acerifolia*	London planetree
PICA	*Pinus canariensis*	Canary Island pine
PIPU	*Picea pungens*	blue spruce
PIPI	*Pinus pinea*	Italian stone pine
QULO	*Quercus lobata*	valley oak
FRUH	*Fraxinus uhdei*	evergreen ash
QUIL2	*Quercus ilex*	holly oak
EUGL	*Eucalyptus globulus*	blue gum eucalyptus
CESI4	*Celtis sinensis*	Chinese hackberry
CICA	*Cinnamomum camphora*	camphor tree
PYCA	*Pyrus calleryana* 'Bradford'	Bradford pear
GLTR	*Gleditsia triacanthos*	honeylocust
GIBI	*Ginkgo biloba*	ginkgo
FRAN2	*Fraxinus angustifolia* 'Raywood'	Raywood ash
MAGR	*Magnolia grandiflora*	southern magnolia
LAIN	*Lagerstroemia indica*	crapemyrtle



Arborists can use this new research to select trees to maximize rainfall interception. Our findings reveal that species selection makes a difference, and the difference tends to increase as trees age. Twenty years after planting, there is an estimated 20-fold difference in storage potential between zelkova and crapemyrtle (0.19 and 0.01 m^3). After 40 years, the difference nearly doubles to 38-fold. Large-stature trees with substantial leaf- and stem-surface area have capacity to store much more rainfall over the long term than smaller-statured trees.

It is important to match the foliation period of a species with the local rainfall pattern so that foliage is present when needed the most. Especially in regions with winter rainfall, evergreens are more effective than deciduous trees. For species not described here, the larger a tree's crown and the more complex its surfaces, the more rainfall it will capture, generally speaking. Rough surfaces, rigid structures, and densely compact clusters of foliage, as with blue spruce, tend to store the most water. Arborists will be well-served by future research that identifies surface storage depths for additional species, records foliation periods for common species, and measures their stem- and leaf-surface areas.

Additional Reading

McPherson, E.G., Natalie S. van Doorn, and Paula J. Peper. 2016. Urban tree database and allometric equations. General Technical Report PSW-253. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, U.S.

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