



Urban Forest Research

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Center for Urban Forest Research • Pacific Southwest Research Station • USDA Forest Service

Is all your rain going down the drain?

Trees are a solution

Have you ever gone outside after a rainstorm and looked around thinking... "where does all this rainwater end up?" Perhaps you can see some running down your driveway into the street. Or you have a large puddle forming on your front lawn. And then there is that flooded intersection at the end of your block because the storm drain is clogged. Sound familiar?

Communities throughout the U.S. are faced with this problem—too much water and not enough places to put it, so much of it is going "down the drain."

You've probably heard it called another name—stormwater runoff. And its not surprising that storm-



Steve Lennartz

water runoff from urban, industrial, and agricultural sources is an environmental nemesis that EPA and other regulators have been trying to control for more than a decade. The agency claims that stormwater run-

off is a leading cause of impairment to nearly 40% of U.S. waterways and led to more than 1,500 beach closings and advisories at coastal and Great Lakes sites in 1998.

Urban Hydrology

As we build our communities, considerable natural landscape is converted to impervious surfaces such as

roads, parking lots, driveways and buildings. Manmade drainage systems such as sewers and storm drains are used to improve water movement through communities

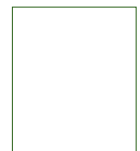
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How Benefits are Calculated

Our interception model accounts for water intercepted by the tree as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Once the leaf is saturated, it drips from the leaf surface and flows down the stem surface to the ground or evaporates.

The volume of water stored in the tree crown was calculated from the crown projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and water depth on the canopy surface. Species-specific factors, such as crown gaps and tree surface saturation values, influence the amount of projected throughfall. Hourly meteorological and rainfall data from local sources are used for the simulations.

To estimate the value of rainfall intercepted by urban trees, we use stormwater management control costs based on minimum requirements for stormwater management in a particular region. For example: In Western Washington, for a 10-acre, single-family residential development on permeable soils it costs approximately \$0.02779/gal to treat and control flows stemming from a 6-month, 24-hr storm event. In Fresno, the average cost for constructing and maintaining a typical detention/retention basin is \$121,439/ac. With a 50% probability of filling 10 times in a 20-year period, the cost of detention/retention is \$0.0077/gal. In Los Angeles, it costs approximately \$0.0183/gal to treat sanitary waste, and we assume a similar cost for stormwater. Runoff control for very large events (100-year, 24-hr storm) was omitted, as trees' effective interception diminishes once surfaces have been saturated.

To calculate benefits, we multiply the management cost by gallons of rainfall intercepted after the first 0.1 inch has fallen for each event (24-hr without rain) during the year, depending on the region. Based on surface detention calculations, the first 0.1 inch of rainfall seldom results in runoff. Thus, interception is not a benefit until precipitation exceeds this amount.

and into drainages and natural waterways. However, water quality suffers when runoff carries contaminants such as oil, metals, or pesticides into streams, wetlands, lakes, and marine waters. Management of stormwater runoff can help reduce this pollution and make waterways healthy for people and fish.

Managing Stormwater Runoff with Trees

Some of the techniques that engineers have been using to manage stormwater runoff include infiltration, flow attenuation, retention, detention, extended detention, and undergrounding. See <http://www.co.ha.md.us/dpww> for more details. What you don't see here, and what engineers are beginning to consider, is the use of trees to retain water on site to slow the flow to waterways.

Our Center's research over the last few years has uncovered some very interesting facts about a tree's ability to retain water and how an urban forest contributes to the management of stormwater runoff.

Trees Retain Rainwater On Site—Our Initial Study

In an initial study in 1998 on individual trees, we found that during a rainfall event, precipitation is either intercepted by leaves, branches, and the trunk, or it falls directly through the tree to the ground. Intercepted water is stored temporarily on leaf and bark surfaces. After about 10 minutes, the tree's rainfall storage potential gets filled, and water begins to drip from leaf surfaces, flow down stem and trunk surfaces to the ground, or evaporate. We define *interception* as the sum of canopy surface water storage and evaporation.

Results are influenced by three factors: character and magnitude of the rainfall event, tree species and their architecture, and weather. Not

What is Interception?

Interception is the sum of canopy surface; water storage on leaves, branches, and trunk bark; and evaporation during rainfall events.

every event will produce the same results because rainfall intensity and duration determine the interception process. Tree architecture, leaf and bark surface area, and routes to store the rainwater and control the flow all differ by tree species.

Temperature, relative humidity, net radiation, and wind speed control the length of time rainfall is retained in storage. For example, we found that trees stored more water during a 1-inch rainfall event that lasted two days versus one that lasted only two hours.

Urban Forests Make A Significant Contribution

After investigating individual trees we wanted to see how an entire urban forest influenced runoff volume. Taking the results of our initial study of individual trees, we created a canopy interception model to examine the storage capacity of the 6 million trees in Sacramento County, California. The results show that for just the land area covered by trees, the county's tree canopy intercepts 11.1% of the annual rainfall, close to reported values for hardwood forests. However, they account



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Editor: Laurie Litman, InfoWright

Fact Sheet #4: Control Stormwater Runoff with Trees

Points to remember

RAINFALL INTERCEPTION is influenced by:

- ☞ Intensity and duration of the rainfall event
- ☞ Tree species—deciduous, broadleaf evergreen, or conifer
- ☞ Tree architecture—size, number of leaves, and arrangement of leaves and branches
- ☞ Weather—temperature, relative humidity, net solar radiation, and wind speed

TREES STORE MORE WATER during a 1-inch rainfall event that lasts two days versus one that lasts only two hours. Therefore:

- ☞ As compared to flood events, small storms are responsible for most of the annual pollutant loading of receiving waters
- ☞ Trees are most effective in intercepting rainfall during small events
- ☞ Urban forests are likely to produce more benefits through water quality protection than flood control.

ONE OF OUR STUDIES FOUND that a typical medium-sized tree can intercept as much as 2380 gallons of rainfall per year.

BROADLEAF EVERGREENS AND CONIFERS intercept more rainfall than deciduous species where winter rainfall patterns prevail.



Renderings by Alan A. Loomis, <http://www.deliriousla.net>

Redesign streets where trees work in combination with grass and porous pavers to retain water on site.

TREES WORK IN COMBINATION with other stormwater controls to produce a comprehensive solution to rainfall interception, runoff and landscape water use:

- ☞ Backyard cisterns capture roof runoff, and provide supplemental irrigation
- ☞ Swales hold overflow
- ☞ Bermed lawn-area retention basins facilitate infiltration
- ☞ Grates/drywells capture driveway runoff

STRATEGIES TO ENHANCE the urban forest and improve the control of stormwater runoff:

- ☞ Plant more trees in appropriate places
- ☞ Improve the maintenance of existing trees
- ☞ Plant species with a higher rate of growth where appropriate

- ☞ Plant species with architectural features that maximize interception
- ☞ Match trees (deciduous, evergreen) to rainfall patterns
- ☞ Plant trees in groves where possible
- ☞ Plant low water-use species
- ☞ Plant broadleaf evergreens where appropriate and avoid south-facing windows
- ☞ Use native plants, which, once established, can easily withstand summer dry seasons and reduce the need for supplemental irrigation.

In Oakland, California, the continuous tree canopy is estimated to intercept 4 inches of rain over one acre in a typical year— about 108,000 gallons.

NOTE: In looking for solutions to stormwater runoff it is important to consider an integrated approach that uses other water conservation, water retention, flood management, and pollution control strategies. Community solutions include but are not limited to: porous pavement, vegetated swales and filter strips, recharge areas under parking lots, holding tanks and cisterns under playfields, surface area holding ponds, turf grass filters, and riparian retention and treatment areas. For more information on these solutions see the TreePeople website at <http://www.treepeople.org/trees/charrette.htm>, and their book, *Second Nature: Adapting Los Angeles' Landscape for Sustainable Living*, edited by Patrick Condon and Stacy Moriarity.

References: Control Stormwater Runoff with Trees

For more information, refer to the following publications:

Chang, G.; J. Parrish; and C. Souer. 1990. The first flush of runoff and its effect on control structure design. Environmental Resource Management Division. Department of Environmental and Conservation Services. City of Austin, Austin, TX. 36 pp.

Claytor, R. A.; and T. R. Schueler. 1996. Design of stormwater filtering systems. The Center for Watershed Protection, Silver Spring, MD.

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Incorporate stormwater treatment into street design by adding trees and swales. From Green Neighborhoods, a publication of NeighborhoodLAB, <http://neighborhood.uoregon.edu/>.

Trees protect water and soil resources.

A healthy urban forest can reduce the amount of runoff and pollutant loading in receiving waters in four primary ways:

- 1) Through evapotranspiration, trees draw moisture from the soil ground surface, thereby increasing soil water storage potential.
- 2) Leaves, branch surfaces, and trunk bark intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.
- 3) Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.
- 4) Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.

Urban forests can dispose of waste water

Urban forests can provide other hydrologic benefits. For example, irrigated tree plantations or nurseries can be a safe and productive means of wastewater treatment and disposal. Reused wastewater can recharge aquifers, reduce stormwater treatment loads, and create income through sales of nursery or wood products. Recycling urban wastewater into green-space areas can be an economical means of treatment and disposal, while at the same time providing other environmental benefits.

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Rainfall Interception Per Event (greater than 1/4")

Species	Dbh (in)	Crown projection (sq ft)*	Interception (gal)		
			Summer	Winter	Total
Large					
Plane Tree ¹	16	1314	99	32	131
Camphor ²	22	1227	62	62	123
Medium					
Chinese Pistache ¹	10	800	45	20	65
Jacaranda ²	11	608	35	15	50
Small					
Crape Myrtle ¹	4	123	5	3	8
Podocarpus ²	9	600	15	15	31

*Crown projection = Area under the drip line.

¹ Modesto, CA, winter rainfall pattern ² Santa Monica, CA, winter rainfall pattern

for only 1.1% of the interception over the entire region because of the region's relatively low tree density and pattern of winter rainfall when deciduous trees are leafless.

The mix of tree species and their sizes influence interception. In Sacramento County, evergreen trees play the most important role in interception because most precipitation occurs in winter. Large trees with evergreen foliage contribute to greater interception than smaller, deciduous trees. In many climates with summer precipitation, deciduous trees make a substantial contribution to rainfall interception.

Planting more trees and improv-

ing maintenance of existing trees are important strategies that will help Sacramento, as well as many other communities, reduce the volume of stormwater runoff.

Rainfall and Tree Effectiveness

One effect that became clear in the Sacramento study was that urban forests become increasingly less effective at reducing stormwater runoff as the amount of precipitation per storm increases. Although trees reduce runoff, they may not be very effective for flood control.

Floods usually occur during major storm events, well after canopy storage has been exceeded. However, by substantially reducing the amount of runoff during less extreme events, urban forests can protect water quality. Small storms, for which urban forest interception is greatest, are responsible for most annual pollutant loading. Infrequently occurring large storms usually produce the greatest flooding damage, and although they may contain significant pollutant loads, their contribution to the annual average pollutant load is quite small (Chang et al. 1990).

Also, because of the infrequent occurrence of large storms, receiving

How much rain are we talking about?

One inch of rain over one acre is about 27,000 gallons.

waters have relatively long periods of recovery between events (Claytor and Schueler 1996). Therefore, urban forests are likely to produce more benefits through water quality protection than flood control.

Taking the Next Step

Since trees are only a partial solution to managing stormwater runoff, the next step we've taken is to investigate other techniques to create a comprehensive approach that communities can take to keep most of their water from going down the drain. In collaboration with TreePeople in Los Angeles, we have selected two single-family sites in LA to evaluate four stormwater management techniques—cisterns, retention/detention basins, swales, and a driveway grate and drywell.

The sites we chose are adjacent lots with the same dimensions (50 ft wide by 150 ft deep). The techniques were installed on the treatment site only; the control site was left unmodified. The 3000-gallon cistern receives and stores filtered roof runoff and functions like a mini-reservoir for both runoff control and summer irrigation. The retention/detention basins (front and back lawns) retain roof runoff. The roof runoff infiltrates, evaporates, or overflows to the swale or to the street. The grate at the end of the driveway drains runoff into a drywell under the lawn, and the overflow is recharged in the retention/detention basin.

Preliminary Results

We have found that all stormwater runoff has been retained on the
(continued)

Shade yields less water use at power plants

Power plants consume water in the process of producing electricity. For example, coal-fired plants use about 0.6 gal/kWh of electricity provided. Trees that reduce the demand for electricity can also reduce water consumed at the power plant (McPherson et al. 1993). Precious surface water resources are preserved, and thermal pollution of rivers is reduced.

treatment site. We also found that the cistern storage provides about 10% of the annual water to irrigate the landscape. At the control site, runoff from half the roof and the entire driveway was discharged to the street.

Based on soil property measurements, both sites are situated on deep, sandy soil. The infiltration rate of these soils is greater than a 50-year flood event. What we don't know about this highly permeable soil: Does this on-site stormwater retention cause groundwater contamination? Are we just transferring the surface water problem to the groundwater?

We also don't know the effective-

In Modesto, CA, each street and park tree was estimated to reduce stormwater runoff by 845 gallons annually, with a benefit valued at \$7 per tree (McPherson et al. 1999). A typical medium-sized tree in coastal southern California was estimated to intercept 2,380 gallons annually, a \$5 per tree benefit (McPherson et al. 2000). These studies showed that broadleaf evergreens and conifers intercept more rainfall than deciduous species where winter rainfall patterns prevail.

ness of on-site runoff retention in different geological settings, soil types, and landscape designs. These questions require further study.

The Future

The goal of this project is to examine and model stormwater management techniques at the residential scale. The hydrologic and ecologic performance of this demonstration site will be monitored over the long term to help determine the problems and opportunities associated with treating each Los Angeles-area site as a mini-watershed.

By combining the model of these traditional techniques with our tree model, we will be able to more completely demonstrate the impact that a comprehensive solution will have on rainfall interception, runoff, and landscape water use. All of the rain does not have to go down the drain. Most, if not all, can be retained on site with a portion used for summertime irrigation.

—Jim Geiger

This research was a partnership between the Forest Service and University of California, Davis, performed by Dr. Qingfu Xiao, research affiliate with the Department of Land, Air, & Water Resources.

Upcoming Presentations

August 27, 2002

Keynote Address: Municipal forestry benefit-cost analysis: a comparison of Modesto and Santa Monica, CA, by Greg McPherson. European Regional Conference of IUFRO, Copenhagen, Denmark.

September 13, 2002

A practical approach to assessing structure, function, and value of street tree populations in small communities, by Scott Maco. 2002 California Urban Forest Conference, Visalia, CA

September 13, 2002

Influencing local decision makers to invest in the urban forest, by Jim Geiger. 2002 California Urban Forest Conference, Visalia, CA

September 14, 2002

Planning for energy savings—using trees to reduce costs, cool communities, cool parking lots, schools, etc., by Jim Simpson. 2002 California Urban Forest Conference, Visalia, CA

September 25, 2002

Preserving the urban forest: creative sidewalk repair and replacement, by Greg McPherson with City of Los Angeles Street Tree Division. American Public Works Association Congress, Kansas City, MO.

September 27, 2002

Costs and benefits of urban trees in relation to smart growth, by Greg McPherson. Community Forestry at its Best, Nebraska City, NB.

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