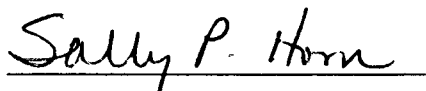


To the Graduate Council:

I am submitting herewith a thesis written by Matthew T. Casey entitled "Throughfall in a Forestry Plantation at La Selva Biological Station, Costa Rica." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

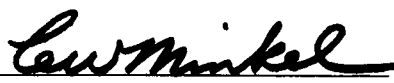

Carol Harden, Major Professor

We have read this thesis
and recommend its acceptance:





Accepted for the Council:


Associate Vice Chancellor and
Dean of The Graduate School

**Throughfall in a Forestry Plantation at the La Selva
Biological Station, Costa Rica**

A Thesis

Presented for the Master of Science

Degree

The University of Tennessee, Knoxville

Matthew Casey

August, 1996

DEDICATION

This thesis is dedicated to my wife

Monica Preble Casey

ACKNOWLEDGMENTS

Graduate level international research is not something that easily falls together, but rather is the result of support from a wide range of individuals. My advisor, Dr. Carol Harden, deserves special thanks for her generous support and encouragement throughout this research. Dr. Sally Horn originally made me aware of the opportunities at La Selva and was helpful in securing my internship. Both she and Dr. Schmudde provided beneficial advice.

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ABSTRACT

Throughfall consists of precipitation that falls straight through the vegetation canopy and precipitation that has been intercepted by the vegetation but then drops to the ground. Throughfall is an important and relatively unstudied component of the water budget, especially in tropical forest and agroforest environments where it distributes nutrients from the canopy to the ground, delivers moisture to the land, and contributes to local climate processes. To investigate throughfall in a tropical agroforestry plantation, I sampled throughfall during November and December, 1994, on the Huertos Plantation, located at the La Selva Biological Station in Costa Rica. This research examines the relationships between throughfall and total rainfall, rainfall intensity and duration, and leaf area index values at the Huertos plantation. Total rainfall was most significantly related to throughfall and provided the strongest throughfall predictions. Overall, throughfall accounted for only 54% of total rainfall. Dry conditions between rain events support the importance of evaporation of moisture from vegetative surfaces in accounting for much of the remaining 46%. Two regression models, one representing throughfall as a function of total rainfall and one representing throughfall as a function of total rainfall, rainfall intensity and rainfall duration, demonstrated that throughfall can be accurately predicted on the basis of total rainfall alone.

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Chapter 1

INTRODUCTION

Accurate estimations of water budgets of wet tropical forest regions are needed to better understand processes of global climate and global climate change. Although the influence of tropical rain forest on local and global climate is poorly understood at present, an important aspect is likely to be the water balance of the forest canopy during and after rainfall (Lloyd and Marques, 1988). A water budget represents the way in which precipitation is partitioned between the processes of evapotranspiration and runoff, taking account of changes in water storage for a particular place and time. Throughfall, a water budget component, consists of precipitation that falls straight through the vegetation canopy and precipitation which has been intercepted by the vegetation but then drips onto the ground (Gurnell, 1985a). Intercepted moisture, precipitation that is trapped on vegetation and other surfaces, contributes to the evaporation component of an area's water budget. Interception loss in extensive rain forest not only affects recharge and streamflow, but, through repeated rainfall-evaporation cycles, may significantly alter the climate (Lettau *et al.*, 1979).

Research is lacking on the effects of various forestry and agroforestry regimes on local water budgets within the tropics (McColl, 1970; Dolman, 1987). When rain forests are converted to forest plantations, numerous hydrological impacts occur, including changes in the rate and overall amount of infiltration, runoff, erosion, and evapotranspiration. The measurement of the interception loss from widely spaced stands

of trees in agroforestry plantations is an essential prerequisite to any quantitative prediction of the effects of agroforestry on the environment (Teklehaimanot *et al.*, 1991). Plantations, as opposed to natural forest, present the opportunity to conduct more controlled experiments to learn about tropical water budgets. In this study, I use the opportunity to monitor throughfall in an agroforestry plantation at the La Selva Biological Station in Costa Rica as a means of developing a better understanding of throughfall and conversely, interception, in wet tropical environments.

The objectives of this research are to examine the relationships between throughfall and total rainfall, rainfall intensity and duration and leaf area index values for an agroforestry plantation and to determine if throughfall can be accurately predicted based on these rainfall variables. In this research, I address the following questions:

- 1) How do different levels of total rainfall, rainfall intensity and duration influence the amount of water that arrives at the ground surface as throughfall?
- 2) What is the relationship between leaf area and throughfall?
- 3) Can a simple model of throughfall based solely on observable variables provide accurate predictions of throughfall values?

I address these questions by measuring rainfall, throughfall and leaf area index values and examining within plot variability, variability between different treatments of the same species and variability between different species. I then develop models for predicting throughfall based on total rainfall, intensity and duration.

Research on throughfall is important for a number of reasons. Accurate measurements of throughfall, combined with measurements or estimates of the other

interception processes, can provide approximate interception amounts. In very general terms, Jackson (1971) states that the process of interception and its influence on the pattern of throughfall is of considerable ecological significance. In terms of biological and meteorological significance, interception influences the consumptive water use (transpiration) of plants, as well as the energy balance of the region (Miranda, 1994). In addition, the redistribution of rainwater is of great importance to the moisture economy of trees, as indicated by root distribution (Voigt, 1960; Ford and Deans, 1978).

This research is significant for several reasons. From the strictly scientific research point of view it provides basic knowledge on the variability of throughfall in relation to both biological and meteorological factors for tropical forestry plantations. Because relatively little research has been conducted on the interception processes in tropical forestry plantations, this study, one of the few to be conducted in Costa Rica, helps fill a research gap. More specifically, the information obtained through this research will be beneficial to Huertos staff members as they develop a water budget for the plantation. The data will be used to obtain a simple linear function of interception with respect to rainfall intensity and quantity. The Huertos staff may also relate some of the data obtained in this research to larger objectives dealing with leaching, soil fertility loss and forest restoration (Bigelow, pers. com., 1995).

Chapter 2

REVIEW OF INTERCEPTION PROCESSES AND PREVIOUS RESEARCH

The main thrust of this research is to examine the relationships between throughfall and various independent variables in a tropical forest plantation. In addition to throughfall, stem flow and litter interception, the process by which water remains unavailable to plants in the litter layer, influence the amount of rain reaching the soil. Collectively these are the processes responsible for interception loss.

Interception Processes

Ideally, all components of the water budget should be studied together since they are interdependent. However, detailed analyses of individual aspects are extremely useful (Jackson, 1971). Incident rainfall is caught by the vegetation canopy and partitioned as throughfall, stem flow, and evaporation from the vegetation (Horton, 1919). Moisture intercepted by leaf surfaces evaporates much more readily than water already in the tree leaves because it does not have to pass through stomata (Bigelow, personal com., 1995).

Throughfall, the focus of this research, consists of rainfall that falls straight through the canopy and rainfall that drips to the ground after being intercepted by the vegetation (Gurnell, 1985a). Throughfall provides a channel between the canopy and ground and permits the transfer of large quantities of nutrients from the canopy to the soil (Manokaran, 1979).

Stem flow is the drainage of intercepted water down the stems of plants (Gurnell, 1985b). Several previous studies have indicated that stem flow is only a minor component

of intercepted precipitation. Based on an interception study conducted in the Amazon rain forest, Lloyd and Marques (1988) determined that stem flow transported 1.8 percent of total rainfall, with a standard error of one percent. A similar conclusion was reached by Nye (1961), who stated that the proportion of rainfall accounted for as stem flow rarely exceeds one percent in tropical forest, and thus that the importance of stem flow can be overlooked in some studies. However, much higher volumes have been measured. Based on work conducted in two tropical rain forests in Australia, Herewitz (1986) recorded stem flow volumes as large as one to two magnitudes greater than the volume of rain that would have been collected in a rain gauge occupying the same area as the trunk basal area. In one of the few published studies conducted on a tropical forest plantation, Miranda (1994) found stem flow in cocoa trees to be only two percent of incident precipitation.

Some of the earliest published research on interception was produced by Horton in 1919. Since that time, most interception research has been conducted in the world's temperate zones (Voigt, 1960; Helvey and Patric, 1965; Helvey, 1971; Gash *et al.*, 1980; Dolman, 1987), both in natural forest settings and in forestry plantations. More recently, research on interception processes in the tropics has increased. However, much of this research has been conducted under natural rain forest canopies (Clements and Colon, 1975; Calder *et al.*, 1986; Lloyd and Marques, 1988), and only a few studies have examined the interception process on tropical forestry plots (Manokaram, 1979; Calder *et al.*, 1993; Miranda, 1994).

Interception Models

One of the goals of this research is to develop a simple model to predict throughfall amounts based solely on observable variables. Other models have been developed previously to predict interception, of which the Gash and Rutter models have been the most widely used (Rutter *et al.*, 1971; Gash, 1979; Dolman, 1987; Teklehaimanot and Jarvis, 1991). Both were developed in temperate regions. The model to be developed in this thesis will predict throughfall values, not interception values. However, interception estimates can be made from a throughfall model.

Until the development of the Rutter model, interception was often predicted through the use of established relationships between interception loss and rainfall, expressed either as percentages or regressions. This method seemed to work surprisingly well in some areas, such as the hardwood forest of the eastern United States (Helvey and Patric, 1965). Zinke (1967) later stated that interception losses, both as absolute amounts and as proportions of gross rainfall, are likely to vary with climate and the intensity and duration of rainfall. Jackson (1971) argued against the use of regression equations expressing throughfall as a function of rainfall, echoing Zinke's arguments and further noting that such equations do not account for the interval between storms.

Rutter *et al.* (1971) used data collected in a plantation of *Pinus nigra* in southeast England to develop a more fundamental analysis of the interception process. The Rutter model calculates a running balance of rainfall, throughfall, evaporation and changes in canopy storage, based on data recorded at hourly intervals (Rutter *et al.*, 1971). Stem

flow was measured, but was infrequent and negligible, and thus was not incorporated into the original model.

Rutter tested his model on data from four storms. For each storm the following variables were either recorded or estimated: duration of rain, mean intensity of rain, mean wind speed, mean evaporation rate, storage capacity, drainage coefficient, and residual drainage. He also applied the model to data for the same variables collected over an 18 month period. Drawbacks to the Rutter model are its complexity, requirement of hourly data and the fact that it cannot accurately be extrapolated to other species or locations. According to Aston (1979), Rutter's model is site-specific because separate coefficients are required for each treatment and because the wind factor cannot be extrapolated to other communities unless it is expressed on a per unit leaf area basis.

Gash (1979) felt that estimating interception via regression equations was inaccurate and that Rutter's physically-based computer model was the most rigorous method for estimating interception available at that time. However, he believed the model had limited feasibility due to its requirement of hourly meteorological data, which are often not available, and its dependence on a complex computer model, which was time consuming to construct and operate (Gash, 1979). Gash intended to construct a model that was simpler and easier to apply than the Rutter model, but still contained much of the objectivity and physical reasoning employed in the Rutter model.

Like Rutter, Gash developed his original model based on data collected for a temperate pine species, *Pinus sylvestris*. Unlike Rutter's time-based model, Gash constructed an analytical model that considers rainfall to occur in a series of discrete

storms consisting of a wetting-up period, a period of saturation, and a period of drying out (Lloyd *et al.*, 1988). It assumes that the canopy has sufficient time to dry between storms. This assumption greatly reduces the applicability of the Gash model in the humid tropics where the canopy may remain saturated, or at least wet, during the interval between storms. Gash's model is considered a simplification of the Rutter model, yet it requires all the same variables, as well as a value for the ratio of the mean evaporation rate to the mean rainfall rate for hours when the canopy is saturated (Lloyd *et al.*, 1988). Gash's model is thus simpler only in terms of calculation. Calculating evapotranspiration from a saturated canopy via the Penman-Monteith equation is crucial in both the Gash and Rutter models.

Need for Further Research

Previous work focused on partitioning incident rainfall into its various components was based both on field observations and mathematical models (Rutter, *et al.*, 1975; Gash and Morton, 1978; Mulder, 1985; Dolman, 1987; Rao, 1987; Lloyd *et al.*, 1988). The variability of interception, and more specifically throughfall, has been a component of some previous work, but generally not the focus. Jackson (1971) stated that there is a need for more detailed studies of individual storms, particularly with an emphasis on intensity. In a more recent article, Miranda (1994) found that interception variations were related to variations in rainfall patterns and leaf flushing, but they were unable to establish a consistent spatial pattern. Both rainfall intensity and the effects of leaf area are

examined through this research. As previous researchers have noted, examination of these two variables is important to more clearly understand the significance of throughfall.

Chapter 3

STUDY SITE

La Selva Biological Research Station

The La Selva Biological Station is a premier research facility owned and administered by the Organization of Tropical Studies, a consortium of United States, Costa Rican, and Puerto Rican universities and research institutions. The Organization's primary objective is to facilitate tropical research and education by providing an accessible field site complete with living and laboratory facilities, which now includes a geographic information system that is unparalleled in the tropics (McDade and Hartshorn, 1994).

La Selva is located at the confluence of the Sarapiquí and Puerto Viejo Rivers in the cantón of Sarapiquí, province of Heredia, Costa Rica (10° 26' N, 83° 59' W), where the foothills of Costa Rica's central volcanic mountain chain gives way to the Caribbean coastal plains (Figure 1). The station's low point is 35 meters above sea level, located along the Rio Puerto Viejo. The high point of 137 meters is located at the southwest corner of the station. The station consists of 1,536 hectares, of which 55 percent is in primary forest, 7 percent in selectively logged primary forest, 11 percent in young secondary forest, 18 percent in early successional pasture, and 8 percent in abandoned plantation. Primary forest refers to those sections of the forest that have not been cleared within recent history. The remaining area is managed for research or development purposes or has been developed (McDade and Hartshorn, 1994). Figure 2 is a map of the station depicting land uses.

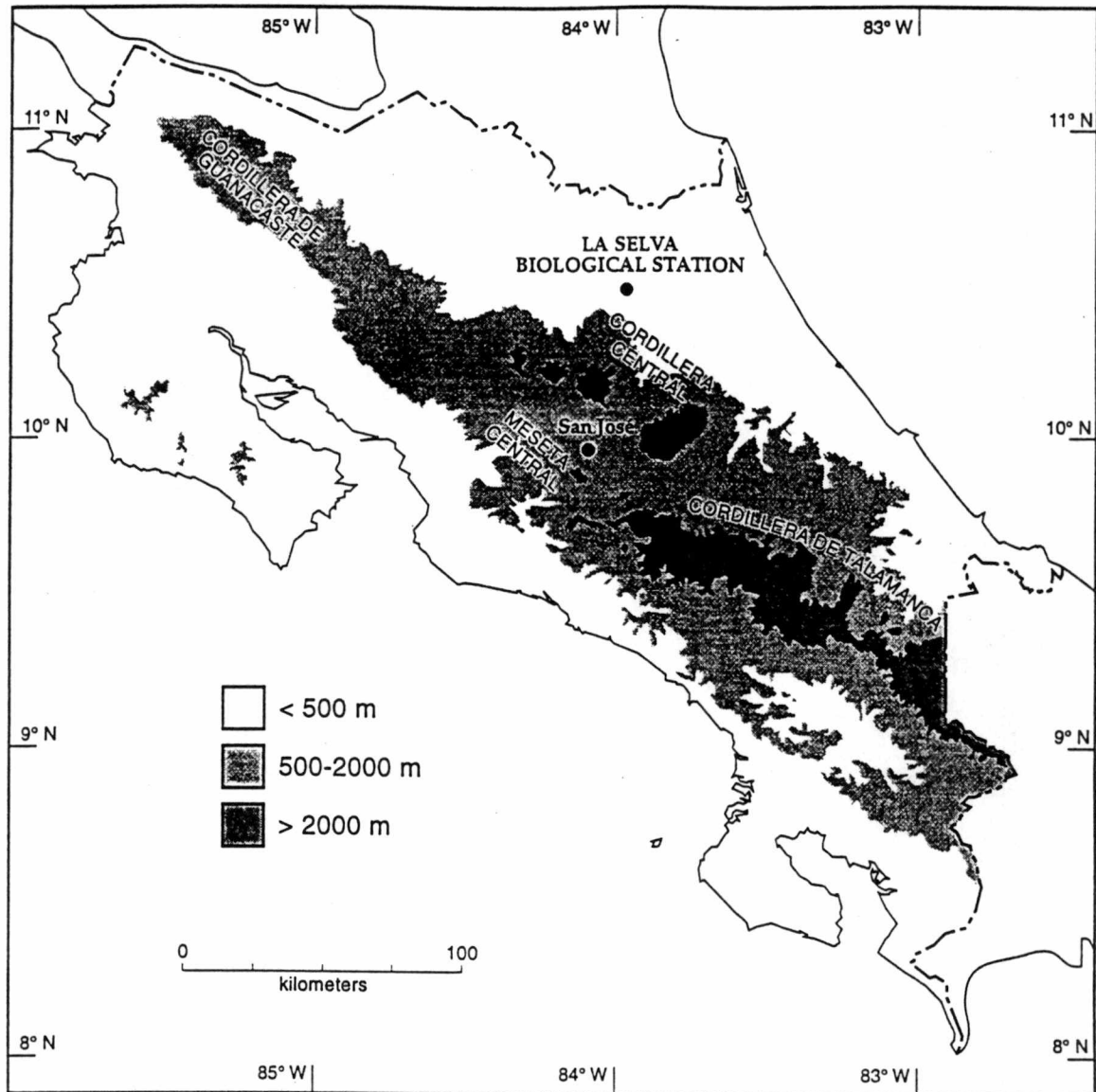


Figure 1: Map of Costa Rica

Source: Provided by the University of Tennessee, Knoxville, Department of Geography, Cartographic Services Laboratory

LA SELVA BIOLOGICAL STATION

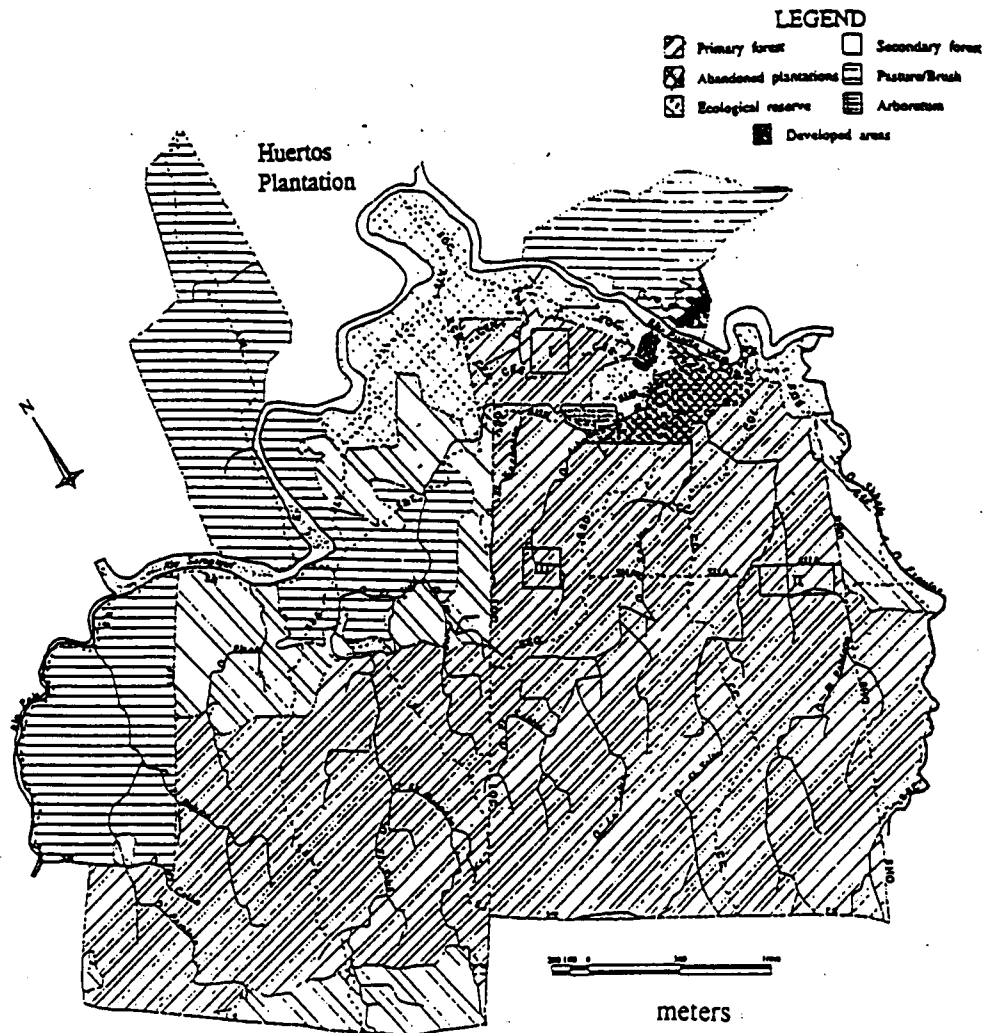


Figure 2: Land use map of La Selva Biological Station

Source: McDade, L.A. and G.S. Hartshorn (1994) *La Selva Biological Station* IN: La Selva: Ecology and Natural History of a Neotropical Rainforest (Eds). L.A. McDade, K.S. Bawa, H.A. Hespenheide and G.S. Hartshorn. Chicago: The University of Chicago Press. 8.

Climate

Climatically, La Selva is considered a tropical wet forest. These areas are found in low-altitude zones within 23°27' of the equator. The two main climatological characteristics of tropical wet forest are: mean annual daily temperature between 18° and 24° Celsius, with more diurnal than seasonal temperature variation; and annual precipitation totals exceeding 2,000 millimeters, with no month receiving less 100 millimeters (Sanford *et al.*, 1994). Precipitation patterns for Costa Rica and most of Central America are controlled by three large-scale circulation patterns: the equatorial low-pressure trough, easterly waves embedded in the trade winds, and the polar trough (Dunn and Miller, 1964). In addition to these major atmospheric circulation patterns, the climate of Costa Rica is greatly influenced by orographic effects due to the mountains of the Central American continental divide.

Climate data for La Selva are essentially limited to daily precipitation records for the past 25 years. Individual researchers have collected other meteorological data, such as net radiation, air temperature, or relative humidity, on a short term basis. A standardized long term record for any measurement other than precipitation does not exist. The long-term average annual precipitation measured for La Selva is 3,962 millimeters, with peaks of more than 400 millimeters per month occurring both in June-July and November-December. February to April is the period with the least precipitation, and March is typically the driest month.

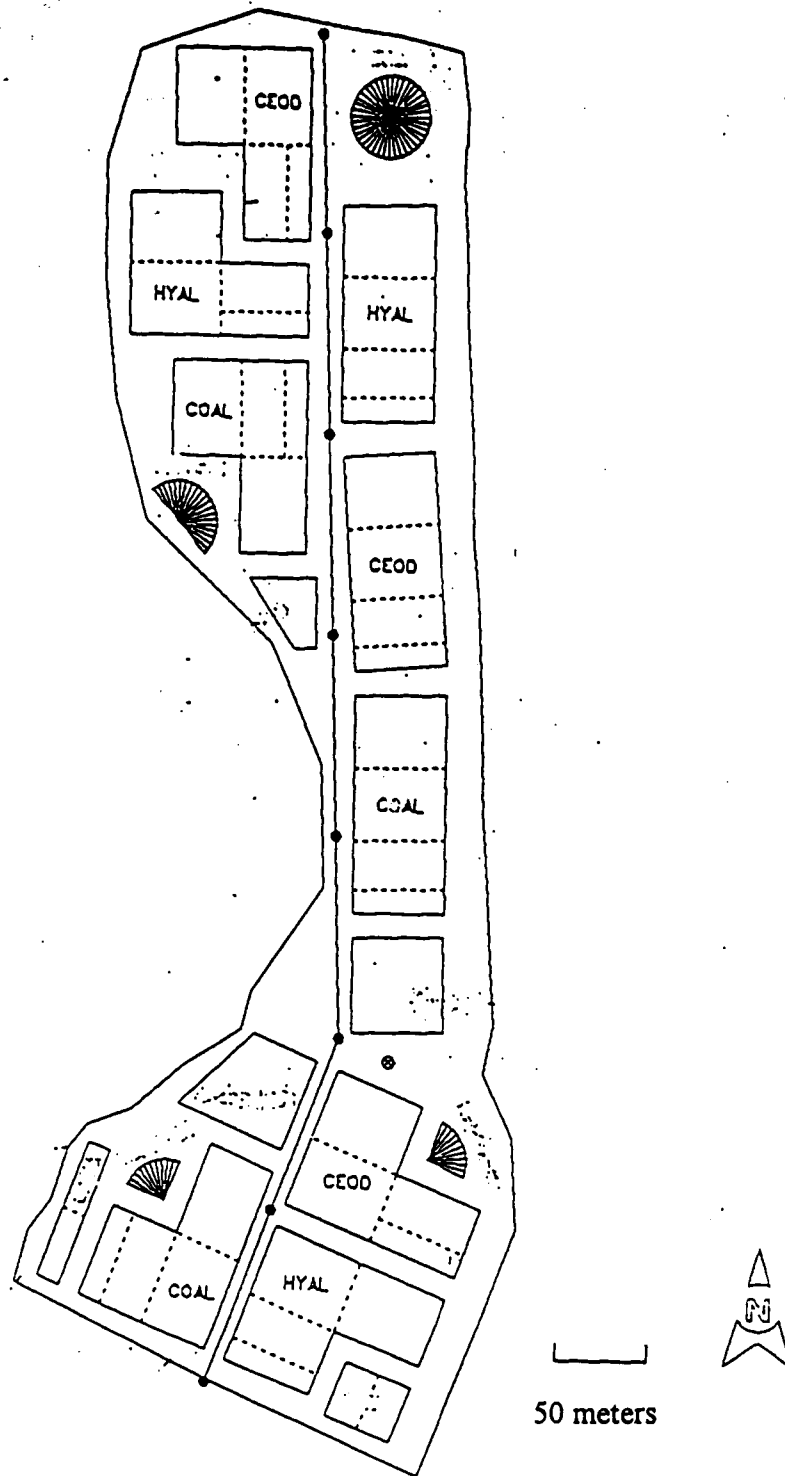
Air temperature has been measured since 1984 at the Bridge Station of La Selva. The average monthly temperature is 25.8° C. The average monthly temperature change of

less than 3° C is minimal compared to the diurnal change of 6° C to 12° C. As with temperature, daily fluctuations in solar radiation are usually greater than month-to-month changes (Sanford *et al.*, 1994).

The Huertos Project

All field work for this experiment was conducted at the Huertos Forestry Plantation, which covers 15 hectares and is located at the confluence of the Sarapiquí and Puerto Viejo Rivers near the northern border of the station (Figure 2). The location of the plantation along the Sendero Tres Rios bicycle path, approximately 2 kilometers from the main research laboratories, made it very accessible by foot or bicycle. The site is on an alluvial terrace with a deep, well-drained soil classified as a mixed, isohyperthermic, possibly andic, fluventic Dystropept, with pH of 6.5 (Haggar and Ewel, unpublished). The site was cleared of an abandoned cocoa plantation in 1991 and the tree plantation was established following manual clearing of charred logs.

The Huertos experiment is a 16 year project under the direction of Dr. Jack Ewel, a professor from the University of Florida's Botany Department. The project's purpose is to examine multiple aspects of planting fast-growing tree species, primarily for timber production in the humid tropics on lands formerly occupied by natural forest. Some of the issues under study are leaching and soil fertility loss, forest restoration, sustainable agriculture, development of a water budget, and biomass allocation (Ewel, personal com., 1994). The Huertos site is divided into three major blocks, each having four treatments of the three study species (Figure 3). The treatments include three monoculture sections that



COAL = *Cordia alliodora*, CEOD = *Cedrela odorata*, HYAL = *Hyeronima alchorneoides*

Figure 3: Map of the Huertos Project Area

Source: Provided by Mr. Seth Bigelow, Huertos Project Manager

are harvested either every year, every four years or at the end of the project. There is also a diculture section that will not be harvested until the end of the project.

Cedrela odorata, *Cordia alliodora*, and *Hyeronima alchorneoides* were selected for the Huertos project based on their contrasting physiognomic characteristics, which indicated a potential for different resource capture capabilities (Hagger and Ewel, unpublished). All three species are fast growing tropical hardwoods native to Costa Rica. *Cordia* is known for its ability to colonize pastures and old fields on fertile soils. A substantial amount of genetic and silvicultural work has been done on *Cordia* by foresters (Greaves and McCarter, 1990). *Cedrela*, a close relative of mahogany, is a Neotropical timber tree of considerable value and is widely planted in the humid tropics (Whitmore, 1976). *Hyeronima* is a promising species for reforestation of degraded pastures (Butterfield, 1990). It is a massive emergent rain forest tree with durable, dense hardwood. Studies indicate that *Hyeronima* saplings are fast-growing and light-demanding, but trees may take 100-300 years to grow to full-size in natural forest (Clark and Clark, 1992).

The trees were produced in a nursery at La Selva, with the *Cordia* and *Cedrela* seeds supplied from Centro Agronomica Tropical de Investigacion y Ensenanza (CATIE). *Hyeronima* seeds were gathered in the station's immediate vicinity. Planting occurred in mid-1991, when three 50 by 40 meter plantations of each species, arranged in a randomized block design were established. Each tree was surrounded by six other trees, each 2 meters away, resulting in a stand density of 2,887 trees per hectare. Each species was planted in monoculture stands and incorporated into a mixed stand with equal

proportions of the study species and palms of the genus *Euterpe*. *Euterpe macrospadix* and *Euterpe oleracea* were alternated at planting points designated for a palm (Haggar and Ewel, unpublished).

The Huertos Forestry Plantation at La Selva offers a unique opportunity to study throughfall with species and tree density controlled. Cooperation from the Huertos staff and the ability to obtain climate data from a nearby weather station made this an ideal location for throughfall sampling.

Chapter 4

RESEARCH METHODS

During the months of November and December 1994, while working as a GIS intern at La Selva, I obtained the data needed for this research. Throughfall values were collected from a network of 36 trough gauges, randomly placed throughout Block Two of the Huertos Plantation. Total rainfall was collected in 12 on-site point gauges placed around the perimeter of Block Two. To meet the objectives of this research, additional rain data were gathered from two automatic recording gauges to allow for the calculation of rain intensity and duration. Leaf area index values were measured for each trough gauge on two occasions.

Sampling

I sampled throughfall on the 16-year monoculture and diculture plots of *Hyeronima alchorneoides* (HYAL), *Cordia alliodora* (COAL), and *Cedrela odorata* (CEOD), located at the Huertos Forestry Plantation in experimental Block Two. The decision to sample from a forestry plantation, as opposed to primary forest, was based on logistical considerations and the opportunity to minimize external variables. By working at the Huertos site, the effects of several external variables such as soil type, topography, distance to major water sources, and the importance of local winds were greatly minimized. Due to time and financial limitations, only a certain number of throughfall gauges could be monitored so I chose to establish a dense network in one particular block, rather than disperse the same number of gauges throughout all three blocks. Because of

the highly variable nature of throughfall, sampling over a very large area with a small number of gauges would have likely provided extremely unreliable results.

The primary objective in selecting a sampling period was to pick a period that allowed the greatest amount of data to be collected in the smallest amount of time. In order to select a period meeting this criteria I examined available precipitation records for La Selva: daily rainfall totals for 1963 to the present from Rafael's Point, and daily rainfall from Bridge Station, established on the east bank of the Rio Puerto Viejo in 1982. Figure 4 shows the annual distribution of precipitation for 1982 - 1992 from La Selva's two weather stations.

July is the wettest month of the year, followed by August and June. There is a short dry period in September and October. November and December are the ninth and eighth wettest months respectively, followed by a rather dry period from January to March. Throughfall sampling began in mid-November 1994 and continued through the end of December. The wet period in November and December is less significant than the major wet period of June through August, but rain during November and December 1994 was sufficient to provide data for this experiment.

Initial Test

To determine the appropriate number of throughfall gauges to be used for the experiment, an initial test was conducted between November 9 and November 13, 1994, during which time six rainfall events occurred. This initial test was conducted in the 16-year monoculture and diculture plots of *Cordia alliodora*. I placed nine gauges

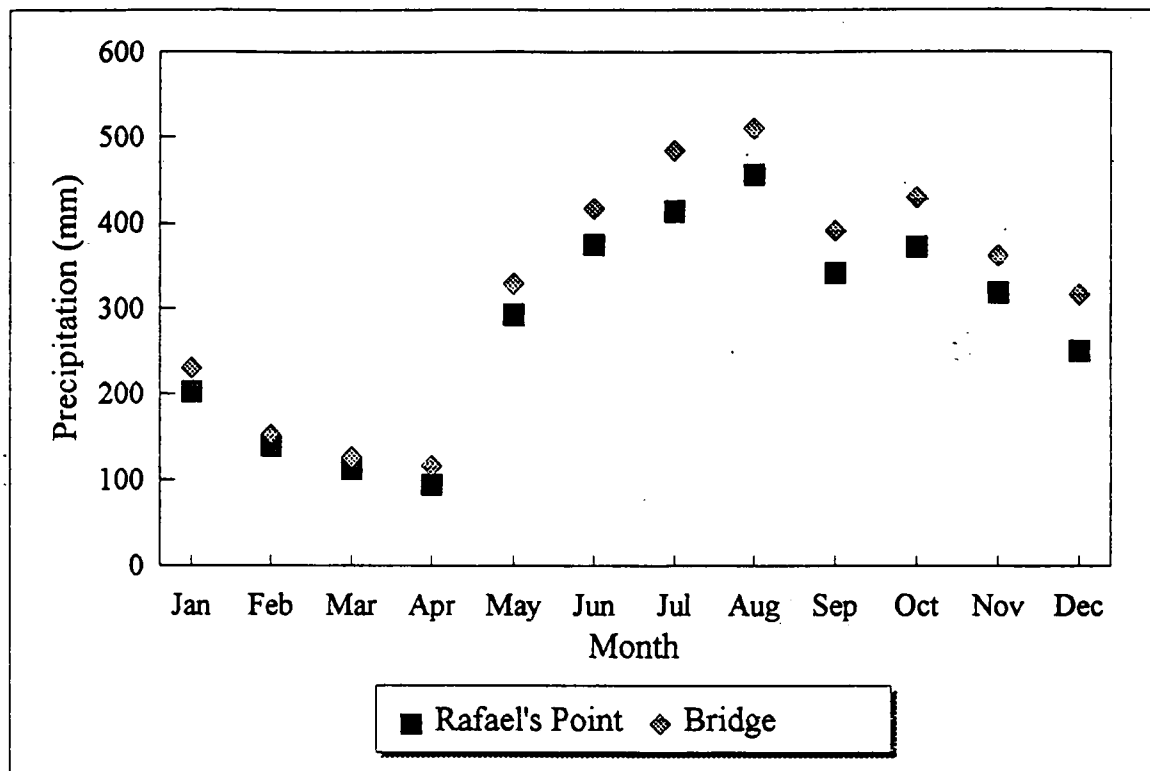


Figure 4: Rainfall data from La Selva's two weather stations, 1982 - 1992
Source: La Selva weather database

randomly within each of the two plots and I sampled throughfall and total rainfall following each rainfall event.

Data from the initial experiment were used with the following formula from Sokal and Rohlf (1969) for determining the number of replicants needed to detect a given difference between means:

$$n \geq 2 \left(\frac{\sigma}{\delta} \right)^2 \{ t_{\alpha[v]} + t_{2(1-p)[v]} \}^2$$

where:

n = number of replicants

σ = true standard deviation

δ = the smallest true difference that is desired to detect (.3 cm)

v = degrees of freedom of the sample standard deviation (16)

α = significance level (.05)

p = desired probability that a difference will be found to be significant (.8)

$t_{\alpha[v]}$ and $t_{2(1-p)[v]}$ = values from a two-tailed t table with v degrees of freedom and corresponding to probabilities of α and $2(1-p)$, respectively.

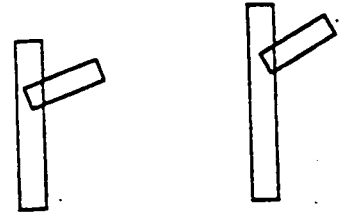
These tests were conducted for the entire data set, for individual precipitation events, and for each treatment. Spatial variability was considerably higher in the diculture plots, so two additional gauges were placed in these treatments for the main experiment.

In addition to determining the number of gauges for the experiment, the initial test helped improve the overall experimental design. The storage portion of throughfall collectors had not been covered in the initial experiment and thus had collected considerable rain splash as well as throughfall. For the main experiment, the storage buckets were covered and the height of all trough stands was increased to avoid contact with the undergrowth and to decrease the possibility of collecting rain splash. Figure 5 is a diagram of the throughfall collection system.

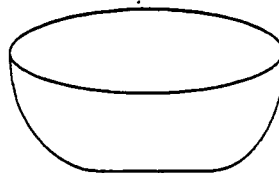
Materials



200 cm PVC piping, cut along length

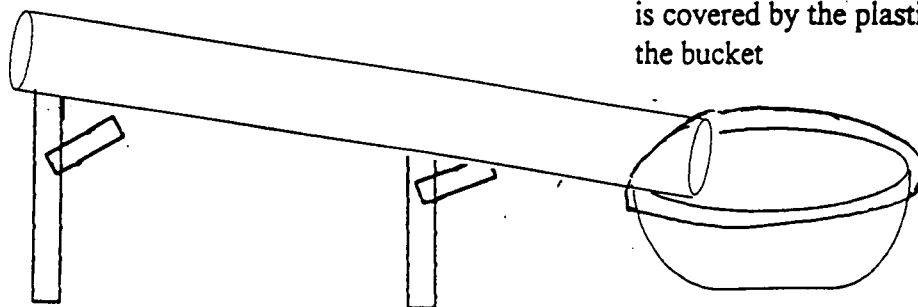


Two wooden stands



Plastic bucket for throughfall collection

Setup



Approximately 20 cm of the pipe is covered by the plastic covering the bucket

Figure 5: Diagram of the throughfall collection system

Sampling Design

Several types of data needed to be collected throughout the entire sampling period to address the questions set forth for this experiment. Total precipitation needed to be recorded as near the site as possible, due to the high spatial variability of tropical precipitation events. Total precipitation also needed to be recorded on a continuous basis with a recording type rain gauge. Continuous data were used to determine the approximate beginning and ending of a precipitation event and thus the length of each event.

Since I was not able to continuously measure precipitation with a recording rain gauge at the exact location of the experimental plots, I developed a bi-level recording method. I measured on-site total precipitation with 12 plastic Sunbeam rain gauges. These point gauges were placed in the clearing around the perimeter of Block Two, to eliminate any canopy interference. The 12 point gauges were used to assess micro-climatic variation around the experimental block, to prevent the loss of data that could occur with using only one gauge, and to provide average precipitation values for each rain event.

The 12 rain gauges located on the Huertos site provided a fairly consistent account of precipitation, but did not provide any temporal information. Two options existed for collecting rainfall data from a recording tipping bucket gauge: La Selva's Bridge Station and a weather station operated at La Selva for the GLASNOST research project. The GLASNOST project, under the direction of Dr. Michael Keller, a physical scientist

employed by the United States Forest Service, maintains several experimental sites along the Sendro Tres Rios to examine the relationships between various land use practices and soil gas emissions. GLASNOST staff members maintain a meteorological station on their plot closest to the Huertos experimental site, approximately 150 meters from Block Two where I sampled for throughfall.

To ensure the most complete data record possible, rainfall data were collected from both the La Selva and GLASNOST automatic weather stations and compared with those from the non-recording point gauges. Differences between all three sites were minimal and could partially be attributed to differences in recording methods. Values associated with the point gauges represent a known quantity of precipitation for an exact amount of time based on the lengths of the collection periods. Data from the GLASNOST and La Selva gauges were recorded at 30 and 60 minute intervals respectively. These time periods, and thus these values, do not correspond exactly to those from the point gauges. There were 12 rainfall events in the La Selva data record for which the exact division of precipitation into distinct sampling periods could not be made, as opposed to only five from the GLASNOST record.

Because the GLASNOST data were recorded at twice the frequency, 30 minutes as opposed to 60, and because the GLASNOST recorder was closer to the experimental sites, I decided to use the GLASNOST data in calculations of intensity and duration of each precipitation event. However, there were three collection periods, 1, 14 and 31, from which the GLASNOST data were unusable due to mechanical failure. Fortunately, on

these dates, the La Selva data closely paralleled that collected at the experimental site, so the La Selva data were used for those three events.

Precisely determining the intensity and duration of individual rainfall events was extremely difficult. I considered an event to start with the first measurement interval recording any rainfall and to stop when a period of no rain was recorded. This means that any record of rainfall, regardless of the amount or time interval, was considered an event. Rainfall intensity and duration calculations were based on the total amount of time over which rainfall was recorded, not the entire length of the collection period. The difference between these two time periods was often very large. For example, the fourth collection period covered approximately 43 hours, but precipitation was recorded in only a 5 hour period.

Throughfall Monitoring

A total of 36 trough gauges were used to monitor throughfall between November 17 and December 25, 1994. Five gauges were placed in the monoculture plots and seven in the diculture plots of each of the sample species. More gauges were placed in the diculture plots because the initial test had indicated greater throughfall variability in those areas. Gauges were made from PVC piping cut in half lengthwise. Each gauge was positioned approximately 30 centimeters above the ground and angled at about ten degrees in order to direct collected water into a sampling bucket. Each pipe was 200 centimeters long, with a inner diameter of 5.5 centimeters. Approximately 20 centimeters of the piping were covered by plastic, which reduced the collection area from 1100

centimeters to 990 centimeters. My decision to cover the buckets with plastic was based on observed problems with the unwanted collection of rain splash during the initial experiment. Covering the buckets also allowed me to use buckets of various dimensions without having to calculate the collection area of each gauge based on bucket size. Throughfall was measured volumetrically in milliliters and then converted to a rain depth amount expressed in centimeters.

Trough gauges were positioned throughout each plot on November 17, 1994, using a random location scheme. For each gauge, three numbers were randomly selected via a random number generating program. A number between 5 and 25 was selected for the north/south direction, between 0 and 40 for the east/west direction, and between 0 and 360 for gauge orientation.

I sampled throughfall as close to the end of a rain event as possible. I was unable to sample at night, and, because of the short interval between precipitation events, most sampling periods included more than one storm. For each gauge, the bucket was detached from the trough, and the trough held vertically over the bucket and shaken to release moisture that had adhered to the trough. The contents of the bucket were then poured into a 1000 milliliter container, measured and recorded. After measurement, the rubber band attaching the plastic to the bucket was checked and then the bucket reconnected to the trough. On average, it took approximately 90 minutes to measure and record the values for all trough gauges and the on-site point gauges used to collect total precipitation.

Leaf Area Index Measurements

To examine how leaf area affects the amount of rainfall that arrives at the ground surface as throughfall, I measured the leaf area corresponding to each throughfall gauge. Leaf area index values were measured using a LiCor LAI-2000, an optical instrument used to measure the attenuation of diffuse sky radiation at five zenith angles simultaneously. It determines the amount of foliage in a canopy by measuring how quickly radiation is weakened as it passes through the canopy. Each measurement consist of a minimum of 10 numbers: five are signals from the five detectors when the optical sensor is measuring open sky conditions, and the remaining five are from when the sensor is below vegetation. Leaf area index values do not correspond to a particular dimension, but can be thought of as $\text{m}^2 \text{ foliage} / \text{m}^2 \text{ ground area}$. The above vegetation measurements are critical because they serve as a reference for incident radiation, thus allowing the sensor to calculate the canopy effect.

I measured leaf area above each throughfall gauge at three locations along the length of the trough in order to obtain an average value on December 26 and again on December 28, 1994. The measurements were made twice to ensure that accurate results were obtained, regardless of sensor faults or variations in sky conditions. Originally, more than two sets of measurements had been scheduled, but the consistent values recorded for each gauge during the first two measurements led me to decide that additional sampling would not be necessary. Incident radiation was measured in a nearby clearing prior to

each under canopy-measurement. This increased the validity of the results by minimizing the amount of time that elapsed between open sky and canopy measurements.

Chapter 5

RESULTS

Results of this research at the Huertos plantation show a general relationship between throughfall and the following variables: total rainfall, leaf cover, and intensity and duration of each precipitation event. All throughfall and on-site point gauge rain data from the main period of throughfall monitoring are provided in Appendix A, on an event basis.

Rainfall

Figure 6, a scatter plot showing the rainfall measured for each rain event from the three data sources: the on-site point gauges, the Glasnost tipping bucket gauge and the tipping bucket gauge at the La Selva Bridge station, shows little variation between the data sources. Also, there were minimal differences in total rainfall collected in the 12 on-site gauges. This lack of variation suggests that micro-variation was not significant for the sampling area and supports the assumption that all throughfall gauges were exposed to equal amounts of total rainfall.

Relationships between average event throughfall and total event rainfall are shown graphically in Figure 7. Tables showing throughfall and rainfall values on both gauge and event bases are provided in Appendix B. Gauge based throughfall values represent the average amount of throughfall collected in each of the 36 trough gauges for the 34 events. Collected throughfall and total rainfall measurements were compared by reporting

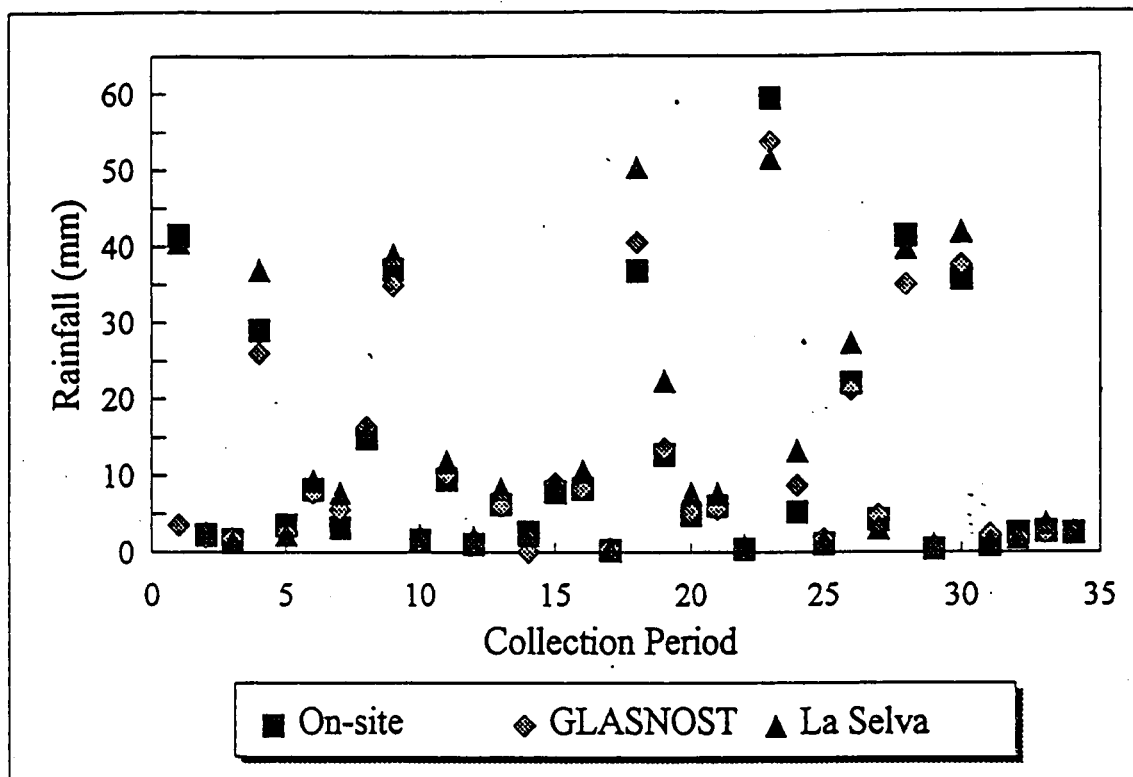


Figure 6: Comparison of three rainfall data sources

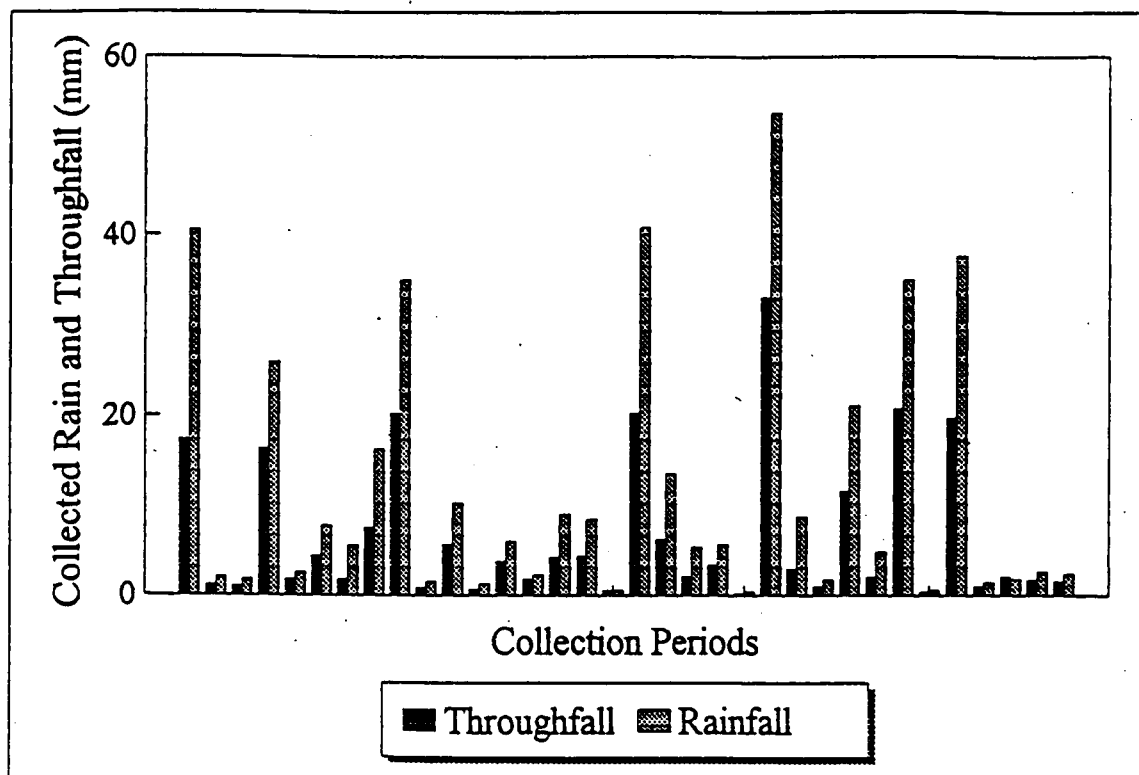


Figure 7: Throughfall and total rainfall from event data

throughfall as a percentage of total rainfall and through regression equations. Both of these methods were described by Helvey and Patric (1965) and used by many other researchers. These methods do not account for differences related to precipitation intensity or duration, but only look at the total collected rainfall regardless of storm regime.

I calculated throughfall as a percent of the total rainfall collected for each unique species and treatment combination, for individual treatments regardless of species, and for each species regardless of treatment. These results are shown in Table 1. The regression line for throughfall against total rainfall is as follows:

$$y = .548x - .099$$

where y = throughfall (mm) (1)
x = total rainfall (mm)

Figure 8 graphically shows the relationship between event-based average throughfall and event-based rainfall. The regression gave an r^2 value of .972 at a high level of significance.

Rainfall Intensity and Duration

The measurement of rainfall intensity and duration proved to be very difficult. Ideally, I would have liked to have monitored enough single rainfall events to perform statistical analyses solely on single storm events, but only eight of the 34 collections were from single events. Both the inability to sample at night and the short time interval between many storms greatly reduced my ability to sample after each rainfall event. For collection periods that involved multiple events, I calculated the duration and intensity

Table 1: Comparisons between throughfall and total rainfall by species and treatment

Species	Treatment	Throughfall (cm)	% of rain partitioned as throughfall
CEOD	M	178.5	86 %
COAL	M	163.1	79 %
CEOD	B	332.2	67 %
HYAL	M	121.3	59 %
CEOD	D	153.7	53 %
HYAL	B	240	48 %
COAL	B	229.9	46 %
HYAL	D	118.7	41 %
COAL	D	66.8	23 %
All	M	462.9	75 %
All	D	339.2	39 %
All	B	802.1	54 %

M = monoculture, D = diculture, B = both treatments
 COAL = *Cordia alliodora*, CEOD = *Cedrela odorata*, HYAL = *Hyeronima
 alchorneoides*

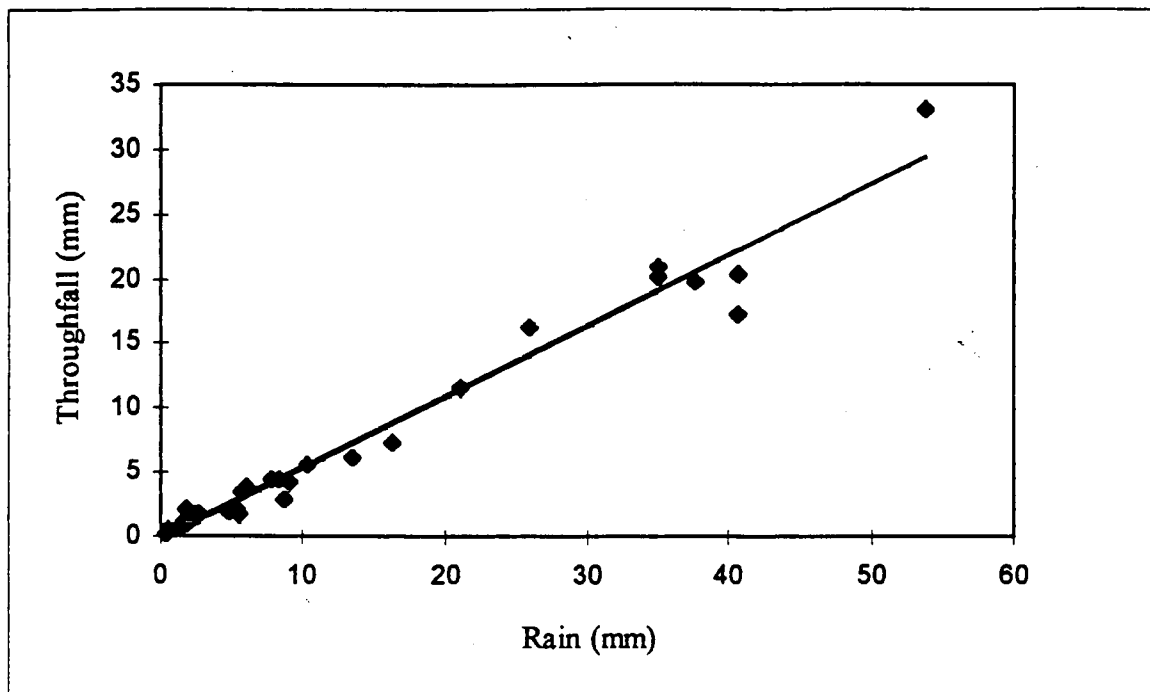


Figure 8: Throughfall as a function of total rainfall

based on the time that rainfall was actually recorded. Rainfall totals, intensity and duration are shown in Table 2.

Differences in total rainfall at the La Selva Bridge gauge and the Glasnost gauge for any given period were minimal, but significant differences occur when rainfall intensity and duration are considered. For the entire sampling period, the La Selva gauge recorded 77 rain events lasting a total of 274 hours and having an average intensity of 0.03 mm/minute. The Glasnost gauge recorded 110 rain events lasting approximately 116 hours with an average intensity of 0.05 mm/minute.

Regressions expressing average event throughfall data as a function of rainfall duration and intensity resulted in r^2 values of .74 and .24 respectively (Figures 9 and 10).

The regression lines are as follows:

$$y = .032x - .974$$

where y = throughfall (mm)
x = duration (min.)

(2)

$$y = 105.06x + 1.69$$

where y = throughfall (mm)
x = intensity (mm/min)

(3)

A multivariate regression, expressing throughfall as a function of both duration and intensity produced an R^2 value of .85. A second multivariate regression was conducted to include the effects of total rainfall and resulted in an R^2 value of .978. These multivariate tests generated the following regression lines:

$$y = .03x_1 + 77.34x_2 - 4.06$$

where y = throughfall (mm)
x₁ = duration (min.)
x₂ = intensity (mm/min)

(4)

Table 2: Total rainfall intensity and duration

Coll. #	Duration of sampling period minutes	Glasnost rain totals (mm)	Glasnost # of storms	Glasnost duration of storms (min.)	Glasnost Intensity mm/min
1	1,327	40.6	3	840	0.05*
2	1,187	2	1	90	0.02
3	385	1.75	1	60	0.03
4	2,590	26	5	300	0.09
5	285	2.5	2	60	0.04
6	1,005	7.75	4	180	0.04
7	330	5.5	1	60	0.09
8	127	16.25	1	90	0.18
9	1,393	35	4	450	0.08
10	455	1.5	4	150	0.01
11	390	10.25	2	210	0.05
12	1,180	1.25	4	120	0.01
13	4,110	6	6	300	0.02
14	1,430	2.2	4	240	0.009*
15	2,885	9	6	270	0.03
16	4,405	8.4	2	90	0.09
17	315	0.5	1	30	0.02
18	1,030	40.7	3	780	0.05
19	490	13.5	4	210	0.06
20	915	5.3	5	240	0.02
21	265	5.6	2	270	0.02
22	145	0.3	1	30	0.01
23	1,425	53.7	11	870	0.06
24	1,130	8.7	3	120	0.07
25	1,515	1.7	5	150	0.01
26	1,225	21.1	8	330	0.06
27	465	4.8	4	180	0.02
28	940	35	6	480	0.07
29	325	0.5	1	30	0.02
30	1,045	37.6	4	300	0.12
31	1,767	1.4	2	300	0.005*
32	8,500	1.8	1	90	0.02
33	327	2.6	2	120	0.02
34	2,705	2.4	4	180	0.01
Total	48,013	374.75	110	6,900	0.05

* = Data are from the La Selva Gauge

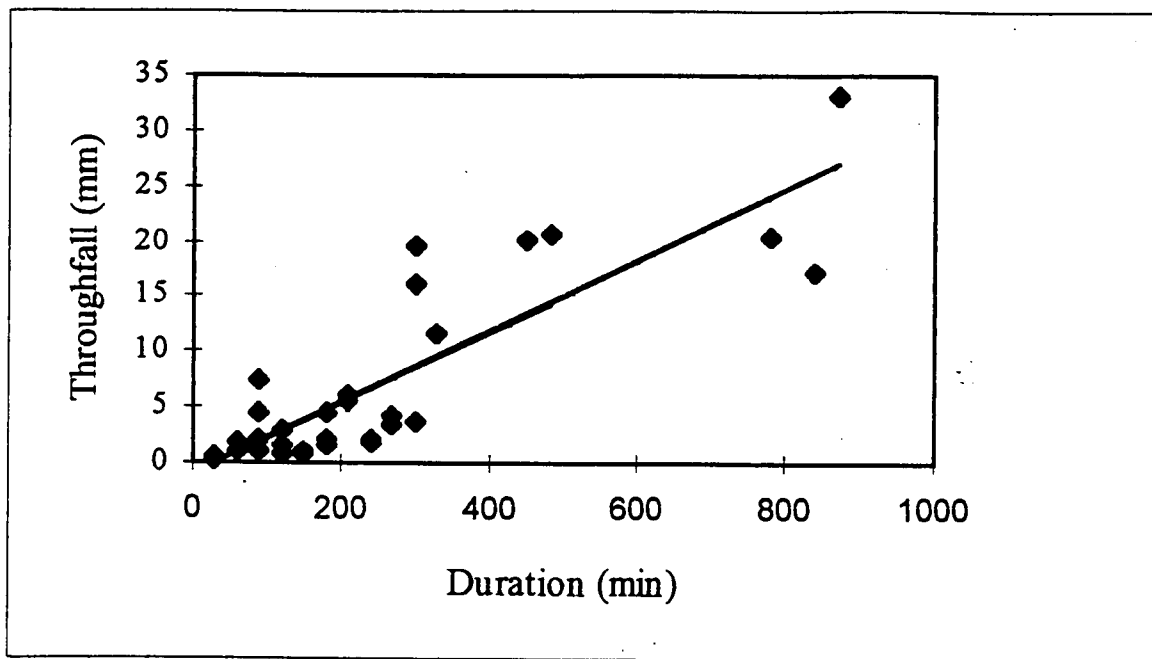


Figure 9: Throughfall as a function of rainfall duration

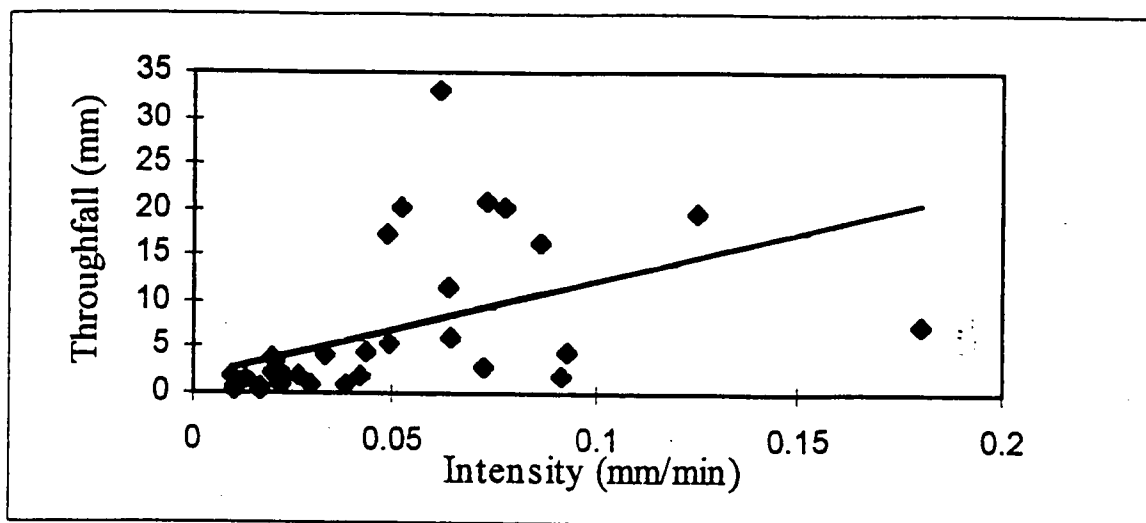


Figure 10: Throughfall as a function of rainfall intensity

$$y = .71x_1 - .009x_2 - 30.47x_3 + 1.5 \quad (5)$$

where y = throughfall (mm)
 x_1 = total rainfall (mm)
 x_2 = duration (min.)
 x_3 = intensity (mm/min.)

Relationships were all highly significant.

Leaf Area

Table 3 shows the data obtained from leaf area index measurements for each gauge. Differences between the measurements for the two days were minimal. An average of the two leaf area values was used for analysis. The mean leaf area value for the study site was 3.57, with 0.27 and 5.35 being the lowest and highest values respectively. Monoculture plots had an average leaf area value of 1.9 and diculture plots had an average value of 4.77. The average leaf index values for each species were as follows: *Cordia*, 3.23; *Cedrela*, 2.83; and *Hyeronima* 4.65.

The relationship between leaf area and throughfall was examined through regression analysis. I examined within plot variability, variability between the two treatments and variability between the three species. Regression comparing the leaf area values for all gauges with their average gauge throughfall amounts had an r^2 of 0.486, at a high level of significance. The regression line is as follows:

$$y = -.402x + 6.2 \quad (6)$$

where y = throughfall (mm)
x = average leaf area in value

Overall, the direct relationship between throughfall and leaf area was quite weak. Table 4 compares average leaf area values with average throughfall as a percent of total rainfall for each species and treatment.

Table 3: Leaf area index values for each gauge

Species	Treatment	Gauge #	12/26 LAI	12/28 LAI	Average LAI	Difference
CEOD	M	3	0.32	0.22	0.27	0.1
CEOD	M	5	0.4	0.22	0.31	0.18
CEOD	M	2	0.45	0.32	0.39	0.13
CEOD	M	4	0.44	0.41	0.43	0.03
CEOD	M	1	0.54	0.36	0.45	0.18
COAL	M	2	0.83	1.13	0.98	-0.3
COAL	M	3	0.91	1.15	1.03	-0.24
COAL	M	5	0	1.08	1.08	-1.08
COAL	M	4	1.03	1.22	1.13	-0.19
COAL	M	1	1.43	1.34	1.39	0.09
CEOD	D	7	3.47	3	3.24	0.47
HYAL	M	2	3.52	3.25	3.39	0.27
HYAL	M	3	3.6	3.82	3.71	-0.22
CEOD	D	1	3.85	3.92	3.89	-0.07
COAL	D	7	4.38	3.59	3.99	0.79
COAL	D	6	4.32	3.87	4.1	0.45
CEOD	D	2	4.49	4.29	4.39	0.2
COAL	D	1	4.58	4.27	4.43	0.31
HYAL	D	5	4.67	4.59	4.63	0.08
HYAL	M	4	4.59	4.68	4.64	-0.09
HYAL	M	5	4.72	4.58	4.65	0.14
HYAL	M	1	4.74	4.78	4.76	-0.04
HYAL	D	3	5.01	4.58	4.8	0.43
COAL	D	2	4.92	4.73	4.83	0.19
HYAL	D	7	4.82	4.93	4.88	-0.11
CEOD	D	5	4.72	5.09	4.91	-0.37
HYAL	D	4	5.01	4.94	4.98	0.07
COAL	D	4	5.09	4.95	5.02	0.14
HYAL	D	1	5.15	5.04	5.1	0.11
HYAL	D	2	5.2	5.07	5.14	0.13
CEOD	D	6	5.37	5.02	5.2	0.35
CEOD	D	3	5.34	5.17	5.26	0.17
HYAL	D	6	5.33	5.21	5.27	0.12
CEOD	D	4	5.11	5.53	5.32	-0.42
COAL	D	5	5.41	5.3	5.36	0.11
COAL	D	3	5.58	5.36	5.47	0.22

LAI = leaf area index

M = monoculture D = diculture

COAL = *Cordia alliodora*, CEOD = *Cedrela odorata*, HYAL = *Hyeronima alchorneoides*

Table 4: Average leaf area compared with average percent of throughfall

<u>Species</u>	<u>Treatment</u>	<u>Average throughfall</u>	<u>Average LAI values</u>
CEOD	M	86.4	0.39
COAL	M	78.96	1.12
All	M	47.96	1.9
CEOD	B	67	2.83
COAL	B	46.38	3.23
All	B	53.93	3.57
HYAL	M	58.71	4.23
CEOD	D	53.15	4.6
HYAL	B	48.4	4.65
COAL	D	23.1	4.74
All	D	50.35	4.77
HYAL	D	41.04	4.97

LAI = leaf area index

M = monoculture D = diculture

COAL = *Cordia alliodora*, CEOD = *Cedrela odorata*, HYAL = *Hyeronima alchorneoides*

To examine the combined effects of leaf area with total rainfall, intensity, and duration, the following multivariate regression equation was derived:

$$y = .691x_1 - 1.21x_2 - .008x_3 - 27.83x_4 + 5.71$$

where y = throughfall (mm) (7)

x_1 = total rainfall (mm)
 x_2 = leaf area index values
 x_3 = rainfall duration (min.)
 x_4 = rainfall intensity (mm/min.)

This regression resulted in an R^2 value of .65 at a high level of significance. There were three event-based variables: total rainfall, rainfall intensity and duration, and two gauge based variables: leaf area index values and throughfall used in this equation. Comparing these two types of data does not violate the assumptions of regression analysis, but due to data repetition the results must be viewed with a certain degree of skepticism. The fact that this regression has a lower R^2 value than equations 4 (page 35) or 5 (page 35) which have fewer independent variables is a good indication that this particular analysis is inaccurate.

Modeling

The third objective addressed by this research is whether or not a simple model based on observable variables can accurately predict throughfall. Models developed from regression appear to be good predictors of throughfall. The first regression model, shown as equation 1 (page 31), predicts throughfall values solely as a function of total rainfall. This model was the most simplistic, but still provided acceptable values. The average

difference between the predicted and actual values was 0.879 mm with a high of 4.85 mm and a low of 0.09 mm.

The second regression model, equation 5 (page 35), also uses event-based data. It predicts throughfall values based on total rainfall, and the intensity and duration of each rain event. Leaf area was omitted in this model since it is a site-specific, rather than an event-specific variable. Predicted values based on the second model were slightly more accurate than those based only on total rainfall. The average difference between the predicted and actual values was 0.826 mm with a high of 3.80 mm and a low of .09 mm. The predicted values from the two models are provided in Figure 11 and Appendix C.

I did not develop a regression model for the prediction of throughfall using all independent variables, including leaf area, due to concerns regarding the validity of statistical tests comparing event-based data with gauge-based data, and because of the weak relationship between leaf area and throughfall. The first model, tested with rainfall data from the initial experiment (November 9-13, 1994), yielded an r^2 value of .98. The second model could not be tested on the initial data because rainfall intensity and duration had not been measured.

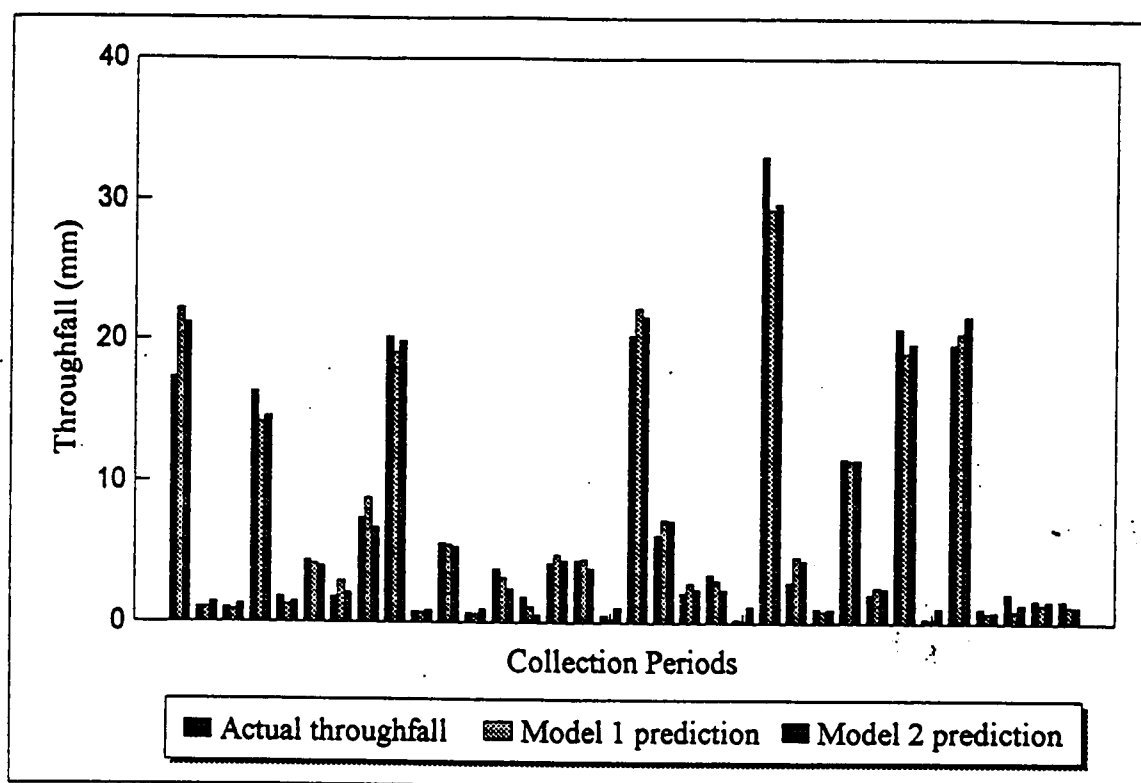


Figure 11: Actual versus predicted throughfall values

Chapter 6

DISCUSSION AND CONCLUSIONS

Rainfall Variables and Throughfall

A measurement of throughfall at any point is a random variable, the accuracy of which depends on gauging errors, gross rainfall and spatial variability related to canopy structure (Lloyd and Marques, 1988). The analysis conducted for this research confirmed that measurable relationships exist between throughfall and various independent variables. It is surprising that total rainfall appears to be the main independent variable in determining throughfall for this particular site. A much stronger relationship between throughfall and leaf area had been expected.

For the length of the experiment there were a total of 223.09 mm of throughfall. Overall, throughfall accounted for 54% of total rainfall. Throughfall accounted for a much lower percentage of total rainfall in the present research than in a previous study at La Selva, in which McColl (1970) found throughfall to be 94% of all rainfall. McColl's research was conducted under a premontane wet forest with trees up to 50 m high, thus his results are not directly comparable to those of this study.

However, it is interesting to note that McColl also conducted his research in November and that total rainfall was 463.5 mm, compared with 413.15 mm in the sampling period of this study. With approximately equal rainfall totals, the percentage accounted for by throughfall varied by 40% between premontane forest and plantation. McColl (1970) collected rainfall and throughfall in triplicate in containers 28 cm in

diameter, from November 14-28, 1969. The present study covered a period of 36 days, but received 50 mm less rain. Rainfall occurred on every day of McColl's sampling period, so that the ecosystem was completely saturated (McColl, 1970). McColl does not state the extent of his sampling region, but it is possible that his use of only three throughfall point gauges did not collect throughfall representative of the entire area. Although leaf area measurements were not taken, it is safe to assume that a premontane forest would have higher leaf area index values than a young forestry plantation. There are many additional variations between the biological physiognomy of the two land covers that would differently affect throughfall and are beyond the scope of this paper. The differences between the present study and McColl's can largely be attributed to differences in methodology, storm regime and biological characteristics of the sampling environment.

One of the few other studies of throughfall for a tropical plantation, conducted on a cocoa plantation in south-east Bahia, Brazil, found that throughfall accounted for 85% of all rainfall (Miranda, 1994). Results from other tropical studies indicate that the percentage of throughfall ranges from 37 to 97% (Clarke, 1987). The results from this study, then, fall within the range of results from previous research.

Even though results from this study fall within the range of previous studies, these throughfall values are near the low end of the reported scale. If throughfall accounted for only 54% of all rainfall, what became of the other 46%? Some of the remaining rain can be accounted for by other interception processes, particularly stem flow. Stem flow was not measured for this experiment, however, and estimation of it is difficult. Based on personal observation, stem flow was occurring. I observed wet trunks and limited stem

flow during and immediately after rain events on some trees. The amount of stem flow was more likely closer to the small amounts reported by Miranda (1994) in a cocoa plantation, than the large volumes measured by Herewitz (1986) in Australia.

With the exception of water lost to measurement error, the remaining water not measured as throughfall or partitioned as stem flow can be considered intercepted moisture. Assuming my observations regarding stem flow are correct, then approximately 40 to 45% of rainfall was intercepted. I believe that the main reason for such a high percentage of interception is mainly due to the rainfall regime during the experiment (Figure 12).

For the 36 day sampling period, no rain occurred on 10 days and an additional 10 days received rain of 5 mm or less. This is significant in terms of throughfall, because it is a fairly good indication that the canopy had time to completely dry between storms. No attempt was made to measure canopy storage capacity, but while working at the Huertos site I observed dry conditions, as evidenced by dusty ground conditions and lack of any moisture on vegetation surfaces. When the canopy is dry at the beginning of a storm, it takes more rain to achieve canopy storage capacity, thus increasing interception and decreasing throughfall.

The dryness of the canopy is due to both the rainfall regime for this particular time period and to the high evaporation rates for this plantation. Evaporation rates may be higher for this plantation because of species composition and a higher level of exposure to incident radiation and wind, as compared with surrounding forest. When large areas are

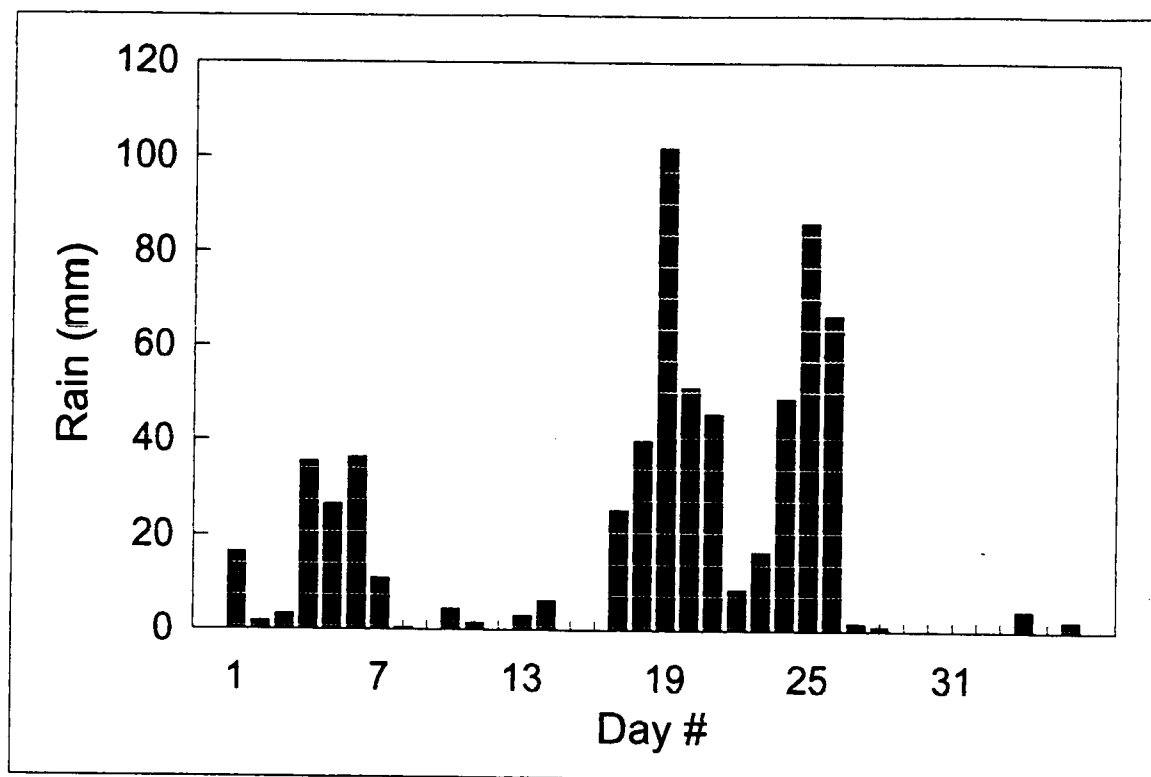


Figure 12: Daily rainfall totals from GLASNOST data, November 19 - December 24, 1994

converted from natural forest to plantations, changes in local hydrology may occur as a result of increased interception and higher evaporation rates.

In terms of total rainfall, variations between the GLASNOST, La Selva Bridge and on-site point gauges were minimal, so I was able to use the GLASNOST data for all statistical comparisons. A regression of throughfall to on-site rainfall totals had an r^2 of .986, slightly higher than the r^2 of .971 obtained using the Glasnost rainfall data. Ideally, I would like to have recorded total rainfall on-site using an automatic tipping bucket gauge, so that all analyses could have been conducted with on-site data. Due to the results of the regression of throughfall as a function of on-site rainfall data and the strong relationship between throughfall and the GLASNOST data, I feel that the lack of automatic, on-site monitoring was not a problem in determining total rainfall.

Neither rainfall intensity or duration nor the combined effects of intensity and duration were critical in predicting throughfall values. In general, however, throughfall tended to increase with increases in storm duration. Storms with a duration of less than 1 hour failed to produce even 1 mm of throughfall, while all storms lasting more than 1 hour produced at least 1 mm, with two exceptions. Eight out of nine storms with a duration greater than 5 hours had at least 11 mm of throughfall, while no storms of shorter duration had such a large amount. I believe that a stronger relationship between throughfall and storm duration could be shown if duration were measured on a truly individual storm basis and sampling covered a much longer period.

The low significance of both rainfall duration and intensity is surprising in light of previous research. Manokaran (1979) found a significant correlation between percent of

throughfall and average rainfall intensity. The apparent insignificance of intensity in this research may partially be due to the manner in which it was calculated. For logistical reasons, intensity had to be calculated as a function of total rainfall for a sampling period, regardless of how many storms occurred within a particular sampling period. Thus the intensity values for the majority of sampling periods represent an aggregation of multiple storms. Only eight of the 34 sampling periods consisted of one storm, and eight others consisted of five or more distinct rain events. A regression of throughfall onto rainfall intensity from the eight single storm events had an r^2 of .869 at a high level of significance. This is much higher than the r^2 of .24 obtained when using all 34 events. Therefore as with duration, I feel that a stronger relationship between rainfall intensity and throughfall could be shown by measuring intensity on a single storm basis and sampling over a longer period of time.

Leaf Area and Throughfall

As with rainfall intensity and duration, leaf area did not prove to be as important in predicting throughfall values as expected. The poor relationship between leaf area and throughfall cannot be attributed directly to measurement errors, since there were minimal differences between leaf area index values obtained on different days and an open-canopy measurement had been taken prior to each under-canopy measurement.

There appears to be a general, but sporadic, decrease in throughfall as leaf area increases. The gauge with the second highest leaf area index value, 5.35, received a total of 208 mm of throughfall for the entire sampling period, which is only slightly less than the

average amount of per gauge throughfall. Even though this research did not show a strong relationship between leaf area index values and throughfall, I still expect that plant physiognomy plays an important role in determining the amount of rain partitioned as throughfall. Unfortunately, leaf area may not be a very good overall indicator of plant physiognomy.

Other researchers have commented on the general significance of leaf area. Based on research conducted in a pine forest in the Netherlands, Mulder (1985) noted there was a considerable increase of interception loss over a number of years. He speculated that this loss was due to changes in the canopy structure. Loustau *et al.* (1992) conducted a study on maritime pine stands in southwest France that had leaf area index values between 1.4 and 4, with throughfall accounting for between 76 to 83% of total rainfall. The authors concluded that interception losses appear to be most sensitive to climatic parameters and less sensitive to canopy storage capacity, which is largely determined by leaf area. A similar conclusion can be drawn for the present study, in which total rainfall and opportunities for evaporation of intercepted rain appear to be far more important than other variables in determining throughfall

Models

Using data from the Huertos plantation at the La Selva Biological Station, I developed two regression models to predict throughfall based on simple observable values. The first model predicted throughfall values based solely on total rainfall values and provided remarkably accurate results when tested with additional data. These results

seem to correspond well with those found by Helvey and Patric (1965), who examined 38 interception studies from the hardwood region of the eastern United States and ran regressions of interception as a function of total rainfall for each study. The relationships examined in their analyses were significant. My results disagree with the arguments against the use of regression equations expressing throughfall as a function of rainfall, as made by Jackson (1971). When the effects of rainfall intensity and duration were introduced in the second model, only slightly more accurate values were obtained. The low level of improvement was not surprising based on the poor relationships obtained in this study between throughfall and rainfall intensity and duration. This research shows, that for this forestry plantation, throughfall can be accurately predicted based solely on total rainfall. The fact that such a small level of improvement was obtained by including additional independent variables would imply that future researchers may not need to measure intensity and duration when attempting to predict throughfall for similar climatic and biological settings.

Future Research

Most research concerning interception processes has occurred in the world's temperate regions. More research needs to occur in tropical regions under native forest cover and especially in areas that have been converted to forestry plantations. In these regions, where most available nutrients are found within the forest canopy, it is crucial to understand all aspects of the hydrologic cycle in order to decrease negative environmental impacts while maximizing economic gains.

As a result of this research, I would like to make several recommendations that could be beneficial to future studies on any aspect of the interception processes of a tropical forestry plantation. First, sampling over a longer duration and under multiple land uses would provide a data set useful for examining the hydrological impacts of major land use changes. Few studies have been conducted that provide throughfall data from both a natural forest setting and a plantation under the same climate conditions.

Second, many researchers recommend that more accurate throughfall measurements may be obtained by using a large number of point gauges randomly relocated throughout the course of an experiment (Lloyd and Marques, 1988). Point gauges are easily obtained and readily positioned in the field (Helvy and Patric, 1965). However, trough gauges are well suited for sampling under row planting due to their ability to integrate over a large area. Research to determine whether or not randomly relocated point gauges would be successful in a forestry plantation, where the effects of row planting are of major concern, would be beneficial.

Although many researchers have questioned the overall importance of stem flow, I feel that, for a complete understanding of interception processes, all variables need to be considered. Additional work on developing a stem flow collector that is inexpensive and does not damage the tree would greatly benefit many interception researchers. At the beginning of this research, I attempted to devise a stem flow measuring method using an absorbent stem flow collar. This device successfully captured stem flow in limited test, but was not used for the duration of the experiment due to logistical problems. Multiple collars would have been required to accurately measure variations within species, and

between different species and treatments. Each collar would have had to be removed, weighed, dried and re-adhered to the tree after each rain event.

Conclusions

This research demonstrated that total rainfall, rainfall intensity and duration, and leaf area were related, to varying degrees, to the amount of precipitation that arrives at the ground as throughfall in a tropical forest plantation. Total rainfall was most significantly related to throughfall and provided the strongest throughfall predictions. The poor relationships and poor predictive abilities of the other dependent variables were unexpected. However, the third objective of this research, to develop a model based on simple observable variables, was successfully attained. This research demonstrates that throughfall can be accurately predicted based solely on total rainfall, at least for the conditions encountered during the course of this study in the Huertos plantation. Under similar climatic and vegetation conditions an individual should be able to obtain an estimate of throughfall from available rainfall data.

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APPENDICES

APPENDIX A
THROUGHFALL AND ON-SITE POINT GAUGE DATA

Date: Nov. 19 Treatment
Time: 13:07 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	2715.0	2.74
3	m	T	2	990	2095.0	2.12
3	m	T	3	990	5220.0	5.27
3	m	T	4	990	3085.0	3.12
3	m	T	5	990	2800.0	2.83
3	p	T	1	990	450.0	0.45
3	p	T	2	990	320.0	0.32
3	p	T	3	990	570.0	0.58
3	p	T	4	990	1315.0	1.33
3	p	T	5	990	12.0	0.01
3	p	T	6	990	135.0	0.14
3	p	T	7	990	870.0	0.88
2	m	T	1	990	3250.0	3.28
2	m	T	2	990	3660.0	3.70
2	m	T	3	990	2090.0	2.11
2	m	T	4	990	3590.0	3.63
2	m	T	5	990	2930.0	2.96
2	p	T	1	990	1300.0	1.31
2	p	T	2	990	340.0	0.34
2	p	T	3	990	1115.0	1.13
2	p	T	4	990	1110.0	1.12
2	p	T	5	990	6750.0	6.82
2	p	T	6	990	1310.0	1.32
2	p	T	7	990	2775.0	2.80
1	m	T	1	990	1380.0	1.39
1	m	T	2	990	800.0	0.81
1	m	T	3	990	1930.0	1.95
1	m	T	4	990	1410.0	1.42
1	m	T	5	990	30.0	0.03
1	p	T	1	990	1210.0	1.22
1	p	T	2	990	1060.0	1.07
1	p	T	3	990	980.0	0.99
1	p	T	4	990	1150.0	1.16
1	p	T	5	990	570.0	0.58
1	p	T	6	990	30.0	0.03
1	p	T	7	990	1310.0	1.32
NA	O	P	1	16	65.0	4.06
NA	O	P	2	16	62.0	3.88
NA	O	P	3	16	62.0	3.88
NA	O	P	4	16	65.0	4.06
NA	O	P	5	16	65.0	4.06
NA	O	P	6	16	70.0	4.38
NA	O	P	7	16	65.0	4.06
NA	O	P	8	16	65.0	4.06
NA	O	P	9	16	70.0	4.38
NA	O	P	10	16	70.0	4.38
NA	O	P	11	16	70.0	4.38
NA	O	P	12	16	65.0	4.06

Date: Nov. 20 Treatment
Time: 8:40 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	190.0	0.19
3	m	T	2	990	120.0	0.12
3	m	T	3	990	220.0	0.22
3	m	T	4	990	215.0	0.22
3	m	T	5	990	150.0	0.15
3	p	T	1	990	28.0	0.03
3	p	T	2	990	25.0	0.03
3	p	T	3	990	31.0	0.03
3	p	T	4	990	95.0	0.10
3	p	T	5	990	150.0	0.15
3	p	T	6	990	13.0	0.01
3	p	T	7	990	50.0	0.05
2	m	T	1	990	310.0	0.31
2	m	T	2	990	210.0	0.21
2	m	T	3	990	180.0	0.18
2	m	T	4	990	220.0	0.22
2	m	T	5	990	185.0	0.19
2	p	T	1	990	23.0	0.02
2	p	T	2	990	12.0	0.01
2	p	T	3	990	110.0	0.11
2	p	T	4	990	100.0	0.10
2	p	T	5	990	215.0	0.22
2	p	T	6	990	80.0	0.08
2	p	T	7	990	105.0	0.11
1	m	T	1	990	45.0	0.05
1	m	T	2	990	50.0	0.05
1	m	T	3	990	140.0	0.14
1	m	T	4	990	110.0	0.11
1	m	T	5	990	105.0	0.11
1	p	T	1	990	85.0	0.09
1	p	T	2	990	45.0	0.05
1	p	T	3	990	40.0	0.04
1	p	T	4	990	54.0	0.05
1	p	T	5	990	45.0	0.05
1	p	T	6	990	36.0	0.04
1	p	T	7	990	105.0	0.11
NA	O	P	1	16	3.0	0.19
NA	O	P	2	16	4.0	0.25
NA	O	P	3	16	3.0	0.19
NA	O	P	4	16	3.5	0.22
NA	O	P	5	16	3.5	0.22
NA	O	P	6	16	3.5	0.22
NA	O	P	7	16	4.0	0.25
NA	O	P	8	16	4.0	0.25
NA	O	P	9	16	4.0	0.25
NA	O	P	10	16	3.5	0.22
NA	O	P	11	16	3.5	0.22
NA	O	P	12	16	3.5	0.22

Date: Nov. 20 Treatment
Time: 15:05 m=mono
Species: p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	110.0	0.11
3	m	T	2	990	160.0	0.16
3	m	T	3	990	210.0	0.21
3	m	T	4	990	190.0	0.19
3	m	T	5	990	165.0	0.17
3	p	T	1	990	32.0	0.03
3	p	T	2	990	8.0	0.01
3	p	T	3	990	41.0	0.04
3	p	T	4	990	105.0	0.11
3	p	T	5	990	110.0	0.11
3	p	T	6	990	9.0	0.01
3	p	T	7	990	26.0	0.03
2	m	T	1	990	170.0	0.17
2	m	T	2	990	180.0	0.18
2	m	T	3	990	175.0	0.18
2	m	T	4	990	170.0	0.17
2	m	T	5	990	155.0	0.16
2	p	T	1	990	70.0	0.07
2	p	T	2	990	26.0	0.03
2	p	T	3	990	75.0	0.08
2	p	T	4	990	65.0	0.07
2	p	T	5	990	150.0	0.15
2	p	T	6	990	50.0	0.05
2	p	T	7	990	110.0	0.11
1	m	T	1	990	65.0	0.07
1	m	T	2	990	70.0	0.07
1	m	T	3	990	105.0	0.11
1	m	T	4	990	110.0	0.11
1	m	T	5	990	80.0	0.08
1	p	T	1	990	85.0	0.09
1	p	T	2	990	60.0	0.06
1	p	T	3	990	70.0	0.07
1	p	T	4	990	70.0	0.07
1	p	T	5	990	70.0	0.07
1	p	T	6	990	55.0	0.06
1	p	T	7	990	85.0	0.09
NA	O	P	1	16	2.5	0.16
NA	O	P	2	16	2.5	0.16
NA	O	P	3	16	2.5	0.16
NA	O	P	4	16	2.5	0.16
NA	O	P	5	16	2.5	0.16
NA	O	P	6	16	2.5	0.16
NA	O	P	7	16	2.5	0.16
NA	O	P	8	16	2.5	0.16
NA	O	P	9	16	2.5	0.16
NA	O	P	10	16	2.5	0.16
NA	O	P	11	16	2.5	0.16
NA	O	P	12	16	2.5	0.16

Date: Nov. 22 Treatment
Time: 10:15 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	2216.0	2.24
3	m	T	2	990	1680.0	1.70
3	m	T	3	990	2550.0	2.58
3	m	T	4	990	2250.0	2.27
3	m	T	5	990	2080.0	2.10
3	p	T	1	990	400.0	0.40
3	p	T	2	990	280.0	0.28
3	p	T	3	990	570.0	0.58
3	p	T	4	990	1810.0	1.83
3	p	T	5	990	1660.0	1.68
3	p	T	6	990	120.0	0.12
3	p	T	7	990	745.0	0.75
2	m	T	1	990	2285.0	2.31
2	m	T	2	990	2410.0	2.43
2	m	T	3	990	2335.0	2.36
2	m	T	4	990	2640.0	2.67
2	m	T	5	990	2210.0	2.23
2	p	T	1	990	1580.0	1.60
2	p	T	2	990	4520.0	4.57
2	p	T	3	990	1290.0	1.30
2	p	T	4	990	720.0	0.73
2	p	T	5	990	1880.0	1.90
2	p	T	6	990	600.0	0.61
2	p	T	7	990	1600.0	1.62
1	m	T	1	990	1415.0	1.43
1	m	T	2	990	1215.0	1.23
1	m	T	3	990	1690.0	1.71
1	m	T	4	990	2360.0	2.38
1	m	T	5	990	2150.0	2.17
1	p	T	1	990	1000.0	1.01
1	p	T	2	990	1180.0	1.19
1	p	T	3	990	910.0	0.92
1	p	T	4	990	1220.0	1.23
1	p	T	5	990	2035.0	2.06
1	p	T	6	990	740.0	0.75
1	p	T	7	990	1585.0	1.60
NA	O	P	1	16	46.0	2.88
NA	O	P	2	16	46.0	2.88
NA	O	P	3	16	46.0	2.88
NA	O	P	4	16	45.0	2.81
NA	O	P	5	16	45.0	2.81
NA	O	P	6	16	45.0	2.81
NA	O	P	7	16	47.0	2.94
NA	O	P	8	16	48.0	3.00
NA	O	P	9	16	48.0	3.00
NA	O	P	10	16	47.0	2.94
NA	O	P	11	16	46.0	2.88
NA	O	P	12	16	47.0	2.94

Date: Nov. 22 Treatment
Time: 15:00 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	210.0	0.21
3	m	T	2	990	210.0	0.21
3	m	T	3	990	330.0	0.33
3	m	T	4	990	265.0	0.27
3	m	T	5	990	240.0	0.24
3	p	T	1	990	40.0	0.04
3	p	T	2	990	35.0	0.04
3	p	T	3	990	75.0	0.08
3	p	T	4	990	210.0	0.21
3	p	T	5	990	290.0	0.29
3	p	T	6	990	13.0	0.01
3	p	T	7	990	42.0	0.04
2	m	T	1	990	280.0	0.28
2	m	T	2	990	300.0	0.30
2	m	T	3	990	300.0	0.30
2	m	T	4	990	305.0	0.31
2	m	T	5	990	290.0	0.29
2	p	T	1	990	80.0	0.08
2	p	T	2	990	345.0	0.35
2	p	T	3	990	110.0	0.11
2	p	T	4	990	90.0	0.09
2	p	T	5	990	170.0	0.17
2	p	T	6	990	65.0	0.07
2	p	T	7	990	240.0	0.24
1	m	T	1	990	115.0	0.12
1	m	T	2	990	130.0	0.13
1	m	T	3	990	210.0	0.21
1	m	T	4	990	260.0	0.26
1	m	T	5	990	205.0	0.21
1	p	T	1	990	155.0	0.16
1	p	T	2	990	155.0	0.16
1	p	T	3	990	105.0	0.11
1	p	T	4	990	130.0	0.13
1	p	T	5	990	145.0	0.15
1	p	T	6	990	105.0	0.11
1	p	T	7	990	120.0	0.12
NA	O	P	1	16	5.0	0.31
NA	O	P	2	16	6.5	0.41
NA	O	P	3	16	7.0	0.44
NA	O	P	4	16	5.5	0.34
NA	O	P	5	16	5.5	0.34
NA	O	P	6	16	5.5	0.34
NA	O	P	7	16	5.5	0.34
NA	O	P	8	16	5.5	0.34
NA	O	P	9	16	5.5	0.34
NA	O	P	10	16	5.5	0.34
NA	O	P	11	16	5.5	0.34
NA	O	P	12	16	5.5	0.34

Date: Nov. 23 Treatment
Time: 7:45 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	645.0	0.65
3	m	T	2	990	550.0	0.56
3	m	T	3	990	755.0	0.76
3	m	T	4	990	685.0	0.69
3	m	T	5	990	625.0	0.63
3	p	T	1	990	110.0	0.11
3	p	T	2	990	54.0	0.05
3	p	T	3	990	170.0	0.17
3	p	T	4	990	290.0	0.29
3	p	T	5	990	515.0	0.52
3	p	T	6	990	28.0	0.03
3	p	T	7	990	155.0	0.16
2	m	T	1	990	760.0	0.77
2	m	T	2	990	735.0	0.74
2	m	T	3	990	710.0	0.72
2	m	T	4	990	830.0	0.84
2	m	T	5	990	720.0	0.73
2	p	T	1	990	480.0	0.48
2	p	T	2	990	745.0	0.75
2	p	T	3	990	350.0	0.35
2	p	T	4	990	220.0	0.22
2	p	T	5	990	480.0	0.48
2	p	T	6	990	110.0	0.11
2	p	T	7	990	745.0	0.75
1	m	T	1	990	420.0	0.42
1	m	T	2	990	320.0	0.32
1	m	T	3	990	585.0	0.59
1	m	T	4	990	700.0	0.71
1	m	T	5	990	365.0	0.37
1	p	T	1	990	290.0	0.29
1	p	T	2	990	370.0	0.37
1	p	T	3	990	160.0	0.16
1	p	T	4	990	290.0	0.29
1	p	T	5	990	350.0	0.35
1	p	T	6	990	190.0	0.19
1	p	T	7	990	285.0	0.29
NA	O	P	1	16	13.0	0.81
NA	O	P	2	16	12.5	0.78
NA	O	P	3	16	13.0	0.81
NA	O	P	4	16	13.0	0.81
NA	O	P	5	16	13.0	0.81
NA	O	P	6	16	13.5	0.84
NA	O	P	7	16	13.5	0.84
NA	O	P	8	16	13.5	0.84
NA	O	P	9	16	13.0	0.81
NA	O	P	10	16	13.0	0.81
NA	O	P	11	16	13.5	0.84
NA	O	P	12	16	13.5	0.84

Date: Nov. 23 Treatment
Time: 13:15 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	260.0	0.26
3	m	T	2	990	260.0	0.26
3	m	T	3	990	310.0	0.31
3	m	T	4	990	390.0	0.39
3	m	T	5	990	315.0	0.32
3	p	T	1	990	80.0	0.08
3	p	T	2	990	55.0	0.06
3	p	T	3	990	90.0	0.09
3	p	T	4	990	110.0	0.11
3	p	T	5	990	210.0	0.21
3	p	T	6	990	27.0	0.03
3	p	T	7	990	17.0	0.02
2	m	T	1	990	280.0	0.28
2	m	T	2	990	280.0	0.28
2	m	T	3	990	300.0	0.30
2	m	T	4	990	310.0	0.31
2	m	T	5	990	215.0	0.22
2	p	T	1	990	250.0	0.25
2	p	T	2	990	120.0	0.12
2	p	T	3	990	115.0	0.12
2	p	T	4	990	160.0	0.16
2	p	T	5	990	185.0	0.19
2	p	T	6	990	65.0	0.07
2	p	T	7	990	210.0	0.21
1	m	T	1	990	150.0	0.15
1	m	T	2	990	155.0	0.16
1	m	T	3	990	235.0	0.24
1	m	T	4	990	215.0	0.22
1	m	T	5	990	140.0	0.14
1	p	T	1	990	120.0	0.12
1	p	T	2	990	150.0	0.15
1	p	T	3	990	90.0	0.09
1	p	T	4	990	150.0	0.15
1	p	T	5	990	130.0	0.13
1	p	T	6	990	90.0	0.09
1	p	T	7	990	155.0	0.16
NA	O	P	1	16	6.0	0.38
NA	O	P	2	16	6.0	0.38
NA	O	P	3	16	5.5	0.34
NA	O	P	4	16	5.0	0.31
NA	O	P	5	16	4.5	0.28
NA	O	P	6	16	4.0	0.25
NA	O	P	7	16	6.0	0.38
NA	O	P	8	16	5.5	0.34
NA	O	P	9	16	5.5	0.34
NA	O	P	10	16	4.5	0.28
NA	O	P	11	16	5.0	0.31
NA	O	P	12	16	4.5	0.28

Date: Nov. 23 Treatment
Time: 15:22 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	900.0	0.91
3	m	T	2	990	775.0	0.78
3	m	T	3	990	1110.0	1.12
3	m	T	4	990	1130.0	1.14
3	m	T	5	990	880.0	0.89
3	p	T	1	990	290.0	0.29
3	p	T	2	990	185.0	0.19
3	p	T	3	990	235.0	0.24
3	p	T	4	990	1040.0	1.05
3	p	T	5	990	635.0	0.64
3	p	T	6	990	70.0	0.07
3	p	T	7	990	260.0	0.26
2	m	T	1	990	900.0	0.91
2	m	T	2	990	1047.0	1.06
2	m	T	3	990	1055.0	1.07
2	m	T	4	990	1008.0	1.02
2	m	T	5	990	840.0	0.85
2	p	T	1	990	700.0	0.71
2	p	T	2	990	1975.0	1.99
2	p	T	3	990	550.0	0.56
2	p	T	4	990	770.0	0.78
2	p	T	5	990	750.0	0.76
2	p	T	6	990	435.0	0.44
2	p	T	7	990	825.0	0.83
1	m	T	1	990	650.0	0.66
1	m	T	2	990	690.0	0.70
1	m	T	3	990	830.0	0.84
1	m	T	4	990	840.0	0.85
1	m	T	5	990	760.0	0.77
1	p	T	1	990	555.0	0.56
1	p	T	2	990	670.0	0.68
1	p	T	3	990	440.0	0.44
1	p	T	4	990	710.0	0.72
1	p	T	5	990	580.0	0.59
1	p	T	6	990	430.0	0.43
1	p	T	7	990	825.0	0.83
NA	O	P	1	16	25.0	1.56
NA	O	P	2	16	24.0	1.50
NA	O	P	3	16	24.0	1.50
NA	O	P	4	16	23.5	1.47
NA	O	P	5	16	23.0	1.44
NA	O	P	6	16	24.0	1.50
NA	O	P	7	16	23.5	1.47
NA	O	P	8	16	23.5	1.47
NA	O	P	9	16	23.5	1.47
NA	O	P	10	16	23.5	1.47
NA	O	P	11	16	24.0	1.50
NA	O	P	12	16	24.0	1.50

Date: Nov. 24 Treatment
Time: 14:35 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	2430.0	2.45
3	m	T	2	990	2140.0	2.16
3	m	T	3	990	5665.0	5.72
3	m	T	4	990	2725.0	2.75
3	m	T	5	990	2515.0	2.54
3	p	T	1	990	730.0	0.74
3	p	T	2	990	490.0	0.49
3	p	T	3	990	530.0	0.54
3	p	T	4	990	1050.0	1.06
3	p	T	5	990	2540.0	2.57
3	p	T	6	990	150.0	0.15
3	p	T	7	990	580.0	0.59
2	m	T	1	990	3100.0	3.13
2	m	T	2	990	3330.0	3.36
2	m	T	3	990	3175.0	3.21
2	m	T	4	990	3450.0	3.48
2	m	T	5	990	2900.0	2.93
2	p	T	1	990	1140.0	1.15
2	p	T	2	990	1440.0	1.45
2	p	T	3	990	2575.0	2.60
2	p	T	4	990	1540.0	1.56
2	p	T	5	990	2130.0	2.15
2	p	T	6	990	600.0	0.61
2	p	T	7	990	2915.0	2.94
1	m	T	1	990	1490.0	1.51
1	m	T	2	990	2420.0	2.44
1	m	T	3	990	2100.0	2.12
1	m	T	4	990	2645.0	2.67
1	m	T	5	990	2220.0	2.24
1	p	T	1	990	1685.0	1.70
1	p	T	2	990	1750.0	1.77
1	p	T	3	990	1095.0	1.11
1	p	T	4	990	1330.0	1.34
1	p	T	5	990	1975.0	1.99
1	p	T	6	990	1425.0	1.44
1	p	T	7	990	1870.0	1.89
NA	O	P	1	16	58.0	3.63
NA	O	P	2	16	59.0	3.69
NA	O	P	3	16	59.0	3.69
NA	O	P	4	16	58.5	3.66
NA	O	P	5	16	59.0	3.69
NA	O	P	6	16	58.0	3.63
NA	O	P	7	16	59.0	3.69
NA	O	P	8	16	59.5	3.72
NA	O	P	9	16	60.5	3.78
NA	O	P	10	16	60.0	3.75
NA	O	P	11	16	60.5	3.78
NA	O	P	12	16	60.5	3.78

Date: Nov. 25 Treatment
Time: 8:10 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	110.0	0.11
3	m	T	2	990	95.0	0.10
3	m	T	3	990	160.0	0.16
3	m	T	4	990	120.0	0.12
3	m	T	5	990	130.0	0.13
3	p	T	1	990	27.0	0.03
3	p	T	2	990	13.0	0.01
3	p	T	3	990	25.0	0.03
3	p	T	4	990	41.0	0.04
3	p	T	5	990	200.0	0.20
3	p	T	6	990	7.0	0.01
3	p	T	7	990	6.0	0.01
2	m	T	1	990	130.0	0.13
2	m	T	2	990	155.0	0.16
2	m	T	3	990	155.0	0.16
2	m	T	4	990	130.0	0.13
2	m	T	5	990	130.0	0.13
2	p	T	1	990	210.0	0.21
2	p	T	2	990	32.0	0.03
2	p	T	3	990	150.0	0.15
2	p	T	4	990	21.0	0.02
2	p	T	5	990	60.0	0.06
2	p	T	6	990	35.0	0.04
2	p	T	7	990	80.0	0.08
1	m	T	1	990	36.0	0.04
1	m	T	2	990	38.0	0.04
1	m	T	3	990	65.0	0.07
1	m	T	4	990	90.0	0.09
1	m	T	5	990	70.0	0.07
1	p	T	1	990	85.0	0.09
1	p	T	2	990	80.0	0.08
1	p	T	3	990	70.0	0.07
1	p	T	4	990	48.0	0.05
1	p	T	5	990	70.0	0.07
1	p	T	6	990	35.0	0.04
1	p	T	7	990	44.0	0.04
NA	O	P	1	16	2.5	0.16
NA	O	P	2	16	2.5	0.16
NA	O	P	3	16	2.5	0.16
NA	O	P	4	16	2.5	0.16
NA	O	P	5	16	2.5	0.16
NA	O	P	6	16	2.5	0.16
NA	O	P	7	16	2.5	0.16
NA	O	P	8	16	2.5	0.16
NA	O	P	9	16	2.5	0.16
NA	O	P	10	16	2.5	0.16
NA	O	P	11	16	2.5	0.16
NA	O	P	12	16	2.5	0.16

Date: Nov. 25 Treatment
Time: 15:40 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	720.0	0.73
3	m	T	2	990	650.0	0.66
3	m	T	3	990	2008.0	2.03
3	m	T	4	990	810.0	0.82
3	m	T	5	990	740.0	0.75
3	p	T	1	990	190.0	0.19
3	p	T	2	990	120.0	0.12
3	p	T	3	990	155.0	0.16
3	p	T	4	990	230.0	0.23
3	p	T	5	990	925.0	0.93
3	p	T	6	990	31.0	0.03
3	p	T	7	990	175.0	0.18
2	m	T	1	990	770.0	0.78
2	m	T	2	990	820.0	0.83
2	m	T	3	990	890.0	0.90
2	m	T	4	990	915.0	0.92
2	m	T	5	990	810.0	0.82
2	p	T	1	990	1510.0	1.53
2	p	T	2	990	160.0	0.16
2	p	T	3	990	670.0	0.68
2	p	T	4	990	200.0	0.20
2	p	T	5	990	470.0	0.47
2	p	T	6	990	180.0	0.18
2	p	T	7	990	455.0	0.46
1	m	T	1	990	500.0	0.51
1	m	T	2	990	390.0	0.39
1	m	T	3	990	600.0	0.61
1	m	T	4	990	500.0	0.51
1	m	T	5	990	515.0	0.52
1	p	T	1	990	460.0	0.46
1	p	T	2	990	380.0	0.38
1	p	T	3	990	190.0	0.19
1	p	T	4	990	370.0	0.37
1	p	T	5	990	480.0	0.48
1	p	T	6	990	420.0	0.42
1	p	T	7	990	390.0	0.39
NA	O	P	1	16	15.0	0.94
NA	O	P	2	16	15.0	0.94
NA	O	P	3	16	15.5	0.97
NA	O	P	4	16	-99.0	-99.0
NA	O	P	5	16	14.5	0.91
NA	O	P	6	16	14.5	0.91
NA	O	P	7	16	16.0	1.00
NA	O	P	8	16	15.5	0.97
NA	O	P	9	16	16.0	1.00
NA	O	P	10	16	15.5	0.97
NA	O	P	11	16	15.0	0.94
NA	O	P	12	16	15.0	0.94

Date: Nov. 26 Treatment
Time: 11:20 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	90.0	0.09
3	m	T	2	990	95.0	0.10
3	m	T	3	990	140.0	0.14
3	m	T	4	990	110.0	0.11
3	m	T	5	990	100.0	0.10
3	p	T	1	990	29.0	0.03
3	p	T	2	990	21.0	0.02
3	p	T	3	990	32.0	0.03
3	p	T	4	990	37.0	0.04
3	p	T	5	990	230.0	0.23
3	p	T	6	990	8.0	0.01
3	p	T	7	990	16.0	0.02
2	m	T	1	990	105.0	0.11
2	m	T	2	990	125.0	0.13
2	m	T	3	990	145.0	0.15
2	m	T	4	990	130.0	0.13
2	m	T	5	990	120.0	0.12
2	p	T	1	990	17.0	0.02
2	p	T	2	990	13.0	0.01
2	p	T	3	990	54.0	0.05
2	p	T	4	990	37.0	0.04
2	p	T	5	990	41.0	0.04
2	p	T	6	990	22.0	0.02
2	p	T	7	990	55.0	0.06
1	m	T	1	990	55.0	0.06
1	m	T	2	990	43.0	0.04
1	m	T	3	990	70.0	0.07
1	m	T	4	990	60.0	0.06
1	m	T	5	990	70.0	0.07
1	p	T	1	990	65.0	0.07
1	p	T	2	990	65.0	0.07
1	p	T	3	990	65.0	0.07
1	p	T	4	990	60.0	0.06
1	p	T	5	990	45.0	0.05
1	p	T	6	990	34.0	0.03
1	p	T	7	990	40.0	0.04
NA	O	P	1	16	2.0	0.13
NA	O	P	2	16	2.0	0.13
NA	O	P	3	16	2.0	0.13
NA	O	P	4	16	1.0	0.06
NA	O	P	5	16	1.0	0.06
NA	O	P	6	16	2.0	0.13
NA	O	P	7	16	1.0	0.06
NA	O	P	8	16	2.0	0.13
NA	O	P	9	16	1.0	0.06
NA	O	P	10	16	2.0	0.13
NA	O	P	11	16	1.0	0.06
NA	O	P	12	16	2.0	0.13

Date: Nov. 29 Treatment
Time: 7:50 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	430.0	0.43
3	m	T	2	990	370.0	0.37
3	m	T	3	990	680.0	0.69
3	m	T	4	990	500.0	0.51
3	m	T	5	990	480.0	0.48
3	p	T	1	990	110.0	0.11
3	p	T	2	990	70.0	0.07
3	p	T	3	990	310.0	0.31
3	p	T	4	990	265.0	0.27
3	p	T	5	990	260.0	0.26
3	p	T	6	990	32.0	0.03
3	p	T	7	990	90.0	0.09
2	m	T	1	990	485.0	0.49
2	m	T	2	990	555.0	0.56
2	m	T	3	990	540.0	0.55
2	m	T	4	990	590.0	0.60
2	m	T	5	990	500.0	0.51
2	p	T	1	990	280.0	0.28
2	p	T	2	990	220.0	0.22
2	p	T	3	990	420.0	0.42
2	p	T	4	990	260.0	0.26
2	p	T	5	990	870.0	0.88
2	p	T	6	990	145.0	0.15
2	p	T	7	990	300.0	0.30
1	m	T	1	990	400.0	0.40
1	m	T	2	990	260.0	0.26
1	m	T	3	990	440.0	0.44
1	m	T	4	990	970.0	0.98
1	m	T	5	990	385.0	0.39
1	p	T	1	990	335.0	0.34
1	p	T	2	990	310.0	0.31
1	p	T	3	990	390.0	0.39
1	p	T	4	990	280.0	0.28
1	p	T	5	990	330.0	0.33
1	p	T	6	990	160.0	0.16
1	p	T	7	990	360.0	0.36
NA	O	P	1	16	9.0	0.56
NA	O	P	2	16	9.5	0.59
NA	O	P	3	16	10.5	0.66
NA	O	P	4	16	10.0	0.63
NA	O	P	5	16	10.0	0.63
NA	O	P	6	16	10.0	0.63
NA	O	P	7	16	9.0	0.56
NA	O	P	8	16	10.0	0.63
NA	O	P	9	16	10.0	0.63
NA	O	P	10	16	11.0	0.69
NA	O	P	11	16	9.5	0.59
NA	O	P	12	16	11.0	0.69

Date: Nov. 30 Treatment
Time: 7:40 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	265.0	0.27
3	m	T	2	990	190.0	0.19
3	m	T	3	990	315.0	0.32
3	m	T	4	990	230.0	0.23
3	m	T	5	990	230.0	0.23
3	p	T	1	990	44.0	0.04
3	p	T	2	990	65.0	0.07
3	p	T	3	990	70.0	0.07
3	p	T	4	990	140.0	0.14
3	p	T	5	990	260.0	0.26
3	p	T	6	990	25.0	0.03
3	p	T	7	990	95.0	0.10
2	m	T	1	990	235.0	0.24
2	m	T	2	990	220.0	0.22
2	m	T	3	990	260.0	0.26
2	m	T	4	990	270.0	0.27
2	m	T	5	990	240.0	0.24
2	p	T	1	990	210.0	0.21
2	p	T	2	990	200.0	0.20
2	p	T	3	990	43.0	0.04
2	p	T	4	990	100.0	0.10
2	p	T	5	990	330.0	0.33
2	p	T	6	990	115.0	0.12
2	p	T	7	990	150.0	0.15
1	m	T	1	990	200.0	0.20
1	m	T	2	990	130.0	0.13
1	m	T	3	990	175.0	0.18
1	m	T	4	990	290.0	0.29
1	m	T	5	990	150.0	0.15
1	p	T	1	990	135.0	0.14
1	p	T	2	990	150.0	0.15
1	p	T	3	990	160.0	0.16
1	p	T	4	990	110.0	0.11
1	p	T	5	990	190.0	0.19
1	p	T	6	990	60.0	0.06
1	p	T	7	990	190.0	0.19
NA	O	P	1	16	4.5	0.28
NA	O	P	2	16	4.0	0.25
NA	O	P	3	16	4.0	0.25
NA	O	P	4	16	4.0	0.25
NA	O	P	5	16	4.0	0.25
NA	O	P	6	16	4.0	0.25
NA	O	P	7	16	4.0	0.25
NA	O	P	8	16	-99.0	-99.0
NA	O	P	9	16	4.0	0.25
NA	O	P	10	16	4.5	0.28
NA	O	P	11	16	4.0	0.25
NA	O	P	12	16	5.0	0.31

Date: Dec 2 Treatment
Time: 7:45 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	480.0	0.48
3	m	T	2	990	390.0	0.39
3	m	T	3	990	800.0	0.81
3	m	T	4	990	700.0	0.71
3	m	T	5	990	630.0	0.64
3	p	T	1	990	110.0	0.11
3	p	T	2	990	100.0	0.10
3	p	T	3	990	140.0	0.14
3	p	T	4	990	245.0	0.25
3	p	T	5	990	475.0	0.48
3	p	T	6	990	44.0	0.04
3	p	T	7	990	390.0	0.39
2	m	T	1	990	650.0	0.66
2	m	T	2	990	680.0	0.69
2	m	T	3	990	580.0	0.59
2	m	T	4	990	815.0	0.82
2	m	T	5	990	685.0	0.69
2	p	T	1	990	600.0	0.61
2	p	T	2	990	80.0	0.08
2	p	T	3	990	405.0	0.41
2	p	T	4	990	200.0	0.20
2	p	T	5	990	985.0	0.99
2	p	T	6	990	140.0	0.14
2	p	T	7	990	180.0	0.18
1	m	T	1	990	530.0	0.54
1	m	T	2	990	400.0	0.40
1	m	T	3	990	500.0	0.51
1	m	T	4	990	580.0	0.59
1	m	T	5	990	390.0	0.39
1	p	T	1	990	310.0	0.31
1	p	T	2	990	280.0	0.28
1	p	T	3	990	360.0	0.36
1	p	T	4	990	260.0	0.26
1	p	T	5	990	350.0	0.35
1	p	T	6	990	120.0	0.12
1	p	T	7	990	500.0	0.51
NA	O	P	1	16	12.5	0.78
NA	O	P	2	16	13.0	0.81
NA	O	P	3	16	13.0	0.81
NA	O	P	4	16	12.5	0.78
NA	O	P	5	16	12.5	0.78
NA	O	P	6	16	12.0	0.75
NA	O	P	7	16	13.0	0.81
NA	O	P	8	16	13.0	0.81
NA	O	P	9	16	13.0	0.81
NA	O	P	10	16	13.0	0.81
NA	O	P	11	16	12.5	0.78
NA	O	P	12	16	11.5	0.72

Date: Dec. 5 Treatment
Time: 9:10 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	470.0	0.47
3	m	T	2	990	370.0	0.37
3	m	T	3	990	700.0	0.71
3	m	T	4	990	730.0	0.74
3	m	T	5	990	690.0	0.70
3	p	T	1	990	120.0	0.12
3	p	T	2	990	95.0	0.10
3	p	T	3	990	140.0	0.14
3	p	T	4	990	290.0	0.29
3	p	T	5	990	530.0	0.54
3	p	T	6	990	60.0	0.06
3	p	T	7	990	200.0	0.20
2	m	T	1	990	670.0	0.68
2	m	T	2	990	715.0	0.72
2	m	T	3	990	630.0	0.64
2	m	T	4	990	855.0	0.86
2	m	T	5	990	715.0	0.72
2	p	T	1	990	320.0	0.32
2	p	T	2	990	420.0	0.42
2	p	T	3	990	420.0	0.42
2	p	T	4	990	220.0	0.22
2	p	T	5	990	710.0	0.72
2	p	T	6	990	160.0	0.16
2	p	T	7	990	300.0	0.30
1	m	T	1	990	480.0	0.48
1	m	T	2	990	430.0	0.43
1	m	T	3	990	555.0	0.56
1	m	T	4	990	820.0	0.83
1	m	T	5	990	420.0	0.42
1	p	T	1	990	350.0	0.35
1	p	T	2	990	330.0	0.33
1	p	T	3	990	280.0	0.28
1	p	T	4	990	345.0	0.35
1	p	T	5	990	420.0	0.42
1	p	T	6	990	200.0	0.20
1	p	T	7	990	650.0	0.66
NA	O	P	1	16	13.0	0.81
NA	O	P	2	16	13.0	0.81
NA	O	P	3	16	14.0	0.88
NA	O	P	4	16	13.0	0.81
NA	O	P	5	16	13.5	0.84
NA	O	P	6	16	13.5	0.84
NA	O	P	7	16	13.0	0.81
NA	O	P	8	16	13.0	0.81
NA	O	P	9	16	13.5	0.84
NA	O	P	10	16	13.0	0.81
NA	O	P	11	16	13.0	0.81
NA	O	P	12	16	13.5	0.84

Date: Dec. 5 Treatment
Time: 15:00 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	65.0	0.07
3	m	T	2	990	27.0	0.03
3	m	T	3	990	80.0	0.08
3	m	T	4	990	60.0	0.06
3	m	T	5	990	65.0	0.07
3	p	T	1	990	25.0	0.03
3	p	T	2	990	7.0	0.01
3	p	T	3	990	17.0	0.02
3	p	T	4	990	25.0	0.03
3	p	T	5	990	60.0	0.06
3	p	T	6	990	7.0	0.01
3	p	T	7	990	8.0	0.01
2	m	T	1	990	80.0	0.08
2	m	T	2	990	85.0	0.09
2	m	T	3	990	70.0	0.07
2	m	T	4	990	65.0	0.07
2	m	T	5	990	70.0	0.07
2	p	T	1	990	70.0	0.07
2	p	T	2	990	23.0	0.02
2	p	T	3	990	26.0	0.03
2	p	T	4	990	26.0	0.03
2	p	T	5	990	70.0	0.07
2	p	T	6	990	27.0	0.03
2	p	T	7	990	43.0	0.04
1	m	T	1	990	60.0	0.06
1	m	T	2	990	65.0	0.07
1	m	T	3	990	70.0	0.07
1	m	T	4	990	110.0	0.11
1	m	T	5	990	70.0	0.07
1	p	T	1	990	50.0	0.05
1	p	T	2	990	55.0	0.06
1	p	T	3	990	35.0	0.04
1	p	T	4	990	50.0	0.05
1	p	T	5	990	55.0	0.06
1	p	T	6	990	24.0	0.02
1	p	T	7	990	50.0	0.05
NA	O	P	1	16	0.2	0.01
NA	O	P	2	16	0.3	0.02
NA	O	P	3	16	0.3	0.02
NA	O	P	4	16	0.4	0.02
NA	O	P	5	16	0.4	0.02
NA	O	P	6	16	0.4	0.02
NA	O	P	7	16	0.2	0.01
NA	O	P	8	16	0.4	0.03
NA	O	P	9	16	0.4	0.02
NA	O	P	10	16	0.4	0.03
NA	O	P	11	16	0.3	0.02
NA	O	P	12	16	0.5	0.03

Date: Dec. 6 Treatment
Time: 8:10 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	2495.0	2.52
3	m	T	2	990	1610.0	1.63
3	m	T	3	990	6800.0	6.87
3	m	T	4	990	2980.0	3.01
3	m	T	5	990	2650.0	2.68
3	p	T	1	990	500.0	0.51
3	p	T	2	990	670.0	0.68
3	p	T	3	990	780.0	0.79
3	p	T	4	990	1410.0	1.42
3	p	T	5	990	1890.0	1.91
3	p	T	6	990	190.0	0.19
3	p	T	7	990	825.0	0.83
2	m	T	1	990	2840.0	2.87
2	m	T	2	990	3150.0	3.18
2	m	T	3	990	2835.0	2.86
2	m	T	4	990	3270.0	3.30
2	m	T	5	990	3180.0	3.21
2	p	T	1	990	3185.0	3.22
2	p	T	2	990	2890.0	2.92
2	p	T	3	990	650.0	0.66
2	p	T	4	990	1380.0	1.39
2	p	T	5	990	2910.0	2.94
2	p	T	6	990	560.0	0.57
2	p	T	7	990	910.0	0.92
1	m	T	1	990	1850.0	1.87
1	m	T	2	990	1520.0	1.54
1	m	T	3	990	2410.0	2.43
1	m	T	4	990	2460.0	2.48
1	m	T	5	990	1960.0	1.98
1	p	T	1	990	1410.0	1.42
1	p	T	2	990	1860.0	1.88
1	p	T	3	990	1135.0	1.15
1	p	T	4	990	1380.0	1.39
1	p	T	5	990	1590.0	1.61
1	p	T	6	990	1770.0	1.79
1	p	T	7	990	2365.0	2.39
NA	O	P	1	16	58.0	3.63
NA	O	P	2	16	59.0	3.69
NA	O	P	3	16	59.0	3.69
NA	O	P	4	16	58.5	3.66
NA	O	P	5	16	58.0	3.63
NA	O	P	6	16	60.0	3.75
NA	O	P	7	16	60.0	3.75
NA	O	P	8	16	59.0	3.69
NA	O	P	9	16	60.0	3.75
NA	O	P	10	16	60.0	3.75
NA	O	P	11	16	58.0	3.63
NA	O	P	12	16	59.0	3.69

Date: Dec 6 Treatment
Time: 16:20 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	855.0	0.86
3	m	T	2	990	485.0	0.49
3	m	T	3	990	970.0	0.98
3	m	T	4	990	1080.0	1.09
3	m	T	5	990	1035.0	1.05
3	p	T	1	990	155.0	0.16
3	p	T	2	990	200.0	0.20
3	p	T	3	990	170.0	0.17
3	p	T	4	990	540.0	0.55
3	p	T	5	990	450.0	0.45
3	p	T	6	990	90.0	0.09
3	p	T	7	990	180.0	0.18
2	m	T	1	990	890.0	0.90
2	m	T	2	990	990.0	1.00
2	m	T	3	990	875.0	0.88
2	m	T	4	990	1180.0	1.19
2	m	T	5	990	980.0	0.99
2	p	T	1	990	1280.0	1.29
2	p	T	2	990	515.0	0.52
2	p	T	3	990	200.0	0.20
2	p	T	4	990	540.0	0.55
2	p	T	5	990	900.0	0.91
2	p	T	6	990	170.0	0.17
2	p	T	7	990	270.0	0.27
1	m	T	1	990	650.0	0.66
1	m	T	2	990	525.0	0.53
1	m	T	3	990	775.0	0.78
1	m	T	4	990	970.0	0.98
1	m	T	5	990	570.0	0.58
1	p	T	1	990	420.0	0.42
1	p	T	2	990	520.0	0.53
1	p	T	3	990	160.0	0.16
1	p	T	4	990	550.0	0.56
1	p	T	5	990	630.0	0.64
1	p	T	6	990	360.0	0.36
1	p	T	7	990	795.0	0.80
NA	O	P	1	16	21.0	1.31
NA	O	P	2	16	20.0	1.25
NA	O	P	3	16	20.5	1.28
NA	O	P	4	16	19.0	1.19
NA	O	P	5	16	19.5	1.22
NA	O	P	6	16	20.0	1.25
NA	O	P	7	16	20.5	1.28
NA	O	P	8	16	21.0	1.31
NA	O	P	9	16	21.0	1.31
NA	O	P	10	16	20.5	1.28
NA	O	P	11	16	20.0	1.25
NA	O	P	12	16	21.0	1.31

Date: Dec. 7 Treatment
Time: 8:10 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	320.0	0.32
3	m	T	2	990	200.0	0.20
3	m	T	3	990	400.0	0.40
3	m	T	4	990	325.0	0.33
3	m	T	5	990	320.0	0.32
3	p	T	1	990	28.0	0.03
3	p	T	2	990	70.0	0.07
3	p	T	3	990	125.0	0.13
3	p	T	4	990	270.0	0.27
3	p	T	5	990	110.0	0.11
3	p	T	6	990	19.0	0.02
3	p	T	7	990	48.0	0.05
2	m	T	1	990	370.0	0.37
2	m	T	2	990	355.0	0.36
2	m	T	3	990	310.0	0.31
2	m	T	4	990	345.0	0.35
2	m	T	5	990	360.0	0.36
2	p	T	1	990	135.0	0.14
2	p	T	2	990	185.0	0.19
2	p	T	3	990	55.0	0.06
2	p	T	4	990	185.0	0.19
2	p	T	5	990	250.0	0.25
2	p	T	6	990	50.0	0.05
2	p	T	7	990	75.0	0.08
1	m	T	1	990	240.0	0.24
1	m	T	2	990	175.0	0.18
1	m	T	3	990	305.0	0.31
1	m	T	4	990	345.0	0.35
1	m	T	5	990	235.0	0.24
1	p	T	1	990	200.0	0.20
1	p	T	2	990	230.0	0.23
1	p	T	3	990	90.0	0.09
1	p	T	4	990	130.0	0.13
1	p	T	5	990	285.0	0.29
1	p	T	6	990	110.0	0.11
1	p	T	7	990	285.0	0.29
NA	O	P	1	16	7.0	0.44
NA	O	P	2	16	6.0	0.38
NA	O	P	3	16	6.0	0.38
NA	O	P	4	16	6.5	0.41
NA	O	P	5	16	7.0	0.44
NA	O	P	6	16	6.5	0.41
NA	O	P	7	16	7.0	0.44
NA	O	P	8	16	7.0	0.44
NA	O	P	9	16	6.5	0.41
NA	O	P	10	16	6.5	0.41
NA	O	P	11	16	6.5	0.41
NA	O	P	12	16	6.5	0.41

Date: Dec. 8 Treatment
Time: 13:15 m=mono
Species p=poly
1=HYAL o=open
2=CFOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	385.0	0.39
3	m	T	2	990	240.0	0.24
3	m	T	3	990	510.0	0.52
3	m	T	4	990	380.0	0.38
3	m	T	5	990	385.0	0.39
3	p	T	1	990	31.0	0.03
3	p	T	2	990	80.0	0.08
3	p	T	3	990	80.0	0.08
3	p	T	4	990	250.0	0.25
3	p	T	5	990	190.0	0.19
3	p	T	6	990	43.0	0.04
3	p	T	7	990	90.0	0.09
2	m	T	1	990	490.0	0.49
2	m	T	2	990	490.0	0.49
2	m	T	3	990	350.0	0.35
2	m	T	4	990	530.0	0.54
2	m	T	5	990	490.0	0.49
2	p	T	1	990	280.0	0.28
2	p	T	2	990	745.0	0.75
2	p	T	3	990	1860.0	1.88
2	p	T	4	990	260.0	0.26
2	p	T	5	990	575.0	0.58
2	p	T	6	990	50.0	0.05
2	p	T	7	990	100.0	0.10
1	m	T	1	990	370.0	0.37
1	m	T	2	990	180.0	0.18
1	m	T	3	990	390.0	0.39
1	m	T	4	990	480.0	0.48
1	m	T	5	990	320.0	0.32
1	p	T	1	990	250.0	0.25
1	p	T	2	990	300.0	0.30
1	p	T	3	990	150.0	0.15
1	p	T	4	990	140.0	0.14
1	p	T	5	990	270.0	0.27
1	p	T	6	990	110.0	0.11
1	p	T	7	990	305.0	0.31
NA	O	P	1	16	10.0	0.63
NA	O	P	2	16	9.0	0.56
NA	O	P	3	16	9.5	0.59
NA	O	P	4	16	9.0	0.56
NA	O	P	5	16	9.5	0.59
NA	O	P	6	16	10.0	0.63
NA	O	P	7	16	9.5	0.59
NA	O	P	8	16	10.0	0.63
NA	O	P	9	16	9.5	0.59
NA	O	P	10	16	9.5	0.59
NA	O	P	11	16	9.5	0.59
NA	O	P	12	16	10.0	0.63

Date: Dec 8 Treatment
Time: 15:40 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	30.0	0.03
3	m	T	2	990	15.0	0.02
3	m	T	3	990	40.0	0.04
3	m	T	4	990	25.0	0.03
3	m	T	5	990	25.0	0.03
3	p	T	1	990	7.0	0.01
3	p	T	2	990	8.0	0.01
3	p	T	3	990	8.0	0.01
3	p	T	4	990	18.0	0.02
3	p	T	5	990	12.0	0.01
3	p	T	6	990	5.0	0.01
3	p	T	7	990	8.0	0.01
2	m	T	1	990	34.0	0.03
2	m	T	2	990	40.0	0.04
2	m	T	3	990	28.0	0.03
2	m	T	4	990	35.0	0.04
2	m	T	5	990	33.0	0.03
2	p	T	1	990	18.0	0.02
2	p	T	2	990	32.0	0.03
2	p	T	3	990	8.0	0.01
2	p	T	4	990	18.0	0.02
2	p	T	5	990	24.0	0.02
2	p	T	6	990	9.0	0.01
2	p	T	7	990	10.0	0.01
1	m	T	1	990	45.0	0.05
1	m	T	2	990	17.0	0.02
1	m	T	3	990	40.0	0.04
1	m	T	4	990	31.0	0.03
1	m	T	5	990	30.0	0.03
1	p	T	1	990	25.0	0.03
1	p	T	2	990	38.0	0.04
1	p	T	3	990	29.0	0.03
1	p	T	4	990	17.0	0.02
1	p	T	5	990	26.0	0.03
1	p	T	6	990	15.0	0.02
1	p	T	7	990	28.0	0.03
NA	O	P	1	16	0.5	0.03
NA	O	P	2	16	0.7	0.04
NA	O	P	3	16	0.6	0.04
NA	O	P	4	16	0.7	0.04
NA	O	P	5	16	0.6	0.04
NA	O	P	6	16	0.6	0.04
NA	O	P	7	16	0.5	0.03
NA	O	P	8	16	0.7	0.04
NA	O	P	9	16	0.6	0.04
NA	O	P	10	16	0.6	0.04
NA	O	P	11	16	0.7	0.04
NA	O	P	12	16	0.5	0.03

Date: Dec 9
Time: 15:25
Species
1=HYAL
2=CEOD
3=COAL

Treatment
m=mono
p=poly
o=open

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	3440.0	3.47
3	m	T	2	990	2350.0	2.37
3	m	T	3	990	8070.0	8.15
3	m	T	4	990	4250.0	4.29
3	m	T	5	990	4450.0	4.49
3	p	T	1	990	575.0	0.58
3	p	T	2	990	900.0	0.91
3	p	T	3	990	775.0	0.78
3	p	T	4	990	1670.0	1.69
3	p	T	5	990	3690.0	3.73
3	p	T	6	990	635.0	0.64
3	p	T	7	990	830.0	0.84
2	m	T	1	990	4640.0	4.69
2	m	T	2	990	4570.0	4.62
2	m	T	3	990	6250.0	6.31
2	m	T	4	990	5310.0	5.36
2	m	T	5	990	4870.0	4.92
2	p	T	1	990	4990.0	5.04
2	p	T	2	990	9560.0	9.66
2	p	T	3	990	740.0	0.75
2	p	T	4	990	2510.0	2.54
2	p	T	5	990	4980.0	5.03
2	p	T	6	990	780.0	0.79
2	p	T	7	990	1400.0	1.41
1	m	T	1	990	3290.0	3.32
1	m	T	2	990	4070.0	4.11
1	m	T	3	990	3445.0	3.48
1	m	T	4	990	5420.0	5.47
1	m	T	5	990	2780.0	2.81
1	p	T	1	990	2610.0	2.64
1	p	T	2	990	2830.0	2.86
1	p	T	3	990	3210.0	3.24
1	p	T	4	990	2440.0	2.46
1	p	T	5	990	2860.0	2.89
1	p	T	6	990	1320.0	1.33
1	p	T	7	990	1620.0	1.64
NA	O	P	1	16	89.0	5.56
NA	O	P	2	16	101.0	6.31
NA	O	P	3	16	95.0	5.94
NA	O	P	4	16	95.0	5.94
NA	O	P	5	16	95.0	5.94
NA	O	P	6	16	95.0	5.94
NA	O	P	7	16	95.0	5.94
NA	O	P	8	16	95.0	5.94
NA	O	P	9	16	95.0	5.94
NA	O	P	10	16	95.0	5.94
NA	O	P	11	16	95.0	5.94
NA	O	P	12	16	95.0	5.94

Date : Dec. 10 Treatment
Time: 10:15 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	450.0	0.45
3	m	T	2	990	290.0	0.29
3	m	T	3	990	470.0	0.47
3	m	T	4	990	485.0	0.49
3	m	T	5	990	470.0	0.47
3	p	T	1	990	70.0	0.07
3	p	T	2	990	100.0	0.10
3	p	T	3	990	110.0	0.11
3	p	T	4	990	245.0	0.25
3	p	T	5	990	500.0	0.51
3	p	T	6	990	130.0	0.13
3	p	T	7	990	80.0	0.08
2	m	T	1	990	380.0	0.38
2	m	T	2	990	480.0	0.48
2	m	T	3	990	340.0	0.34
2	m	T	4	990	495.0	0.50
2	m	T	5	990	400.0	0.40
2	p	T	1	990	590.0	0.60
2	p	T	2	990	400.0	0.40
2	p	T	3	990	70.0	0.07
2	p	T	4	990	190.0	0.19
2	p	T	5	990	430.0	0.43
2	p	T	6	990	90.0	0.09
2	p	T	7	990	165.0	0.17
1	m	T	1	990	250.0	0.25
1	m	T	2	990	220.0	0.22
1	m	T	3	990	310.0	0.31
1	m	T	4	990	500.0	0.51
1	m	T	5	990	210.0	0.21
1	p	T	1	990	190.0	0.19
1	p	T	2	990	230.0	0.23
1	p	T	3	990	140.0	0.14
1	p	T	4	990	280.0	0.28
1	p	T	5	990	190.0	0.19
1	p	T	6	990	90.0	0.09
1	p	T	7	990	190.0	0.19
NA	O	P	1	16	10.0	0.63
NA	O	P	2	16	9.0	0.56
NA	O	P	3	16	9.0	0.56
NA	O	P	4	16	8.0	0.50
NA	O	P	5	16	8.0	0.50
NA	O	P	6	16	7.5	0.47
NA	O	P	7	16	10.0	0.63
NA	O	P	8	16	8.5	0.53
NA	O	P	9	16	9.0	0.56
NA	O	P	10	16	8.5	0.53
NA	O	P	11	16	8.0	0.50
NA	O	P	12	16	7.0	0.44

Date: Dec.11 Treatment
Species m=mono
Time: 11:30 p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	120.0	0.12
3	m	T	2	990	90.0	0.09
3	m	T	3	990	160.0	0.16
3	m	T	4	990	145.0	0.15
3	m	T	5	990	140.0	0.14
3	p	T	1	990	9.0	0.01
3	p	T	2	990	22.0	0.02
3	p	T	3	990	60.0	0.06
3	p	T	4	990	100.0	0.10
3	p	T	5	990	38.0	0.04
3	p	T	6	990	9.0	0.01
3	p	T	7	990	28.0	0.03
2	m	T	1	990	135.0	0.14
2	m	T	2	990	150.0	0.15
2	m	T	3	990	110.0	0.11
2	m	T	4	990	155.0	0.16
2	m	T	5	990	160.0	0.16
2	p	T	1	990	200.0	0.20
2	p	T	2	990	45.0	0.05
2	p	T	3	990	31.0	0.03
2	p	T	4	990	60.0	0.06
2	p	T	5	990	310.0	0.31
2	p	T	6	990	11.0	0.01
2	p	T	7	990	29.0	0.03
1	m	T	1	990	90.0	0.09
1	m	T	2	990	120.0	0.12
1	m	T	3	990	85.0	0.09
1	m	T	4	990	150.0	0.15
1	m	T	5	990	95.0	0.10
1	p	T	1	990	95.0	0.10
1	p	T	2	990	115.0	0.12
1	p	T	3	990	60.0	0.06
1	p	T	4	990	55.0	0.06
1	p	T	5	990	105.0	0.11
1	p	T	6	990	40.0	0.04
1	p	T	7	990	115.0	0.12
NA	O	P	1	16	1.3	0.08
NA	O	P	2	16	1.5	0.09
NA	O	P	3	16	1.2	0.08
NA	O	P	4	16	1.6	0.10
NA	O	P	5	16	1.4	0.09
NA	O	P	6	16	2.0	0.13
NA	O	P	7	16	1.2	0.08
NA	O	P	8	16	2.0	0.13
NA	O	P	9	16	2.0	0.13
NA	O	P	10	16	1.9	0.12
NA	O	P	11	16	1.6	0.10
NA	O	P	12	16	2.2	0.14

Date: Dec. 12 Treatment
Time: 7:55 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	1240.0	1.25
3	m	T	2	990	885.0	0.89
3	m	T	3	990	1725.0	1.74
3	m	T	4	990	1600.0	1.62
3	m	T	5	990	1510.0	1.53
3	p	T	1	990	150.0	0.15
3	p	T	2	990	330.0	0.33
3	p	T	3	990	420.0	0.42
3	p	T	4	990	920.0	0.93
3	p	T	5	990	930.0	0.94
3	p	T	6	990	160.0	0.16
3	p	T	7	990	525.0	0.53
2	m	T	1	990	1670.0	1.69
2	m	T	2	990	3013.0	3.04
2	m	T	3	990	1330.0	1.34
2	m	T	4	990	2480.0	2.51
2	m	T	5	990	1750.0	1.77
2	p	T	1	990	3660.0	3.70
2	p	T	2	990	530.0	0.54
2	p	T	3	990	260.0	0.26
2	p	T	4	990	665.0	0.67
2	p	T	5	990	1760.0	1.78
2	p	T	6	990	215.0	0.22
2	p	T	7	990	1160.0	1.17
1	m	T	1	990	1735.0	1.75
1	m	T	2	990	1030.0	1.04
1	m	T	3	990	1300.0	1.31
1	m	T	4	990	1850.0	1.87
1	m	T	5	990	1080.0	1.09
1	p	T	1	990	100.0	0.10
1	p	T	2	990	1110.0	1.12
1	p	T	3	990	880.0	0.89
1	p	T	4	990	880.0	0.89
1	p	T	5	990	880.0	0.89
1	p	T	6	990	530.0	0.54
1	p	T	7	990	1000.0	1.01
NA	O	P	1	16	35.0	2.19
NA	O	P	2	16	35.0	2.19
NA	O	P	3	16	35.0	2.19
NA	O	P	4	16	35.0	2.19
NA	O	P	5	16	36.0	2.25
NA	O	P	6	16	35.0	2.19
NA	O	P	7	16	34.0	2.13
NA	O	P	8	16	36.0	2.25
NA	O	P	9	16	35.0	2.19
NA	O	P	10	16	36.0	2.25
NA	O	P	11	16	35.0	2.19
NA	O	P	12	16	36.0	2.25

Date: Dec. 12 Treatment
Time: 15:40 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	260.0	0.26
3	m	T	2	990	180.0	0.18
3	m	T	3	990	410.0	0.41
3	m	T	4	990	320.0	0.32
3	m	T	5	990	350.0	0.35
3	p	T	1	990	23.0	0.02
3	p	T	2	990	35.0	0.04
3	p	T	3	990	70.0	0.07
3	p	T	4	990	180.0	0.18
3	p	T	5	990	100.0	0.10
3	p	T	6	990	23.0	0.02
3	p	T	7	990	45.0	0.05
2	m	T	1	990	355.0	0.36
2	m	T	2	990	390.0	0.39
2	m	T	3	990	305.0	0.31
2	m	T	4	990	410.0	0.41
2	m	T	5	990	370.0	0.37
2	p	T	1	990	350.0	0.35
2	p	T	2	990	38.0	0.04
2	p	T	3	990	47.0	0.05
2	p	T	4	990	125.0	0.13
2	p	T	5	990	340.0	0.34
2	p	T	6	990	48.0	0.05
2	p	T	7	990	160.0	0.16
1	m	T	1	990	290.0	0.29
1	m	T	2	990	190.0	0.19
1	m	T	3	990	230.0	0.23
1	m	T	4	990	270.0	0.27
1	m	T	5	990	210.0	0.21
1	p	T	1	990	160.0	0.16
1	p	T	2	990	160.0	0.16
1	p	T	3	990	120.0	0.12
1	p	T	4	990	100.0	0.10
1	p	T	5	990	180.0	0.18
1	p	T	6	990	30.0	0.03
1	p	T	7	990	130.0	0.13
NA	O	P	1	16	7.0	0.44
NA	O	P	2	16	7.0	0.44
NA	O	P	3	16	6.0	0.38
NA	O	P	4	16	6.0	0.38
NA	O	P	5	16	6.0	0.38
NA	O	P	6	16	6.0	0.38
NA	O	P	7	16	7.5	0.47
NA	O	P	8	16	7.5	0.47
NA	O	P	9	16	7.0	0.44
NA	O	P	10	16	8.0	0.50
NA	O	P	11	16	7.5	0.47
NA	O	P	12	16	6.0	0.38

Date: Dec. 14 Treatment
Time: 8:50 m=mono
Species p=poly
1=ITYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	2580.0	2.61
3	m	T	2	990	3600.0	3.64
3	m	T	3	990	3040.0	3.07
3	m	T	4	990	2800.0	2.83
3	m	T	5	990	3120.0	3.15
3	p	T	1	990	270.0	0.27
3	p	T	2	990	475.0	0.48
3	p	T	3	990	745.0	0.75
3	p	T	4	990	275.0	0.28
3	p	T	5	990	1775.0	1.79
3	p	T	6	990	400.0	0.40
3	p	T	7	990	1300.0	1.31
2	m	T	1	990	3910.0	3.95
2	m	T	2	990	3270.0	3.30
2	m	T	3	990	2720.0	2.75
2	m	T	4	990	3800.0	3.84
2	m	T	5	990	3230.0	3.26
2	p	T	1	990	4060.0	4.10
2	p	T	2	990	1670.0	1.69
2	p	T	3	990	1010.0	1.02
2	p	T	4	990	1330.0	1.34
2	p	T	5	990	3145.0	3.18
2	p	T	6	990	430.0	0.43
2	p	T	7	990	1920.0	1.94
1	m	T	1	990	2100.0	2.12
1	m	T	2	990	2720.0	2.75
1	m	T	3	990	2450.0	2.47
1	m	T	4	990	2640.0	2.67
1	m	T	5	990	2680.0	2.71
1	p	T	1	990	1530.0	1.55
1	p	T	2	990	2050.0	2.07
1	p	T	3	990	1170.0	1.18
1	p	T	4	990	2100.0	2.12
1	p	T	5	990	920.0	0.93
1	p	T	6	990	940.0	0.95
1	p	T	7	990	2060.0	2.08
NA	O	P	1	16	70.0	4.38
NA	O	P	2	16	70.0	4.38
NA	O	P	3	16	70.0	4.38
NA	O	P	4	16	65.0	4.06
NA	O	P	5	16	65.0	4.06
NA	O	P	6	16	65.0	4.06
NA	O	P	7	16	65.0	4.06
NA	O	P	8	16	70.0	4.38
NA	O	P	9	16	65.0	4.06
NA	O	P	10	16	65.0	4.06
NA	O	P	11	16	65.0	4.06
NA	O	P	12	16	60.0	3.75

Date: Dec. 14 Treatment
Time: 14:15 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	26.0	0.03
3	m	T	2	990	22.0	0.02
3	m	T	3	990	36.0	0.04
3	m	T	4	990	36.0	0.04
3	m	T	5	990	41.0	0.04
3	p	T	1	990	7.0	0.01
3	p	T	2	990	7.0	0.01
3	p	T	3	990	12.0	0.01
3	p	T	4	990	22.0	0.02
3	p	T	5	990	10.0	0.01
3	p	T	6	990	6.0	0.01
3	p	T	7	990	5.0	0.01
2	m	T	1	990	65.0	0.07
2	m	T	2	990	69.0	0.07
2	m	T	3	990	56.0	0.06
2	m	T	4	990	65.0	0.07
2	m	T	5	990	72.0	0.07
2	p	T	1	990	47.0	0.05
2	p	T	2	990	11.0	0.01
2	p	T	3	990	9.0	0.01
2	p	T	4	990	33.0	0.03
2	p	T	5	990	28.0	0.03
2	p	T	6	990	14.0	0.01
2	p	T	7	990	22.0	0.02
1	m	T	1	990	41.0	0.04
1	m	T	2	990	33.0	0.03
1	m	T	3	990	35.0	0.04
1	m	T	4	990	34.0	0.03
1	m	T	5	990	42.0	0.04
1	p	T	1	990	22.0	0.02
1	p	T	2	990	46.0	0.05
1	p	T	3	990	14.0	0.01
1	p	T	4	990	20.0	0.02
1	p	T	5	990	58.0	0.06
1	p	T	6	990	13.0	0.01
1	p	T	7	990	29.0	0.03
NA	O	P	1	16	0.4	0.03
NA	O	P	2	16	0.6	0.04
NA	O	P	3	16	0.5	0.03
NA	O	P	4	16	0.5	0.03
NA	O	P	5	16	0.7	0.04
NA	O	P	6	16	0.7	0.04
NA	O	P	7	16	0.7	0.04
NA	O	P	8	16	1.0	0.06
NA	O	P	9	16	1.0	0.06
NA	O	P	10	16	0.9	0.06
NA	O	P	11	16	0.5	0.03
NA	O	P	12	16	0.9	0.06

Date: Dec. 15 Treatment
Time: 7:40 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	2220.0	2.24
3	m	T	2	990	2490.0	2.52
3	m	T	3	990	2785.0	2.81
3	m	T	4	990	2900.0	2.93
3	m	T	5	990	2915.0	2.94
3	p	T	1	990	250.0	0.25
3	p	T	2	990	1580.0	1.60
3	p	T	3	990	495.0	0.50
3	p	T	4	990	1290.0	1.30
3	p	T	5	990	1170.0	1.18
3	p	T	6	990	375.0	0.38
3	p	T	7	990	1035.0	1.05
2	m	T	1	990	2680.0	2.71
2	m	T	2	990	5320.0	5.37
2	m	T	3	990	2305.0	2.33
2	m	T	4	990	3275.0	3.31
2	m	T	5	990	2910.0	2.94
2	p	T	1	990	2790.0	2.82
2	p	T	2	990	1320.0	1.33
2	p	T	3	990	520.0	0.53
2	p	T	4	990	1320.0	1.33
2	p	T	5	990	2590.0	2.62
2	p	T	6	990	420.0	0.42
2	p	T	7	990	1510.0	1.53
1	m	T	1	990	2010.0	2.03
1	m	T	2	990	2380.0	2.40
1	m	T	3	990	2430.0	2.45
1	m	T	4	990	2785.0	2.81
1	m	T	5	990	1790.0	1.81
1	p	T	1	990	1330.0	1.34
1	p	T	2	990	1940.0	1.96
1	p	T	3	990	1150.0	1.16
1	p	T	4	990	2200.0	2.22
1	p	T	5	990	1835.0	1.85
1	p	T	6	990	1670.0	1.69
1	p	T	7	990	2260.0	2.28
NA	O	P	1	16	55.0	3.44
NA	O	P	2	16	56.0	3.50
NA	O	P	3	16	57.0	3.56
NA	O	P	4	16	56.5	3.53
NA	O	P	5	16	57.0	3.56
NA	O	P	6	16	58.0	3.63
NA	O	P	7	16	57.0	3.56
NA	O	P	8	16	56.0	3.50
NA	O	P	9	16	57.0	3.56
NA	O	P	10	16	59.0	3.69
NA	O	P	11	16	58.0	3.63
NA	O	P	12	16	58.0	3.63

Date: Dec. 16 Treatment
Time: m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	110.0	0.11
3	m	T	2	990	85.0	0.09
3	m	T	3	990	160.0	0.16
3	m	T	4	990	155.0	0.16
3	m	T	5	990	140.0	0.14
3	p	T	1	990	16.0	0.02
3	p	T	2	990	9.0	0.01
3	p	T	3	990	120.0	0.12
3	p	T	4	990	49.0	0.05
3	p	T	5	990	140.0	0.14
3	p	T	6	990	4.0	0.00
3	p	T	7	990	48.0	0.05
2	m	T	1	990	120.0	0.12
2	m	T	2	990	140.0	0.14
2	m	T	3	990	230.0	0.23
2	m	T	4	990	125.0	0.13
2	m	T	5	990	140.0	0.14
2	p	T	1	990	315.0	0.32
2	p	T	2	990	70.0	0.07
2	p	T	3	990	14.0	0.01
2	p	T	4	990	70.0	0.07
2	p	T	5	990	135.0	0.14
2	p	T	6	990	8.0	0.01
2	p	T	7	990	35.0	0.04
1	m	T	1	990	150.0	0.15
1	m	T	2	990	44.0	0.04
1	m	T	3	990	105.0	0.11
1	m	T	4	990	150.0	0.15
1	m	T	5	990	75.0	0.08
1	p	T	1	990	55.0	0.06
1	p	T	2	990	75.0	0.08
1	p	T	3	990	70.0	0.07
1	p	T	4	990	110.0	0.11
1	p	T	5	990	110.0	0.11
1	p	T	6	990	17.0	0.02
1	p	T	7	990	80.0	0.08
NA	O	P	1	16	0.6	0.04
NA	O	P	2	16	2.0	0.13
NA	O	P	3	16	0.8	0.05
NA	O	P	4	16	1.1	0.07
NA	O	P	5	16	0.8	0.05
NA	O	P	6	16	0.8	0.05
NA	O	P	7	16	1.2	0.08
NA	O	P	8	16	1.8	0.11
NA	O	P	9	16	1.5	0.09
NA	O	P	10	16	1.7	0.11
NA	O	P	11	16	1.0	0.06
NA	O	P	12	16	1.8	0.11

Date: Dec. 22 Treatment
Time: 10:47 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	155.0	0.16
3	m	T	2	990	190.0	0.19
3	m	T	3	990	260.0	0.26
3	m	T	4	990	210.0	0.21
3	m	T	5	990	180.0	0.18
3	p	T	1	990	8.0	0.01
3	p	T	2	990	18.0	0.02
3	p	T	3	990	18.0	0.02
3	p	T	4	990	140.0	0.14
3	p	T	5	990	210.0	0.21
3	p	T	6	990	3.0	0.00
3	p	T	7	990	90.0	0.09
2	m	T	1	990	220.0	0.22
2	m	T	2	990	240.0	0.24
2	m	T	3	990	170.0	0.17
2	m	T	4	990	425.0	0.43
2	m	T	5	990	225.0	0.23
2	p	T	1	990	610.0	0.62
2	p	T	2	990	180.0	0.18
2	p	T	3	990	65.0	0.07
2	p	T	4	990	80.0	0.08
2	p	T	5	990	340.0	0.34
2	p	T	6	990	22.0	0.02
2	p	T	7	990	130.0	0.13
1	m	T	1	990	290.0	0.29
1	m	T	2	990	160.0	0.16
1	m	T	3	990	300.0	0.30
1	m	T	4	990	360.0	0.36
1	m	T	5	990	260.0	0.26
1	p	T	1	990	225.0	0.23
1	p	T	2	990	240.0	0.24
1	p	T	3	990	230.0	0.23
1	p	T	4	990	280.0	0.28
1	p	T	5	990	250.0	0.25
1	p	T	6	990	240.0	0.24
1	p	T	7	990	370.0	0.37
NA	O	P	1	16	3.5	0.22
NA	O	P	2	16	3.5	0.22
NA	O	P	3	16	3.5	0.22
NA	O	P	4	16	3.0	0.19
NA	O	P	5	16	3.5	0.22
NA	O	P	6	16	6.0	0.38
NA	O	P	7	16	3.5	0.22
NA	O	P	8	16	4.0	0.25
NA	O	P	9	16	4.0	0.25
NA	O	P	10	16	4.0	0.25
NA	O	P	11	16	3.0	0.19
NA	O	P	12	16	7.0	0.44

Date: Dec 22 Treatment
Time: 16:15 m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	165.0	0.17
3	m	T	2	990	160.0	0.16
3	m	T	3	990	240.0	0.24
3	m	T	4	990	230.0	0.23
3	m	T	5	990	215.0	0.22
3	p	T	1	990	10.0	0.01
3	p	T	2	990	25.0	0.03
3	p	T	3	990	21.0	0.02
3	p	T	4	990	110.0	0.11
3	p	T	5	990	130.0	0.13
3	p	T	6	990	3.0	0.00
3	p	T	7	990	80.0	0.08
2	m	T	1	990	255.0	0.26
2	m	T	2	990	280.0	0.28
2	m	T	3	990	215.0	0.22
2	m	T	4	990	260.0	0.26
2	m	T	5	990	250.0	0.25
2	p	T	1	990	500.0	0.51
2	p	T	2	990	46.0	0.05
2	p	T	3	990	45.0	0.05
2	p	T	4	990	130.0	0.13
2	p	T	5	990	490.0	0.49
2	p	T	6	990	21.0	0.02
2	p	T	7	990	140.0	0.14
1	m	T	1	990	230.0	0.23
1	m	T	2	990	80.0	0.08
1	m	T	3	990	155.0	0.16
1	m	T	4	990	360.0	0.36
1	m	T	5	990	180.0	0.18
1	p	T	1	990	140.0	0.14
1	p	T	2	990	160.0	0.16
1	p	T	3	990	135.0	0.14
1	p	T	4	990	150.0	0.15
1	p	T	5	990	160.0	0.16
1	p	T	6	990	70.0	0.07
1	p	T	7	990	160.0	0.16
NA	O	P	1	16	4.0	0.25
NA	O	P	2	16	4.0	0.25
NA	O	P	3	16	4.0	0.25
NA	O	P	4	16	4.0	0.25
NA	O	P	5	16	4.0	0.25
NA	O	P	6	16	5.0	0.31
NA	O	P	7	16	4.0	0.25
NA	O	P	8	16	4.5	0.28
NA	O	P	9	16	4.5	0.28
NA	O	P	10	16	4.5	0.28
NA	O	P	11	16	4.5	0.28
NA	O	P	12	16	5.0	0.31

Date: Dec. 24 Treatment
Time: m=mono
Species p=poly
1=HYAL o=open
2=CEOD
3=COAL

Species	Treat.	Gauge Type	Gauge #	Area	Vol. (ml)	Depth (cm)
3	m	T	1	990	170.0	0.17
3	m	T	2	990	155.0	0.16
3	m	T	3	990	260.0	0.26
3	m	T	4	990	230.0	0.23
3	m	T	5	990	230.0	0.23
3	p	T	1	990	7.0	0.01
3	p	T	2	990	30.0	0.03
3	p	T	3	990	13.0	0.01
3	p	T	4	990	210.0	0.21
3	p	T	5	990	190.0	0.19
3	p	T	6	990	0.0	0.00
3	p	T	7	990	100.0	0.10
2	m	T	1	990	200.0	0.20
2	m	T	2	990	225.0	0.23
2	m	T	3	990	210.0	0.21
2	m	T	4	990	245.0	0.25
2	m	T	5	990	250.0	0.25
2	p	T	1	990	340.0	0.34
2	p	T	2	990	95.0	0.10
2	p	T	3	990	6.0	0.01
2	p	T	4	990	145.0	0.15
2	p	T	5	990	230.0	0.23
2	p	T	6	990	9.0	0.01
2	p	T	7	990	200.0	0.20
1	m	T	1	990	190.0	0.19
1	m	T	2	990	70.0	0.07
1	m	T	3	990	230.0	0.23
1	m	T	4	990	180.0	0.18
1	m	T	5	990	130.0	0.13
1	p	T	1	990	160.0	0.16
1	p	T	2	990	205.0	0.21
1	p	T	3	990	100.0	0.10
1	p	T	4	990	250.0	0.25
1	p	T	5	990	190.0	0.19
1	p	T	6	990	55.0	0.06
1	p	T	7	990	155.0	0.16
NA	O	P	1	16	3.5	0.22
NA	O	P	2	16	4.0	0.25
NA	O	P	3	16	4.0	0.25
NA	O	P	4	16	3.5	0.22
NA	O	P	5	16	4.0	0.25
NA	O	P	6	16	4.5	0.28
NA	O	P	7	16	3.5	0.22
NA	O	P	8	16	4.0	0.25
NA	O	P	9	16	4.0	0.25
NA	O	P	10	16	4.0	0.25
NA	O	P	11	16	4.0	0.25
NA	O	P	12	16	4.5	0.28

APPENDIX B

AVERAGE THROUGHFALL AND RAINFALL VALUES ON BOTH GAUGE AND EVENT BASES

Throughfall as a Percentage of Total Rainfall on a Per Gauge Basis

Species	Treatment	Gauge #	Throughfall (cm)	% of rain partitioned as throughfall
COAL	M	3	48.1	116
CEOD	M	4	39.1	95
CEOD	M	2	39.1	95
CEOD	D	5	36	87
CEOD	M	1	34.1	82
CEOD	M	5	33.7	82
COAL	M	4	32.7	79
CEOD	M	3	32.6	79
CEOD	D	1	32.5	79
HYAL	M	4	31.4	76
COAL	M	5	31.3	76
CEOD	D	2	29.3	71
COAL	M	1	27.6	67
HYAL	M	3	25.6	62
COAL	M	2	23.5	57
HYAL	M	1	22	53
HYAL	M	2	21.4	52
HYAL	M	5	21	51
COAL	D	5	20.8	50
HYAL	D	7	20.7	50
CEOD	D	7	19.5	47
HYAL	D	2	19.4	47
HYAL	D	5	18.6	45
HYAL	D	4	17.9	43
HYAL	D	1	16.1	39
COAL	D	4	15.2	37
CEOD	D	4	15	36
HYAL	D	3	14.4	35
CEOD	D	3	14.2	34
HYAL	D	6	11.7	28
COAL	D	7	9.1	22
COAL	D	3	7.3	18
CEOD	D	6	7.1	17
COAL	D	2	6.6	16
COAL	D	1	5	12
COAL	D	6	2.9	7

M = monoculture, D = diculture

COAL = *Cordia alliodora*, CEOD = *Cedrela odorata*, HYAL = *Hyeronima alchorneoides*

Throughfall as a Percentage of Total Rainfall on a Per Storm Basis

Sampling period #	Throughfall (cm)	Average rainfall (mm)	% of rain partitioned as throughfall
1	1.73	40.6	42.62
2	0.109	2	54.67
3	0.1	1.75	56.62
4	1.63	26	62.52
5	0.18	2.5	71.49
6	0.44	7.75	51.17
7	0.18	5.5	32.62
8	0.74	16.25	45.49
9	2.02	35	58.43
10	0.08	1.5	55.24
11	0.56	10.25	54.2
12	0.07	1.25	54.86
13	0.38	6	93.87
14	0.18	2.2	79.61
15	0.42	9	47.03
16	0.44	8.4	52.81
17	0.05	0.5	100.73
18	2.03	40.7	49.82
19	0.62	13.5	46.49
20	0.21	5.3	39.92
21	0.34	5.6	60.87
22	0.02	0.3	77.72
23	3.31	53.7	61.72
24	0.29	8.7	32.99
25	0.1	1.7	56.81
26	1.16	21.1	54.87
27	0.2	4.8	40.94
28	2.08	35	59.51
29	0.03	0.5	62.18
30	1.97	37.6	52.42
31	0.1	1.4	69.73
32	0.21	1.8	115.26
33	0.17	2.6	64.76
34	0.16	2.4	66.23

APPENDIX C
PREDICTED THROUGHFALL VALUES

Event Number	Actual throughfall values (mm)	Model 1 predicted throughfall values (mm)	Model 2 predicted throughfall values (mm)
1	17.3	22.15	21.1
2	1.09	1	1.42
3	1	0.86	1.31
4	16.3	14.15	11.59
5	1.8	1.27	1.47
6	4.4	4.15	4.04
7	1.8	2.92	2.08
8	7.4	8.81	6.75
9	20.2	19.08	19.87
10	0.8	0.72	0.87
11	5.6	5.52	5.36
12	0.7	0.59	0.97
13	3.8	3.19	2.37
14	1.8	1.11	0.56
15	4.2	4.83	4.38
16	4.4	4.51	3.81
17	0.5	0.18	1.08
18	20.3	22.21	21.61
19	6.2	7.3	7.21
20	2.1	2.81	2.37
21	3.4	2.97	2.34
22	0.2	0.07	1.14
23	33.1	29.33	29.74
24	2.9	4.67	4.38
25	1	0.83	0.98
26	11.6	11.47	11.51
27	2	2.53	2.44
28	20.8	19.08	19.73
29	0.3	0.18	1.08
30	19.7	20.51	21.67
31	1	0.67	0.78
32	2.1	0.89	1.35
33	1.7	1.33	1.58
34	1.6	1.22	1.13

Model 1: Throughfall predictions based solely on total rainfall

Model 2: Throughfall predictions based on total rainfall, rainfall intensity and rainfall duration

VITA

Matthew Theodore Casey was born in Kingsport, Tennessee on April 4, 1971. He attended schools in the public system of Kingsport, Tennessee, where he graduated from Dobyns-Bennett High School in May, 1989. He entered the University of Tennessee at Knoxville during September of 1989 where in May, 1993, he graduated summa cum laude with a Bachelor of Arts in Geography. While pursuing his undergraduate degree, he worked as a research assistant in the ecology department and participated in two field programs in the High Arctic. He entered the Master's program in Geography at the University of Tennessee at Knoxville in September of 1993, officially receiving the Master's degree in August, 1996. During his time as a graduate student, he served as a teaching assistant for both physical geography and GIS, worked as a GIS analyst in the Water Resources Division of TVA, and served as an Organization of Tropical Studies GIS intern at La Selva in Costa Rica.

He is presently working as a systems analyst for Knox Geographic Information Systems in Knoxville, Tennessee.