R. Pitt
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Urban Tree Rainfall Interception Measurements
Version 8: Winter, Spring, Summer, and Fall Seasons

Contents

Objectives of Interception Measurements

Recently, the role of urban trees in stormwater management has received increasing interest. The interception of rainfall by urban trees has been proposed to provide substantial benefits by reducing runoff rates and quantities. However, limited studies are available for rainfall interception of trees in typical urban settings and do not reflect the wide range and types of trees used in urban landscaping. More common is research from natural forests having dense standings of trees. Data needs include how interception changes for different seasonal changes in urban tree canopies for different types of trees, how these interception values vary for different rains (and during rains), and the fate of throughfall under trees that is not intercepted.

There is also a possibility for double counting some of these benefits. For example, calibrated stormwater models rely on monitored outfall flow measurements of existing areas. These areas have varying amounts of trees through their landscapes. Adding additional interception to these calibrated models can result in improper estimates of runoff. However, if new trees are planted in an area, interception benefits may increase. The following figures are examples of monitored medium density residential areas used in WinSLAMM calibrations showing the contrast of mature trees in older areas and the few young trees in new developments. These residential areas were separated based on age of development to account for the differences in vegetation during the model calibration process. However, the outfall monitored runoff characteristics did not indicate any differences between the old and new developments, beyond which was explained by differences in directly connected impervious area types and other land surface areas.

New residential areas with minimal trees

Residential area with few isolated trees

Older medium density residential area with more mature trees

Older medium density residential areas with mature trees.

If a tree is located in a pervious area of the watershed (over lawns or other non-paved areas), interception may not affect outfall runoff quantities much; any un-intercepted rainfall (throughfall) is likely to be infiltrated with or without the trees. However, trees likely maintain good soil characteristics and minimize compaction, which would improve the infiltration of rainfall. The largest hydrological benefit of urban trees would be when directly connected impervious areas (such as roofs, walkways, parking areas, and streets) are heavily covered by an overstory of trees. If tree-covered impervious areas are directly connected to the drainage system, these benefits would be the greatest, but if the tree-covered impervious areas drain to pervious areas (such as disconnected roofs or walks surrounded by lawns), the benefits would be lower. Obviously, trees add substantially to the quality of life in urban areas, but nuisance conditions and increase public works leaf removal activities may occur.

This paper describes a series of direct measurements of throughfall under urban trees (canopy interception) to quantify some of these hydrologic benefits for inclusion in WinSLAMM. This study, described below, includes a standard rain gage located in an open area and rain gages under deciduous oak and evergreen pine trees. The results of the 75 events monitored from early December 2018 through January 2020 have been statistically evaluated and summarized. These results have been used to add urban tree interception benefits to WinSLAMM for appropriate conditions (tree overstory above directly connected paved areas for different types of trees, seasons and rain quantities). Only direct canopy interception is considered, as stemflow is assumed to infiltrate near the base of an urban tree in the surrounding landscaped or tree planter box area. These tests are part of the Ph.D. research being conducted by Ryan Bean at the University of Alabama which includes similar interception measurements from other locations, along with other associated tests, building upon his early research on urban landscaping evapotranspiration (ET) (as summarized in Bean and Pitt 2012).

Literature Review on Benefits of Urban Trees

Data needs for calculating the benefits of urban trees in stormwater management have been frequently recognized at many different locations. The following briefly reviews some of the recent studies that have described these data needs. Livesley, *et al*. (2016) examined 14 studies on the role of trees on water, heat, and pollution cycles at different local scales. They outlined a framework of multidisciplinary studies to obtain additional understandings on the biogeochemical aspects of urban trees. Berland, *et al.* (2017) examined the literature on how interacting mechanisms associated with urban trees affect urban hydrology. They concluded that many of these interactions are poorly understood, especially at the spatial and temporal scales most important for stormwater management. Based on a literature review, Kuehler, *et al*. (2017) concluded that "inadequate research quantifying the urban tree contribution to rainfall/runoff processes limits their promotion by stormwater managers." Researchers in Belgium (Smets, *et al.* 2019) reported that "an important knowledge gap in current urban hydrological models are reliable, generic data about interception storage capacities of small urban plant species." They conducted several modeling studies to examine the sensitivity of tree characteristics on interception. Based on the available tree characteristics database, biomass (tree height and diameter) was determined to be most important for calculating interception.

Sudies have relied on modeling to help identify the important factors affecting rain interception associated with urban trees. A tree rainfall interception model was developed by California researchers (Xiao, *et al.* 2000) and compared to direct measurements for throughfall and stemflow. Interception losses were about 15% for a pear tree and 27% for an oak tree. Interception was greatest at the start of the rain events. They also found that rainfall frequency was more important than rain intensity affecting interception losses. Increased rain intensity and wind speed increased stemflow, while reducing throughfall. During a Canadian study, Kirnbauer, *et al*. (2013) modeled the effects of planting trees on vacant urban land to benefit stormwater. They found that planted trees could reduce (intercept and evaporate) from 7 to 27% of the rainfall from a planted lot. Local tree growth information was needed to improve the reliability of the modeled values. Gonzalez-Sosa, *et al*. (2017) modeled the benefits of literature-based tree interception losses on different aspects of urban hydrology and their benefits in combined sewer areas. They concluded that 10 to 20% runoff volume reductions and peak delays of 10 to 15 minutes could be expected by the use of street trees. Indoor simulated rainfall interception experiments were conducted by Baptista, *et al.* (2018) to study the factors affecting the tree's rainfall storage capacity. They found that the canopy rainfall storage capacity was well correlated to the plant surface area and area density, reflected in types and abundance of leaves on the trees

Field experiments have also been conducted at many locations to directly measure interception and other losses associated with urban trees, although most of these were limited in the number and types of trees and extent of the investigations. Some of these studies are mentioned below. Guevara-Escobar, *et al*. (2007) examined the distribution patterns of precipitation around the canopy of a single evergreen tree during 19 storms in Mexico. During late summer to early fall months, they measured 38% throughfall, 2.4% stemflow, and 60% interception by the tree canopy. They also measured an average time of 20 min. before canopy saturation. Rainfall screening was also important in the area surrounding the tree (about 18% losses). Kermavnar and Vilhar (2007) measured urban tree interception from a mixed upland forest in the city center to a riparian pine forest and floodplain hardwood forest in Slovenia. Tree species, canopy cover, and tree dimensions were the main determining factors affecting interception. The mixed forest had an average interception amount of 18%, while the pine forest only had 4% interception of the rainfall and the mixed hardwood forest had 7% interception. Besides changing tree characteristics (leaf vs. leafless periods), rainfall intensity was also found to be an important factor affecting the portioning of the losses during the seasons. Asadian and Weiler (2009) studied rainfall interception under six different urban trees during seven rains in British Columbia. Average canopy interception during these events for Douglas fir and western red cedar were about 49 and 60%, respectively. The trees also caused a delay in the rain thoughfall reaching the ground. These losses were found to be dependent on canopy structure, climatic conditions, and rain characteristics. During Australian research, Livesley, *et al.* (2014) studied interception of two eucalyptus tree species used as street trees. The variety having a greater density intercepted 44% of the annual rainfall compared to 29% for the variety that was less dense. Also, stemflow (only 5% of the intercepted amount) was less for the rough bark variety compare to the smooth bark variety. Overall, they expected up to 20% runoff reductions associated with street tree use. Van Stan, *et al.* (2015) studied two common northeastern US urban tree species (beech and poplar). The poplar having rougher bark, lower branch inclination, and thinner canopy had greater losses compared to the beech which allowed greater amounts of the rainfall to reach the underlying soil. Rainfall throughfall measurements were made during 10 rains in Brazil by Alves, *et al.* (2018). They found that rainfall interception was highly dependent on tree species type. Researchers in Slovenia (Zabret, *et al.* 2018) studied pine and birch rainfall losses over 180 events. The amount of rainfall was found to be the most important variable, with rain intensity and number of raindrops also being important. San Juan researchers (Nytch, *et al.* 2019) studied 6 trees during 13 storms to measure factors affecting interception losses. Deciduous trees had 23% interception losses while evergreen trees had 17% interception losses. The tree types effected the interception for low and moderately intense rains, but not for high intensity rains.

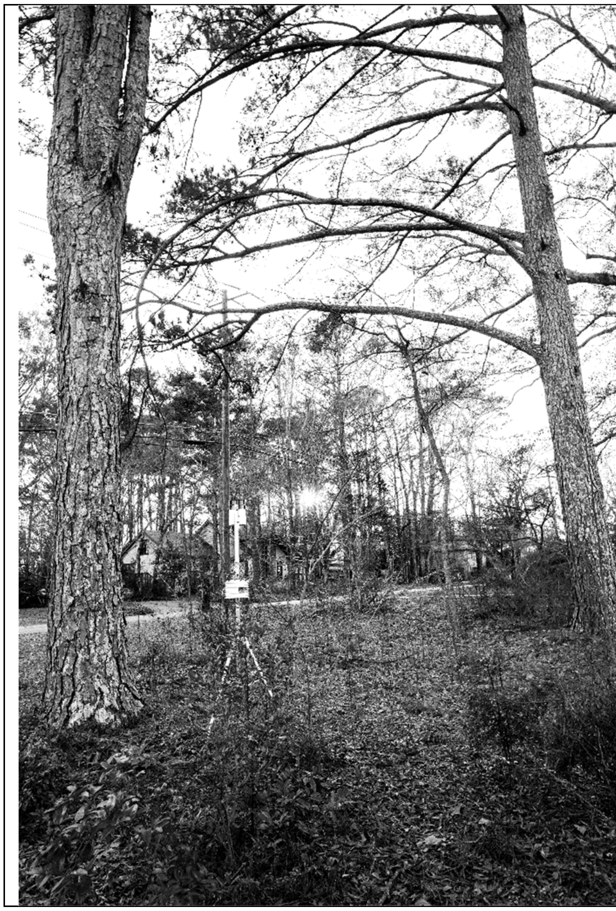
Besides interception of rainfall by tree canopies, trees can also reduce runoff quantities and flow rates by enhancing underlying soils, as noted by the following researchers. Schooling and Carlyle-Moses (2015) stated that "generalizations that deciduous canopies reduce stormwater are based largely on closed-canopy forests, highlighting the need for more detailed study of isolated urban trees." They examined isolated deciduous trees in Germany. Stemflow was a maximum of 23% of the canopy interception and funneling was about 1/5 of the maximum stemflow. They concluded that infiltration at the base of isolated urban trees needs to be considered as part of stormwater management schemes. Kuehler, *et al*. (2017) found that soil benefits of urban trees should also be considered and integrated in the design of urban tree stormwater practices. Improved soil conditions beneath urban trees in Germany were studied by Rahmana, *et al.* (2019). Higher infiltration rates were associated with trees having fast growth rates which had increased root mass.

The experiments described in this paper were conducted to comprehensively examine canopy interception by direct measurements of throughfall under isolated or low density stands of mature urban deciduous and evergreen trees in the Southeast of the US. These measurements resulted in throughfall data for 55 (oak) to 75 (pine) rains over all seasons to determine statistically significant relationships for use in the WinSLAMM urban stormwater quality model. Additional measurements are currently being conducted under smaller trees.

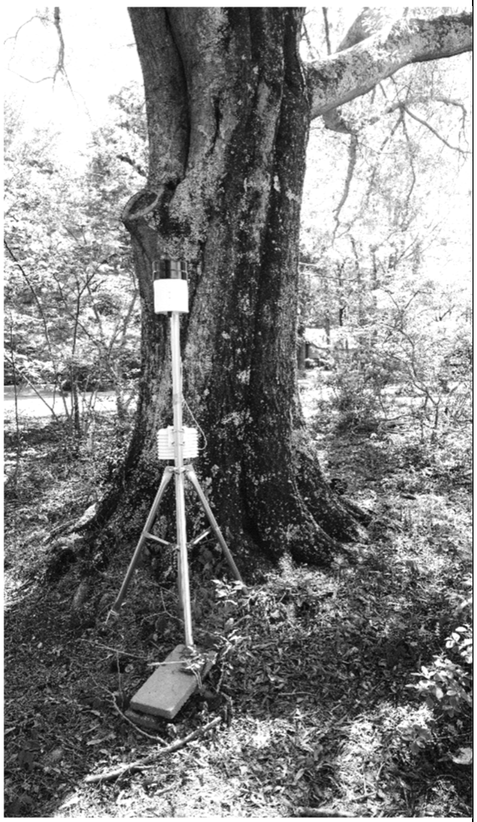
Description of Measurement Locations and Instruments

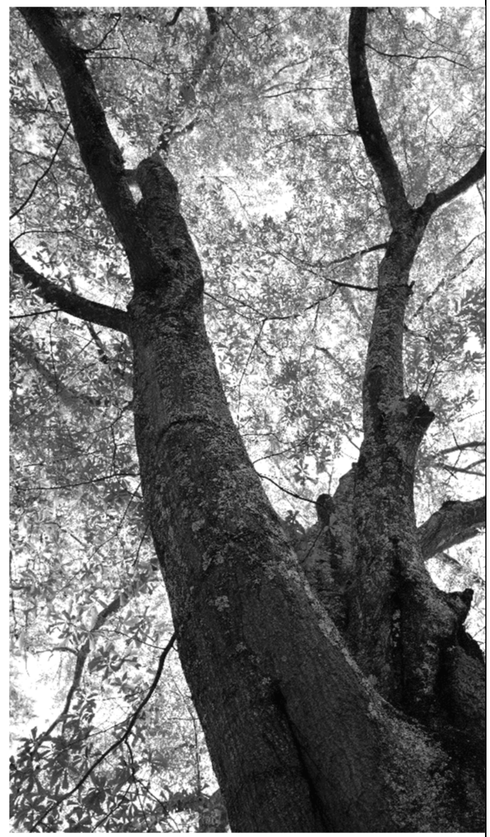
The rain gauges (HOBO Data Logging Rain Gauge RG3) were installed on December 10, 2018. The initial rain, starting on December 11, was over 3 days (described below). The data loggers record temperature (every 5 minutes) and time for every tip of the rain gage (0.01 in). A Davis Vantage Pro2 weather station is also located in the open area for most measurements (wind, temp, rain, UV, humidity, pressure, ET), but these are only available on 30-minute time steps.

Rain gauge located under evergreen pine:




Rain gauge located under deciduous oak:

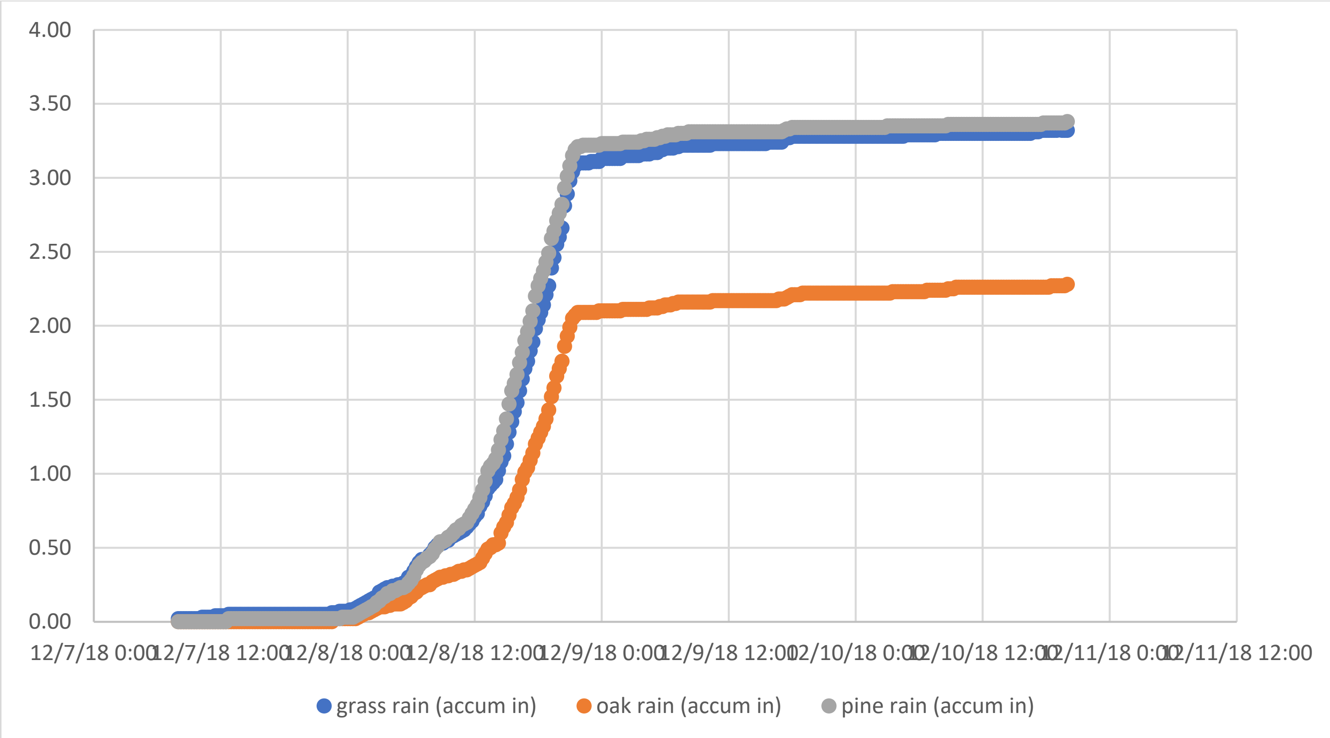




Standard ("grass") location showing Davis and HOBO rain gauges surrounded by grass with no nearby trees:

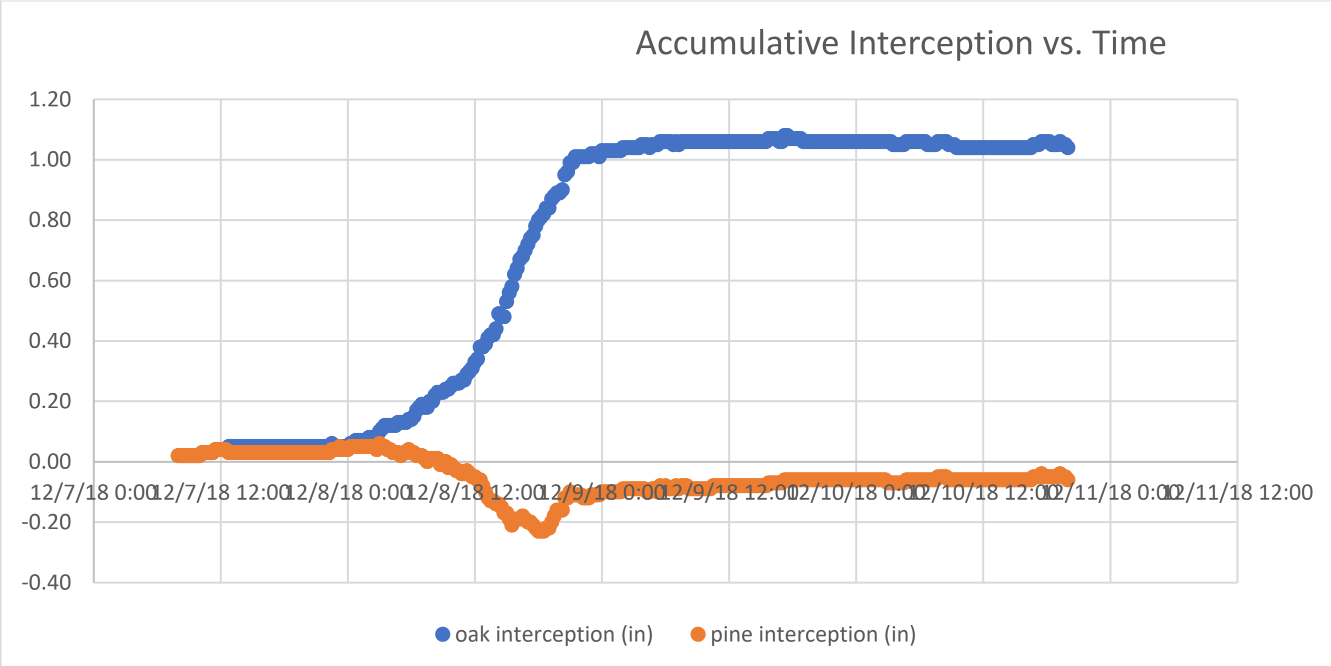
Initial Rain Data (December 7 to 11, 2018)

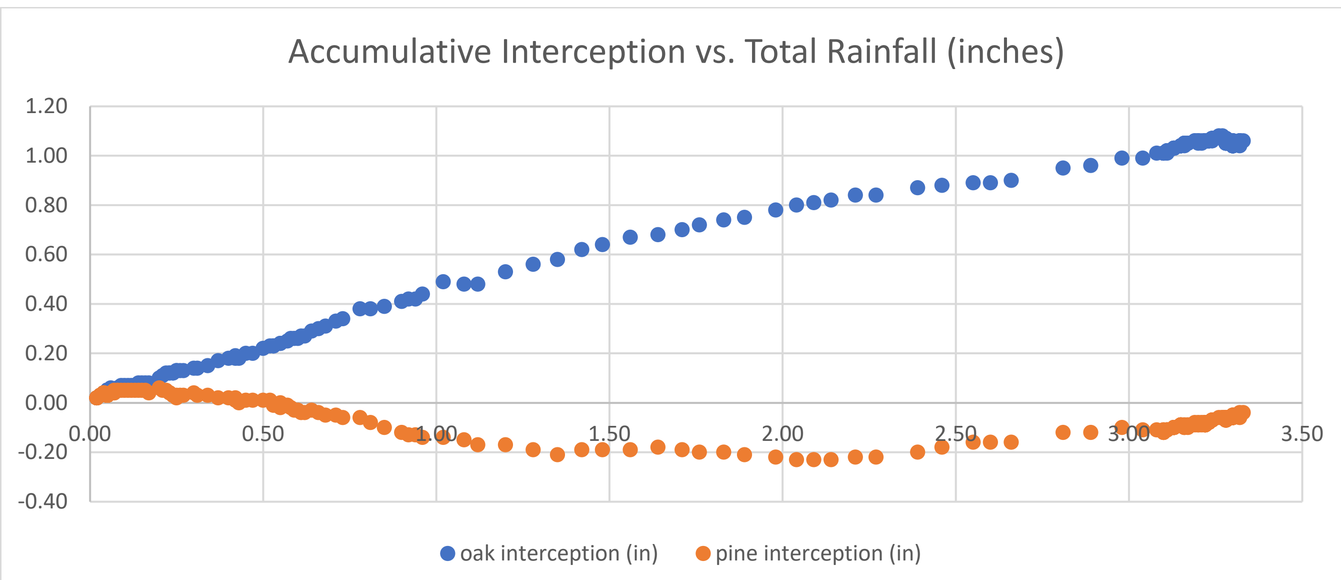
The following plot is the accumulative rainfall at the background location (surrounded by grass) vs. the accumulative rainfall measured under the pine and oak trees:



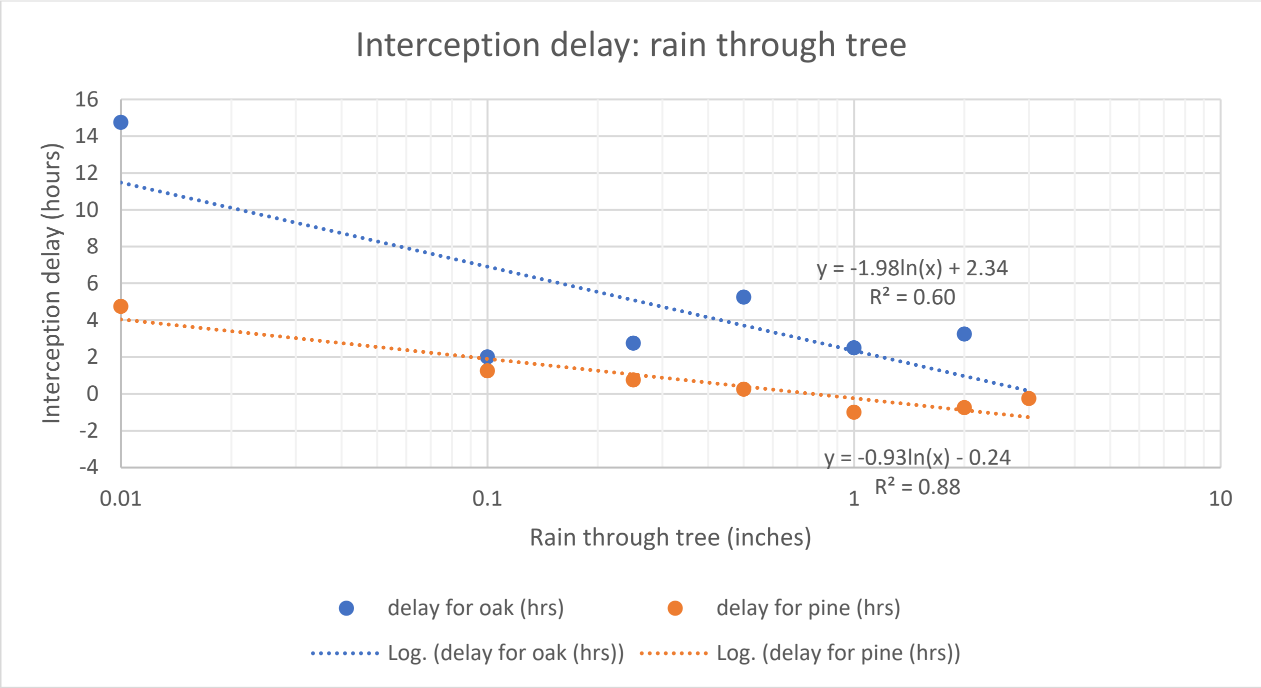
It is obvious that the measured rain under the pines had little difference compared to the background rainfall, while the oak had a substantial reduction. The total rain for this event was about 3.32 inches. The steepest portion of the accumulated rain curve indicated about 2.1 inches over 7.25 hours, for a fairly constant rain intensity of about 0.29 inches per hour.

The following charts show the accumulative interception vs. time during the rain and the accumulative interception vs. total rainfall. The pine trees do not indicate any obvious interception during this rain, while the oak trees show substantial interception. The plot of interception vs. total rain shows a steady increase of interception for the oaks, indicating losses of about 30 to 40% of the total rainfall over this range of rains up to about 3 inches. There may be a slight increase (as a percentage) of interception before about 1.5 inches of rain compared to the later portions of the rain. The pine tree interception shows an odd trend, but basically is zero over the rain time and depth. The variations in the pine interception may be due to wind during the storm.



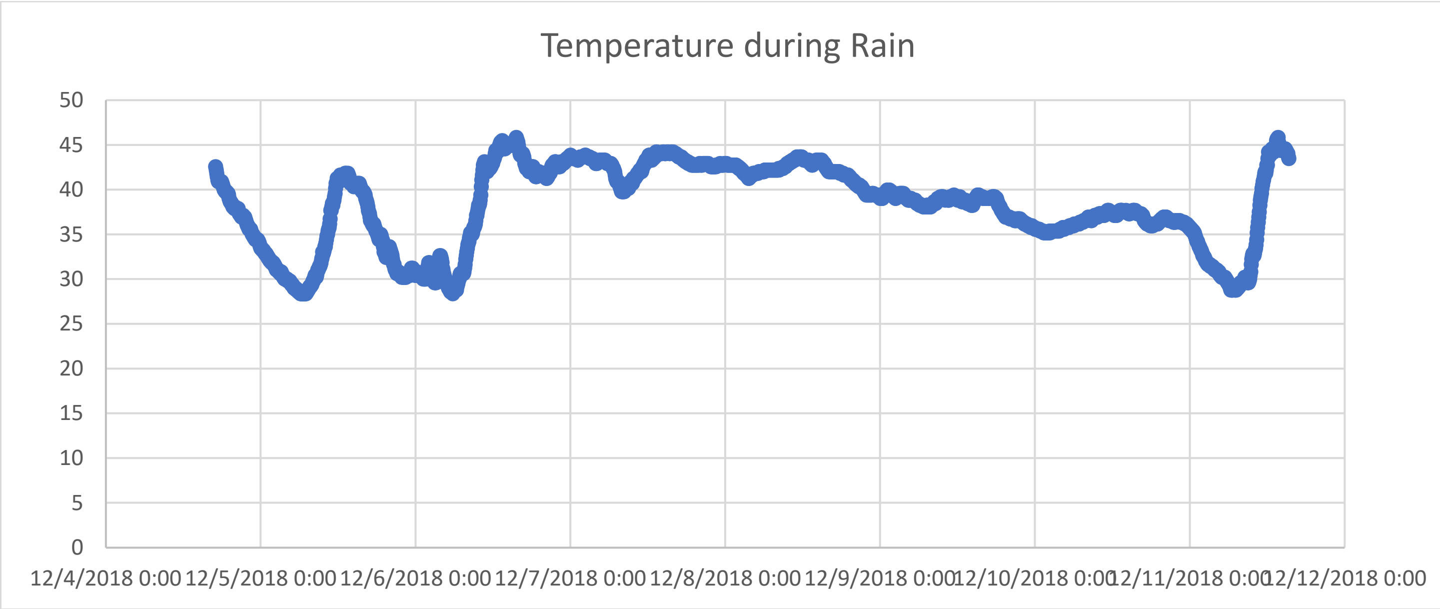


The following chart shows the total accumulative rainfall through the trees compared to the time since that total rainfall started at the background location. As an example, 0.1 inches of rainfall through the pines occurred about 2 hours after 0.1 inches fell at the standard background location. In contrast, 1 inch of rainfall fell through the oak trees about 2 hours after 1 inch of rain was measured at the standard location. However, there was basically no delay when 1 inch was measured under the pine trees compared to when 1 inch of rain was measured at the standard background location.



The oak trees therefore provided substantial interception losses and relative long delays, while the pine trees had minimal interception losses and relative short delays (and only for the small rains).

The following plot shows the temperature during these rains. The temperature cycled from highs of about 44°F to lows of about 28°F before and after the rain period, and slowly dropped from about 45°F to 40°F during the 2 days of rain.



This initial rain interception measurement test was supplemented with many more rains through January 24, 2020. In the Birmingham area, about 50 rains occur per year having >0.1 inches of rain (and about 100 rains >0.01 inches). This initial rain was one of the largest expected, but we usually receive a few rains between 2- and 5-inches total per year. These large amounts of data enabled the significant factors affection interception of urban trees to be identified and quantified. The factors examined by factorial analyses included: tree type, season (tree canopy coverage), rain intensity and depth, along with wind speed.

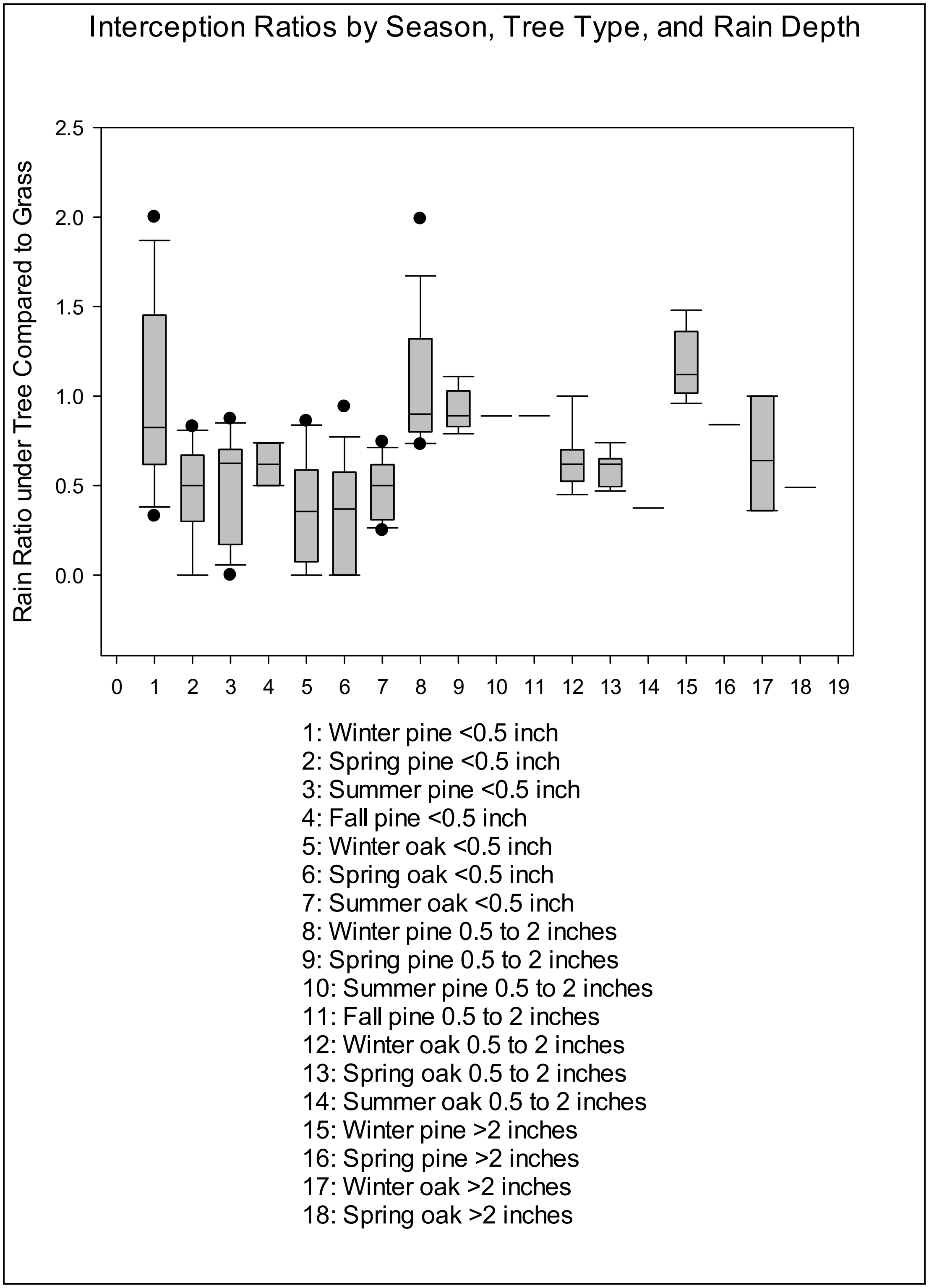
Summary of Seasonal Rains

Appendix A lists the observed rainfall conditions at the three rain gages for the period from December 7, 2018 through January 26, 2020. A total of 78 rains were monitored during this period, 32 during the winter season (December through February), 26 during the spring season (March through May), 14 during the summer season (June through August), and 3 during the fall season (September through November). Few fall rains were monitored due to an unusual dry period and equipment problems (data logger resetting due to cold weather and interference of the tipping mechanism by long stem leaves). The rain depths ranged from 0.02 to 4.9 inches, with a median rain depth of 0.78 inches during the winter period, 0.25 inches during the spring period, 0.26 inches during the summer period, and 0.46 inches during the fall period. The maximum rain depths were 4.9 inches during the winter, 2.5 inches during the spring, 1.4 inches during the summer, and 1.6 inches during the fall. The interevent periods ranged from about 7 hours to 24 days. The rain durations ranged from about 0.1 to 70 hours, with a median duration of about 16 hours during the winter, 4 hours during the spring, a short 0.6 hours during the summer, and 11 hours during the fall.

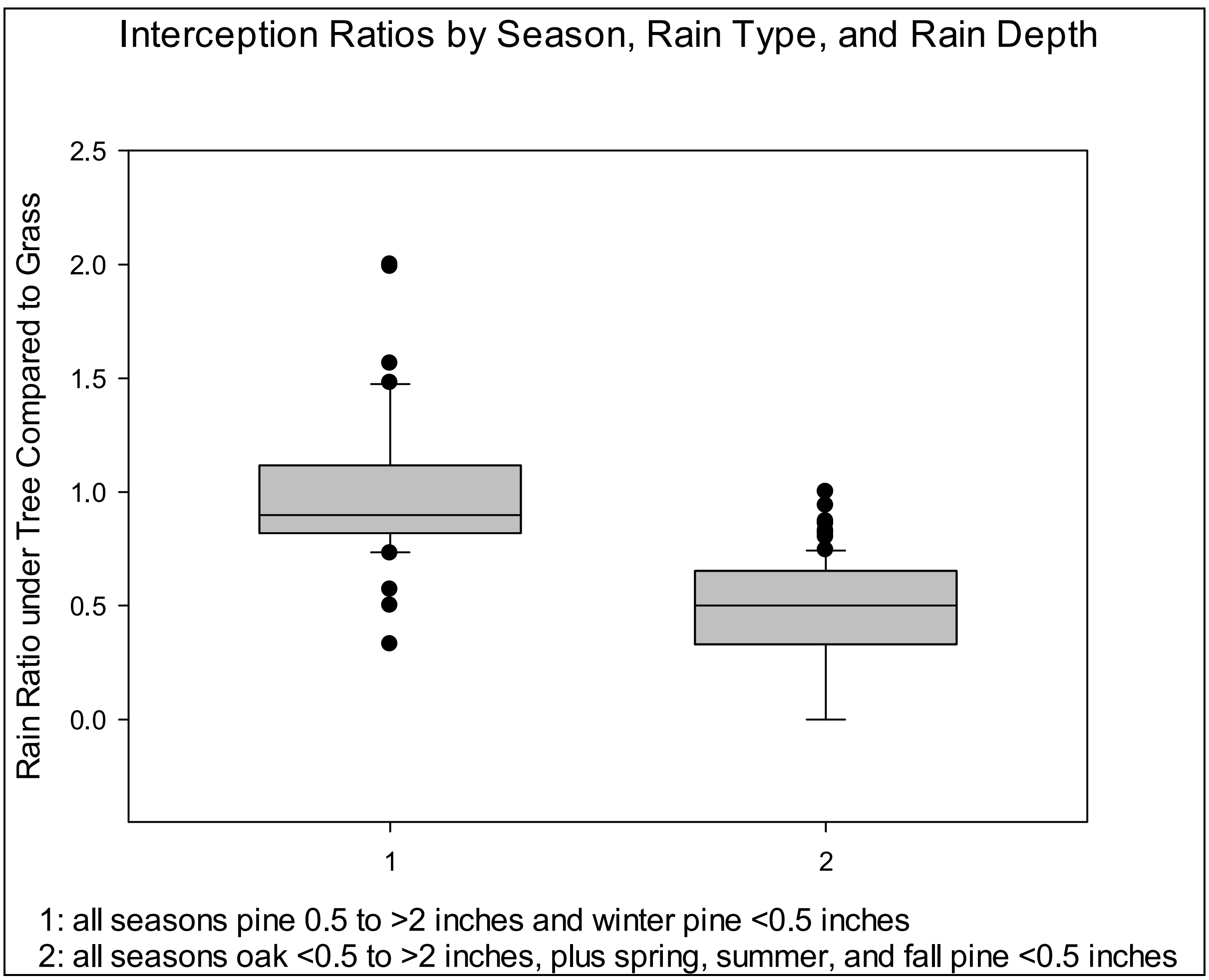
Appendix B shows the results of the calibration tests that were conducted during this period. Calibration tests were conducted before the rain data were downloaded from the data loggers. If there were any debris on the rain gage screens, another calibration test was conducted after the debris were removed. If the calibrations were very close to 1.00, then the prior data was deemed satisfactory. The first calibration for the Oak rain gage was only 0.85 inches and the last calibration at this location was only 0.63 inches, possibly due to interference of a long leaf stem interfering with the tipping mechanism. When the event data were compared to the grass rain gage data for the period prior to this calibration, it was determined that 3 of the initial winter events and all of the last fall and winter events had questionable data and were therefore not included in the summary or analyses.

A 2^3 full factorial analysis was conducted and found that all three factors (season, tree type, and rain category) were significant when determining the throughfall (rain depth under the trees vs. rain depth at the grass location). The tree type (oak vs. pine) had the greatest effects on the throughfall, followed by the rain depth, while the seasonal differences had only marginally significant effects.

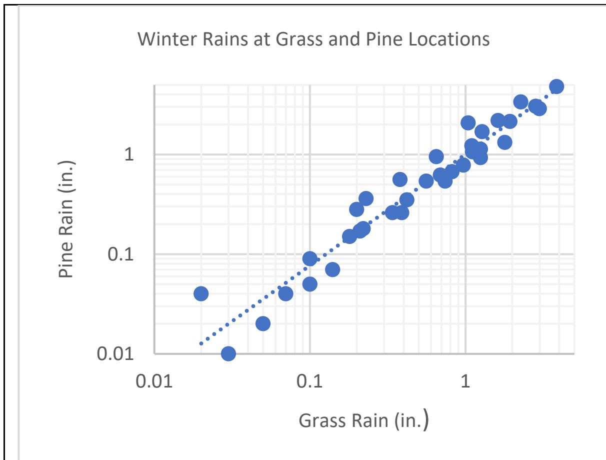
Paired t-tests were conducted to compare the individual rain depths (in log10 space) measured under the two trees with the rain depths measures at the gage surrounded by grass. The grass vs. pine gage and the grass vs. oak gage data differences were significantly different ($p = <0.001$) for the number of data available ($n = 72$ for the pine and $n = 52$ for the oak). The data were further subdivided by season, tree type, and rain depth category (<0.5, 0.5 to 2, and >2 inches) for comparisons. Kruskal-Wallis One Way Analysis of Variance on Ranks tests indicated a number of significant differences between these subgroups, as shown on the following box and whisker plot.



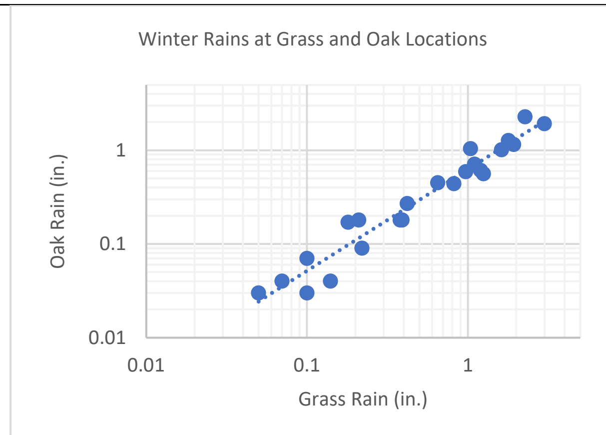
The box and whisker plot indicated that the throughfall ratios were greatest (largest abstractions) for the small events compared to the larger events. Also, the pine rain ratio observations were greater than the oak rain ratios. There were no large differences in the seasonal rain ratios for each category, except for the winter vs. spring pine values for the smallest rains. Kruskal-Wallis One Way Analyses of Variance on Ranks confirmed the obvious overlaps of the data for these different categories. The following group box and whisker plot shows the final two combined categories of rain ratios that were statistically significantly different: Most of the pine tree observations are in the category having the largest ratio of rains under the tree compared to the grass area (least interception losses), while all of the oak observations and some of the pine observations (spring, summer, and fall small rains) are in the category having the smaller ratios (largest interception losses).



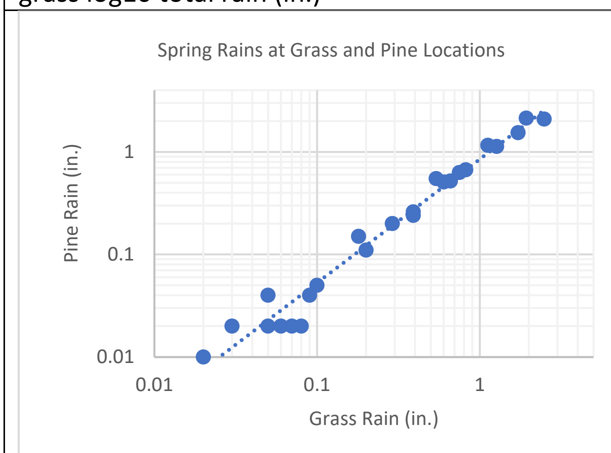
The following scatterplots are for the total rain depths under the pine tree and the oak tree plotted against the rain depths at the grass gage, for the winter, spring, and summer seasons. The plots and ANOVA statistical tests were conducted on log10 transformed rain depth data, indicating highly significant regressions. The pine data for winter, spring, and summer periods did not result in significant constant (intercept) terms, so those regressions only have a slope coefficient term, while the oak data (and the fall pine data) had both significant intercept and slope coefficients. The following scatterplots show the fitted regression lines along with the actual data. The residual analyses indicated satisfactory patters (example shown below for winter pine observations).



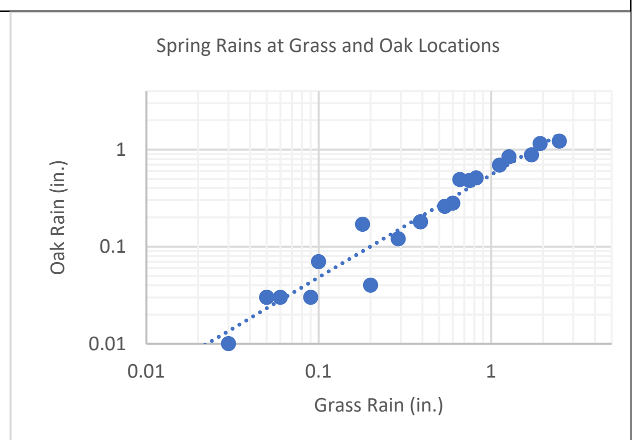
Winter pine log10 total rain (in.) = 1.07 Winter grass log10 total rain (in.)



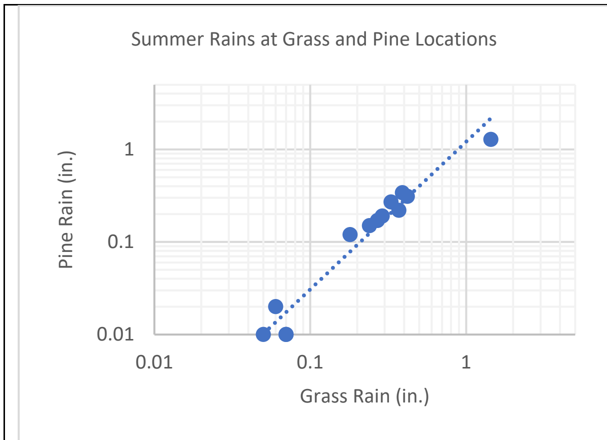
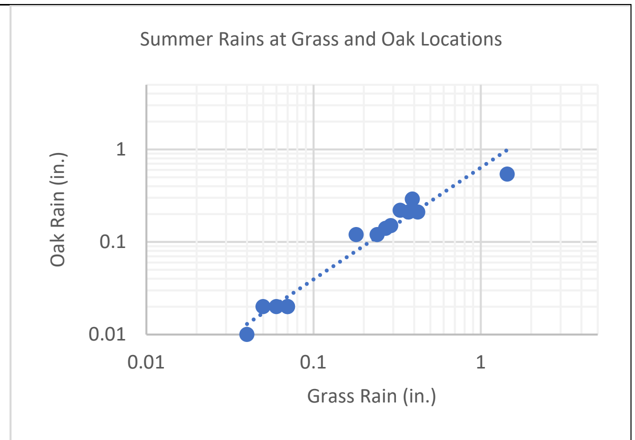
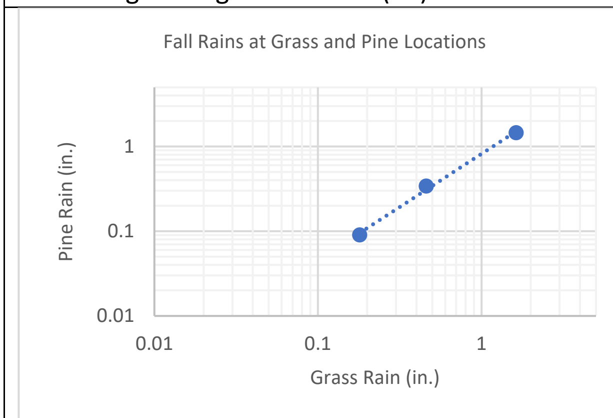
Winter oak log10 total rain (in.) = - 0.203 + 1.17 Winter grass log10 total rain (in.)

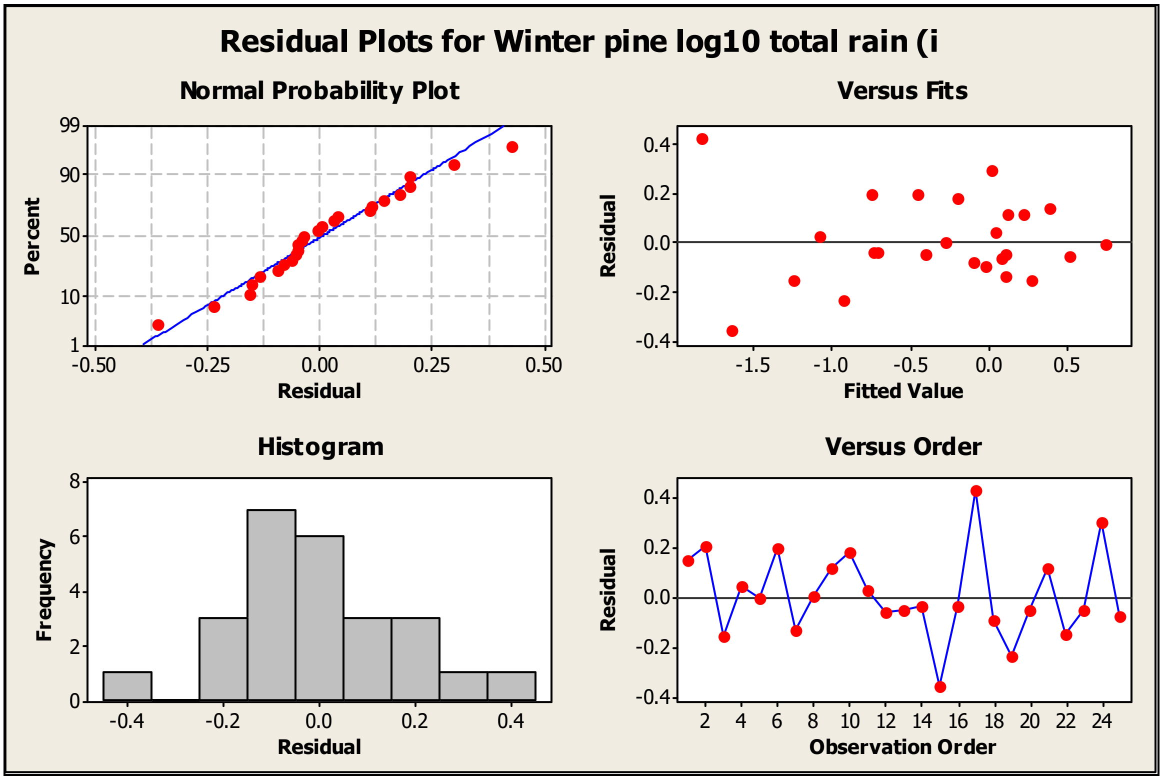


Spring pine log10 total rain (in.) = 1.26 Spring grass log10 total rain (in.)



Spring oak log10 total rain (in.) = - 0.260 + 1.06 Spring grass log10 total rain (in.)

 Summer pine log10 total rain (in.) = 1.51 Summer grass log10 total rain (in.)	 Summer oak log10 total rain (in.) = - 0.215 + 1.17 Summer grass log10 total rain (in.)
 Fall pine log10 total rain (in.) = -0.0871 +1.255 fall grass log10 total rain (in.)	



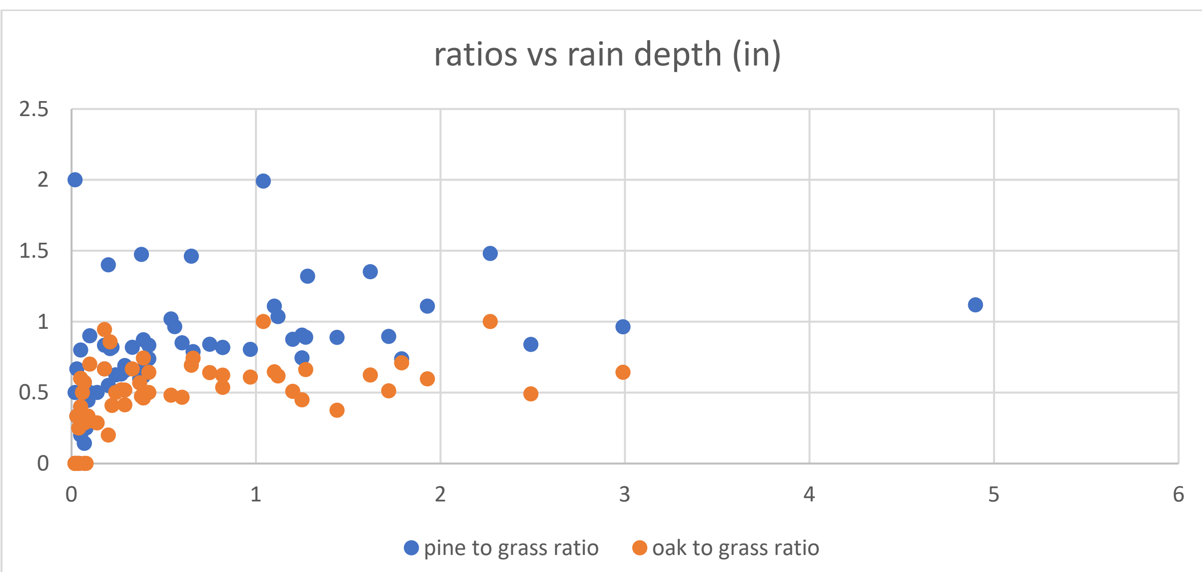
The following table shows the calculated rain depths under the trees, compared to the grass rain depths up to the maximum rain depth recorded (4.9 inches for the winter season, 2.5 inches for the spring season, 1.4 inches for the summer season, and 1.6 inches for the fall season). The equations can result in rain depths under the pine trees larger than the grass rain depths for rains larger than about 1 inch for any of the seasons, so the grass rain depths are shown as the maximum rain depths under the pine. Increased rain depths were consistently recorded under the pine tree for the large rains compared to the grass location, possibly associated with funneling of rain into the rain gage from overhanging branches. The most notable difference is the spring, summer, and fall pine conditions for the small rains which are similar to the oak values and much less than observed for the winter-pine conditions (as indicated in the box and whisker plot categories).

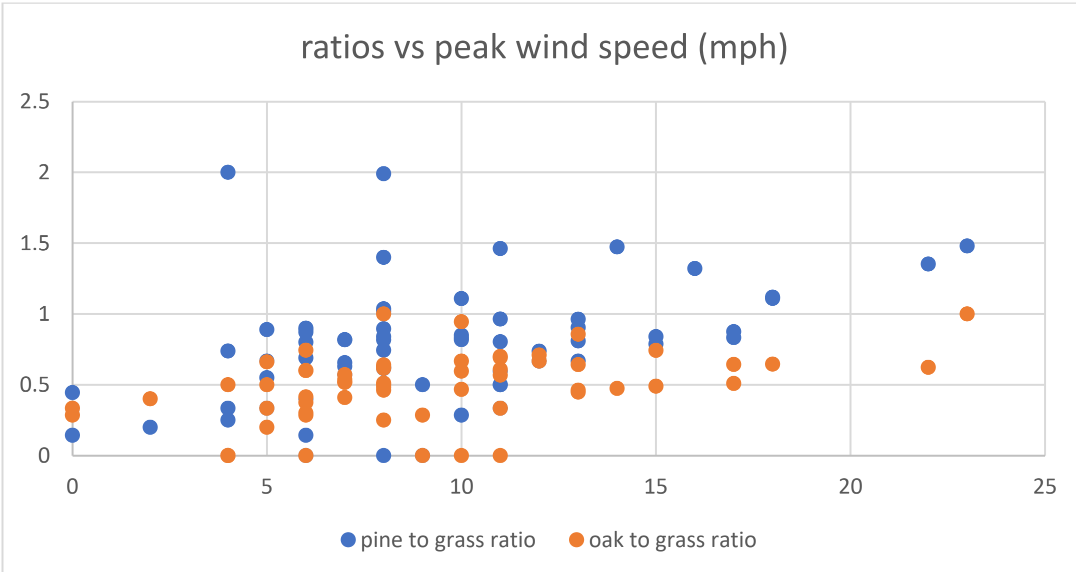
grass rain (in)	Winter pine	Spring pine	Summer pine	Fall pine	Winter oak	Spring oak	Summer oak
0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01
0.08	0.07	0.04	0.02	0.03	0.03	0.04	0.03
0.1	0.09	0.05	0.03	0.05	0.04	0.05	0.04
0.3	0.28	0.22	0.16	0.18	0.15	0.15	0.15
0.8	0.79	0.75	0.71	0.62	0.48	0.43	0.47
1	1.00	1.00	1.00	0.82	0.63	0.55	0.61

2	2.00	2.00	2.00	1.95	1.41	1.15	1.37
3	3.00	3.00	3.00		2.27	1.76	
4	4.00	4.00	4.00		3.17		
5	5.00	5.00	5.00		4.12		

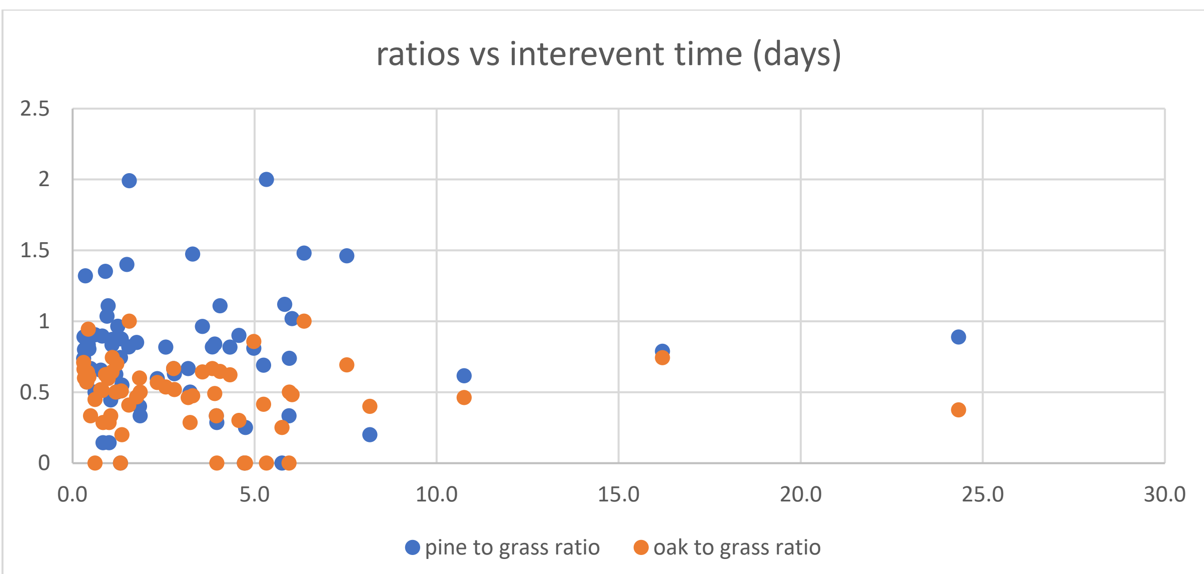
The time delay until the onset of recorded rain under the pine and oak trees were also examined. There were substantial variations in the rain delays, with medians of about 5 to 20 minutes. No significant relationships were noted affecting the delays for different rain depths, intensities, and wind speeds, although there were apparent larger delays associated with smaller rains, smaller rain intensities, and lighter winds, compared to larger rains, intensities, and winds. These trends were more apparent for the oak data than for the pine data.

Wind data were also available from the Davis Vantage Pro2 weather station located near the grass rain gage. Full factorial analyses were therefore conducted to identify significant factors that may affect the observed interception ratios. However, even with 75 data sets, there were some missing and under-represented conditions for the eight possible combinations (2^3) when average rain intensity, total rain, and peak wind speed were evaluated. When just total rain and peak wind speed were examined ($2^2 = 4$ combinations), large rains with low winds were still under-represented (stormy conditions associated with large rains likely have large winds). Apparent relationships of total rain with throughfall and peak rain intensity with throughfall were noted, as shown below. As noted previously, 2^3 full-factorial analyses examined tree type, season, and rain depth and their interactions, with all three factors being significant alone than for any of the meteorological conditions or factor interactions, with the tree type being the most important significant factor, and the rain depth and season having somewhat less effects.

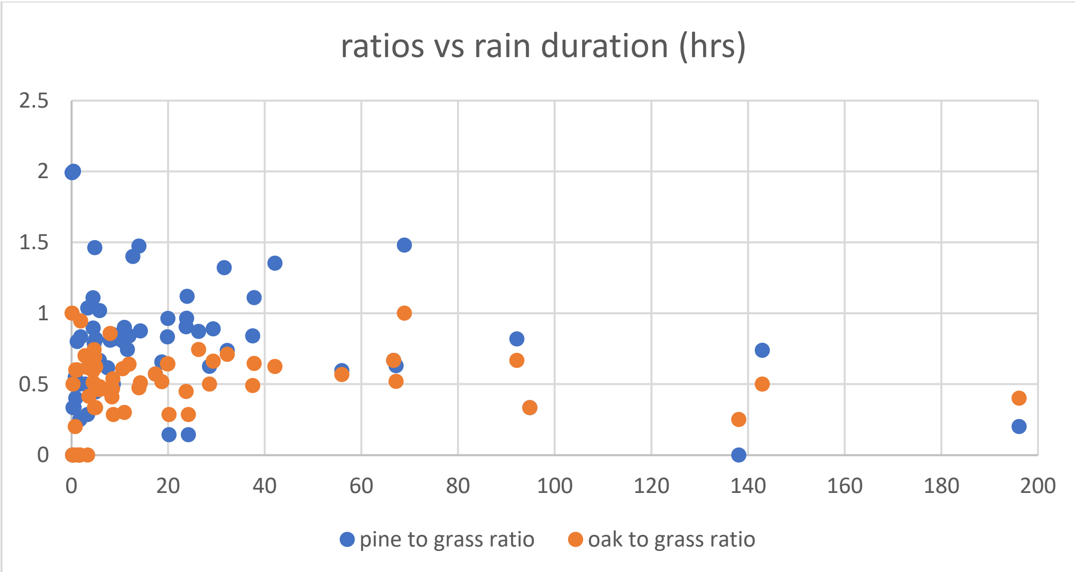




ratios vs peak wind speed (mph)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
pine to grass ratio
oak to grass ratio



ratios vs interevent time (days)
2.5
2
1.5
1
0.5
0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
pine to grass ratio
oak to grass ratio



Calibration Data

Appendix B shows the measured calibration results. Before all downloads, each rain gauge calibration is checked using a Texas Electronics Field Calibration Device FC-500. This unit provides 1.00 inches of rain for the 0.01 inch per tip, 6-inch diameter HOBO rain gauges. The calibration check median values are:

Grass: 1.06 inches (COV = 0.02, 21 tests)
Pine: 1.03 inches (COV = 0.01, 15 tests)
Oak: 1.03 inches (COV = 0.01, 14 tests)

Therefore, on average, there is less than about a 3% variance in the measured values due to measurement errors of rainfall between the three rain gages.

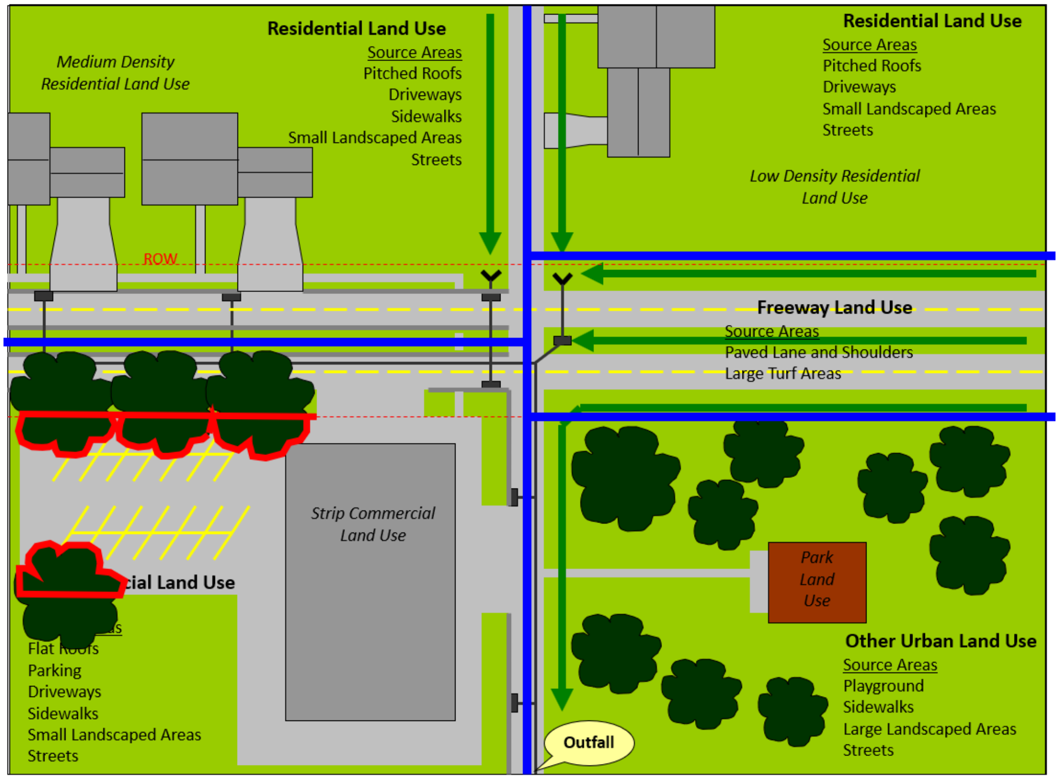
Conclusions

Literature reviews have concluded that the interacting mechanisms of urban trees affecting urban hydrology are poorly understood. Past canopy throughfall measurements of urban trees have identified important differences between tree types. Projected runoff volume reductions due to extensive use of urban trees have been found to be about 10 to 20%. Field studies have also concluded that stemflow is usually a small portion of the total tree runoff yield to runoff (usually <10% of the canopy throughfall). Soil characteristics under urban trees are also expected to affect understory runoff yields, with trees expected to improve soil structure (decreased compaction and increased organic matter).

Very limited data of throughfall are available for urban trees in the southeastern US. Measurements of throughfall were made during 78 rains from December 2018 through January 2020, resulting in throughfall data for 55 events for the deciduous oak tree and for 75 events for the evergreen conifer tree. The rain depths for the monitored rains ranged from 0.02 to 4.9 inches, with a median rain depth of 0.78 inches.

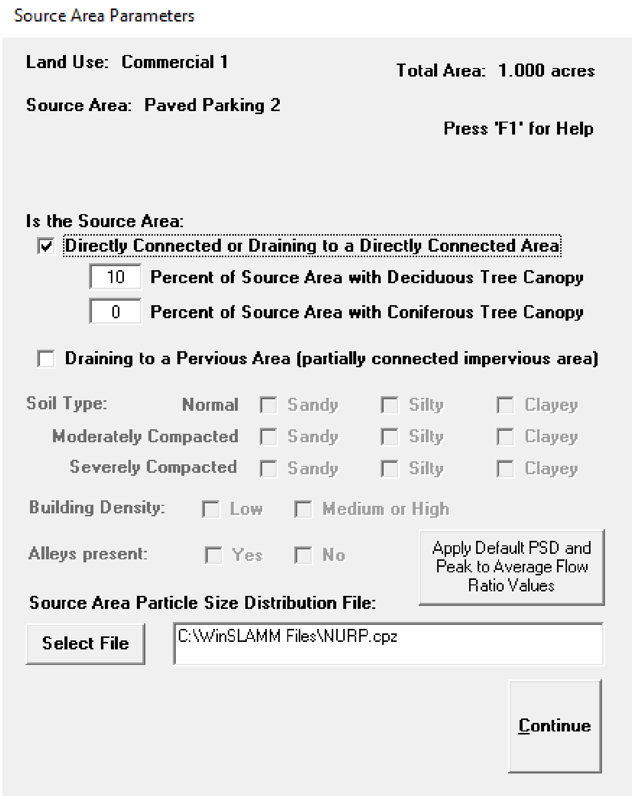
A full 2^3 factorial analysis was conducted using the throughfall and corresponding meteorological data. The tree type (oak vs. pine) had the greatest effects on the throughfall, followed by the rain depth, while the seasonal differences had only marginally significant effects. Kruskal-Wallis One Way Analysis of Variance on Ranks tests indicated a number of significant differences between tree types, rain category and seasonal subgroups. The throughfall ratios were greatest (largest abstractions) for the small events compared to the larger events. Also, the pine throughfall ratio observations were much greater than the oak rain ratios (less abstractions). There were no large differences in the seasonal rain ratios for each category, except for the winter vs. spring pine values for the smallest rains. There were two combined categories of throughfall ratios that were significantly different: Most of the pine tree observations are in the category having the largest throughfall ratio of rains under the tree compared to the grass area (least interception losses), while all of the oak observations and some of the pine observations (spring, summer, and fall small rains) are in the other category having the smaller throughfall ratios (largest interception losses).

Highly significant regression equations relating rain depth and throughfall were developed for conifer and deciduous trees for the different seasons for implementation in WinSLAMM. As noted previously, tree interception effects on throughfall in stormwater management is only relevant for newly planted trees that shade directly connected impervious areas. Counting the benefits of existing trees in a calibrated model likely would result in double-counting the benefits. Also, the benefits of new trees shading uncompacted soils during small and intermediate rains are likely small as the throughfall would likely be almost completely infiltrated, as would the total rainfall for these areas. During large rains, the canopy interception fraction is much reduced, also resulting in minimal differences in runoff compared to uncompacted soil areas having no trees. WinSLAMM was therefore modified to directly calculate the benefits of trees over directly connected impervious areas, as shown on the following figure.



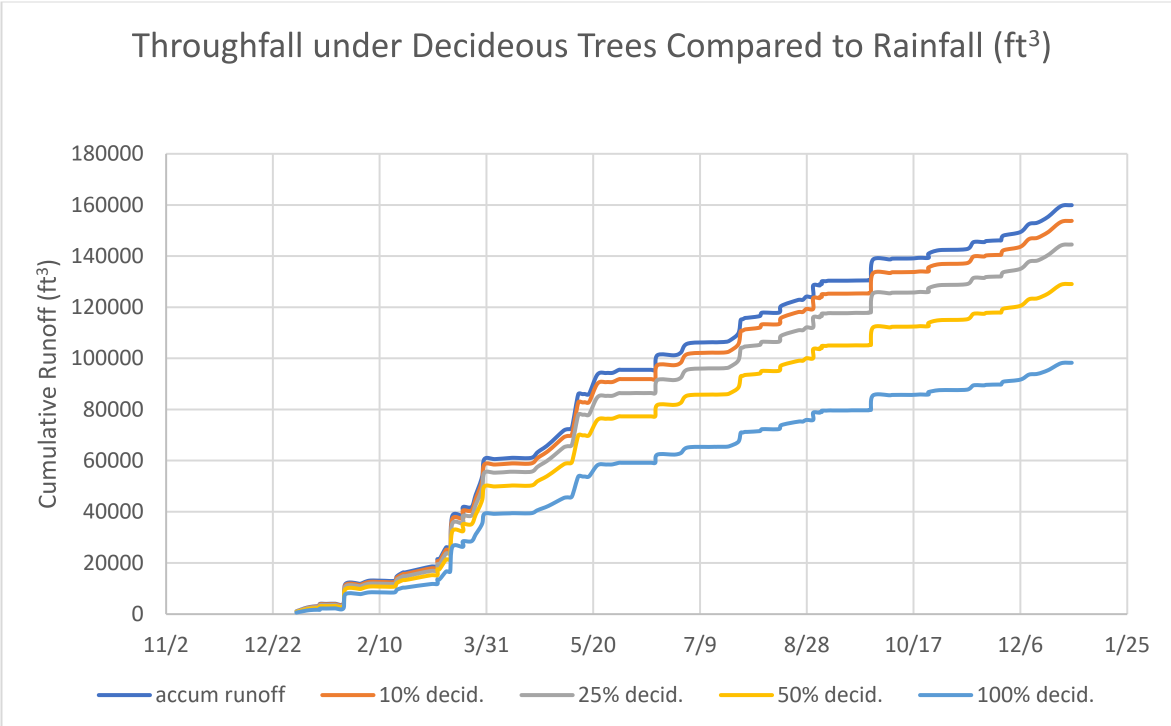
Tree canopy interception shading over directly connected impervious areas (shown in red outline).

The following screen shot of a paved parking area in WinSLAMM shows how the tree canopy shading values are entered for directly connected areas.



Paved parking area information input screen.

The following plots show cumulative runoff for one year (1977, previously identified as being close to an average rain year in total amount, monthly distribution, and numbers of events) of rains for Birmingham, AL, from a one-acre paved parking area having varying amounts of shading by tree canopies. The deciduous trees show the greatest potential benefit. With 100% shading, the deciduous trees may provide about 35% reductions in runoff from paved areas. The benefits are linear, with half this maximum benefit with 50% canopy shading, for example. The conifer example shows much smaller benefits, especially for the early months of the year. The maximum benefit of shading of impervious areas by conifer trees are about half of the canopy interception benefit of the oak tree. Both the pine and oak had almost complete interception of the smallest rains monitored, but the pine's interception benefits decreased much more rapidly as the rain depths increased.



There relatively low runoff reduction values are in contrast with rural forested areas where the runoff amounts of heavily wooded areas (both conifers and deciduous trees) is very small. These major forest benefits are mostly associated with the forest duff (thick layers of partially and completely decomposed organic material) beneath the trees and large infiltration rates. In urban areas (especially for thinly planted or isolated trees, if relatively young and with common leaf removal by homeowners), the benefits of trees on underlying soils is important, but much reduced compared to thick stands of mature trees having deep layers of organic material covering the soil. Duff has no effect on paved areas, although it may build up near the trunk in tree planter boxes or other small areas. Therefore, the main effect of urban trees on urban hydrology is the limited canopy interception amounts.

Continued throughfall measurements are planned for smaller urban trees. Other monitoring planned include throughfall measurement variations under trees and rainfall distributions surrounding trees, amongst other tasks.

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Appendix A: Interception Data Summaries for Winter and Spring Rains

Grass event summaries										
event #	Season	beginning time	ending time	interevent time (days)	rain duration (hrs)	Grass total rain (in)	avg int (in/hr)	30-min avg wind speed (mph)	peak wind speed (mph)	peak rain int (in/hr)
1	Winter	12/7/2018 23:13	12/10/2018 20:07	6.4	68.9	2.27	0.033	8	23	1.03
2	Winter	12/14/2018 03:24	12/14/2018 17:24	3.3	14.0	0.38	0.027	3	14	0.35
3	Winter	12/15/2018 02:47	12/15/2018 20:09	0.4	17.4	0.07	0.004	1	7	<0.01
6	Winter	12/19/2018 21:29	12/21/2018 11:17	4.1	37.8	1.10	0.029	6	18	0.23
7	Winter	12/27/2018 07:12	12/28/2018 07:09	5.8	24.0	4.90	0.205	4	18	3.56
9	Winter	12/29/2018 19:04	12/30/2018 07:47	1.5	12.7	0.20	0.016	3	8	1.46
10	Winter	12/31/2018 15:24	1/1/2019 02:59	1.3	11.6	1.25	0.108	2	8	3.76
11	Winter	1/2/2019 08:54	1/3/2019 08:45	1.2	23.8	0.56	0.023	3	11	1.68
12	Winter	1/3/2019 17:21	1/5/2019 00:59	0.4	31.6	1.28	0.040	4	16	1.24
13	Winter	1/12/2019 13:52	1/12/2019 18:42	7.5	4.8	0.65	0.135	4	11	0.58
14	Winter	1/17/2019 08:28	1/17/2019 19:27	4.6	11.0	0.10	0.009	1	6	0.10
15	Winter	1/19/2019 03:40	1/19/2019 17:56	1.3	14.3	1.20	0.084	4	17	8.35
16	Winter	1/23/2019 07:41	1/24/2019 03:40	3.6	20.0	2.99	0.150	4	13	3.79
17	Winter	1/29/2019 03:13	1/29/2019 11:15	5.0	8.0	0.21	0.026	3	13	0.18
18	Winter	2/4/2019 09:59	2/4/2019 10:34	5.9	0.6	0.03	0.051	1	4	0.18
19	Winter	2/5/2019 23:43	2/6/2019 08:05	1.5	8.4	0.22	0.026	1	7	2.48
20	Winter	2/11/2019 16:02	2/11/2019 16:28	5.3	0.4	0.02	0.046	1	4	<0.01
21	Winter	2/12/2019 03:20	2/12/2019 13:56	0.5	10.6	0.97	0.092	3	11	2.34
22	Winter	2/15/2019 19:33	2/16/2019 04:13	3.2	8.7	0.14	0.016	2	9	0.97
23	Winter	2/17/2019 06:19	2/18/2019 02:12	1.1	19.9	0.42	0.021	3	17	0.69
24	Winter	2/19/2019 00:00	2/20/2019 18:08	0.9	42.1	1.62	0.038	7	22	0.98
26	Winter	2/21/2019 01:31	2/22/2019 09:46	0.3	32.3	1.79	0.056	4	12	2.76
26	Winter	2/23/2019 00:38	2/24/2019 00:22	0.6	23.7	1.25	0.053	2	13	4.06
27	Winter	2/25/2019 13:49	2/25/2019 13:58	1.6	0.1	1.04	7.131	2	8	n/a
28	Winter	2/28/2019 03:30	2/28/2019 12:06	2.6	8.6	0.82	0.095	1	7	1.45
72	Winter	12/6/19 11:37	12/6/19 13:02	5.4	1.4	0.34	0.24	0.5	5	0.43
73	Winter	12/9/19 22:59	12/10/19 23:51	3.4	24.9	1.11	0.04	1	5	1.1
74	Winter	12/13/19 1:21	12/13/19 22:10	2.1	20.8	0.23	0.01	2	10	0.06
75	Winter	12/16/19 21:23	12/17/19 4:59	3.0	7.6	0.69	0.09	1	7	0.37
76	Winter	12/21/19 14:53	12/23/19 11:09	4.4	44.3	2.83	0.06	1.5	18	0.31
77	Winter	12/29/19 3:51	12/29/19 21:46	5.7	17.9	0.74	0.04	1	10	0.61
78	Winter	1/2/20 3:02	1/4/20 6:57	3.2	51.9	3.86	0.07	1.5	10	0.5
29	Spring	3/2/2019 08:22	3/2/2019 09:17	1.8	0.9	0.05	0.055	1	6	0.24
30	Spring	3/3/2019 08:47	3/3/2019 13:16	1.0	4.5	1.93	0.431	3	10	5.43
31	Spring	3/8/2019 06:35	3/8/2019 08:07	4.7	1.5	0.02	0.013	1	6	<0.01
32	Spring	3/9/2019 15:45	3/9/2019 15:59	1.3	0.2	0.04	0.169	2	9	0.42
33	Spring	3/10/2019 02:26	3/10/2019 04:22	0.4	1.9	0.18	0.093	3	10	0.55
34	Spring	3/11/2019 09:37	3/11/2019 12:25	1.2	2.8	0.10	0.036	3	11	0.05
35	Spring	3/14/2019 16:44	3/14/2019 22:33	3.2	5.8	0.39	0.067	2	13	2.33
36	Spring	3/25/2019 09:14	3/25/2019 16:43	10.8	7.5	0.39	0.052	1	8	10.90
37	Spring	3/30/2019 22:49	3/31/2019 03:31	16.2	4.7	0.66	0.140	4	15	2.39
38	Spring	4/4/2019 19:50	4/4/2019 21:37	4.8	1.8	0.08	0.045	1	4	0.07
39	Spring	4/5/2019 04:43	4/5/2019 09:30	0.5	4.8	0.03	0.006	1	5	<0.01
40	Spring	4/6/2019 19:16	4/7/2019 03:48	1.8	8.5	0.60	0.070	1	10	4.50
41	Spring	4/8/2019 11:36	4/8/2019 12:24	1.4	0.8	0.20	0.245	1	5	1.17

42	Spring	4/9/2019 07:48	4/9/2019 11:10	0.9	3.4	1.12	0.332	2	8	4.11
43	Spring	4/13/2019 07:00	4/13/2019 10:20	4.0	3.3	0.07	0.021	2	10	0.11
44	Spring	4/14/2019 01:29	4/14/2019 05:59	0.8	4.5	1.72	0.383	2	8	4.61
45	Spring	4/14/2019 19:12	4/14/2019 20:52	0.6	1.7	0.02	0.012	2	11	0.07
46	Spring	4/18/2019 18:44	4/20/2019 08:15	3.9	37.5	2.49	0.066	1	15	0.33
47	Spring	4/25/2019 14:12	4/25/2019 17:49	5.2	3.6	0.29	0.080	1	6	0.2
48	Spring	4/26/2019 01:47	4/26/2019 03:00	0.3	1.2	0.05	0.041	0.5	6	0.23
49	Spring	5/2/2019 03:45	5/2/2019 09:36	6.0	5.8	0.54	0.092	1	8	3.84
50	Spring	5/4/2019 06:15	5/4/2019 06:35	1.9	0.3	0.06	0.185	0.5	5	0.25
51	Spring	5/4/2019 16:31	5/5/2019 04:26	0.4	11.9	0.75	0.063	1	8	0.26
52	Spring	5/9/2019 12:19	5/9/2019 17:21	4.3	5.0	0.82	0.163	1	8	2.21
53	Spring	5/10/2019 18:33	5/10/2019 23:33	1.0	5.0	0.09	0.018	0	0	<0.01
54	Spring	5/11/2019 07:13	5/12/2019 12:33	0.3	29.3	1.27	0.043	0.5	5	0.81
55	Summer	6/5/19 20:42	6/8/2019 15:10	24.3	60.7	1.44	0.022	0.5	6	1.14
56	Summer	6/9/19 17:31	6/9/2019 18:48	1.1	1.6	0.39	0.304	0.5	6	2.12
57	Summer	6/17/19 22:54	6/17/2019 22:57	8.2	0.1	0.05	0.989	0	2	1.31
58	Summer	6/18/19 17:40	6/19/2019 03:06	0.8	10.3	0.29	0.031	0.5	7	2.33
59	Summer	6/20/19 3:18	6/20/2019 07:06	1.0	0.1	0.07	0.018	0	0	<0.01
60	Summer	6/22/19 15:05	6/22/2019 20:32	2.3	4.8	0.37	0.068	1	11	2.23
61	Summer	6/26/19 19:23	6/26/2019 19:34	4.0	0.1	0.06	0.348	1	11	0.58
62	Summer	6/30/19 15:46	6/30/2019 18:22	3.8	0.1	0.33	0.126	0.5	10	5.43
63	Summer	7/3/19 13:34	7/3/2019 18:57	2.8	3.9	0.27	0.050	0.5	7	3.31
64	Summer	7/4/19 15:10	7/4/2019 17:33	0.8	0.1	0.07	0.029	0.5	6	0.36
65	Summer	7/7/19 12:14	7/7/2019 12:52	2.8	0.6	0.18	0.280	0.5	12	2.43
66	Summer	7/13/19 11:52	7/13/2019 12:23	6.0	0.6	0.42	0.795	0.5	4	2.09
67	Summer	7/14/19 16:59	7/14/2019 20:16	1.2	0.3	0.24	0.073	0.5	8	2.23
68	Summer	7/20/19 14:22	7/20/2019 14:27	5.8		0.04	0.554	0.5	8	0.84
69	fall	11/22/19 1:41	11/23/19 9:13	n/a	19.5	1.63	0.083	1.0	13	1.18
70	fall	11/26/19 19:49	11/27/19 7:09	3.4	11.3	0.46	0.041	1.5	15	1.24
71	fall	11/30/19 23:58	12/1/19 3:07	3.7	3.2	0.18	0.057	1.0	14	1.19

Grass Event Summaries: All Season Combined							
	interevent time (days)	rain duration (hrs)	total rain (in)	avg int (in/hr)	30-min avg wind speed (mph)	peak wind speed (mph)	peak rain int (in/hr)
number	74	74	75	75	75	75	68
total:		900.0	55.7				
min	0.3	0.1	0.02	0.0	0.0	0.0	0.1
max	24.3	68.9	4.90	7.1	8.0	23.0	10.9
avg	3.4	12.2	0.74	0.2	1.8	9.5	1.8
median	2.7	5.8	0.39	0.1	1.0	8.0	1.2
stdev	3.7	15.0	0.9	0.8	1.6	4.6	2.0
COV	1.09	1.23	1.25	3.91	0.87	0.49	1.12

Grass Event Summaries: Winter Season							
	interevent time (days)	rain duration (hrs)	total rain (in)	avg int (in/hr)	30-min avg wind speed (mph)	peak wind speed (mph)	peak rain int (in/hr)
number	32	32	32	32	32	32	29
total:		624.1	35.3				
min	0.3	0.1	0.02	0.0	0.5	4.0	0.1
max	7.5	68.9	4.90	7.1	8.0	23.0	8.4
avg	3.0	19.5	1.10	0.3	2.7	11.3	1.6
median	3.1	15.8	0.78	0.0	2.0	10.5	1.0
stdev	2.1	16.0	1.2	1.3	1.8	5.1	1.8
COV	0.69	0.82	1.05	4.41	0.69	0.45	1.14

Grass Event Summaries: Spring Season							
	interevent time (days)	rain duration (hrs)	total rain (in)	avg int (in/hr)	30-min avg wind speed (mph)	peak wind speed (mph)	peak rain int (in/hr)
number	26	26	26	26	26	26	23
total:		158.5	13.96				
min	0.3	0.2	0.02	0.006	0.0	0.0	0.05
max	16.2	37.5	2.49	0.431	4.0	15.0	10.90
avg	3.0	6.1	0.54	0.112	1.5	8.1	1.96
median	1.6	4.0	0.25	0.067	1.0	8.0	0.55
stdev	3.6	8.6	0.67	0.116	1.0	3.4	2.63
COV	1.19	1.41	1.24	1.03	0.64	0.42	1.34

Grass Event Summaries: Summer Season							
	interevent time (days)	rain duration (hrs)	total rain (in)	avg int (in/hr)	30-min avg wind speed (mph)	peak wind speed (mph)	peak rain int (in/hr)
number	14	14	14	14	14	14	13
total:		83.4	4.22				
min	0.8	0.1	0.04	0.018	0.0	0.0	0.36
max	24.3	60.7	1.44	0.989	1.0	12.0	5.43
avg	4.6	6.4	0.30	0.263	0.5	7.0	2.03
median	2.8	0.6	0.26	0.100	0.5	7.0	2.12
stdev	6.1	16.6	0.36	0.312	0.3	3.4	1.33
COV	1.32	2.58	1.18	1.19	0.55	0.49	0.65

Grass Event Summaries: Fall Season							
	interevent time (days)	rain duration (hrs)	total rain (in)	avg int (in/hr)	30-min avg wind speed (mph)	peak wind speed (mph)	peak rain int (in/hr)
number	2	3	3	3	3	3	3
total:		34.0	2.3				
min	3.4	3.2	0.18	0.0	1.0	13.0	1.2
max	3.7	19.5	1.63	0.1	1.5	15.0	1.2
avg	3.6	11.3	0.76	0.1	1.2	14.0	1.2
median	3.6	11.3	0.46	0.1	1.0	14.0	1.2
stdev	0.2	8.2	0.8	0.0	0.3	1.0	0.0
COV	0.05	0.72	1.02	0.36	0.25	0.07	0.03

Pine event summaries								
event #	Season	beginning time	ending time	interevent time (days)	rain duration (hrs)	Pine total rain (in)	pine/grass rain total ratio	avg int (in/hr)
1	Winter	12/7/2018 23:32	12/10/2018 20:04	6.4	68.5	3.36	1.48	0.049
2	Winter	12/14/2018 04:08	12/14/2018 17:45	3.3	13.6	0.56	1.47	0.041
3	Winter	12/15/2018 13:48	12/15/2018 20:09	0.8	6.3	0.04	0.57	0.006
5	Winter	12/19/2018 21:59	12/21/2018 10:57	4.1	37.0	1.22	1.11	0.033
6	Winter	12/27/2018 14:40	12/28/2018 08:16	6.2	17.6	5.48	1.12	0.311
7	Winter	12/29/2018 20:33	12/31/2018 05:28	1.5	32.9	0.28	1.40	0.009
9	Winter	12/31/2018 15:35	1/1/2019 03:05	0.4	11.5	0.93	0.74	0.081
11	Winter	1/2/2019 08:56	1/3/2019 08:20	1.2	23.4	0.54	0.96	0.023
12	Winter	1/3/2019 16:09	1/4/2019 05:46	0.3	13.6	1.69	1.32	0.124
13	Winter	1/12/2019 14:13	1/12/2019 20:51	8.4	6.6	0.95	1.46	0.143
14	Winter	1/17/2019 08:55	1/18/2019 08:39	4.5	23.7	0.09	0.90	0.004
15	Winter	1/19/2019 03:59	1/19/2019 18:16	0.8	14.3	1.05	0.88	0.074
16	Winter	1/23/2019 08:04	1/24/2019 06:41	3.6	22.6	2.88	0.96	0.127
17	Winter	1/29/2019 03:30	1/29/2019 11:20	4.9	7.8	0.17	0.81	0.022
18	Winter	2/4/2019 10:11	2/4/2019 10:11	6.0	<1	0.01	0.33	n/a
19	Winter	2/5/2019 07:16	2/6/2019 06:57	0.9	23.7	0.18	0.82	0.008
20	Winter	2/11/2019 16:05	2/11/2019 23:55	5.4	7.8	0.04	2.00	0.005
21	Winter	2/12/2019 07:58	2/12/2019 14:45	0.3	6.8	0.78	0.80	0.115
22	Winter	2/15/2019 19:49	2/16/2019 04:18	3.2	8.5	0.07	0.50	0.008
23	Winter	2/17/2019 08:26	2/18/2019 02:16	1.2	17.8	0.35	0.83	0.020
24	Winter	2/19/2019 01:01	2/21/2019 05:49	0.9	52.8	2.19	1.35	0.041
26	Winter	2/21/2019 17:21	2/22/2019 09:29	0.5	16.1	1.32	0.74	0.082
26	Winter	2/23/2019 00:22	2/24/19 0:40	0.6	24.3	1.13	0.90	0.047
27	Winter	2/25/2019 14:08	2/25/2019 14:42	1.6	0.6	2.07	1.99	3.726
28	Winter	2/28/2019 04:39	2/28/2019 12:17	2.6	7.6	0.67	0.82	0.088
72	Winter	12/6/19 11:58	12/6/19 13:51	5.4	1.9	0.26	0.14	0.765
73	Winter	12/9/19 23:09	12/11/19 0:32	3.4	25.4	1.06	0.04	0.955
74	Winter	12/13/19 1:31	12/13/19 22:04	2.0	20.5	0.36	0.02	1.565
75	Winter	12/16/19 7:43	12/17/19 8:30	1.0	24.8	0.62	0.03	0.899
76	Winter	12/21/19 18:45	12/23/19 7:31	4.4	36.8	3.04	0.08	1.074
77	Winter	12/29/19 7:52	12/29/19 18:10	6.0	10.3	0.54	0.05	0.730
78	Winter	1/2/20 4:25	1/4/20 5:08	3.4	48.7	4.79	0.10	1.241
29	Spring	3/2/2019 08:44	3/2/2019 09:05	1.9	0.4	0.02	0.40	0.057
30	Spring	3/3/2019 08:48	3/3/2019 15:14	1.0	6.4	2.14	1.11	0.333
31	Spring	3/8/2019 06:35	no rain under pine	n/a	n/a	0.00	0.00	n/a
32	Spring	3/9/2019 15:45	no rain under pine	n/a	n/a	0.00	0.00	n/a
33	Spring	3/10/2019 02:27	3/10/2019 03:34	6.5	1.1	0.15	0.83	0.136
34	Spring	3/11/2019 09:39	3/11/2019 12:27	1.3	2.8	0.05	0.50	0.018
35	Spring	3/14/2019 20:50	3/14/2019 23:18	3.3	2.5	0.26	0.67	0.105
36	Spring	3/25/2019 15:54	3/25/2019 16:43	10.7	0.8	0.24	0.62	0.297
37	Spring	3/30/2019 22:56	3/31/2019 03:34	5.5	4.6	0.52	0.79	0.112
38	Spring	4/4/2019 20:57	4/4/2019 21:43	4.8	0.8	0.02	0.25	0.026
39	Spring	4/5/2019 06:26	4/5/2019 10:11	0.5	3.8	0.02	0.67	0.005
40	Spring	4/6/2019 21:02	4/7/2019 05:49	1.8	8.8	0.51	0.85	0.058
41	Spring	4/8/2019 11:43	4/8/2019 13:02	1.3	1.3	0.11	0.55	0.084
42	Spring	4/9/2019 07:59	4/9/2019 11:55	1.0	3.9	1.16	1.04	0.295
43	Spring	4/13/2019 08:57	4/13/2019 10:29	3.9	1.5	0.02	0.29	0.013
44	Spring	4/14/2019 02:47	4/14/2019 06:06	0.8	3.3	1.54	0.90	0.462
45	Spring	4/14/2019 20:02	4/14/2019 20:06	0.6	0.1	0.01	0.50	0.122
46	Spring	4/18/2019 18:56	4/20/2019 05:49	4.0	8.5	2.09	0.84	0.246
47	Spring	4/25/2019 14:42	4/25/2019 17:36	5.4	2.9	0.2	0.69	0.069

48	Spring	4/26/2019 01:50	4/26/2019 03:24	0.3	1.6	0.04	0.80	0.026
49	Spring	5/2/2019 03:46	5/2/2019 04:32	6.0	0.8	0.55	1.02	0.728
50	Spring	5/4/2019 06:28	5/4/2019 06:36	2.1	0.1	0.02	0.33	0.155
51	Spring	5/4/2019 16:57	5/5/2019 04:58	0.4	12.0	0.63	0.84	0.052
52	Spring	5/9/2019 12:25	5/9/2019 16:52	4.3	4.4	0.67	0.82	0.151
53	Spring	5/10/2019 11:44	5/10/2019 23:27	0.8	11.7	0.04	0.44	0.003
54	Spring	5/11/2019 20:47	5/12/2019 12:24	0.9	15.6	1.13	0.89	0.072
55	Summer	6/6/2019 02:35	6/8/2019 15:18	24.6	60.7	1.28	0.89	0.021
56	Summer	6/9/2019 17:35	6/9/2019 19:11	1.1	1.6	0.34	0.87	0.213
57	Summer	6/17/2019 22:59	6/17/2019 23:04	8.2	0.1	0.01	0.20	0.147
58	Summer	6/18/2019 17:43	6/19/2019 04:03	0.8	10.3	0.19	0.66	0.018
59	Summer	6/20/2019 07:06	6/20/2019 07:11	1.1	0.1	0.01	0.14	0.120
60	Summer	6/22/2019 15:08	6/22/2019 19:56	2.3	4.8	0.22	0.59	0.046
61	Summer	6/26/2019 19:29	6/26/2019 19:36	4.0	0.1	0.02	0.33	0.196
62	Summer	6/30/2019 18:20	6/30/2019 18:29	3.9	0.1	0.27	0.82	1.827
63	Summer	7/3/2019 13:37	7/3/2019 17:34	2.8	3.9	0.17	0.63	0.043
64	Summer	7/4/2019 17:25	7/4/2019 17:30	1.0	0.1	0.01	0.14	0.120
65	Summer	7/7/2019 12:16	7/7/2019 12:51	2.8	0.6	0.12	0.67	0.205
66	Summer	7/13/2019 11:56	7/13/2019 12:34	6.0	0.6	0.31	0.74	0.487
67	Summer	7/14/2019 20:09	7/14/2019 20:29	1.3	0.3	0.15	0.63	0.446
68	Summer	7/20/19 14:22	no rain under pine	n/a	n/a	0.00	0.00	n/a
69	fall	11/22/19 18:54	11/23/19 9:20	n/a	14.4	1.45	0.10	0.890
70	fall	11/27/19 3:16	11/27/19 7:21	3.7	4.1	0.34	0.08	0.739
71	fall	12/1/19 0:11	12/1/19 3:20	3.7	3.2	0.09	0.03	0.500

Pine Event Summaries: All Season Combined					
	interevent time (days)	rain duration (hrs)	Pine total rain (in)	pine/grass rain total ratio	avg int (in/hr)
number	71	71	75	75	71
total:		838.8	55.84		
min	0.3	0.1	0.00	0.00	0.00
max	24.6	68.5	5.48	2.00	3.73
avg	3.3	11.8	0.74	0.68	0.31
median	2.6	6.6	0.31	0.74	0.11
stdev	3.4	14.7	1.06	0.45	0.56
COV	1.06	1.25	1.43	0.67	1.80

Pine Event Summaries: Winter Season					
	interevent time (days)	rain duration (hrs)	total rain (in)	pine/grass rain total ratio	avg int (in/hr)
number	32	31	32	32	31
total:		634.0	38.72		
min	0.3	0.6	0.01	0.02	0.004
max	8.4	68.5	5.48	2.00	3.726
avg	3.0	20.5	1.21	0.84	0.400
median	2.9	17.6	0.73	0.83	0.081
stdev	2.2	15.5	1.37	0.55	0.755
COV	0.75	0.76	1.13	0.66	1.88

Pine Event Summaries: Spring Season					
	interevent time (days)	rain duration (hrs)	total rain (in)	pine/grass rain total ratio	avg int (in/hr)
number	24	24	26	26	24
total:		99.7	12.14		
min	0.3	0.1	0.00	0.00	0.003
max	10.7	15.6	2.14	1.11	0.728
avg	2.9	4.2	0.47	0.64	0.151
median	1.8	2.8	0.18	0.68	0.095
stdev	2.6	4.3	0.64	0.30	0.171
COV	0.91	1.02	1.37	0.47	1.13

Pine Event Summaries: Summer Season					
	interevent time (days)	rain duration (hrs)	total rain (in)	pine/grass rain total ratio	avg int (in/hr)
number	13	13	14	14	14
total:		83.4	3.10		
min	0.8	0.1	0.00	0.00	0.000
max	24.6	60.7	1.28	0.89	1.827
avg	4.6	6.4	0.22	0.52	0.278
median	2.8	0.6	0.16	0.63	0.133
stdev	6.4	16.6	0.33	0.30	0.470
COV	1.39	2.58	1.48	0.57	1.69

Pine Event Summaries: Fall Season					
	interevent time (days)	rain duration (hrs)	total rain (in)	pine/grass rain total ratio	avg int (in/hr)
number	2	3	3	3	3
total:		21.7	1.88		
min	3.7	3.2	0.09	0.03	0.500
max	3.7	14.4	1.45	0.10	0.890
avg	3.7	7.2	0.63	0.07	0.710
median	3.7	4.1	0.34	0.08	0.739
stdev	0.0	6.3	0.72	0.04	0.196
COV	0.01	0.87	1.16	0.53	0.28

Oak event summaries								
event #	Season	beginning time	ending time	interevent time (days)	rain duration (hrs)	Oak total rain (in)	oak/grass rain total ratio	avg int (in/hr)
1	Winter	12/7/2018 23:13	12/10/2018 20:07	6.4	68.9	2.27	1.00	0.033
3	Winter	12/14/2018 04:53	12/14/2018 17:48	3.4	12.9	0.18	0.47	0.014
4	Winter	12/15/2018 13:53	12/15/2018 20:03	0.8	6.2	0.04	0.57	0.006
6	Winter	12/19/2018 22:15	12/21/2018 10:09	4.1	35.9	0.71	0.65	0.020
7	Winter	12/27/2018 14:41	12/28/2018 04:40	6.2	14.0	1.75	0.36	0.125
8	Winter	12/29/2018 19:09	12/29/2018 19:09	1.6	<1	0.02	0.10	n/a
	Winter					?		
	Winter					?		
	Winter					?		
13	Winter	1/12/2019 14:54	1/12/2019 18:24	?	3.5	0.45	0.69	0.129
14	Winter	1/17/2019 11:45	1/18/2019 03:26	4.7	15.7	0.03	0.30	0.002
15	Winter	1/19/2019 04:08	1/19/2019 17:55	1.0	13.8	0.61	0.51	0.044
16	Winter	1/23/2019 08:02	1/24/2019 04:11	3.6	20.2	1.92	0.64	0.095
17	Winter	1/29/2019 03:25	1/29/2019 11:14	5.0	7.8	0.18	0.86	0.023
18	Winter			n/a	0.0	0.00	0.00	n/a
19	Winter	2/6/2019 00:17	2/6/2019 06:32	7.5	6.2	0.09	0.41	0.014
20	Winter			n/a	0.0	0.00	0.00	n/a
21	Winter	2/12/2019 03:26	2/12/2019 13:45	5.9	10.3	0.59	0.61	0.057
22	Winter	2/15/2019 19:58	2/16/2019 03:51	3.3	7.9	0.04	0.29	0.005
23	Winter	2/17/2019 09:37	2/18/2019 02:14	1.2	16.6	0.27	0.64	0.016
24	Winter	2/19/2019 00:04	2/20/2019 17:05	0.9	41.0	1.01	0.62	0.025
26	Winter	2/21/2019 00:12	2/22/2019 09:25	0.3	33.2	1.27	0.71	0.038
26	Winter	2/23/2019 00:40	2/24/2019 00:25	0.6	23.7	0.56	0.45	0.024
27	Winter	2/25/2019 14:20	2/25/2019 14:29	1.6	0.2	1.04	1.00	6.908
28	Winter	2/28/2019 04:33	2/28/2019 12:06	2.6	7.6	0.44	0.54	0.058
29	Spring	3/2/2019 08:36	3/2/2019 09:12	1.9	0.6	0.03	0.60	0.049
30	Spring	3/3/2019 09:25	3/3/2019 13:16	1.0	3.9	1.15	0.60	0.298
31	Spring		3/8/2019 06:35	n/a	n/a	0.00	0.00	n/a
32	Spring		3/9/2019 15:45	n/a	n/a	0.00	0.00	n/a
33	Spring	3/10/2019 02:28	3/10/2019 03:33	6.6	1.1	0.17	0.94	0.156
34	Spring	3/11/2019 09:39	3/11/2019 12:14	1.3	2.6	0.07	0.70	0.027
35	Spring	3/14/2019 20:49	3/14/2019 22:34	3.4	1.7	0.18	0.46	0.103
36	Spring	3/25/2019 15:54	3/25/2019 16:44	10.8	0.8	0.18	0.46	0.216
37	Spring	3/30/2019 22:56	3/31/2019 02:27	5.4	3.5	0.49	0.74	0.139
38	Spring	4/4/2019 19:50	4/4/2019 21:37			0.00	0.00	
39	Spring	4/5/2019 05:13	4/5/2019 05:18	5.1	0.1	0.01	0.33	0.123
40	Spring	4/6/2019 19:22	4/7/2019 03:08	1.9	7.8	0.28	0.47	0.036
41	Spring	4/8/2019 11:44	4/8/2019 12:19	1.4	0.6	0.04	0.20	0.069
42	Spring	4/9/2019 07:49	4/9/2019 11:10	1.0	3.3	0.69	0.62	0.206
43	Spring	4/13/2019 07:00	4/13/2019 10:20			0.00	0.00	
44	Spring	4/14/2019 01:50	4/14/2019 06:08	4.8	4.3	0.88	0.51	0.205
45	Spring	4/14/2019 19:12	4/14/2019 20:52			0.00	0.00	
46	Spring	4/18/2019 19:08	4/20/2019 06:39	3.9	9.0	1.22	0.49	0.135
47	Spring	4/25/2019 14:38	4/25/2019 17:11	5.3	2.6	0.12	0.41	0.047

48	Spring	4/26/2019 01:50	4/26/2019 03:15	0.4	1.4	0.03	0.60	0.021
49	Spring	5/2/2019 03:47	5/2/2019 04:27	6.0	0.7	0.26	0.48	0.391
50	Spring	5/4/2019 06:24	5/4/2019 06:47	2.1	0.4	0.03	0.50	0.079
51	Spring	5/4/2019 16:50	5/5/2019 04:51	0.4	12.0	0.48	0.64	0.040
52	Spring	5/9/2019 12:23	5/9/2019 16:41	4.3	4.3	0.51	0.62	0.119
53	Spring	5/10/2019 18:36	5/10/2019 20:52	1.1	2.3	0.03	0.33	0.013
54	Spring	5/11/2019 07:31	5/12/2019 12:27	0.4	28.9	0.84	0.66	0.029
55	Summer	6/6/2019 01:27	6/8/2019 15:03	24.5	61.6	0.54	0.38	0.009
56	Summer	6/9/2019 17:33	6/9/2019 18:43	1.1	1.2	0.29	0.74	0.247
57	Summer	6/17/2019 22:57	6/17/2019 23:05	8.2	0.1	0.02	0.40	0.143
58	Summer	6/18/2019 17:42	6/19/2019 03:07	0.8	9.4	0.15	0.52	0.016
59	Summer	6/20/2019 03:23	6/20/2019 07:08	1.0	3.8	0.02	0.29	0.005
60	Summer	6/22/2019 15:07	6/22/2019 19:48	2.3	4.7	0.21	0.57	0.045
61	Summer	6/26/2019 19:30	6/26/2019 19:36	4.0	0.1	0.02	0.33	0.190
62	Summer	6/30/2019 18:19	6/30/2019 18:24	3.9	0.1	0.22	0.67	2.393
63	Summer	7/3/2019 13:36	7/3/2019 19:29	2.8	5.9	0.14	0.52	0.024
64	Summer	7/4/2019 17:27	7/4/2019 17:33	0.9	0.1	0.02	0.29	0.202
65	Summer	7/7/2019 12:15	7/7/2019 12:46	2.8	0.5	0.12	0.67	0.235
66	Summer	7/13/2019 11:56	7/13/2019 12:32	6.0	0.6	0.21	0.50	0.350
67	Summer	7/14/2019 20:08	7/14/2019 20:28	1.3	0.3	0.12	0.50	0.365
68	Summer	7/20/2019 14:39	7/20/2019 14:44	5.8	0.1	0.01	0.25	0.120

Oak Event Summaries: All Season Combined					
	interevent time (days)	rain duration (hrs)	Oak total rain (in)	oak/grass rain total ratio	avg int (in/hr)
number	54	56	62	62	54
total:		525.8	23.25		
min	0.3	0.0	0.00	0.00	0.002
max	24.5	68.9	2.27	1.00	6.908
avg	3.6	9.4	0.38	0.47	0.268
median	2.8	3.8	0.18	0.50	0.058
stdev	3.8	14.5	0.50	0.25	0.977
COV	1.04	1.54	1.34	0.52	3.64

Oak Event Summaries: Winter Season					
	interevent time (days)	rain duration (hrs)	Oak total rain (in)	oak/grass rain total ratio	avg int (in/hr)
number	19	21	22	22	19
total:		345.5	13.47		
min	0.3	0.0	0.00	0.00	0.002
max	7.5	68.9	2.27	1.00	6.908
avg	3.2	16.5	0.61	0.52	0.402
median	3.3	12.9	0.45	0.55	0.025
stdev	2.3	16.7	0.67	0.27	1.576
COV	0.71	1.01	1.10	0.53	3.92

Oak Event Summaries: Spring Season					
	interevent time (days)	rain duration (hrs)	Oak total rain (in)	oak/grass rain total ratio	avg int (in/hr)
number	21	21	26	26	21
total:		91.8	7.69		
min	0.4	0.1	0.00	0.00	0.013
max	10.8	28.9	1.22	0.94	0.391
avg	3.3	4.4	0.30	0.44	0.119
median	2.1	2.6	0.15	0.49	0.103
stdev	2.7	6.4	0.37	0.26	0.099
COV	0.82	1.47	1.26	0.60	0.83

Oak Event Summaries: Summer Season					
	interevent time (days)	rain duration (hrs)	total rain (in)	oak/grass rain total ratio	avg int (in/hr)
number	14	14	14	14	14
total:		88.4	2.09		
min	0.8	0.1	0.01	0.25	0.005
max	24.5	61.6	0.54	0.74	2.393
avg	4.7	6.3	0.15	0.47	0.310
median	2.8	0.6	0.13	0.50	0.167
stdev	6.1	16.2	0.14	0.16	0.612
COV	1.31	2.56	0.97	0.33	1.97

Appendix B: Calibration Results

Grass Calibration Summaries:		
	1 inch calib	
Jan 7 calib	1.04	
Jan 8 calib	1.02	
Jan 26 calib	1.06	
Feb 25 calib	1.03	
March 23 calib	1.09	
March 24-1	1.05	
March 24-2	1.08	Replicate to check variation
March 24-3	1.07	Replicate to check variation
March 24-4	1.06	Replicate to check variation
March 24-5	1.08	Replicate to check variation
March 24-6	1.04	Replicate to check variation
March 24-7	1.07	Replicate to check variation
March 24-8	1.04	Replicate to check variation
March 24-9	1.04	Replicate to check variation
Apr 16 calib	1.08	with small debris
Apr 16 calib	1.08	with small debris removed
June 3 calib	1.04	
July 25 calib	1.04	
Nov 11 calib	1.04	
Jan 24 2020 calib	1.04	minor leaf debris
Jan 24 2020 calib	1.04	after minor leaf debris removed
number	21	
min	1.02	
max	1.09	
avg	1.05	
med	1.06	
stdev	0.02	
COV	0.02	

Pine Calibration Summary:			
calib 1 Jan 7 2019		1.03	
calib 2 Jan 8 2019		1.04	
calib 3 Jan 26 2019		1.06	
calib 4 Jan 26 2019		1.03	
calib 5 Feb 25 2019		1.02	(with piece of bark on screen)
calib 6 Feb 25 2019		1.03	(after removal of bark)
March 23 calib		1.02	with small debris
March 23 calib		1.04	with small debris removed
Apr 16 calib		1.04	with small debris
Apr 16 calib		1.04	with small debris removed
June 3 calib		1.07	with small debris
June 3 calib		1.05	with small debris removed
July 25 calib		1.06	with small debris
July 25 calib		1.04	with small debris removed
Nov 20 calib		1.04	after cleaning and reset (Jan calib not recorded due to reset in Dec)
	number	15	
	min	1.02	
	max	1.07	
	avg	1.04	
	med	1.03	
	stdev	0.01	
	COV	0.01	

Oak Calibration Summaries:		
	calib value (compared to 1.00)	
jan 7 calib X	0.85	too low; didn't use data due to leaf stem interferences on tip?
jan 8 calib 1	1.02	
jan 26 calib 2	1.02	
jan 26 calib 3	1.02	
feb 25 2019	1.03	
23-Mar	1.03	with small debris
23-Mar	1.07	small debris removed
Apr 16 calib	1.03	with small debris
Apr 16 calib	1.05	with small debris removed
june 3 calib	1.05	with small debris
june 3 calib	1.03	small debris removed
July 25 calib	1.03	with small debris
July 25 calib	1.04	with small debris removed
Nov 20 calib	1.02	
Jan 24 2020 calibX	0.63	minor leaf debris; long stem likely interferred with tipping mech; son't use data
Jan 24 2020 calib	1.03	after removal of debris
ignoring calib X		
number	14	
min	1.02	
max	1.07	
avg	1.03	
med	1.03	
stdev	0.01	
COV	0.01	