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Feature Article:
The Hydrological Effects of Urban Forests, with reference to the maritime Pacific Northwest

Introduction

This bulletin conceptually describes the multifaceted nature of the relationship between urban forests and urban hydrology. A growing number of urban design researchers and practitioners suggest that establishing urban forests that mimic native forests is key to more sustainable stormwater treatment. However, sustainable design principles drawn from other parts of North America may not be applicable in this region with its particular hydrological and vegetative characteristics. The Pacific Northwest region has unique precipitation characteristics, and is a place where the structure of urban forests is dramatically different from that of the native forests that they have replaced.

The hydrological effects of urban trees and forests can be conceptually broken down into 3 strata: *above-ground effects*, *ground surface effects* and *below-ground effects*. Most of these effects tend to reduce storm runoff amounts and peak runoff rates, but the amounts of these effects are extremely variable between sites and seasons.

Above Ground effects involve:

- the *interception of precipitation* by the leaves, stems and branches of trees (Figure 6-2);
- the *evaporation* of some of this intercepted precipitation off the surface of the tree (Figure 6-3); and
- the *absorption* of a small portion of the precipitation into the leaves or stems of the tree.

Most of the intercepted precipitation eventually reaches the ground, by either dripping off the leaves or branches, after their storage capacity has been exceeded, or by stemflow down the trunk. In this case, the hydrological effects are:

- the effective *delay of precipitation* onto the ground; and
- the possible concurrent dampening of peak runoff amounts for storms which are most intense at their outset, before the storage capacity of the tree canopy is reached (Sanders 1986).

The amounts of these effects on runoff are primarily dependent on season (for deciduous trees), on the leaf area index of a tree and on its density of twigs and branches. The leaf area index (LAI) measures the surface area of leaves in relation to ground surface area: for instance, a leaf area index of 5 means that the total surface area of leaves on a tree would "cover" the ground below its canopy 5 times. Large trees with dense canopies and high LAI scores have the greatest effect on the amount and timing of precipitation reaching the ground. The evaporation rate is also crucial in influencing the above-ground effects; this rate is determined by air temperature, humidity and the intensity of solar radiation. "With a large amount of leaf-surface area exposed to the sun and wind, water loss from the leaves is high" (Watson 1989). Greater surface area due to foliage also increases the potential evaporation from the surface.

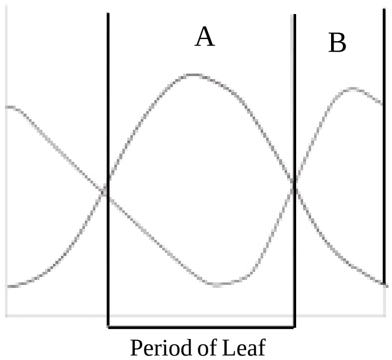


Figure 6-1 - Precipitation (B) and potential evapo-transpiration (A)pattern in the Pacific Northwest.

In the maritime lowlands of the Pacific Northwest, where the bulk of precipitation falls as rain between October and March when deciduous trees are leafless (Figure 6-1), the above-ground effects on runoff amounts are relatively small. However, these effects are relatively substantial during the summer months when rain events are typically smaller and less frequent. These smaller, infrequent rain events yield more highly polluted runoff, since they flush the pollutants and sediments which have accumulated on surfaces between rainfalls. Furthermore, dissolved pollutants are more concentrated in the smaller quantities of runoff and in the low summer flows of receiving watercourses. Therefore, the above-ground effects of urban trees in the Pacific Northwest are likely to be more significant in terms of stormwater runoff *quality* than runoff *quantity*.

Ground Surface effects of urban forests include:

- the temporary *storage of water* in surface depressions on the immediate site; and
- trees' influence on the evaporation of surface water.

Leaf litter and other organic matter can hold precipitation and stemflow on a site, reducing the amount and/or the peak rates of runoff. Also, the roots and trunk bases of mature trees tend to create hollows and hummocks on the ground. Puddles which form in these hollows may store a significant amount of stormwater on a site (Kimmins, 1973). This water will either be evaporated or infiltrated into the soil following a storm, or will delay runoff, thus reducing peak runoff rates from a site. One slight counter effect is that shade from trees can *reduce rates of evaporation* of water from ground surfaces or the upper horizon of soil.

These effects on runoff are influenced primarily by the size and age of trees. Older, larger trees generate more litter per area, and their roots modify micro-topography around them more dramatically. Site management is also important, especially the degree to which organic litter is removed or retained on a site and whether site surfaces are maintained to be smooth. On the other side of the ledger, leaf density and canopy size will determine the amount of reduced surface evaporation.

The characteristic precipitation patterns of the Pacific Northwest make surface effects particularly important. Major storm events here tend to be longer but of a lesser intensity than in other temperate regions of North America which experience short but very intense thunderstorms. Gradual precipitation accumulation means that a greater proportion of stormwater is able to infiltrate or evaporate during long storms; infiltration rates are better able to "keep up with" precipitation rates under these conditions. This is not possible if precipitation is so intense that it runs off a site before it has a chance to infiltrate or evaporate. However, this net reduction of runoff can only occur if stormwater is retained on a site's surface until conditions favor infiltration or evaporation.

Below Ground effects include the influence of trees on:

- infiltration of stormwater into the soil;
- soil moisture holding capacity; and
- removal of water from the upper soil horizons by percolation or uptake.

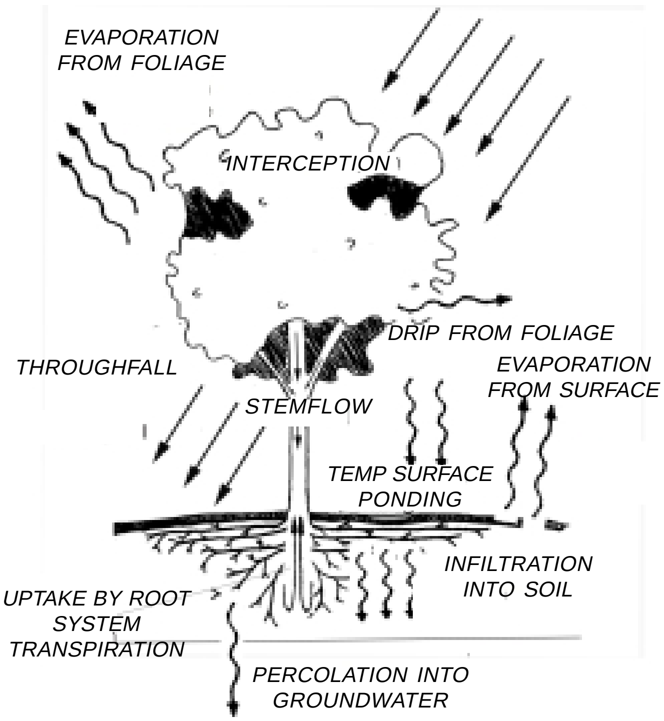
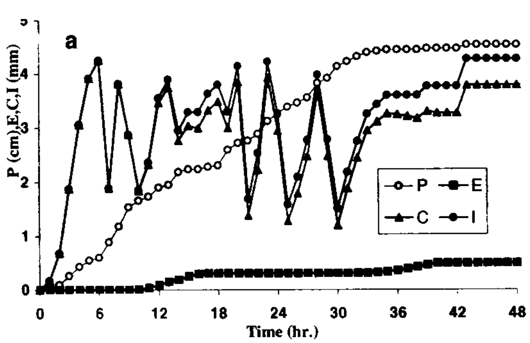


Figure 6-2 - Above-ground, ground-level, and below-ground effects of the urban forest on hydrological processes.

Organic material from leaf litter and other tree detritus tends to *increase infiltration rates* by increasing pore spaces in soil. By the same token, this material increases the *moisture-holding capacity* of most soils. The root mats of trees also tend to break up most soils, further improving infiltration and moisture holding capacity (Lee 1980). It is possible that roots may marginally reduce the moisture holding capacity of some highly porous soils, filling pore spaces between stones in an infiltration trench, for example. Deep roots tend to improve the rates of *percolation* of water from upper soil horizons into lower substrates, particularly when hardpan or impervious layers impede this flow. Finally, during their growing season, trees take up water through their roots that is eventually transpired onto leaf surfaces and evaporated (in the process known as *evapotranspiration*).

These effects on runoff are mostly influenced by soil types, since the effects of roots and the addition of organic matter will be greatest on those soils with low moisture holding capacity, with impervious layers and lenses and low rates of percolation. It may be that in very rapidly draining soil (gravels, primarily) root masses may theoretically reduce soil drainage and moisture holding capacity, especially during the dormant seasons when tree roots are "taking up space" but not taking up water. However, such effects are likely to be marginal at best, and then only very localized. The effects on infiltration are by far the most significant factor determining the influence of urban forests on stormwater runoff.

Evapotranspiration rates are influenced by tree species, season (deciduous trees are dormant in winter; evergreen trees also draw much less water in winter), and by air temperature and humidity levels. In the Pacific Northwest the pronounced winter rainy season results in the upper layers of many soils becoming saturated in mid and late winter. In this condition, the most significant effect of tree roots may be in enhancing deep percolation, thus increasing the infiltration potential and moisture holding capacity of soils.



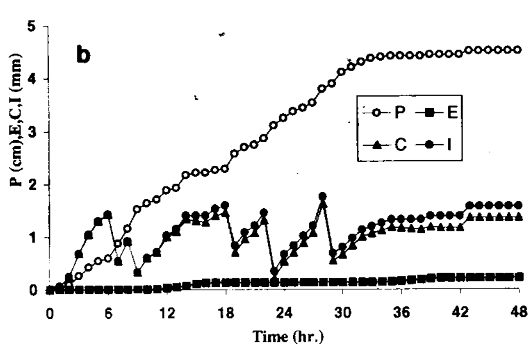


Figure 6-3 - Temporal distribution of rainfall interception processes in a rural sample area (a) and a city sample area (b) during a winter storm in Sacramento, CA. P is gross precipitation, E is evaporation, C is canopy storage, and I is canopy rainfall interception. Canopy storage steadily increased for about 6 hours, then declined once water began to drip off leaves and stems of saturated canopies. This pattern was repeated throughout the storm event as the canopy intercepted and lost rainfall in response to precipitation, leaf drip, and evaporation. Sacramento's precipitation patterns are similar to those in the Lower Mainland of British Columbia.

Reproduced with permission from: Journal of Arboriculture 24(4) :Xiao et al, 1998.

Summary

In summary, while the impact of urban trees on hydrology is extremely variable and complex, in general, increases in tree cover and tree size over a site will result in reduced total runoff amounts and peak runoff rates. A study in Dayton, OH suggests that for a one-year return storm (6 hours, 46 mm of rain) in that region, the current urban forest (22% canopy coverage) reduces the amount of storm runoff by 7%. This same forest reduces the peak runoff volumes by a similar amount (Sanders, 1986). However, this study did not attempt to break down these effects into component parts. Instead, it uses SCS runoff curves that "blend" the various forest effects of rainfall interception, temporary surface storage and enhanced infiltration to arrive at estimated reductions of runoff amounts and rates for different types of land use and land cover. This method uses average conditions to determine runoff effects, but is not sensitive to more subtle conditions (like the LAI of trees on site, or ground depressions) that may vary greatly between sites.

However, the overall effects of urban forests on storm runoff are variable and subject to a number of qualifications. The literature suggests that these effects are greatest during the growing season when most trees are in leaf and when transpiration and evaporation rates are highest. The effects of urban trees are greatest on sites whose soils are relatively impermeable rather than relatively permeable. Further, trees have a relatively greater effect on small storm runoff amounts than on large storm runoff. In a study by Xiao et al (1998), runoff reduction, due to interception alone, averaged 15.2% on storms of <5mm/day, and 7.1% on storms of >25mm/day in Sacramento, CA. Surface and below-ground effects are much more significant than the above-ground effects, and all of the effects on runoff are greatest when urban trees are large and well-established.

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