EVALUATION OF THE EFFECT OF CANOPY COVER ON THE VOLUME AND INTENSITY OF RAIN THROUGHFALL

by

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ABSTRACT OF THESIS
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Increasing storm water runoff and decreasing storm water quality plague areas of the country experiencing rapid population growth and the accompanying changes in land use from forest and farm to residential and commercial. Increasing runoff is the result of several factors, including soil compaction and increases in impermeable surfaces. Another directly contributing factor may also be the decrease in tree canopy cover. This study was performed to determine whether or not quantifiable differences occur in the volume and intensity of rain throughfall between areas with good canopy cover and open areas.

With the permission of the developers of a planned community in Shelby County, Alabama, rain gauges were placed in an open area and adjacent areas with intact canopy cover. Rain was measured for a period of 12 consecutive months. The intensity and volume of rainwater reaching the ground in the open area was compared with the intensity and volume of rain reaching the ground in the areas with canopy cover.

DEDICATION

This paper is dedicated to the memory of my father. I only wish that he had been able to see me complete another step one year later. His sacrifices did not go unnoticed nor has the presence of a father's love gone unnoticed. I can only say thank you and I love you dad.

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Finally I would like to thank Ken, Heather , Kyle, and Mary. You four have tolerated the burdens of a sometimes-moody graduate student with the up most support. Mary deserves special thanks. Without your pushing and helpful "nagging" I would not have completed this research project. You have helped to make me a better person, and for that I want to say thank you.

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INTRODUCTION

Increasing storm water runoff and decreasing storm water quality plague areas of the country experiencing rapid population growth and the accompanying changes in land use from forest and farm to residential and commercial. Increasing runoff is the result of several factors, including soil compaction and increases in impermeable soil surfaces. Another directly contributing factor may also be the decrease in tree canopy cover. This study was performed to determine whether or not quantifiable differences occur in the volume and intensity of rain throughfall between areas with good canopy cover and open areas.

The population of Shelby County Alabama is increasing at a rate that puts it in the top 4% nationally. The area population has nearly doubled in the past 10 years. In spite of storm water runoff concerns, the current status quo for building in Alabama is to strip an area of tree cover before starting construction. Vast acreage along the 280 corridor has been clear cut for development. Pictures taken as development of specific areas progressed showed clear evidence of severe erosion control management problems, including but not limited to mud completely covering erosion control fences, mud clogging drains, severe scouring on hillsides, and retention ponds filling completely with mud. A new look at development practices, which might promote better stewardship of the land, was clearly called for. One area of interest is the role canopy cover plays in intercepting rainfall and reducing both volume and intensity of throughfall. A planned community near the 280 corridor provided the ideal location to investigate whether leaving existing canopy cover in place had an impact on the rainfall reaching the ground. The community had open areas, including a small public commercial area and parking lot, but was composed mostly of individual residential home sites with only the footprint of the house cleared. Other development techniques were also in place to reduce stormwater runoff volume. Sidewalks were pavers, and parking areas for several public parks were permeable pavers. The developer described the property as follows:

> "The Mt Laurel development team is dedicated to saving the existing trees, hills and natural watersheds at Mt Laurel. The philosophy behind this policy is rooted in the belief that we should work with the land, not in opposition to it. Thus, grading is minimized and trees preserved (tree saving includes groups of various sizes and types of trees, not just a single larger tree); high points in the landscape and natural drainage corridors are safeguarded; plants, trees, ground cover and stone removed during construction are reused later in the construction process whenever possible; and landscaping is limited to native plants" (Mt Laurel, EBSCO Development Company, Inc., 2001-2003)

Mount Laurel developers gave this researcher permission to collect data throughout the development for the duration of the study reported here.

PREVIOUS STUDIES

Some initial studies were done around the early to mid-1900s. It is known that percent reduction by canopy interception in Conifer stands ranges from 15% to 40%, and in hardwood stands it ranges from 10% to 20% (Zinke, 1967). The first rainfall interception models relied on balance equations based on the canopy surface water storage (Rutter et al., 1971, 1975; Rutter and Morton, 1977). Factors such as drip from the canopy, evaporation in the canopy, and the amount of rainfall above the canopy were included in the research. Although the Rutters equation has been modified over the years and has been modified for urban water studies out west (Xiao, 1998), none of the researched studies included significantly large sample sizes. The search continued for more current research that would stand up to statistical analysis as well as providing a simpler understanding of the reduction amount, if any, for developers. Other studies were found that dealt with the run-off and statewide rain intensity. Both of these variables are found in the Revised Universal Soil Loss Equation (RUSLE) soil loss equation and the TR-55 run-off calculation method. The TR-55 method also incorporates the variable of land cover, but most of the effect of land cover is incorporated into the time of concentration or travel time for run-off. These aspects of the TR-55 are for calculating the time of runoff, or how the forested area affects the rainfall runoff after it has contacted the ground. The RUSLE predicts rill and interill erosion.

The variables in the RUSLE equation are defined below.

$$A = (R) * (K) * (LS) * (C) * (P) \tag{1}$$

A = total soil loss

R = the rain energy factor for the time period,

K = soil erodibility factor

LS = length of slope

C = degree of soil cover factor,

P = conservation practices (agricultural tilling, not construction sit control).

Looking at the variables above, there is not a quantified value that is applicable to testing the hypothesis of this project.

A few current studies have looked at issues more relevant to this project. One study, *What is the Canopy Effect on Rainfall Amount and its Chemical Composition?* (Enloe), was conducted in the rainforest of Costa Rica. This particular study looked at the effect the canopy cover had on the rainfall amount and the ph. The study used four 250 ml buckets. Two buckets were located in an area with no canopy cover, and the other two were located underneath the rainforest canopy cover. The sites were located approximately 100 m apart. The canopy-covered area was determined to provide 80%-100% canopy cover by sighting it through a 4 cm circle held over the buckets. The buckets were partially buried in the ground for stability. The bucket samples were collected on 24-hr intervals, and the collected rainfall amount was measured on site, (results are shown in Table 1).

The results indicate that tree canopy permanently intercepts a significant amount of rainfall. The trend in this study shows that the larger volume storms have a smaller

TABLE 1. Results of Rainforest Study
(Enloe)

Time Hr:min	Field Volume (mL)	Forest Volume(mL)	Difference (%)	Standard Deviation
16:30	14.0	5.5	-60.71	6.01
22:30	33.5	12.0	-64.18	15.20
7:00	73.0	40.0	-45.21	23.33
10:30	106.0	96.5	-8.96	6.72

percent reduction. However, some questions arise from this study. Is the smaller percent difference due to the fact the intensity of the last two storms was greater than the intensity of the first two storms? The time intervals for the last two events are the shortest, but they are also the two largest in volume. The second question concerns sample size. It is difficult to reject or fail to reject a hypothesis with just four samples.

The second study *Rainfall Interception by Sacramento's Urban Forest* (Xiao, 1998) looked at the effect the urban forest had on the volume of rainfall. Remote sensing and ground sampling was used to obtain the rainfall amounts. This study began to apply a model to describe the canopy reduction effect by looking at the gross precipitation, leaf drip, stem flow, and evaporation. The results are shown in Table 2 and Table 3.

Table 2 results showed that the type of tree or type of canopy cover impacts the amount of reduction measured during a rain event. These values were calculated based on five events. The larger the leaf structure the larger the percent reduction, which implies that the more surface area present the larger the amount of evaporation. Table 3 provided the percent reduction of rainfall by canopy cover based on location instead of tree species.

TABLE 2. Percent Reduction in Sacramento Study Based on Species (Xiao,1998).

Reduction by type of Area and Tree makeup		
% Reduction	Leaf Area Index	Tree Type
36%	6.1	Large broadleaf evergreen and conifers
18%	3.7	Medium size conifers and deciduous trees

TABLE 3. Percent Reduction in Sacramento Study Based on Land Use (Xiao,1998).

Overall Results	
Location	% Reduction
Urban Forest Canopy Cover	11.1%
Entire County	1.1%

METHODOLOGY

The hypothesis of this study is that the rain throughfall in the canopy-covered area is less than the rainfall in the open area, and the intensity of rainfall in the canopy-covered area is less than the intensity in the open area. Data to determine the validity of this hypothesis were acquired through the use of rain gauges equipped with data loggers. Each rain gauge operated by using a tipping bucket, with metal contacts that completed a circuit when the bucket tipped. The battery in the data logger supplied the current. The data loggers assigned and recorded a number to each tip as well as the date and time of each tip. Each successive tip was assigned a number by an increasing value of one. The data loggers downloaded the recorded data onto a laptop computer through a serial port cable using the Boxcar software that came with the data loggers. The files were then imported into a spreadsheet program such as Excel for analysis.

The data imported into Excel showed date in one column, time in another column, and the tip number in a third column. Table 4 is a small sample of the format of the data once it is input into Excel.

This recording period started on 11/2/2002 at 14:00:00. This time was assigned a zero for its tip number as the starting point for recording tips. The first .01" of rain fell the next day, 11/03/2002 at 14:37:15, which is 2:37:15 p.m. The time format can be displayed any number of ways in Excel. Twenty-four hour or "Military" time was chosen for the visual convenience of discerning start and stop times. For example, if there were two recorded events on the same date that both occurred around 2 o'clock

TABLE 4. Sample of Format of Recorded Values From Data Logger in Military Time.

Date	Time	Tip #
11/2/2002	14:00:00	0
11/3/2002	14:37:15	1
11/3/2002	14:37:15	2
11/3/2002	15:28:29	3
11/3/2002	15:33:46	4
11/3/2002	15:33:46	5
11/3/2002	15:36:47	6
11/3/2002	15:39:39	7

but one was a.m. and the other was p.m., it would be easy to mistake them for one event instead of two.

Table 5 is an example of how the 12-hr time format can mislead the eyes when looking through a column of over one thousand entries. The rain events are considered to be two different events if there is at least 4 hr between tips, meaning that between tips 4 and 5 there was a time lapse of 12 hr, so tip 4 would represent the end of the first rain event and tip 5 would represent the beginning of the second rain event.

The storms are not broken down into separate events if the storm carries into the next day. For the first two dates listed in Table 6, 10/6/2002 and 10/7/2002, the tips continued throughout the night of the 6th into the 7th without a 4-hr time difference between tips. Excel is unable to give a total time for a rain event if the event continues through the midnight hour. Even if converted to military time, the subtraction function in Excel tries to subtract, for example, 4 o'clock in the morning from 10 o'clock the night before. Even if military time is used, Excel still tries to subtract 4 from 22, which returns an "unable to calculate" response. The Time of Rain column represents the total time of

TABLE 5. Sample of Format of Recorded Values From Data Logger not in Military Time.

Date	Time	Tip #
11/2/2002	2:00:00 a.m.	0
11/3/2002	2:37:15 a.m.	1
11/3/2002	2:37:15 a.m.	2
11/3/2002	3:28:29 a.m.	3
11/3/2002	3:33:46 a.m.	4
11/3/2002	3:33:50 p.m.	5
11/3/2002	3:36:58 p.m.	6
11/3/2002	3:39:39 p.m.	7

rain on that date. Because the rain event carried over to the next day, the Time of Event column shows the combining of the time for the 6th and 7th into one event. Also the # Tips column shows the number of tips on each day. Because the event carried over from the 6th to the 7th, the number of tips will be combined as well. Each tip represents .01inches, so the number of tips is divided by 100 to get the equivalent amount of rain.

TABLE 6. Sample of Organization of Calculated Values.

Date (Month/Day/Year)	Event #	Time of Rain (Hr:Min:Sec)	Time of Event (Hr:Min:Sec)	# Tips	# Of Tips Per Event	Total Rainfall Per Event	Event Intensity (in/hr)
10/6/2002		7:33:08	-	101	-	-	-
10/7/2002	1	13:56:22	21:29:29	108	209	2.09	2.33
10/10/2002		12:17:33	-	12	-	-	-
10/11/2002	2	7:00:19	19:17:52	13	25	0.25	0.31
10/12/2002	3	0:48:24	0:48:24	60	60	0.60	17.85
10/15/2002	4	19:42:33	19:42:33	66	66	0.66	0.80
10/16/2002	5	0:00:00	0:00:00	1	1	0.01	0.00
10/20/2002	6	9:32:12	9:32:12	13	13	0.13	0.33
10/23/2002	7	0:33:29	0:33:29	2	2	0.02	0.86
10/25/2002	8	0:37:42	0:37:42	2	2	0.02	0.76

Equipment

Four rain gauges with recording ability were prepared for use in this study. Three of the gauges were Qualimetric 6011-A rain gauges with HOBO Event Data Loggers. The Qualimetric rain gauges use a tipping bucket style method of measuring the rainfall.

The HOBO data logger components are kept in a weatherproof enclosure placed inside the utility box on the Qualimetric rain gauges. The HOBO data loggers have a recording capacity for 8000 tips (80 inches once calibrated), preprogrammed start and stop times, replaceable battery, an LED light that flashes to signal functionality, and a connection port for programming and downloading that connects through the serial port.

The fourth rain gauge was an ONSET RG2 Data Logging Rain Gauge. It is smaller than the other three Qualimetric rain gauges. Inside of the ONSET rain gauges is a tipping bucket that is very similar in operation to the Qualimetric rain gauges and uses the same HOBO data logger. The data loggers record a date and time stamp every time the tipping bucket completes the circuit, using the electricity from the battery in the data logger. Once calibrated, all four rain gauges tip every .01" (inches) of collected rainfall. The water that is collected in the tipping buckets passes through drain holes in the bottom of the rain gauges to keep rainfall from collecting in the rain gauge. All four rain gauges have a debris screen on top, which keeps leaves and large particles from falling through and potentially clogging the funnel that leads to the tipping buckets. Rain gauges were calibrated according to manufacturer's instructions.

Software

Boxcar version 3.7.3 was used to program the data loggers to record the tips. Connection to the data loggers is made through a cable that connects to the serial port on a computer running a Microsoft Windows based operating system. This cable then connects to a 2.5 mm sensor cable port that is contained inside the data logger. The Boxcar software clock programs the date and time values into the data logger. A delayed start time can be programmed for the data loggers as well. The retrieval of the data uses the same interface cable. The Boxcar software can produce a plot that shows the tip number on the y-axis and the date on the x-axis. This is not as useful as its ability to export the data in a text file format that is preset to be easily imported into Excel. Once imported into Excel the data is presented with the date of the tip in the first column, the time of the tip in the second column, and the tip number in the third column. It is important to note that the tip number is different from the number of tips. The data logger and its software cannot compute the start and end times of the rain events, therefore the software can not calculate or record the number of tips per event. The start and end time of the events as well as the number of tips per event is to be defined through analysis once it is in Excel. In Excel the data can be analyzed into any form necessary for calculations.

Location

One of the Qualimetric rain gauges was used in the open area. The placement of this rain gauge was on the inside wooden fence that was used to hide the trash dumpster and utilities in the parking lot located behind the retail center at Mount Laurel. The parking lot helped to assure that there would not be any trees close enough to taint the open area results. With the gauge's location being on the inside of a wooden fence, the gauge was relatively out of sight, which provided added security and minimized possible tampering.

The second Qualimetric rain gauge was located in a small wooded area that is directly across the street from an open field. This location was directly across the street from one of the designers that worked at Mount Laurel. The benefit of having an employee of the development being able to observe the condition of the rain gauge significantly influenced this location. The canopy-covered area for this rain gauge was large enough that there would be no error introduced into the recording of data by the open field.

The third Qualimetric rain gauge was located approximately 100 yards downhill from the development's man made dam. The dam serves as a control measure for the lake on the development. This location was a wooded area with an intact canopy cover. This location was also not slated for immediate construction, which would allow the gauge to stay operational in the same location for a substantial length of time.

The ONSET rain gauge was located on the inside of a resident's fence. Mr. Ward Tishler allowed the gauge to be placed on his property to provide residential lot canopy cover as well as adding security. With the gauge located on his property, he would be able to keep an eye on the gauge.

Installation

The Qualimetric rain gauges were configured for surface mounting only. Three threaded mounting rods are used to attach the rain gauges. These three threaded rods have nuts on each rod that will be used for leveling purposes after the gauges are mounted

A 3/4 inch thick piece of plywood was used as a backing to attach these gauges to utility boxes. Then two 2 x 4 pressure-treated pine boards were vertically attached on the back and to the side of the plywood backing. A 3rd piece of pressure treated 2 x 4 was placed on the front of the plywood backing board. This board had a 45-degree cut at the top that allowed it to be mounted at a 45-degree angle immediately underneath the utility box. This 3rd board provided support to keep the gauge from tipping over since it was front heavy due to the gauge and box being mounted on the one side. All support legs were buried at least 18 inches into the ground with the holes backfilled and packed around the 2 x 4 supports.

The Qualimetric rain gauges have a bulls-eye level that sits on the bottom inside of the gauge, and it is easily read once the protective housing is removed from the gauge. The bulls-eye level helps to ensure that the gauge is mounted plum. If not mounted plum, then the gravitational force acting on the tipping bucket would not be equal for both buckets. This would cause recording of tips that were not equal to one another nor would the tips be equal to .01". To ensure a plum installation of the Qualimetric gauges, the support stand was installed as close to plum as possible. Then using the three adjustable mounting screws on the bottom of the rain gauge, the Qualimetric gauges were adjusted until the bulls-eye gauge showed a plum installation.

The installation of the ONSET rain gauge followed the manufacturers specifications. The ONSET rain gauge comes with mounting hardware already attached to mount the gauge on a surface or to a mast. It must also be mounted where there is a minimal amount of vibration, to help circumvent any false tip readings. The ONSET rain gauge was mast mounted onto the inside face of a 4 x 4 fence post. The fence was located on the property of a Mt. Laurel resident who allowed the gauge to be placed in his yard for canopy cover readings. This location also provided added security. The gauge was attached using deck wood screws, and plum was achieved by using shims between the brackets and the fence post.

ASSUMPTIONS

The assumption was made that the rain gauge locations are close enough to one another so there is not a significant change in the rainfall or the intensity of the storms. All of the recorded storms are assumed to be homogeneous and produce the same amount of rain in the same amount of time at all of the rain gauges. It is assumed that the number of tips for rainstorms in this area do not exceed an intensity greater than 2 tips per second, which equates to 72 inches per hour. If the recorded tips exceed the 2 tips per second rate, the gauge will then be operating outside of the suggested operating parameters, and that event will be removed from the data used for the statistical analyses. It is also assumed that all other environmental variables such as temperature, humidity, dewpoint, wind speed, and wind direction are equal at all rain gauge locations. A final assumption is that routine maintenance taking place once a month will be sufficient to record accurate data. Maintenance is carried out to check the calibration of the tipping buckets and dirt, bugs' nests, and various other debris from the moving parts.

DESCRIPTION OF STATISTICAL ANALYSIS

t-Tests

In order to ultimately prove the value of the results, certain statistical analyses must be carried out. The project hypothesis is based on the idea that the mean rainfall reaching the ground in open areas is greater than the mean rainfall reaching the ground in canopy covered areas. Because this test involves sampling and a comparison of means, a t-test was performed. One form of a t-test is the 2-tail t-test for means. In a 2-tail t-test for means, a statistical test is performed based on a null and alternate hypothesis, to determine if the compared values are significantly different or equal. If the values are equal the null hypothesis will be true. The null hypothesis is generally displayed as

$$H_o : \mu_1 = \mu_2$$

The alternate hypothesis is displayed as

$$H_1 : \mu_1 \neq \mu_2$$

In these statements of hypothesis, μ_1 represents a population mean, and μ_2 represents some specific value that μ_1 is being compared to (Zar, 1999). In this case, μ_1 represents the mean of the canopy covered area, and μ_2 represents the mean of the open area.

However, the hypothesis of this project is based on proving that μ_1 is less than μ_2. A 1-tail t-test for means is more suited for determining if means are significantly greater than or less than a specific value. For a 1-tail t-test for means, the null hypothesis is slightly different. The null hypothesis for a 1-tail t-test for means is displayed as

$$H_o : \mu_1 \geq \mu_2$$

The alternate hypothesis for a 1-tail t-test for means is displayed as

$$H_1 : \mu_1 < \mu_2$$

The stated hypothesis is to prove that the mean rainfall reaching the ground from the canopy cover area is less than the mean rainfall reaching the ground in the open area. This equates to the alternative hypothesis, with μ_1 being less than μ_2. If μ_1 (mean of canopy cover rainfall) is equal to or greater than μ_2, then the null hypothesis will not be rejected. The problem with using a 1-tail or 2-tail test for means is that the means of the three groups cannot be considered independent. The open area and canopy-covered data are considered two samples. Both the open area and canopy-covered areas' data come from the same rainfall events. Therefore, the two sample groups are considered paired data as opposed to independent data. For every event, there is data from the open area as well as data from the canopy-covered areas. A t-test can still be performed, but additional steps are called for to make this a Paired Sample t-test. Because the goal is still to determine if there is a reduction in the mean values of the canopy cover when compared to the open area, a 1-tail Paired Samples t-test will be conducted.

Some reworking of the hypothesis statement is required before the Paired 1-tail t-test is performed. As before, there will be a null and alternate hypothesis. However, now the mean population can be defined as μ_d.

$$\mu_d = \mu_1 - \mu_2$$

The null hypothesis is rewritten to include μ_d.

$$H_0 : \mu_d \geq \mu_0$$

The alternate hypothesis for a Paired 1-tail t-test is also rewritten.

$$H_1 : \mu_d < \mu_0$$

Generally μ_0 will equate to zero. If some substitution takes place, the hypothesis difference between a 1-tail t-test for means is essentially the same as the Paired 1-tail t-test (Zar, 1999).

$$\mu_d = \mu_1 - \mu_2 \xrightarrow{substituting(\mu_1 - \mu_2)} H_0 : \mu_1 - \mu_2 \geq \mu_0$$

$$if\ \mu_0 = 0 \xrightarrow{substitute(0\ for \mu_0)} H_0 : \mu_1 - \mu_2 \geq 0 \xrightarrow{simplified} H_0 : \mu_1 = \mu_2$$

Looking at a small sample of data in Table 7 for total rainfall, the average of the two canopy-covered areas is computed.

TABLE 7. Calculated Differences Based on Each Event

Date	Open (in)	Field Canopy Covered (in)	Yard Canopy Covered (in)	Average of Field & Yard (in)	Difference (in)	Squared Difference (in^2)
3/4/2003	0.05	0.06	0.05	0.06	-0.01	0.001
3/6/2003	2.78	2.78	2.61	2.70	0.08	0.0064
3/6/2003	0.03	0.01	0.02	0.01	0.02	0.004
3/15/2003	0.70	0.71	0.65	0.68	0.02	0.004
3/17/2003	0.60	0.72	0.67	0.70	-0.10	0.01
3/17/2003	0.02	0.02	0.00	0.01	0.01	0.001
3/18/2003	0.20	0.20	0.04	0.12	0.08	0.0064

Because the display is set at two decimal places, the displayed average is rounded up, but Excel keeps the exact value of 0.055" for the first event for use in the calculations. During the calculations for the Paired 1-tail t-test, the open area column Open and the canopy-covered area, which is now the Average of Field & Yard column, will be compared against each other to determine if there is a reduction in rainfall amount in the canopy-covered area.

The following is an example of a Paired 1-tail t-test for mean.

1) Choose a value for α. For all of the t-test performed $\alpha = 0.05$.
2) The sums of the difference between samples $\left(\sum d\right)$ must be calculated:

$$\sum d = d_1 + d_2 + d_3 + \ldots\ldots d_n \qquad (2)$$

$$\sum d = (-.01) + .08 + .02 + .02 + (-.10) + .01 + .08 = .1$$

3) The squares of the difference must be calculated.

$$\sum d^2 = d_1^2 + d_2^2 + d_3^2 + \ldots\ldots d_n^2 \qquad (3)$$

$$\sum d^2 = .001 + .0064 + .004 + .004 + .01 + .001 + .0064 = .0328$$

4) The mean must be found for the difference *(d)*.

$$n = \text{Number of samples}$$

$$\bar{d} = \frac{\sum d}{n} = \text{Arithmetic mean} \qquad (4)$$

$$\bar{d} = \frac{.1}{7} = .014$$

5) The Standard Deviation.

$$S_d = \sqrt{\frac{n\sum d^2 - \left(\sum d\right)^2}{n(n-1)}} \tag{5}$$

$$S_d = \sqrt{\frac{7(.0328)-(.1)^2}{7(7-1)}} = \sqrt{\frac{.2196}{42}} = .0723$$

6) The Standard Error $\left(S_{\bar{d}}\right)$.

$$S_{\bar{d}} = \frac{S_d}{\sqrt{n}} \tag{6}$$

$$S_{\bar{d}} = \frac{.0723}{\sqrt{7}} = \frac{.0723}{2.645} = .0273$$

7) Now a $t_{calculated}$ must be determined in order to compare it to a $t_{critical\ (1\text{-}tail)}$ value.

$$t_{calculated} = \left(\frac{\left(\bar{d} - \mu_o\right)}{S_{\bar{d}}}\right) \tag{7}$$

$$t_{calculated} = \left(\frac{(.014-0)}{.0273}\right) = .513$$

8) $t_{critical}$ is determined by using a critical t values table available in most statistics books.

Using the degrees of freedom (d.f.) or v on the left of the table cross referenced with the chosen α for a 1-tail test will give a $t_{critical}$.

d.f. (degrees of freedom) = $n-1$

10) ***IF*** $|t_{calculated}| \geq t_{critical}$, ***THEN*** $p_{(\alpha-1tail)} \leq .05$, which means we reject H_o. (8)

11) ***IF*** $|t_{calculated}| < t_{critical}$, ***THEN*** $p_{(\alpha-1tail)} > .05$, means we fail to reject H_o. (9)

12) Determine an exact *p* (probability). Find the degrees of freedom on the left of the chart and move across the table until the $t_{calculated}$ value is found. Read the α (1-tail) value at the top of the table directly above the found value. If it is not printed but does exist between two printed values, interpolate the *p* value. One can also use the built-in functions in Excel to calculate an exact *p* value for any $t_{calculated.}$

The 2-tail Paired t-test can easily be run on Excel. The Excel output returns the *p* value for both a 1 tail and a 2 tail paired t-test.

General Linear Model ANOVA

It is possible to average the value of the two canopy-covered areas and then use the averaged values in a Paired t-test versus the open area. The problem with relying solely on a Paired t-test is that error is introduced by averaging the values of the canopy-covered area. To avoid this problem, an additional test is called for. A General Linear Model (GLM) (Analysis of Variance) ANOVA is best suited for this project; therefore, ANOVA test will be performed using SYSTAT 10.2. This test is very similar to an test. A GLM ANOVA essentially conducts a Paired analysis t-test, but it is applicable for comparing more than two sample groups. In this case there are three sample groups, one open area with no canopy cover and two samples sets coming from areas with canopy cover. The p values obtained through a Paired t-test would not be exact but merely approximate to the true p value obtained by the GLM ANOVA test. A GLM ANOVA test was performed to determine if there is any significant difference in rainfall volume and intensity between any of the three gauges.

Tukey Test

The Tukey test was conducted after the initial GLM ANOVA tests were completed. This test determines which group or groups are significantly different from one another (Zar, 1999). In this project it is used to determine which gauges are responsible for recording the significantly less rainfall as reported by the GLM ANOVA test results. In this case the value that will be checked is the value of the recorded rainfall. The Tukey test has a null and an alternate hypothesis used to determine the equality of the recorded values. The null hypothesis is generally displayed as

$$H_o : \mu_{parking(open)} = \mu_{\text{field(canopy)}} = \mu_{yard(canopy)}$$

The alternate hypothesis is displayed as

$$H_1 : \text{Not all } \mu \text{ are equal to each other}$$

Equation of Best Fit

Recorded data rarely follow a straight line due to inherent variability of sampling in research. The equation of best fit is a line through the plotted data points on an XY scatter plot that uses the concept of least squares. Least squares considers the amount of the vertical deviation and defines the best-fit line as the line that minimizes the sum of the squares of those vertical deviations. Certain assumptions must be made in order to test the studies hypothesis about regression (Zar, 1999).

1) For any value of Y there exists a normal distribution X and viceversa.

2) Assuming homogeneity of variances.

3) The population mean of the Y's at a given X lies on a straight line with all other mean Y's at the other X's. The actual relationship in the population is linear.

4) Selecting a particular Y values is not dependent upon the selection of any other Y.

5) The measurements of X are achieved without error. Since this is almost impossible, it is assumed that the error in X is negligible.

Calculated R^2 values have three violations that need to be avoided before those values can be accepted (Walpole, 1998). Those three vilations are presence of outliers, heterogeneous error in the variances, and model misspecifications.

The presence of outliers is addressed in figures 2 and 3. If a point is an outlier and is then removed from the plotted points, the R^2 usually increases. If an R^2 value of 0.80 is calculated, this means that 80% of the variation in Y can be explained by the variation in X and vice versa (Zar, 1999).

RESULTS

The data obtained from the rain gauges were collected over a period of 12 months from October of 2002 through September of 2003. During the Fall and Winter months, data was collected from four rain gauges, one in the open area and three in a canopy-covered area. Unfortunately, vandals destroyed one of the Qualimetric rain gauges in the canopy-covered area, leaving the study with three usable rain gauges. All of the data from the vandalized rain gauge data were removed from the analysis. This was done to keep the number of samples and the significance of both time periods equal. Also, any rain events that exceeded an intensity greater than 72 inches per hour were removed before any analysis or statistical tests were performed. The rain gauges require that the operation of the gauges not exceed two tips per second, which equates to 72 inches per hour. If that rate of rainfall is exceeded, the gauge is no longer recording 0.01" per tip, and it is therefore operating outside of its established parameters.

During the project year, the amount of canopy cover over the rain gauges changed with the seasons, but there was no change over the one gauge in the open area. It was determined through observation that the canopy cover over the two covered gauges did not return to full coverage until March of 2003. All data for the spring comparison of the canopy cover versus the open area include data collected on March 4th of 2003 through September 21st of 2003. This grouping provides a comparison between the Fall and Winter months' impact on rainfall reaching the ground compared to the Spring and

Summer months. A total of 49 recorded rain events took place in the Fall and Winter months of October through March. Through the Spring and Summer months, there were 83 separate rain events.

t-Test Results

The 2-tail paired t-test was conducted to determine if any of the data from the rain gauges were significantly different from one another. The hypothesis is that the seasonal decrease in canopy cover will reduce the observed reduction of rainfall amount and intensity in the originally covered areas. The result of the paired t-tests for varying rainfall amounts in the Spring and Summer months are given in Tables 8 through 20.

TABLE 8. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.1".

≤0.1"	Open	Average of 2
Mean	0.04	0.02
Variance	0.00	0.00
Observations	23	23
Pearson Correlation	0.78	-
Hypothesized Mean Difference	0.00	-
Df	22	-
t Stat	3.05	-
P(T<=t) one-tail	2.94 E-03	-
t Critical one-tail	1.72	-
P(T<=t) two-tail	5.87 E-03	-
t Critical two-tail	2.07	-

TABLE 9. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.2".

≤0.2"	Open	Average of 2
Mean	0.07	0.05
Variance	0.00	0.00
Observations	36	36
Pearson Correlation	0.94	-
Hypothesized Mean Difference	0.00	-
Df	35	-
t Stat	5.28	-
P(T<=t) one-tail	3.39 E-06	-
t Critical one-tail	1.69	-
P(T<=t) two-tail	6.79 E-06	-
t Critical two-tail	2.03	-

TABLE 10. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.3".

≤0.3"	Open	Average of 2
Mean	0.12	0.09
Variance	0.01	0.01
Observations	46	46
Pearson Correlation	0.94	-
Hypothesized Mean Difference	0.00	-
Df	45	-
t Stat	5.20	-
P(T<=t) one-tail	2.38 E-06	-
t Critical one-tail	1.68	-
P(T<=t) two-tail	4.77 E-06	-
t Critical two-tail	2.01	-

TABLE 11. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.4".

≤0.4"	Open	Average of 2
Mean	0.12	0.09
Variance	0.01	0.01
Observations	47	47
Pearson Correlation	0.95	-
Hypothesized Mean Difference	0.00	-
Df	46	-
t Stat	5.33	-
P(T<=t) one-tail	1.46 E-06	-
t Critical one-tail	1.68	-
P(T<=t) two-tail	2.91 E-06	-
t Critical two-tail	2.01	-

TABLE 12. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.5".

≤0.5"	Open	Average of 2
Mean	0.17	0.134168
Variance	0.02	0.01713
Observations	55.00	55
Pearson Correlation	0.95	-
Hypothesized Mean Difference	0.00	-
Df	54.00	-
t Stat	5.18	-
P(T<=t) one-tail	1.67E-06	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	3.35E-06	-
t Critical two-tail	2.00	-

TABLE 13. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.6".

≤0.6"	Open	Average of 2
Mean	0.21	0.17
Variance	0.03	0.04
Observations	61	61
Pearson Correlation	0.92	-
Hypothesized Mean Difference	0.00	-
Df	60	-
t Stat	3.20	-
P(T<=t) one-tail	1.10 E-03	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	2.21 E-03	-
t Critical two-tail	2.00	-

TABLE 14. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.7".

≤0.7"	Open	Average of 2
Mean	0.23	0.20
Variance	0.04	0.04
Observations	64	64
Pearson Correlation	0.94	-
Hypothesized Mean Difference	0.00	-
Df	63	-
t Stat	3.11	-
P(T<=t) one-tail	1.40 E-03	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	2.79 E-03	-
t Critical two-tail	2.00	-

TABLE 15. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.8".

≤0.8"	Open	Average of 2
Mean	0.24	0.21
Variance	0.05	0.05
Observations	66	66
Pearson Correlation	0.93	-
Hypothesized Mean Difference	0.00	-
Df	65	-
t Stat	3.50	-
P(T<=t) one-tail	4.25 E-04	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	8.51 E-04	-
t Critical two-tail	2.00	-

TABLE 16. t-Test: Paired Two Sample for Means
Spring and Summer ≤0.9".

≤0.9"	Open	Average of 2
Mean	0.24	0.21
Variance	0.05	0.05
Observations	66	66
Pearson Correlation	0.93	-
Hypothesized Mean Difference	0.00	-
Df	65	-
t Stat	3.50	-
P(T<=t) one-tail	4.25 E-04	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	8.51 E-04	-
t Critical two-tail	2.00	-

TABLE 17. t-Test: Paired Two Sample for Means Spring and Summer ≤1.0".

≤1.0"	Open	Average of 2
Mean	0.24	0.21
Variance	0.05	0.05
Observations	66	66
Pearson Correlation	0.93	-
Hypothesized Mean Difference	0.00	-
Df	65	-
t Stat	3.50	-
P(T<=t) one-tail	4.25 E-04	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	8.51 E-04	-
t Critical two-tail	2.00	-

TABLE 18. t-Test: Paired Two Sample for Means Spring and Summer ≤1.5".

≤1.5"	Open	Average of 2
Mean	0.35	0.29
Variance	0.14	0.10
Observations	74	74
Pearson Correlation	0.96	-
Hypothesized Mean Difference	0.00	-
Df	73	-
t Stat	4.59	-
P(T<=t) one-tail	9.07 E-06	-
t Critical one-tail	1.67	-
P(T<=t) two-tail	1.81 E-05	-
t Critical two-tail	1.99	-

TABLE 19. t-Test: Paired Two Sample for Means
Spring and Summer ≤2.0".

≤2.0"	Open	Average of 2
Mean	0.42	0.34
Variance	0.24	0.15
Observations	78	78
Pearson Correlation	0.97	-
Hypothesized Mean Difference	0.00	-
Df	77	-
t Stat	5.05	-
P(T<=t) one-tail	1.43 E-06	-
t Critical one-tail	1.66	-
P(T<=t) two-tail	2.86 E-06	-
t Critical two-tail	1.99	-

TABLE 20. t-Test: Paired Two Sample for Means
Spring and Summer ≤5.26".

≤5.26"	Open	Average of 2
Mean	0.60	0.51
Variance	0.59	0.47
Observations	85	85
Pearson Correlation	0.98	-
Hypothesized Mean Difference	0.00	-
Df	84	-
t Stat	5.41	-
P(T<=t) one-tail	2.92 E-07	-
t Critical one-tail	1.66	-
P(T<=t) two-tail	5.84 E-07	-
t Critical two-tail	1.99	-

Multiple Paired t-tests were performed to determine if there was a significant difference in the variation of rainfall volume between open and canopy-covered locations based merely on the event volume. Excel calculates the probability of a 2-tail and a 1-tail t-test. If the p values are greater than 0.05, then the null hypothesis is not rejected, and the rainfall volumes are not significantly different. None of the t-tests performed on the various ranges of rainfall returned a p value greater than 0.05. One-tail p values are calculated to determine if the canopy-covered rainfall is significantly greater than or less than the open area rainfall volume. If the 1-tail p value is less than 0.05 then the null hypothesis is rejected, and rainfall volume in the canopy covered area is significantly less than the rainfall volume in the open area. All of the Paired 1-tail t-tests calculated a p value less than 0.05, concluding that the average rainfall volume in the canopy-covered areas are significantly less than the rainfall volume in the open area.

General Linear Model Anova Results

A GLM ANOVA test was carried out to reduce error introduced by the data restructuring in the Paired t-test. Surprisingly the *p* values for both tests were so extreme that the end conclusions from both the Paired t-test and the GLM ANOVA were the same. Table 21 shows the probability that the observed variation in rainfall data results from chance is equal to 0.000.

Since the probability that chance accounts for the variations in the rainfall amounts of all the events is much less than 0.05, the null hypothesis is rejected, and it is concluded that all the rain events are not equal in rainfall amount.

TABLE 21. Analysis of Variance
Spring and Summer Events≤5.26

Dep Var: RAIN N: 249 Multiple R: 0.991 Squared multiple R: 0.982

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
EVENT	125.897	83	1.535	106.351	0.000
SITE	0.508	2	0.254	17.591	0.000
Error	2.368	164	0.014	-	-

Table 21 also shows the probability of chance accounting for the rainfall variation between the sites. With the calculated p in the Site row being 0.000, the null hypothesis can be rejected, and it is determined that the variation by site does not happen by chance.

The GLM ANOVA test presented in Table 22 includes all Spring and Summer rain events less than 2.5" in rainfall.

TABLE 22. Analysis of Variance
Spring and Summer Events ≤2.5"

Dep Var: RAIN N: 240 Multiple R: 0.982 Squared multiple R: 0.964

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
EVENT	54.123	79	0.685	53.151	0.000
SITE	0.427	2	0.213	16.547	0.000
Error	2.037	158	0.013	-	-

Table 23 shows the same results as the previous table. This test was performed to determine if there were outlier points in the higher rainfall events that could cause inaccurate *p* values. However, this test shows that the variation in rainfall volumes less than 2.5" between sites does not happen by chance.

TABLE 23. Analysis of Variance
Spring and Summer Events ≤1.5"

Dep Var: RAIN N:222 Multiple R: 0.974 Squared multiple R: 0.949

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
EVENT	24.864	73	0.341	37.246	0.000
SITE	0.187	2	0.093	10.199	0.000
Error	1.335	146	0.009	-	-

The test results in Table 24 are the closest that any of the GLM ANOVA tests came to the critical 0.05 mark for probability. However, with a value of 0.02 it is still less than 0.05 and it is not close enough to 0.05 to cause concern. This particular test shows that the variation in rainfall volume between sites was still proven to not have happened by chance.

TABLE 24. Analysis of Variance
Spring and Summer Events ≤1.0"

Dep Var: RAIN N: 198 Multiple R: 0.952 Squared multiple R: 0.906

Source	Sum-of-Squares	Df	Mean-Square	F-ratio	p
EVENT	8.740	65	0.134	19.207	0.000
SITE	0.056	2	0.028	4.018	0.020
Error	0.910	130	0.007	-	-

Tables 25 and 26 results do not show a p value greater than 0.05, which leads to the conclusion that the entire range of rainfall volumes, 0.00" to 5.26", does not have to be broken down into separate groups for analysis. Therefore Table 21's results are acceptable.

TABLE 25. Analysis of Variance
Spring and Summer Events ≤0.5"

Dep Var: RAIN N: 165 Multiple R: 0.976 Squared multiple R: 0.953

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
EVENT	2.973	54	0.055	39.634	0.000
SITE	0.042	2	0.021	15.157	0.000
Error	0.150	108	0.001	-	-

TABLE 26. Analysis of Variance
Spring and Summer Events ≤0.3".

Dep Var: RAIN N: 138 Multiple R: 0.963 Squared multiple R: 0.928.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
SITE	0.022	2	0.011	12.484	0.000
EVENT	1.017	45	0.023	25.142	0.000
Error	0.081	90	0.001	-	-

Table 27 presents results from a GLM ANOVA test on all of the rainfall events during the Fall and Winter months. The p value for the events is 0.00, which is expected as has been discussed previously in this section. The p value for Site is 0.358. Because this value is greater than 0.05, the null hypothesis is not rejected. Therefore, there is not a significant difference in rainfall amounts between sites. This also helps to show that the leaves in a canopy cover play a bigger role in the reduction of the rainfall amounts than do the other variables.

TABLE 27. Analysis of Variance
All Winter Storms

Dep Var: RAIN N: 147 Multiple R: 0.995 Squared multiple R: 0. 989.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	p
EVENT	521188.851	48	10858.101	185.771	0.000
SITE	121.329	2	60.664	1.038	0.358
Error	5611.093	96	58.449	-	-

Table 28 shows the results of a GLM ANOVA test done on the calculated intensity values for all of the Spring and Summer rainfall events. Because the p value in the SITE row is greater than 0.05, we fail to reject the null hypothesis, which means there is not a significant difference in intensity values between the three sites.

Table 28. Analysis of Variance
Intensity of All Spring and Summer Rain Events

Dep Var: INTENSITY N: 249 Multiple R: 0.902 Squared multiple R: 0.813.

Source	Sum-of-Squares	Df	Mean-Square	F-ratio	p
SITE	73.188	2	36.594	1.980	0.141
EVENT	13091.562	82	159.653	8.640	0.000
Error	3030.436	164	18.478	-	-

Tukey Test Results

The probability values given in Table 29 determine if the null hypothesis is rejected. If the p value is greater than 0.05, then reject the null hypothesis is rejected. However, if the p value is less than or equal to 0.05, then the null hypothesis is not rejected. Open has a p value of 0.000 when compared to the Canopy Cover 1. Since p <<0.05 the null hypothesis is rejected, and the recorded values of rainfall between Open and Canopy Cover 1 are concluded to be significantly different. The p value for Canopy Cover1 and Canopy Cover 2 is 0.906, which is greater than .05, so the null hypothesis is not rejected, and the recorded rainfall for the gauge Canopy Cover 1 is not concluded to be significantly different than the recorded rainfall for the gauge Canopy Cover 2.

The values are not reported for the column labeled Open and the Canopy Cover 1 row because that comparison has already been made. The calculated p value for Open versus the Canopy Cover 2 is 0.000. With p much less than 0.05, it is concluded that the recorded rainfall values for Open are significantly different when compared to the recorded rainfall values of the gauge Canopy Cover 2. Due to the results of the GLM

ANOVA test on rainfall, the Paired t-tests on rainfall, and the Tukey test, it is concluded that the canopy-covered gauges recorded significantly less rainfall when compared to the open area rainfall.

TABLE 29. Tukey HSD Multiple Comparisons
Matrix of Pairwise Comparison Probabilities
Spring and Summer Events.

	Canopy Cover 1 (Next to Field)	Open	Canopy Cover 2 (Resident's backyard)
Canopy Cover1	1.000	-	-
Open	0.000	1.000	-
Canopy Cover2	0.906	0.000	1.000

Chart Results

Figures 1, 2, and 3 show the relationship of Open area intensity versus Canopy Covered Intensity. Figure 1 has an R^2 value of 0.7726. Unfortunately this chart is not valid because some of the intensity points on this chart violate the maximum intensity allowed by the rain gauges of 72 inches per hour. Figure 2 is within the protocol boundaries of the rain gauges, but it appears to have an outlier point at approximately (15,50) on the chart. Figure 3 is without the suspected outlier and produces a linear trendline $R^2 = 0.7625$ as opposed to $R^2 = 0.4915$ in Figure 2. Figure 4 analyzes the intensity relationship of the areas in a smaller range of 0.00 to 6.00 inches per hour. It is evident that the smaller the intensity range the more the variance increases, which decreases the ability to get an acceptable R^2 value. This reduced range has an $R^2 =$ 0.2593, which is substantially less than the $R^2 = 0.7625$ obtained from the range of 0.00 to 60.00 inches per hour in Figure 3. Unfortunately, what appears to be over a 30%

reduction on Figure 3 ends up not being statistically valid when those included points are run through a GLM ANOVA test (Table 28).

Figures 5 through 7 look for a relationship between the Open area intensity versus the average canopy cover rainfall intensity. The intensity range is 0.00 to 60.00 inches per hour. The points are scattered and produce a $R^2 = -0.3041$. The intensity range is reduced for Figure 6 to 0.00 to 20.00 inches per hour. The best-fit trendline produced $R^2 = -0.204$, which led to one more analysis with another reduction in the intensity range. Figure 7 has an intensity range of 0.00 to 5.00 inches per hour. This range of intensity produces $R^2 = -0.0938$. The low R^2 values for Figures 5 through 7 imply that there is not a significant relationship between Open rainfall intensity and the Average Canopy Rainfall.

Figures 8 through 13 are plots of Open Rainfall Volume versus the Average Canopy Covered Rainfall Volume. Figure 8 includes all Spring and Summer rain events except for the events with intensities greater than the operating parameters of the rain gauges required. A summary of the equation of best fit, R^2, and range of included rainfall is given in Table 30.

The summarization of the previous charts shows that, across the entire range of rainfall volume in this study, there is a relatively high (0.85 and up) R^2 value associated with each trendline equation. This means that over 85% of the variability in the canopy-covered rainfall volume is explained by the variation in open area rainfall volume. The equation of best fit with the highest R^2 value also includes all of the data points in the study. All events, 0.00" through 5.26", produce a trendline equation of $y = 0.8652x$ with $R^2 = 0.968$. Figure 8 is an XY scatter plot of all the Spring and Summer rainfall events.

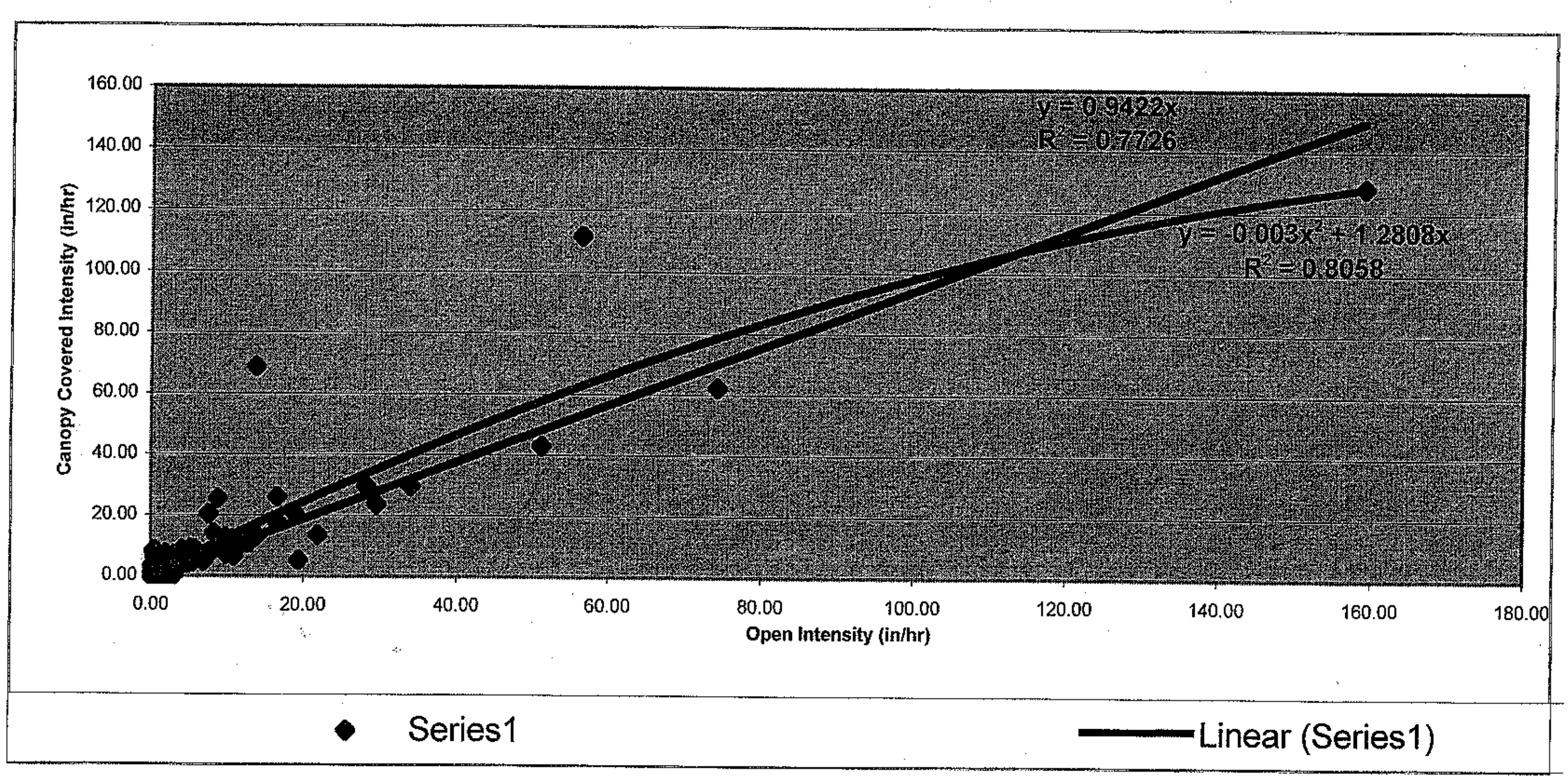
TABLE 30. Open Rainfall Volume vs. Average Canopy Covered Rainfall Volume Equations and R^2 for Various Ranges of Rainfall

Values obtained by Using Excel Trend line Analysis

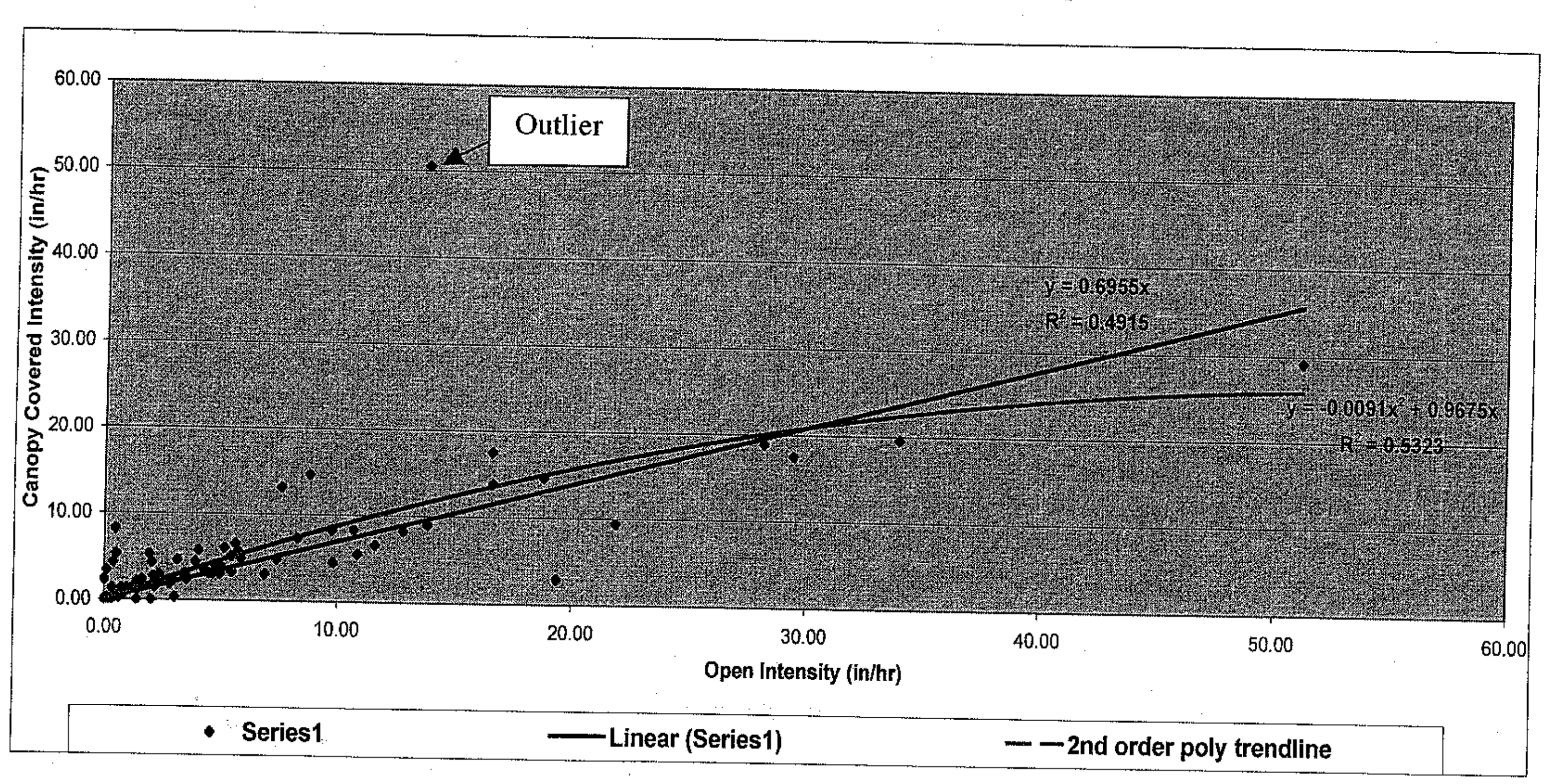
Figure	Included Rainfall Range	Equation of Best Fit	R^2 Value
8	≤5.50"	$Y = 0.8652x$	0.968
		$Y^2 = -0.0023x^2+0.8722x$	0.968
9	≤4.00"	$Y = 0.8884x$	0.9641
10	≤2.00"	$Y = 0.7925x$	0.9473
11	≤1.00"	$Y = 0.8755x$	0.8549
12	≤0.50"	$Y = 0.8204x$	0.9016
13	≤0.25"	$Y = 0.7807x$	0.9019

If there was no reduction of rainfall in the canopy-covered area, then the equation for the trendline of this graph would be $y = x$. However, the equation for the trendline is $y = 0.8652x$. The fact that this equation is not $y = x$ is not just a result of sampling error. Through all of the statistical analyses of the rain throughfall comparisons, it was determined that there was a significant difference in rainfall amounts. It was also determined through the Tukey test that the canopy-covered rain gauges were the gauges responsible for recording less rain throughfall than the open area gauge. The trendline equation $y = 0.8652$ could be used to predict the rainfall volume in an urban forest canopy-covered area based on the open area rainfall amount. Using the trendline equation for all of the Spring and Summer Events calculates a 13.48% reduction in rainfall volume just from the inclusion of canopy cover in the path of the rainfall. Originally it was anticipated that the larger storms would have a lower percent reduction based on variables such as intensity and saturation of the canopy cover. It was expected that the plot of open area rainfall versus canopy-covered rainfall would follow more of a polynomial trendline. With this in mind, Excel was used to calculate a 2nd order polynomial trendline and to calculate the R^2 value. Surprisingly, the R^2 value that was returned for all events, Figure 8, was the same as the R^2 value for a linear trendline. Using the 2nd order equation of best fit, sample calculations were run to determine the percent reduction for the 2nd order polynomial. The 2nd order polynomial equation produced a percent reduction in the canopy-covered area of 12.8% at .1" of open area rainfall and 13.97% reduction in the canopy-covered area at 5.26" of open area rainfall. The linear percent reduction is a constant of 13.48%. Although there is a difference in the percent reduction between a linear and 2nd order polynomial, the difference is no greater than 0.5%. Because R^2 values are identical and linear equations are easier to use, the linear trendline equation will be used for further discussion.

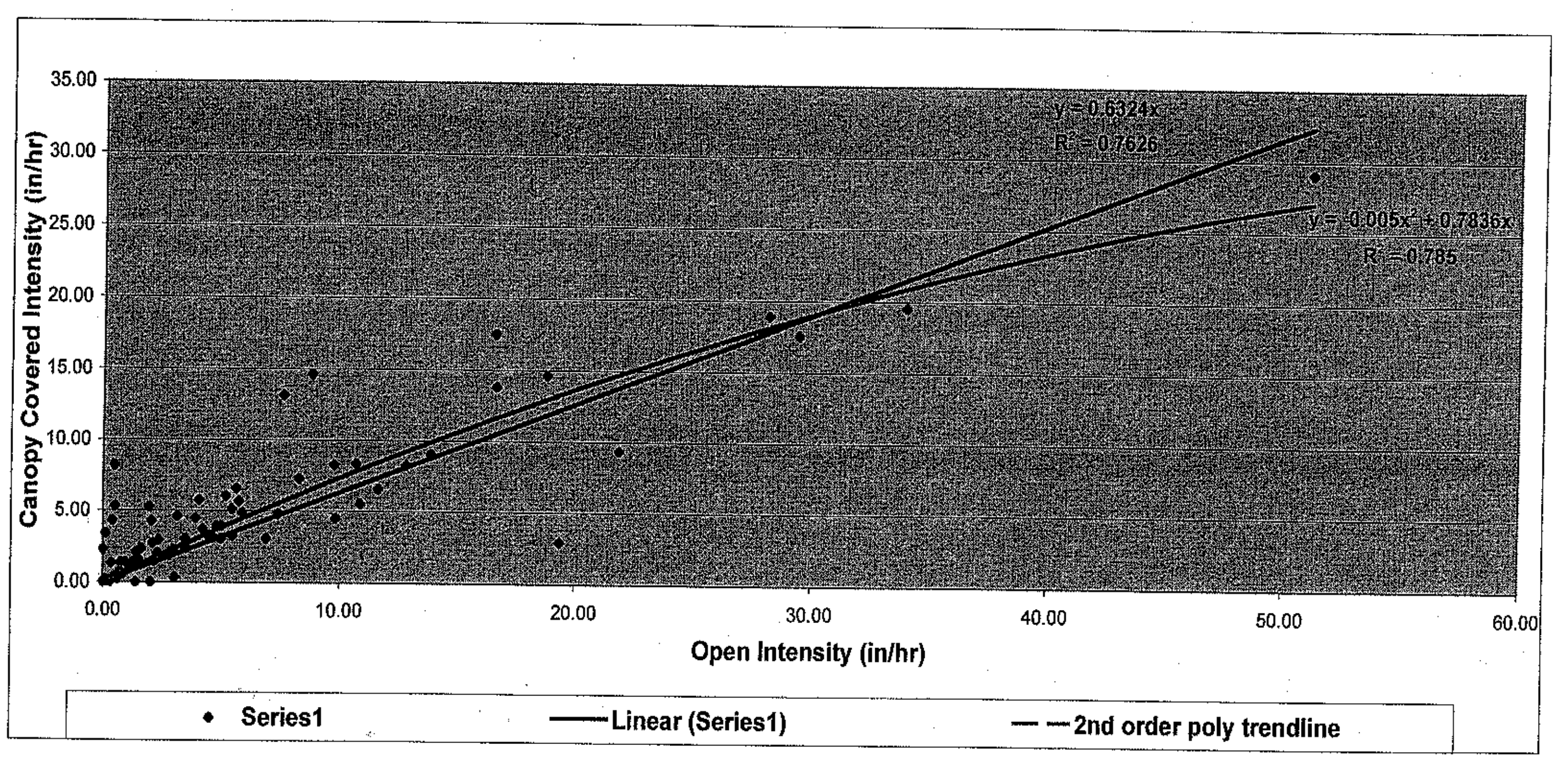
Figure 14 is an intensity scatter plot, which is a visual representation of the intensity of each rainfall event present in Figure 8. The points with the darkest color represent the highest intensity within the range of plotted points. Black represents an intensity of 56.41 inches per hour. The lightest gray colored points represent the lowest intensity. This chart was used to visually determine if there were any outlier points in the graph based on intensity of the plotted points. It was determined that the rainfall points did not visually show a group separation based on intensity.



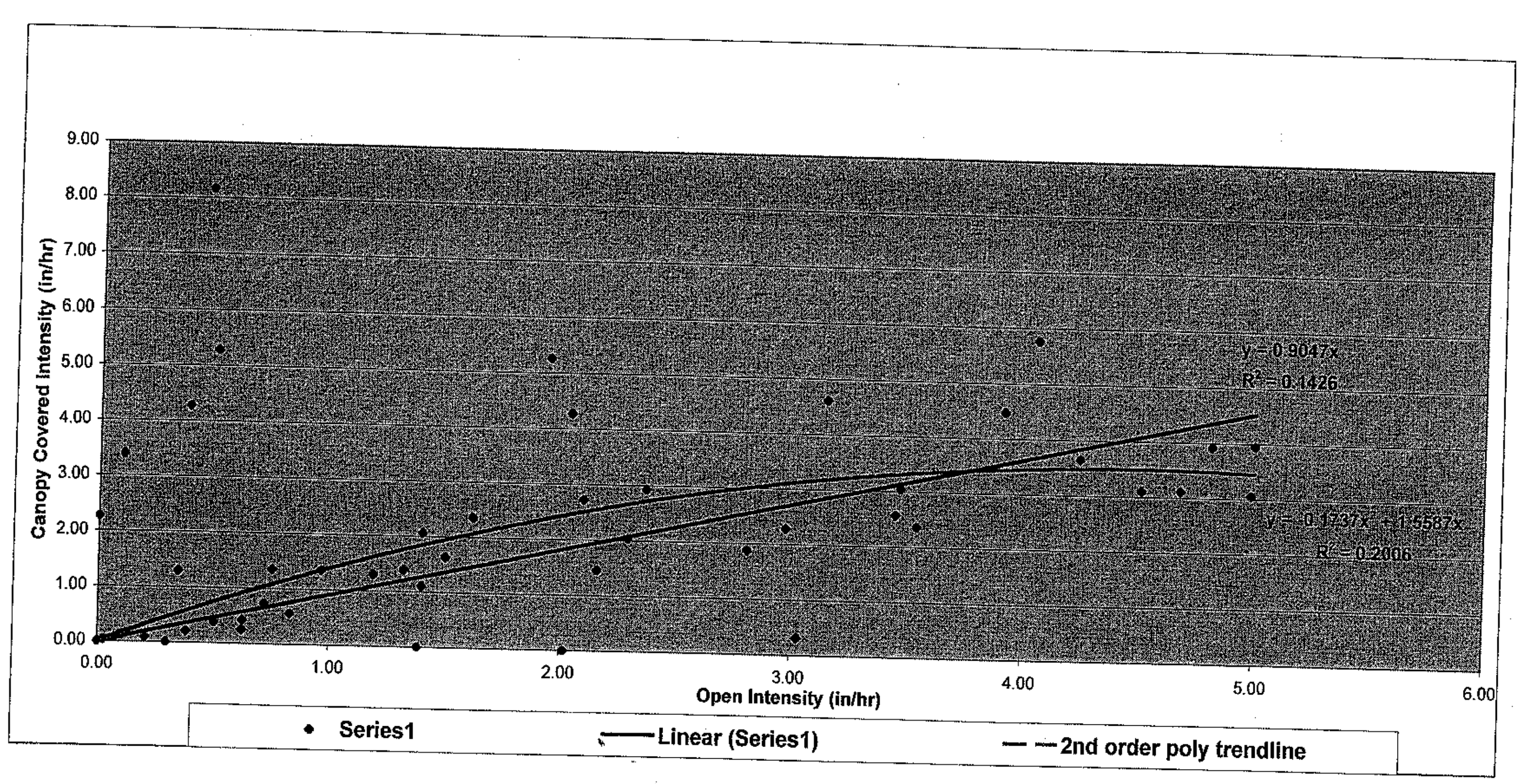
Open Intensity vs. Canopy Cover Intensity
All Spring Events
Figure 1.



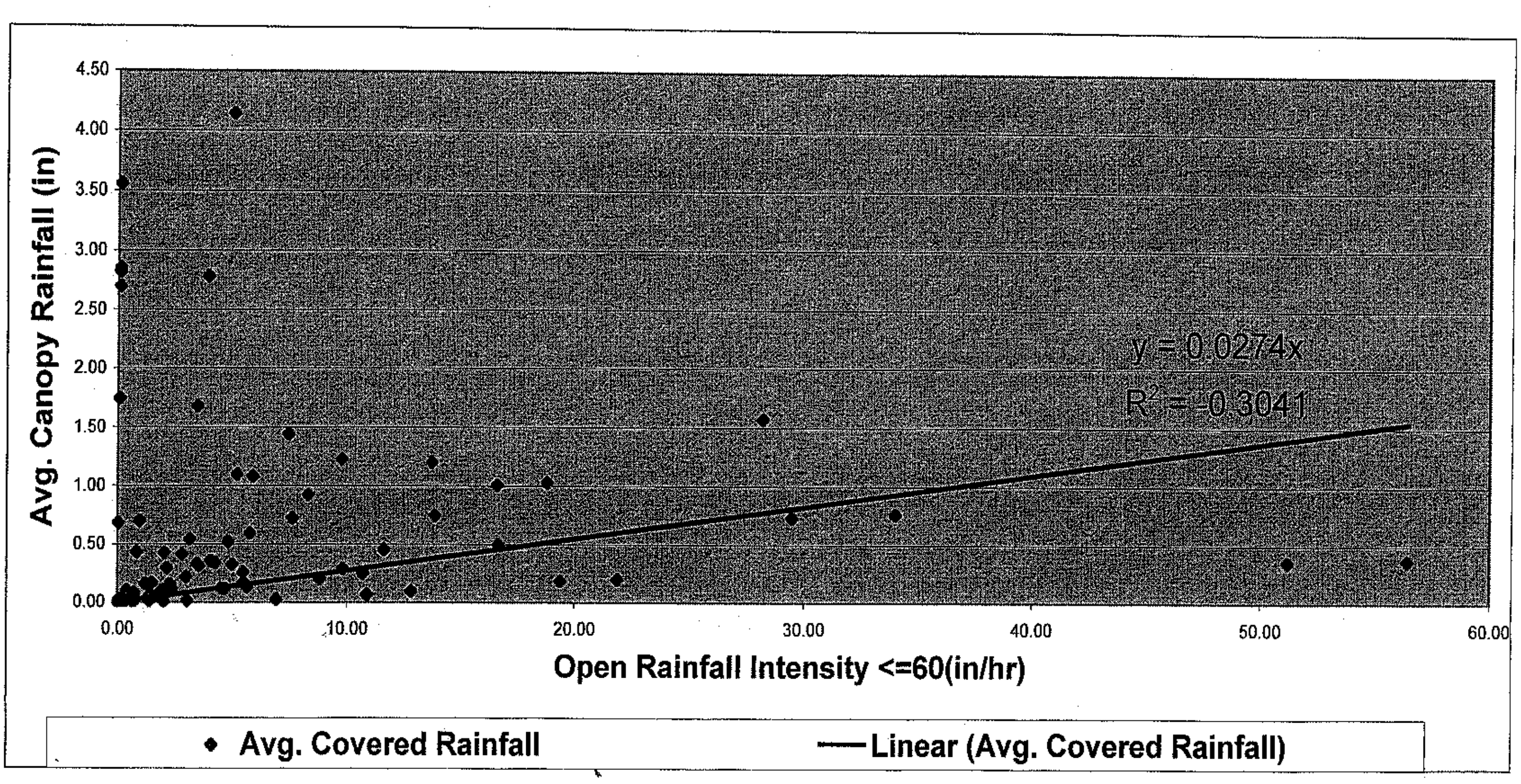
Open Intensity vs. Canopy Cover Intensity
Spring less than or equal to 60 in/hr
with Possible Outlier
Figure 2.



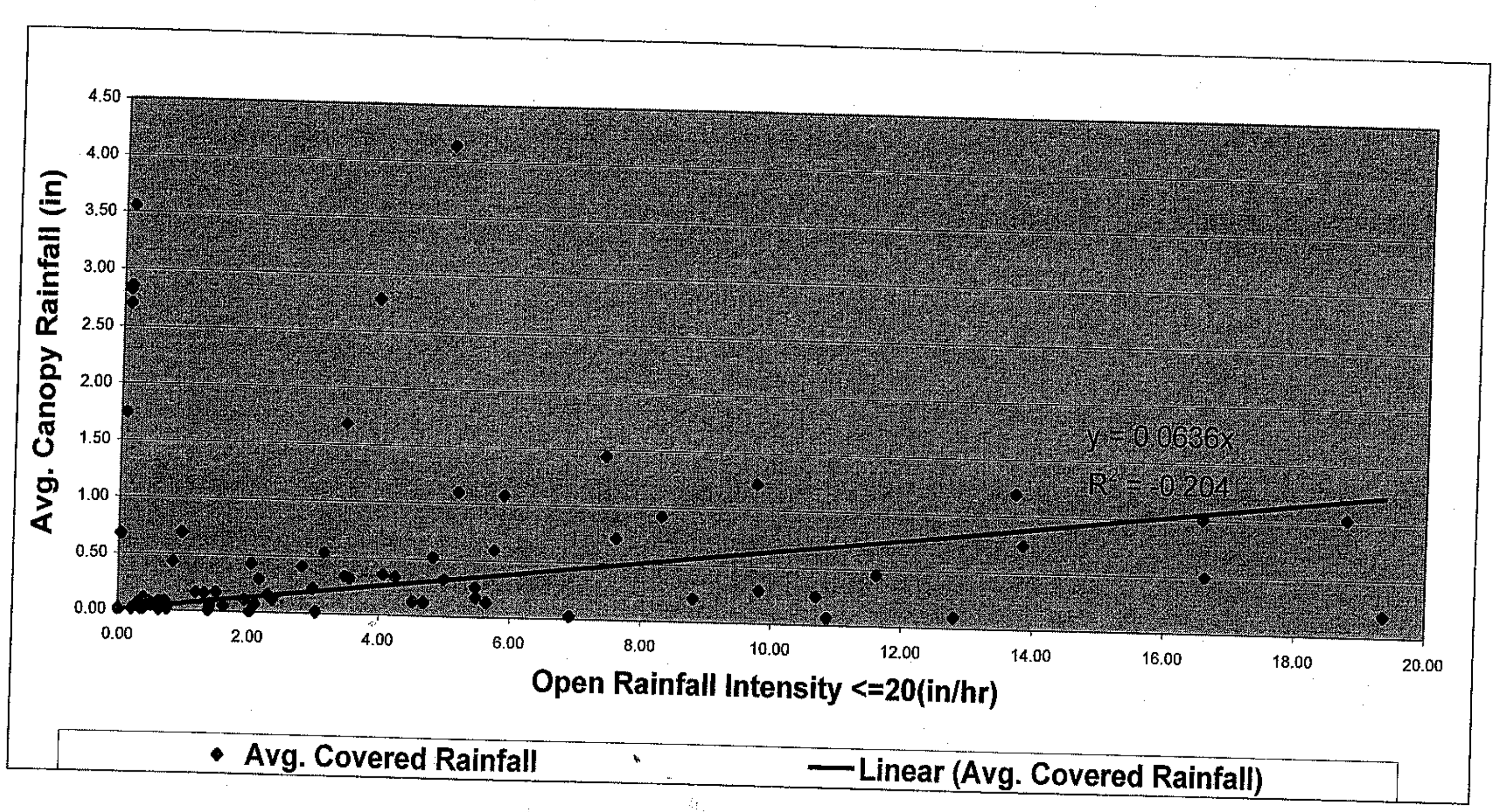
Open Intensity vs. Canopy Cover Intensity
Spring less than or equal to 60 in/hr
without Possible Outlier
Figure 3.



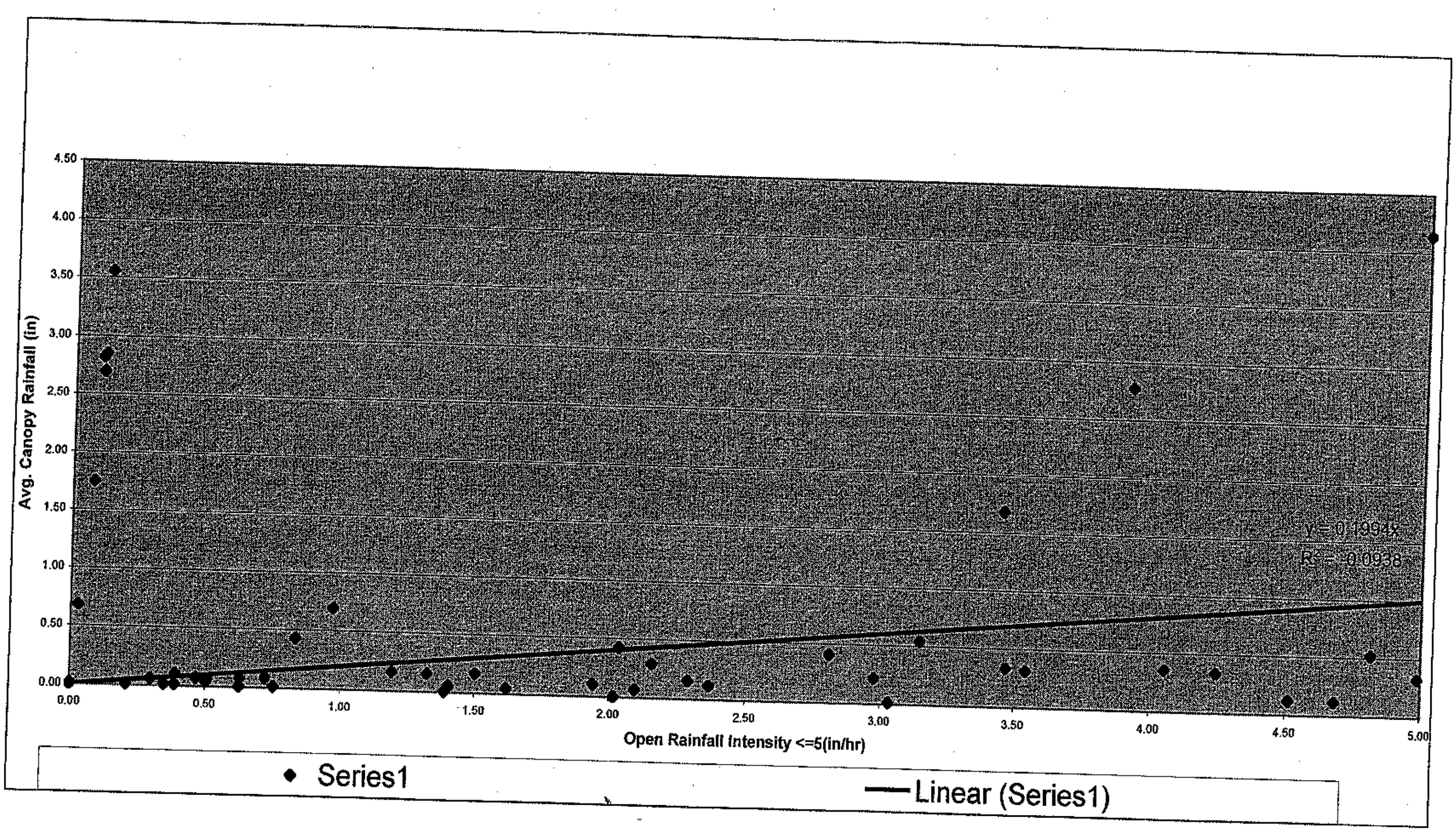
Open Intensity vs. Canopy Cover Intensity
Spring Events less than or equal to 6 in/h
Figure 4.



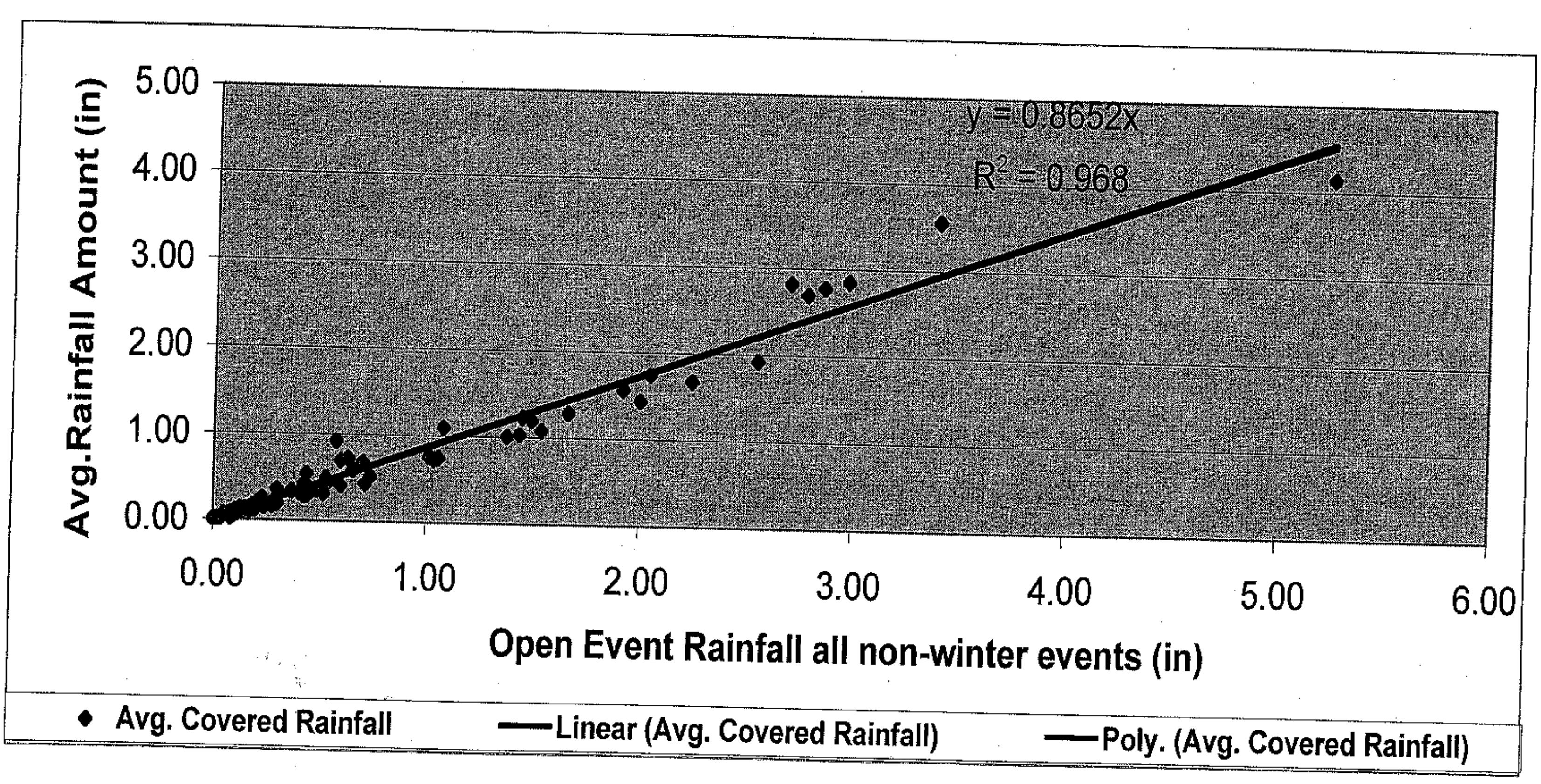
Open Intensity vs. Average Canopy Covered Rainfall
Open Intensity less than or equal to 60 (in/hr)
Figure 5.



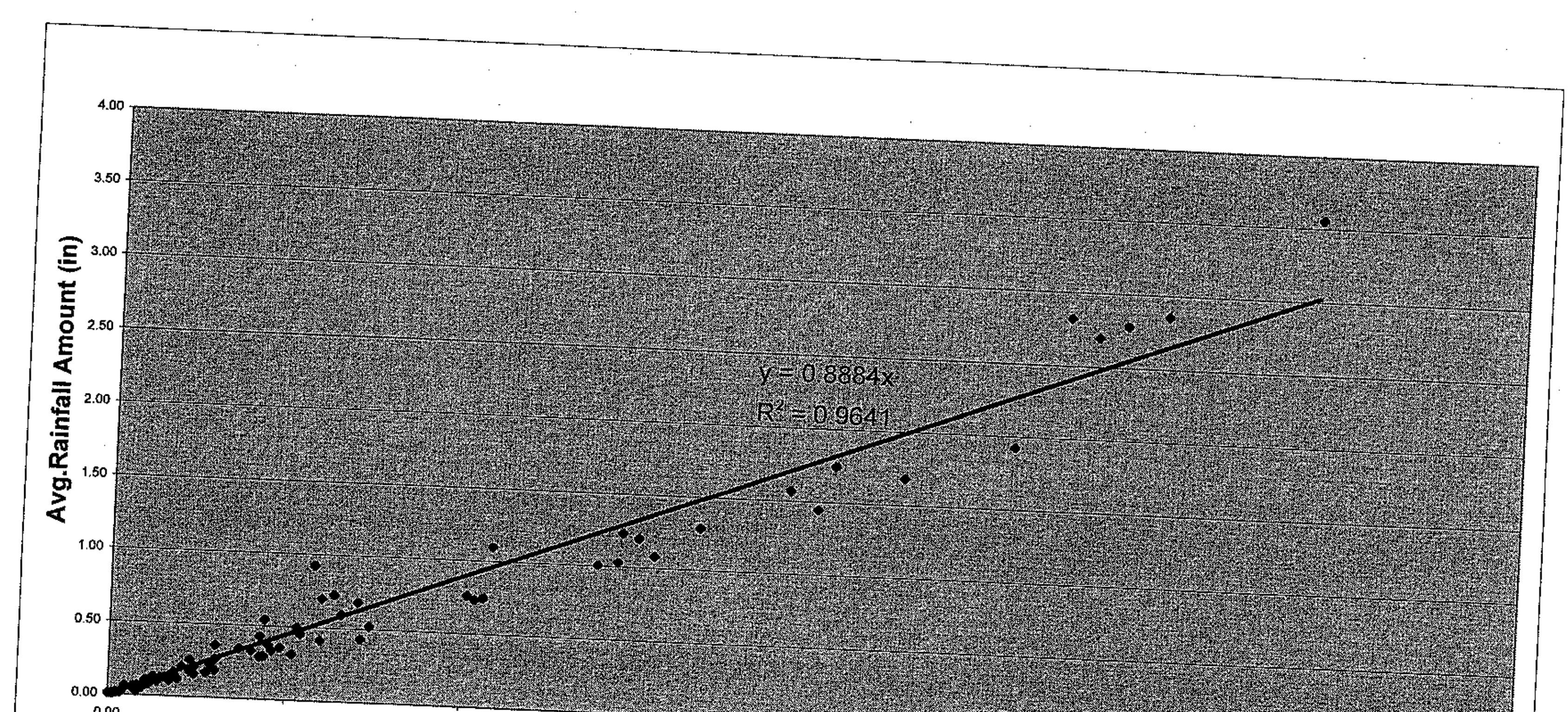
Open Intensity vs. Average Canopy Covered Rainfall
Open Intensity less than or equal to 20 (in/hr)
Figure 6.



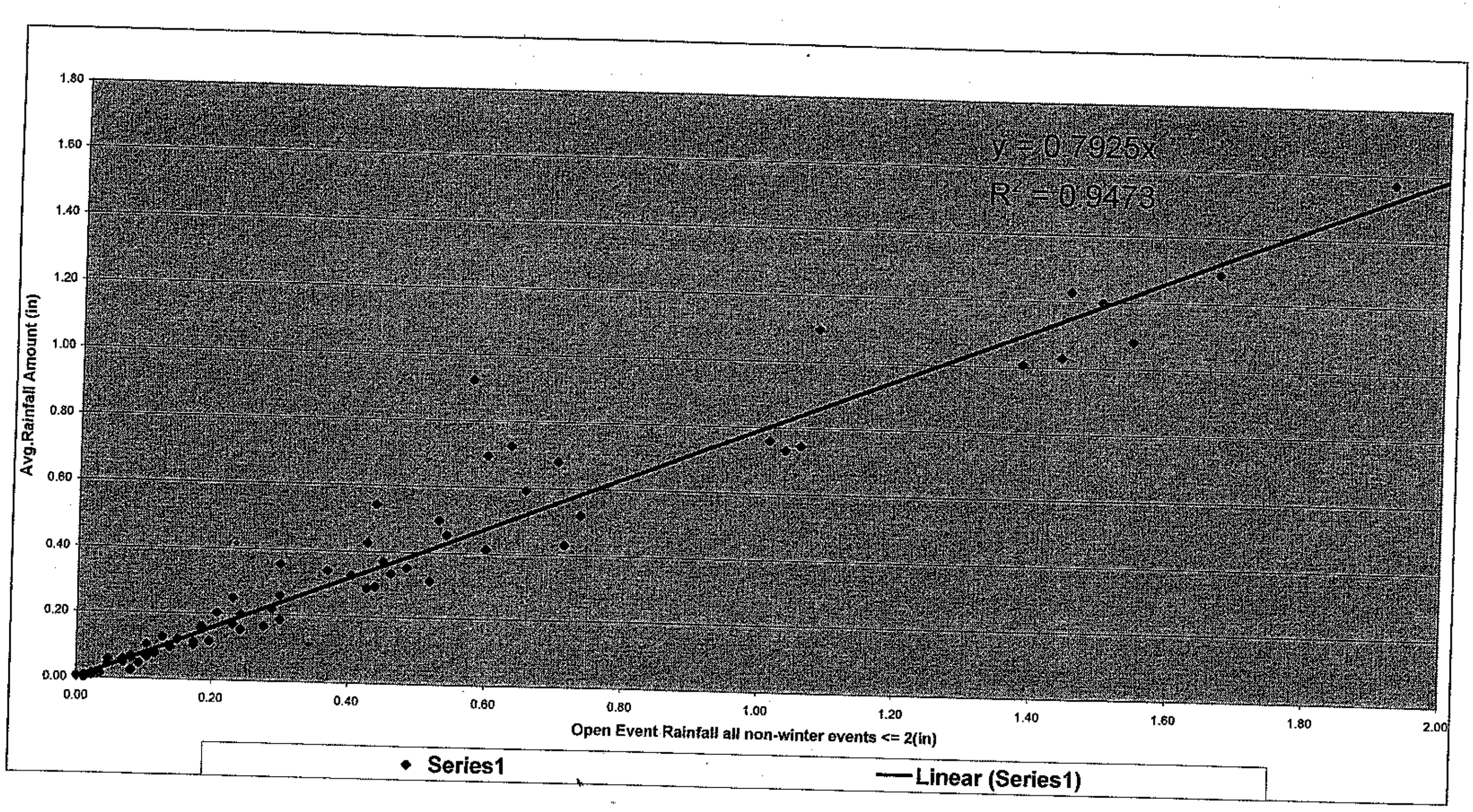
Open Intensity vs. Average Canopy Covered Rainfall
Open Intensity less than or equal to 5 (in/hr)
Figure 7.



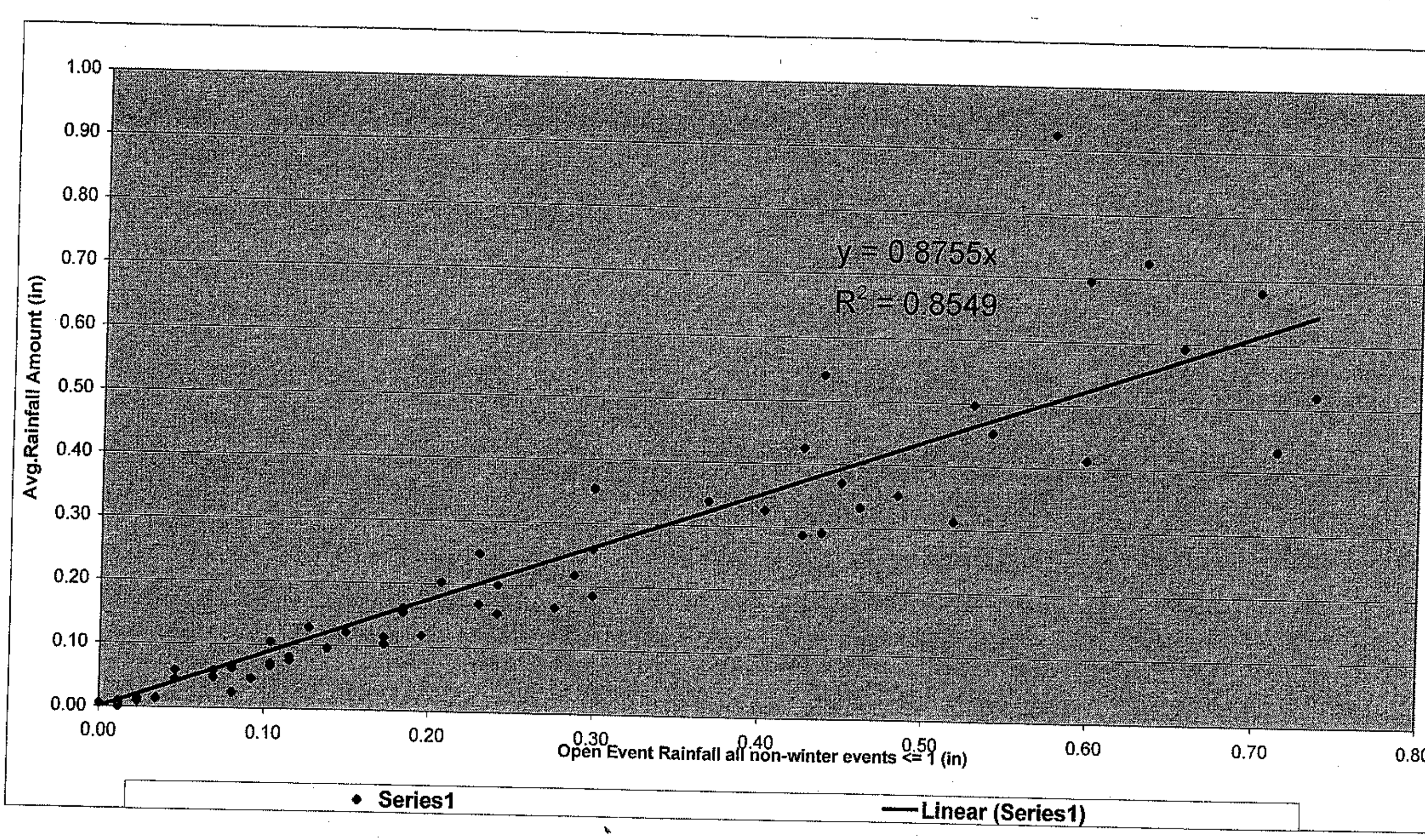
Open Rainfall vs. Average of Canopy Covered Rainfall
All Spring and Summer Events
Figure 8.



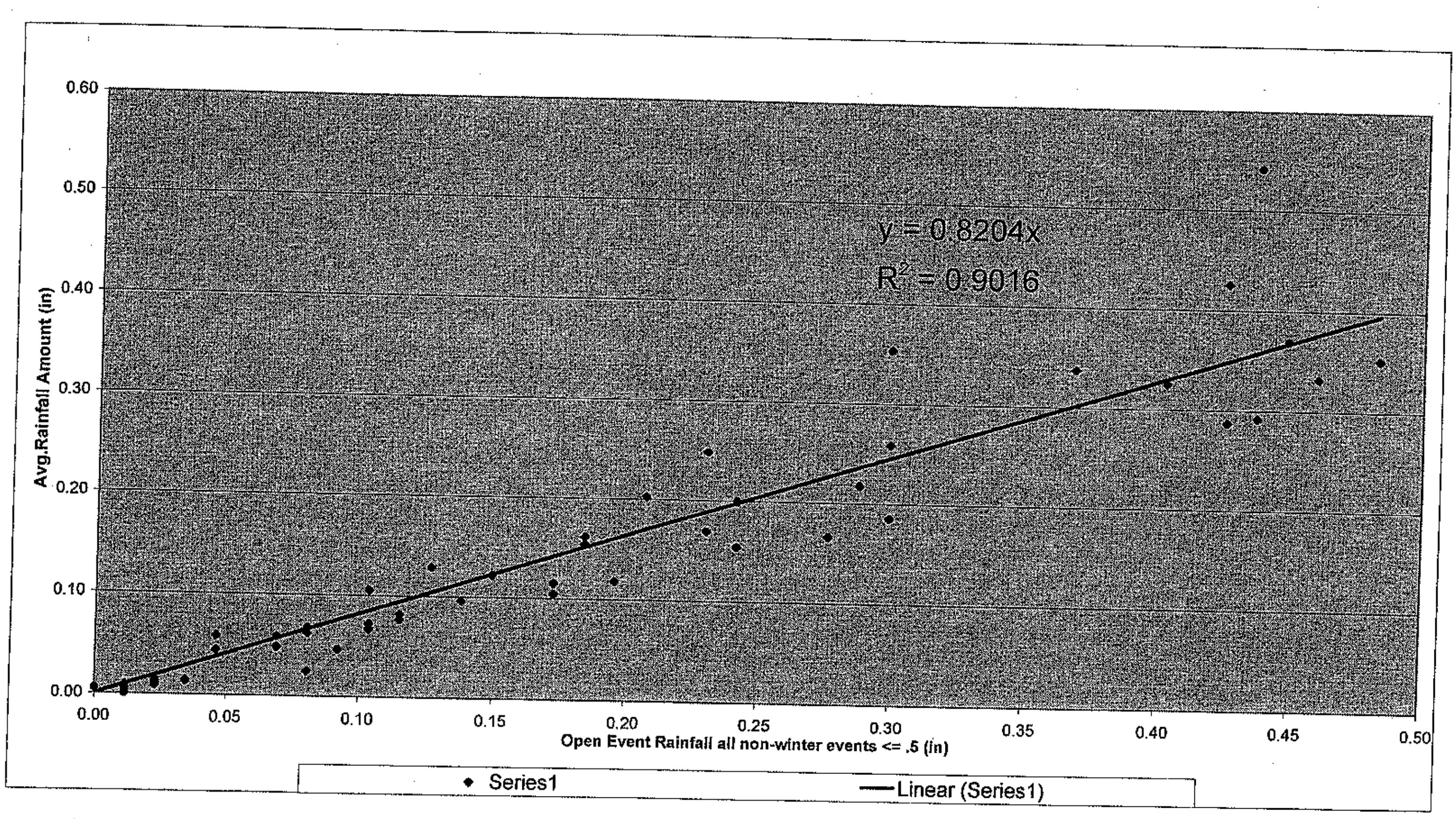
Open Rainfall vs. Average of Canopy Covered Rainfall
less than or equal to 4 (in)
Figure 9.



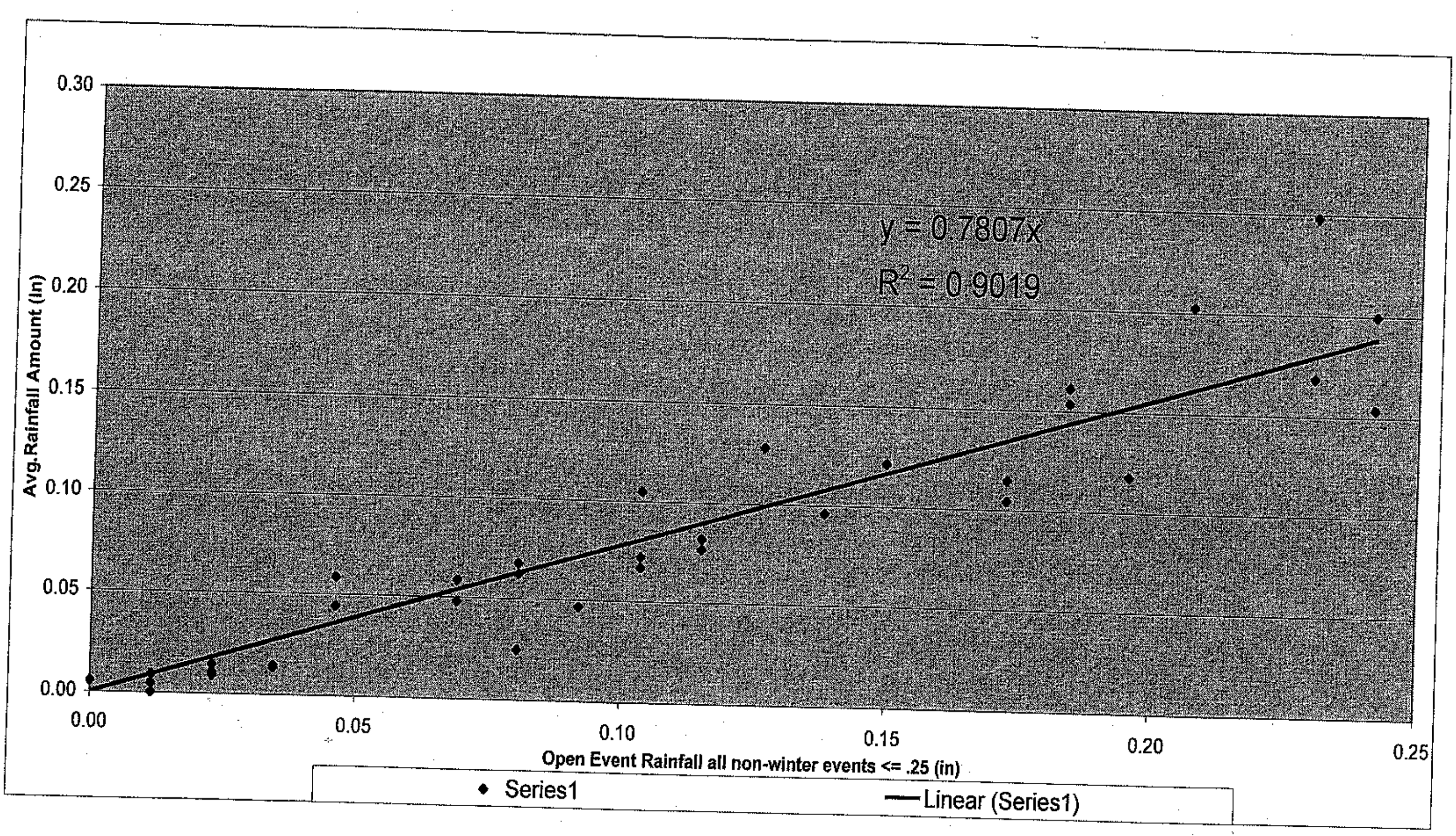
Open Rainfall vs. Average of Canopy Covered Rainfall
Less than or equal to 2 (in)
Figure 10.



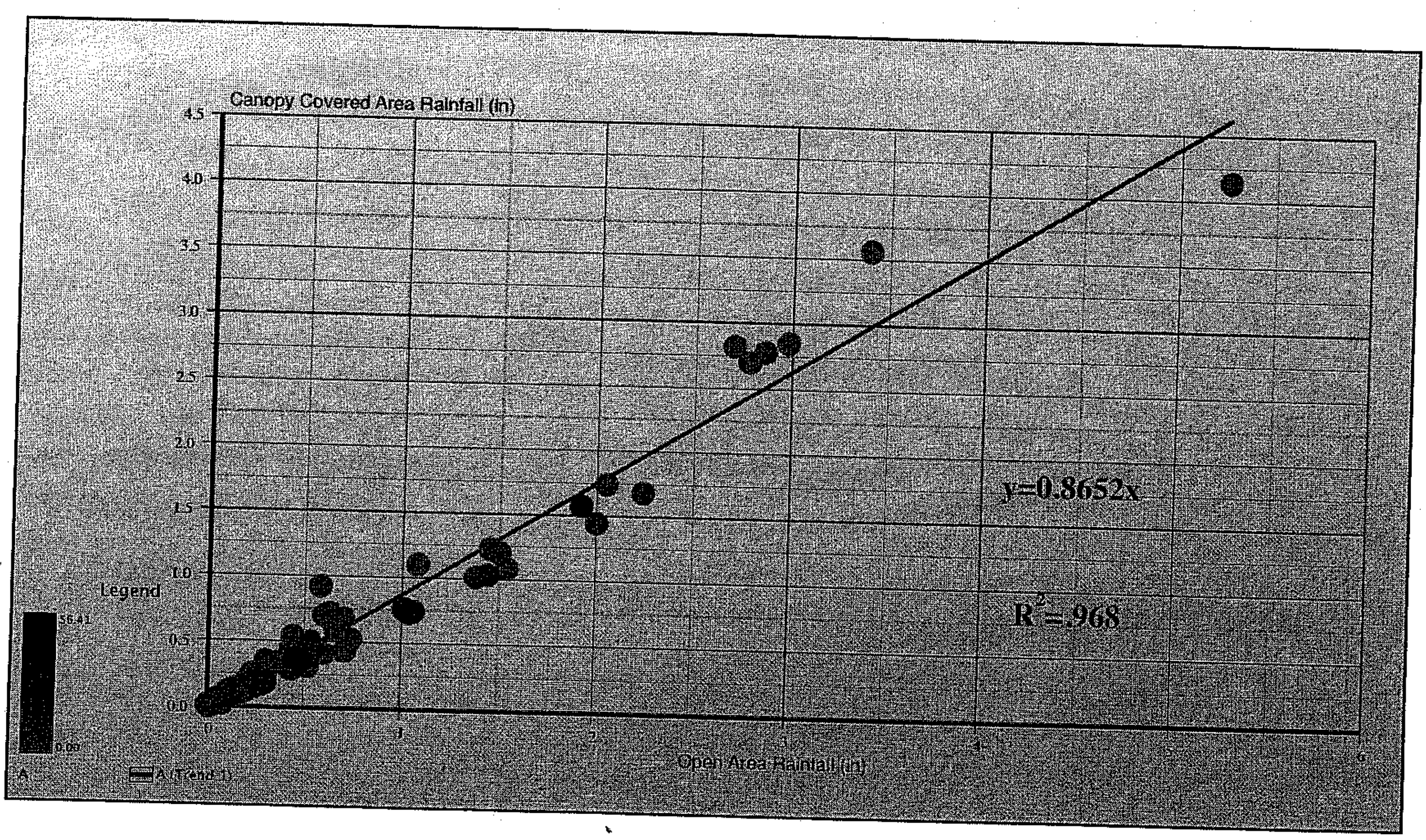
Open Rainfall vs. Average of Canopy Covered Rainfall
Less than or equal to 0.80 (in)
Figure 11.



Open Rainfall vs. Average of Canopy Covered Rainfall
Less than or equal to 0.50 (in)
Figure 12.



Open Rainfall vs. Average of Canopy Covered Rainfall
Less than or equal to 0.25 (in)
Figure 13.



Intensity Scatter Plot of Open Rainfall vs. Average of Canopy Covered Rainfall
Less than or equal to 0.25 (in)
Figure 14.

CONCLUSIONS

The collected data showed rainfall that reached the ground to be reduced by canopy cover. In areas which the natural canopy was left undisturbed or disturbed as little as possible, an average reduction in rainfall reaching the ground during the Spring and Summer months averaged 13.48%. Data were collected over a period of 12 months. Although a slight reduction in rainfall volume was observed during the fall and Winter months, the difference was not statistically significant. Also, the intensity for the Spring and Summer months had an average reduction, but again not enough of a difference to be statistically significant. Subjective observations were made concerning rainfall effect on erosion. During the course of the year, erosion occurring on clear-cut developments was visually and photographically compared with erosion on the sites that were selectively cut. Even heavy rainfall on the selectively cleared sights caused visibly less erosion and scouring than rainfall on the clear-cut sights.

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