# Information and Citations on Urban Tree Canopy and Water Quality

For use by Chesapeake Bay Program partners

This paper summarizes pertinent information regarding the nutrient and sediment benefits of an urban tree canopy (UTC) land cover that is being newly considered in Phase 6 of the Chesapeake Bay Model. It does not intend to be exhaustive, but sufficient to deduce a target loading rate for this land cover in the Chesapeake Bay model that is unique from forest and urban pervious. The likely target loading would be between those two land cover classes (see table below).

Current loading averages in CB Model Phase 5:

| | TN lbs/ac/yr | TP lbs/ac/yr | TSS tons/ac/yr |
|---|---|---|---|
| Urban Pervious | 9.43 | 0.57 | 0.07 |
| Not Urban, not Ag (includes forest) | 3.1 | 0.13 | 0.03 |
| Forest (estimate for Phase 6) | 2.0 | ~0.13 | ~0.02 |

Trees and tree canopy modify stormwater runoff in two ways: by reducing the impact from precipitation and by treating stormwater runoff flowing from other lands. Tree structure--from roots to canopy-- allow for greater interception of precipitation and more opportunity/time for evapotranspiration (ET) and water infiltration into soils to occur.

Xiao et al. (2000) showed how tree canopies interception treated 12-40% of precipitation, and stems intercepted another 1-15% (see his and other studies summarized in table below). Canopies can act like many little cups to hold precipitation—the greater the leaf area and depth of canopy, the higher the interception. That is, large healthy trees are more effective than small trees. Larger healthy vegetation also has greater ET. It is ET that allows the vegetation to increase water storage capacity in soil, which is likely to reduce runoff even more. There is only evaporation on deciduous trees during the leaf-off period. ET can also vary with:

- tree shape, species
- climate, season
- storm intensity, frequency, duration
- proximity to impervious surface

Trees in developed areas also treat stormwater runoff from other sources. The same dynamics---interception, evapotranspiration, water storage in soil--- are at play, but runoff varies greatly depending on amount of impervious surface. The i-Tree Hydro model shows how the relative effect of trees on flow (percent change in flow per percent change in tree cover) increases as percent impervious cover increases, while the relative effect of impervious surface on flows decreases as percent tree cover increases.

**Interception**
**% of precipitation (12-40%)**

| Study | | Leaf-On | Leaf-Off |
|---|---|---|---|
| Xiao et al. (Davis, CA) | | | |
| | Bradford pear | | 15 |
| | Cork oak | | 27 |
| Xiao et al. (Oakland, CA) | | | |
| | Lemon | 27 | 40 |
| | Sweetgum | 27 | 13 |
| | Ginkgo | 38 | 27 |
| Link et al. (Western Cascades) | | 25 | |
| Pypker et al. (Western Cascades) | | 21 | |
| Heal et al. (Great Britain) | | 44 | |
| Zimmerman et al. (Europe) | | 51 | |

Dave Nowak (USFS) and others have published data on the i-Tree Hydro model, which is designed to predict the effect that varying amounts of tree canopy and impervious cover will have on stream flow volume (see attached slideshow and article). This tool has been the best tool, to date, that indicates the nutrient and sediment reductions attributable to tree canopy.

Vegetation/land cover: i-Tree Hydro distinguishes tree canopy from "short vegetation", which includes grass and shrubs. This model has been used in multiple urban watersheds in the Chesapeake region and Northeast. The modeling results suggest that the urban forest canopy reduces stormwater runoff volumes by 8-27% more than grass.

Data from i-Tree Hydro showed that on average, tree interception was more than twice that of grass/shrub (e.g., in Mill Creek, 30% interception trees v 13% interception grass/shrub).

Flow: i-Tree Hydro uses changes in stream flow due to trees to indicate stormwater benefits. Increasing tree cover typically reduces base flow, as well as runoff regenerated from both pervious and impervious areas.

Soil is important when looking at both subsurface and overland flow. Undisturbed forest-like soil--- soil that is allowed to develop naturally, that is not compacted and has substantial organic matter --- has both physical and biological processes that treat stormwater. Tree roots can be large and deep which allows flow to penetrate deeper than within other land cover, further reducing stormwater runoff. This reduction happens in forested areas as well as some urban treed areas.

Impervious Factor: The amount of impervious cover/gray infrastructure is a strong indicator of how effective a tree canopy will be. Herrera (1996) has shown how tree canopy over impervious surface is more effective than tree canopy over pervious surface. The i-Tree Hydro model shows how the relative effect of trees on flow (percent change in flow per percent change in tree cover) increases as percent impervious cover increases, while the relative effect of impervious surface on flows decreases as percent tree cover increases. Rough examples from this model estimate that with little impervious cover (<10%), the tree canopy acts like a forest. With a medium amount of impervious cover (10-20%), the tree canopy is still very effective at reducing stormwater runoff. With high amounts of impervious cover (>50%), the canopy is less effective.

i-Tree Hydro uses national median or mean EMC values to estimate pollution reduction due to decreased runoff.  Accuracy of pollution estimates will be increased by using locally derived coefficients.

**Runoff Reduction values**

| | | |
|---|---|---|
| **Baldwin 1938** | 60% | Old growth |
| **Xiao and McPherson 2002** | 15-27% | Urban, California |
| **Herrera 1998** | 30-40% | Washington state |
| **Zinke 1967** | 15-40% | urban coniferous stands |
| **Zinke 1967** | 10-20% | urban hardwood stands |
| **iTree** | 51-61% * | |
| **Elmendorf pub** | ~75% | engineered tree bioswale in MA |

The unresolved nutrient loading of organic matter from trees in the storm system needs more research.  Tree canopy provides a huge net reduction, intercepting rainfall and reducing stormwater runoff.  A fraction tree leaves that fall get into the storm and stream system and can be a nutrient and sediment source in streams.

*The iTree value varies depending on amount of tree and impervious cover, as well as the watershed and rainfall—this range is what was seen in the subwatersheds tested.

<u>The Regional Hydro Ecological Simulation System (RHESSyS)</u>

Band et al. (2010)  used RHESSyS and a direct surface and subsurface routing algorithm on three subwatersheds and compared results with i-Tree Hydro analyses (see Table below).  Unlike i-Tree and Top Model, RHESSyS allows for the computation and prediction of runoff and infiltration with spatially explicit flowpaths and high resolution land cover.  They were able to compare tree cover to other pervious cover.

**Table 12.** Cover estimates for three catchments used for RHESSys simulations

| Watershed | Impervious | Tree | Grass/shrub |
|---|---|---|---|
| Glyndon | 25 | 42 | 33 |
| Baisman Run W3 | 7 | 65 | 27 |
| Pond Branch | 0 | 95 | 5 |

In running these subwatersheds through RHESSyS, Band et al. discovered that the major effect of tree canopy on runoff production was its ability to remove soil water by transpiration, producing greater available pore space for infiltration.  They also found that interception of rainfall by the canopy had a small contribution by comparison.  While lawns can have large infiltration capacity, they can produce saturation overland flow due to limited transpiration compared to areas with trees.

Suggested target loading:  The reduction of stormwater from tree canopy compared to urban pervious land cover is clear.  It becomes less clear when a watershed's impervious cover is included because that signal is so much stronger. Even though there is additional biological activity in treed areas v. grass that could further reduce nitrogen/phosphorus/sediment, the values considered are derived from stormwater reduction.  The table below is a suggested starting point to consider the loading of the tree canopy land cover—it is midway between what Phase 5 of CB Model attributes to forest and pervious urban land covers.  This is a conservative estimate for the new tree canopy land cover.

| | TN lbs/ac/yr | TP lbs/ac/yr | TSS tons/ac/yr |
|---|---|---|---|
| Tree Canopy | 5.7 | 0.35 | 0.045 |

Submitted to Forestry Workgroup, TetraTech, Devereux Consulting and new Urban Tree Canopy Expert Panel for their consideration by Sally Claggett