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Precipitation, Inter-Event Dry Periods, and Reuse Design Curves for selected areas of Florida

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EXECUTIVE SUMMARY

The increase in the pollution of existing water bodies due to poor management of stormwater runoff has demanded continuous re-evaluation of present design methods for stormwater management facilities. Current criteria used in determining water quality (treatment) volumes in pond design neglect antecedent conditions resulting from preceding rainfall. During the dry period between rainfall events, treatment of stormwater proceeds and is considered complete after a specific time period. The inter-event dry period refers to that time period (hours) which occurs between rainfall events. The minimum inter-event dry period used for pollution control design should be consistent with the time required for infiltration, chemical precipitation, sediment removal, and biological assimilation; as well as the period of time required for the transport system (pipes, open channels, and other structural controls) to return to their design elevations.

Spreadsheet programming was used for calculations using fifteen years of data from seventeen rainfall stations in the State of Florida. A minimum inter-event dry period was specified and all rainfall volume was cumulated before the minimum inter-event dry period. Exceedence probability

distributions were calculated for rainfall precipitation volume (**P**) given inter-event dry periods (**I**) of 4, 12, 24, 48, 72, 96, and 120 hours. The precipitation volume for each inter-event dry period and specified frequency (**F**), or return period was calculated and the results are presented in graphical form and are called **PIF** curves.

Statistical data on rainfall volumes and duration for each minimum inter-event dry period were also developed. These statistics are useful when probability distribution functions are used for hydrologic and stormwater designs. For minimum 4-hour and 72-hour inter-event dry periods, the average precipitation volumes were 0.53 and 1.48 inches respectively.

This work also includes a diversion volume analysis for each of the seventeen rainfall stations. The diversion volume calculations using rainfall data are directed specifically towards use in off-line retention systems. A cumulative distribution function was generated from the fifteen year database for inter-event rainfall records of 4, 24, and 72 hours. Diversion volume curves were developed for each rainfall station and are presented in this report.

Consideration of the inter-event dry period through the use of the design curves developed in this research provide a design where initial conditions are more accurately defined. Water quantity volumes which produce the desired level of treatment for stormwater runoff can be more accurately

determined as a result of this type of design.

The precipitation volume for any given minimum inter-event time period and return period do not have significant variability among the seventeen state-wide locations. It is recommended that the average precipitation volume for a given minimum inter-event time and return period from among the seventeen locations should be used as a State-wide standard. However, some local governments may wish to adopt higher standards based on this work.

CHAPTER ONE

INTRODUCTION

Philosophy

Florida, "The Sunshine State", a state in which the average annual rainfall ranges from 40 to 65 inches (NOAA, 1900-1989), commands the advent of the realization that clean and plentiful water resources are essential to Florida's economy and the quality of life. No longer can we afford to waste or misuse, unnecessarily, one of Florida's most precious natural resources. Stormwater is the water that results from a rainfall event and it must be carefully managed to insure that it does not pollute our existing water bodies, flood developed lands, destroy natural habitats, and yet is returned to the environment to eventually replenish and maintain the natural hydrologic cycle.

The disturbance of natural lands, land development, and the resulting increase of "imperviousness", have all manifested their existence by a decrease in the quality and an increase in the quantity of stormwater runoff. Erosion, sedimentation, accumulation of pollutants on impervious surfaces , and the debris of society have caused stormwater to be a major source of pollution. Historically, attention has been given to

stormwater runoff rates and volume with the singular intent of preventing or controlling flooding. In some parts of Florida, the flooding is prevented in part by a system of "ditching, ponding, and draining" which has led to the proliferation of stormwater systems constructed solely for flood protection. These "drainage systems" were designed to carry stormwater away from developed areas as quickly as possible and deliver it to the nearest lake, river, sinkhole, bay or other surface waters. Today, these systems are the major contributors of stormwater pollutants and have caused the decline of water quality in many Florida waters (Livingston, 1990).

The Design Storm

A stormwater management facility consists of a conveyance system that collects and transports stormwater runoff to a storage area for treatment, typically a detention or retention pond. Due to the stochastic nature of rainfall, it is impossible to define a precipitation volume which would never be exceeded, therefore dictating the need for a "Design Storm" which is consistent with a reasonable risk of failure. Runoff rates and volumes are currently calculated using a design storm that is based on rainfall intensities. The risk of failure is related to a precipitation volume and a maximum intensity associated with a specified return period, typically 2-year, 3-year, 5-year, 10-year, 25-year, 50-year, and 100-year. For example, using a design storm associated with a return period

of 25-years, it is expected that the designed transport and storage system will fail on the average once every 25 years, given a long period of record.

Frequency-Intensity-Duration (F-I-D) curves developed from rainfall data have traditionally been used for the selection of the design storm intensity and the determination of the required storage volume for the detention or retention pond to attenuate peak discharge. For a specified average rain duration (hours), an average rainfall intensity (inches per hour) which is associated with a given return period (or risk of failure) is read from F-I-D curves. Design based on the "Design Storm" concept using F-I-D curves assume an initial condition in which conveyance systems are empty and the ponds are at a control elevation at the beginning of the storm event. There are no design considerations addressing the variable pond or rainfall antecedent conditions.

The Inter-Event Dry Period

The inter-event dry period is the period of time, typically measured in hours, beyond which the occurrence of rainfall marks the beginning of an another rainfall event (the number of dry hours between storm events). Independent rainfall events result when the inter-event dry period is of length sufficiently long so that one event will not effect the probability of the occurrence of the other. When designing stormwater transport and pollution control systems, the inter-

event dry period between two successive rainfall events should be greater than or equal to the time required for pollution control and be greater than the recovery time of the stormwater transport system and the detention/retention pond. Rainfall events not separated by the specified minimum inter-event dry period should be combined to develop a maximum rainfall volume consistent with a risk of violation.

An effective pond design is that which improves the water quality by providing storage of the stormwater runoff for a period of time long enough to sufficiently "treat" the stormwater, thereby reducing the pollutants discharged to receiving waters. For example, if it is determined that stormwater should be stored for 72 hours to achieve a desired level of biological assimilation, an effective pond design would be one which could recover to it's initial conditions in 72 hours with a storage volume based on rainfall with an inter-event dry period of 72 hours. Other inter-event time periods are associated with other treatment objectives, such as, sedimentation in 12 hours and alum treatment in 24 hours. The association of a design storm with a specific inter-event dry period will produce a design based on initial conditions which are more accurately defined and allow for the flexibility of acquiring a desired treatment level of pollutants based on the detention time of stormwater.

Objective

The purpose of this section is to develop rainfall volumes based on a desired minimum inter-event dry period. These volumes will be used for the design of stormwater management facilities. A statistical analysis of selected rainfall stations in the State of Florida can be developed to relate inter-event dry periods (hours) and precipitation volume (inches) to specified return periods. These curves are called Precipitation-Inter-Event Dry Period-Frequency Curves, or **P-I-F** Curves, and could be used to calculate the volume used for water quality control in detention ponds.

This section of the report also includes a Diversion Volume Analysis for 4-hour, 24-hour, and 72-hour inter-event dry periods. Volume data have been generated from this analysis which can be used in the design of off-line systems, including retention ponds, other infiltration systems, and systems which employ the use of chemical treatment. Also, the annual average treatment efficiency associated with reuse of stormwater can be estimated, and is presented in detail in the second section of this report.

The directive of this section is to demonstrate the relevance of the minimum inter-event dry period as it relates to the time required for water quality treatment. To achieve a desired level of treatment, antecedent conditions must be considered when determining storage volumes in detention or retention ponds. Integration of the inter-event dry period

concept into design procedures will implement a more rational basis for the design of Best Management Practices (BMP's).

Limitations

The analysis of rainfall is limited to the State of Florida. The use of the results requires an estimate of time for treatment, and in general assumes that no treatment occurs during the storm event. If treatment during the event were possible, the minimum inter-event time is calculated as the summation of the time during and between events.

The diversion analysis assumes that no "first flush" of pollutants occurs, and if used for pollution control of smaller watersheds the design volume will be over-estimated. First flush describes the washing action that stormwater has on accumulated pollutants in the watershed during the early part of a rainfall event. The effects of first flush generally diminish as the size of the drainage basin increases and the amount of impervious area decreases (F.D.E.R., 1988).

CHAPTER TWO

THEORY AND METHODOLOGY

Runoff-Rainfall Relation

As a result of a storm event, a watershed area will typically produce a runoff volume, or rainfall excess. The amount of this rainfall excess depends on several factors including:

A. The precipitation volume and intensity.

B. The percent of impervious area.

C. The percent of directly connected impervious area, or that area transported directly to the detention or retention pond.

D. The underlying soil types for the pervious areas, and their degree of saturation resulting from previous rainfall.

E. The initial condition of the conveyance system and detention/retention pond resulting from antecedent rainfall.

In the design of a stormwater management facility, the watershed characteristics producing runoff must be determined.

The runoff coefficient, designated C, as defined by equation (1), is the ratio of rainfall excess to precipitation (Mulvaney, 1851).

$$C=\frac{R}{P} \tag{1}$$

where: C = runoff coefficient (dimensionless)
R = rainfall excess or runoff volume
P = precipitation (rainfall) volume

The runoff coefficient, C, ranges in values from 0 to 1; where a value of C = 0 would occur for pervious areas that do not produce runoff, and a value of C = 1 could be expected for completely impervious areas where the total precipitation results in rainfall excess.

Typically in design, a watershed area will be composed of many different surfaces and underlying soil types, resulting in several distinct runoff coefficients. For this case, a composite runoff coefficient is calculated using equation (2).

$$C=\frac{(C_1A_1+C_2A_2+...+C_NA_N)}{(A_1+A_2+...+A_N)} \tag{2}$$

where: C_N = runoff coefficient for surface N
A_N = area of surface N

The resulting composite value for the runoff coefficient is expressed as the effective runoff coefficient of the watershed and can be used to represent the entire watershed area in analysis.

Equivalent Impervious Area

The product of the total watershed area and the calculated effective runoff coefficient is equal to the equivalent impervious area (EIA) for the watershed, shown in equation (3).

$$EIA = C x A \tag{3}$$

The equivalent impervious area calculation equates a watershed area of mixed land uses to an equivalent watershed area comprised of only one completely impervious surface with no initial abstraction. The resulting EIA will be used in conjunction with the P-I-F curves for the design of detention or retention ponds later in this report.

If a watershed area consists of only directly connected impervious area (DCIA) that has no initial abstraction, and there is no runoff contribution from off-site or adjacent basins, then the resulting equivalent impervious area is equal to the total watershed area.

$$EIA = DCIA \tag{4}$$

When a watershed is comprised of both impervious and pervious surfaces, a runoff coefficient for the pervious areas based on the underlying soil types and their hydrologic characteristics must be determined. The following illustrates three methods by which this runoff coefficient can be derived.

Method I

By using an infiltrometer, an exponential curve (Horton Equation) can be developed describing the potential infiltration rate of a soil as a function of time. The total volume of infiltrate is determined by integrating the area under the curve (Horton, 1940).

$$F=\int_0^t f(t)=f_c t+\frac{(f_0-f_c)}{K}(1-e^{-Kt}) \tag{5}$$

where:
- F = total volume of infiltrate (inches)
- $f(t)$ = infiltration rate (inches/hour)
- f_c = ultimate infiltration rate (inches/hour)
- f_0 = initial infiltration rate (inches/hour)
- K = recession constant (1/hour)
- t = time (hour)

The total precipitation less the volume of rainfall which infiltrates into the soil is equal to the amount of rainfall excess, or runoff volume from the pervious area, R_p.

$$R_p=P-F \tag{6}$$

The runoff coefficient for the pervious area, C_p, with infiltration based on the Horton equation, can now be computed using equation (7).

$$C_p=\frac{R_p}{P} \tag{7}$$

Method II

The United States Soil Conservation Service (SCS) has developed a procedure for estimating rainfall excess based on soil types and ground covers found in the United States. It is called the SCS Soil-Cover Complex Method and uses a Curve Number (CN) that can be determined from the soil and ground cover in the watershed. The maximum storage of the soil, S', is related to the curve number by the following equation (Kent, 1973).

$$S' = \frac{1000}{CN} - 10 \qquad (8)$$

where: S' = maximum soil storage (inches)

The rainfall excess can now be computed using equations (9) and (10).

$$R_p = \frac{(P - 0.2S')^2}{(P - 0.8S')} \; if P > 0.2S' \qquad (9)$$

and

$$R_p = 0 \; if P \leq 0.2S' \qquad (10)$$

where: P = precipitation (inches)

With the calculated R_p from the SCS Curve Number, equation (7) can be used to determine the runoff coefficient.

Method III

The State of Florida Department of Transportation uses an equation developed by Johnson and Meadows to estimate a runoff coefficient using the SCS Curve Number (FDOT, 1987).

$$C_T=1-\frac{S'}{P_T}\left(1.2 - \frac{S'}{(P_T+0.8S')}\right) \quad (11)$$

where: C_T = runoff coefficient for return period, T
S' = maximum soil storage (inches)
P_T = precipitation depth for return period, T, (inches)

The calculated value of C_T can be used as the runoff coefficient for the pervious area in the watershed.

The resulting values for the runoff coefficient for the preceding three methods can now be used in equation (3) to determine the EIA, or by the following.

$$EIA = C_T(A) = C_P(A) \quad (12)$$

Historical Rules and Current Design Criteria

The Water Resources Act of 1972, Florida Statues Chapter 373, Part IV, established five water management districts in the State of Florida and granted them the authority to implement broad regulatory programs for the purpose of protecting the water resources of the State. The Florida

Department of Environment Regulation (D.E.R.) governs the five water management districts and their authority to administer and enforce the Management and Storage of Surface Waters (MSSW) permitting program. Chapter 17-25 of the Florida Administrative Code, the State Stormwater Rule, was adopted in 1982 with the purpose of preventing the pollution of "the Waters of the State". More recently, on December 6, 1990, the Department of Environmental Regulation adopted a State Water Policy, Chapter 17.40, which specifies a percent reduction in the mass of stormwater related pollutants and the reuse of stormwater.

Detention refers to the temporary storage of runoff volume near the area of generation and its' gradual release over time from the storage area. Runoff is held for a short period of time and is slowly released to a natural or man-made water course, usually at a rate no greater than the pre-development peak discharge rate. The historical use of a detention facility is to regulate the runoff from a given rainfall event and more recently to control pollution discharges to reduce the impact on downstream stormwater systems, either natural or manmade (F.D.E.R., 1988). Wet detention systems, consisting of permanent pool storage, treatment volume with gradual release, and vegetated littoral zones, can provide treatment of stormwater runoff by biological, chemical, and physical processes (Wilkening, 1990). The schematic of a typical wet detention system is shown in Figure 2-1. Dry detention

facilities, as opposed to wet detention, permit to pond to drain to a dry bottom condition. They are not common nor are typically permitted in the State.

Stormwater retention ponds, or infiltration basins, retain stormwater on site thus reducing the contamination of downstream waters. Their purpose is to incorporate pollution control and groundwater recharge concepts into the design and construction of storage areas for the percolation of stormwater runoff, so that the adverse impact of urban type development on receiving waters can be minimized. Retention systems do not release stored waters for surface discharge. The most significant limiting factors concerning the use of retention systems are the soil conditions and the availability of sufficient land area to provide the necessary storage volume. Typical pond design volume is calculated as the runoff from the first inch of rainfall with the system recovering the full design storage volume in a maximum of 72 hours following a storm event (F.D.E.R., 1988).

Another typical design volume in the State is used when stormwater is being discharged into Outstanding Florida Waters. One-Hundred Fifty (150) percent of the volumes required for retention or detention must be provided (F.D.E.R., 1988). However, not all of the current design criteria for stormwater detention and retention ponds are the same among the water management districts. Part of the differences relate to the meteorological conditions of the region.

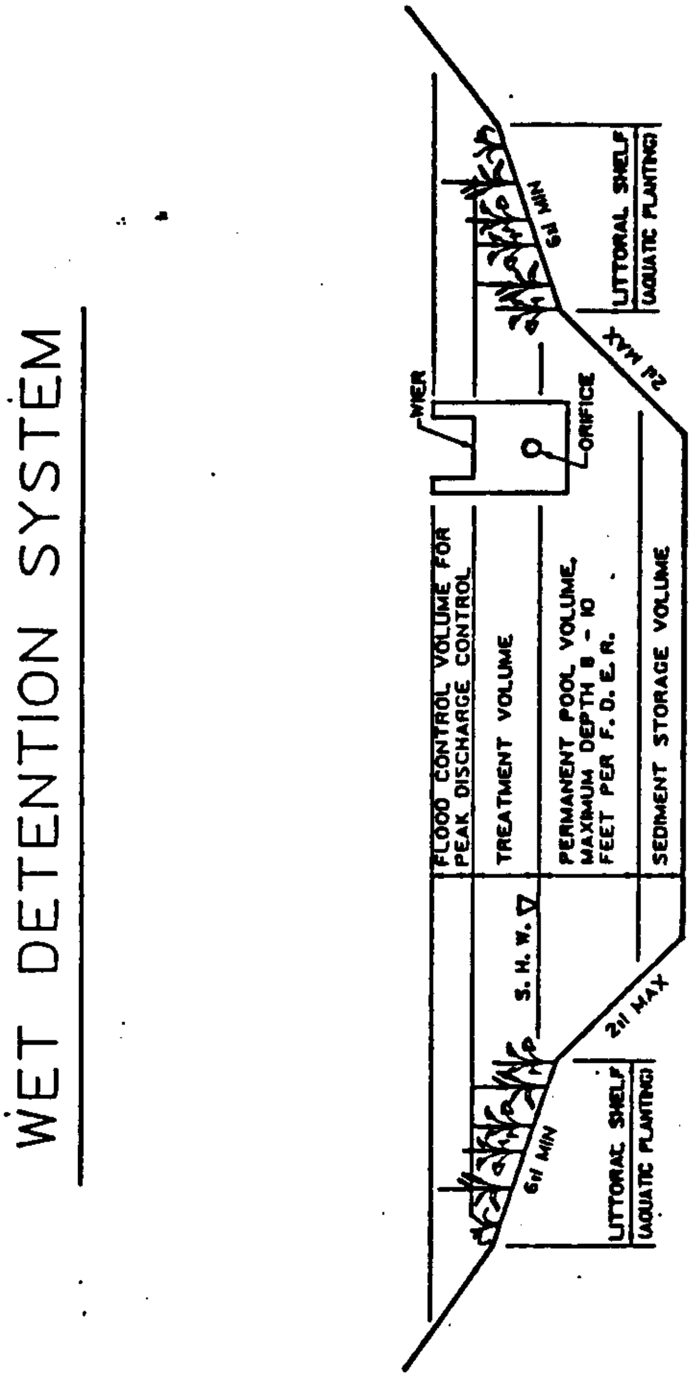

Figure 2-1
Source: Southwest Florida Water Management District Management and Storage of Surface Water, Permit Information Manual, Vol. I, March 1988.

The division of the five water management districts was determined geographically, and they are as follows:

1. Northwest Florida Water Management District
2. Suawannee River Water Management District
3. St. John's River Water Management District
4. Southwest Florida Water Management District
5. South Florida Water Management District

Regulatory staff from the water management districts meet regularly to coordinate rule development with the goal of consistency between water management district rules when appropriate. However, some rule criteria does and will continue to vary between the districts as progress is made in addressing stormwater management on a geographic and meteorological basis. The present criteria governing design of the formerly described detention and retention facilities were detailed for each water management district. Those issues not addressed by the water management district will follow the guidelines set forth by the Florida Department of Environment Regulation.

Northwest Florida Water Management District:

Northwest Florida policy adheres to criteria established by the Department of Environmental Regulation, specifically to the State water quality standards of Chapter 17-3, and the State Stormwater Rule of Chapter 17-25, Florida Administrative Code. The Northwest Florida Water Management District, as of June 1991, has not yet received the authority to regulate it's own surface waters, however the drafting process for such rules are currently underway. For this reason, the following

criteria specifically reflects that which has been set forth by the Department of Environmental Regulation.

Criteria for wet detention systems water quality volume require the detention of the first 1 inch of runoff over the watershed or 2.5 times the percent impervious, whichever is greater. This volume is detained for treatment, and is referred to as the treatment volume. This volume is to be recovered at a rate such that one-half of the total treatment volume is discharged in no less than the first sixty hours following an event, and the entire treatment volume is discharged in 120 hours or greater.

Retention facilities built in accordance with Chapter 17-25, F.A.C., must have the capacity to store and percolate either the runoff from the first inch of rainfall or (a minimum of) the first one-half inch of runoff within 72 hours. Small watershed areas (e.g., those of 100 acres or less) are only required to provide for the minimum first one-half inch level of retention. The runoff exceeding this volume is diverted to a flood control structure (F.D.E.R., 1988).

South Florida Water Management District:

Stormwater discharge must meet State water quality standards per Chapter 17-3, Florida Administrative Code. Any direct discharge to sensitive receiving water (Class I, Class II, or Outstanding Florida Waters) will receive close review and may require monitoring by the water management district.

Wet detention volume (treatment volume) shall be provided

for the first inch of runoff from the developed project, or the total runoff of 2.5 inches times the percentage of impervious area, whichever is greater. Gravity control devices shall be used for the release of the treatment volume which should not exceed one-half inch in 24 hours. Dry detention refers to an on-line pond with no permanent pool, or a pond where the stored runoff volume infiltrates to make a dry bottom. The dry detention volume is equal to 75 percent of wet detention volume.

Retention volume shall be provided equal to 50 percent of the above computed volume for wet detention. Retention volume included in flood protection calculations requires calculations to demonstrate long term system bleed down ability (South Florida Water Management District, 1987).

Southwest Florida Water Management District:

State Standards for water quality as detailed in Chapter 17-3 of the Florida Administrative Code must be realized for all stormwater discharge.

Wet detention facilities must detain (treatment volume) one inch from the entire site plus any contributing areas. Discharge of not more than one-half of the treatment volume should occur in the first 60 hours following the storm event. Release of the total treatment volume should not take less than 120 hours.

The volume required for retention is that amount of runoff produced from 1 inch of rainfall over the watershed area, or

0.5 inches times the watershed area, whichever is greater. The retention pond must recover the water quality volume within 72 hours following the storm event (Southwest Florida Water Management District, 1988).

St. John's River Water Management District:

Discharge must meet State water quality standards of Chapter 17-3, Florida Administrative Code. If stormwater is being discharged into Outstanding Florida Waters, 150 percent of the following outlined retention/detention volume must be provided with the first 0.5 inch treated in an off-line retention facility.

The treatment volume for a wet detention pond is defined by the first 1 inch of rainfall or 2.5 inches times the percentage of impervious area, whichever is greater. Detention basins shall again provide the capacity for the specified treatment volume of stormwater within 72 hours following a storm event.

Retention ponds must be design to store a volume resulting from the first inch of rainfall over the watershed. Retention basins should be able to provide the capacity for the given volume of stormwater within 72 hours following a storm event. The additional storage volume must be provided by a decrease of stored water caused only by percolation through soil, evaporation or evapotranspiration (Saint Johns River Water Management District, 1990).

Suwannee River Water Management District (S.R.W.M.D.):

Water quality data which are representative of water discharged from the permitted system, shall be submitted as requested. These may include, but are not necessarily limited to Chapter 17-3, Florida Administrative Code, parameters.

Suwannee River Water Management District states the stormwater management systems must be designed to provide a minimum level of treatment for water quality purposes. The Water Management District has detailed four levels of required treatment volumes in their guidelines, dependent upon proposed land use and watershed characteristics.

Both detention and retention systems must recover the required treatment volume within 72 hours following the storm event. Retention systems with percolation are the most desirable method for achieving water quality design and should be used where possible (S.R.W.M.D., 1991).

Critique

The above criteria specifies, for a design storm, a volume of rainfall for water quality design and an inter-event time during which the water quality volumes (treatment volumes) must be discharged. Because of the stochastic nature of rainfall and the randomness associated with each conditional rainfall volume, pond volumes will be exceeded a fraction of the time and the desired level of treatment will not be achieved. The probability of the pond volume being exceeded, assuming the pond is at the control elevation, can be

determined from frequency distributions of rainfall volume given an inter-event dry time. This information will help determine the risk of failure.

Precipitation data have been analyzed in the past to determine the relationship between inter-event dry periods and precipitation volumes. These studies were for only 3 areas, including Baltimore Maryland, Tallahassee Florida and Odense Denmark (Hvitved-Jacobsen, Yousef, and Wanielista, 1988). There have been no analyses, prior to this research, extensively covering the State of Florida for the evaluation of precipitation and inter-event dry periods.

CHAPTER THREE

RAINFALL DATA AND STATION SELECTION

Historical Data

The findings of this research are directly related to the amount and accuracy of historical rainfall data available for the State of Florida and the National Climatic Data Center was the source of the hourly rainfall data. Meteorological information for approximately 50 stations in the State of Florida is collected, compiled, and published by the National Oceanic and Atmospheric Association. The data were obtained, for the purposes of this study, in digital format on Compact Disc-ROM through EarthInfo, Inc. of Boulder, Colorado, in a package called Climatedata. Complete hourly rainfall records for all National Oceanic and Atmospheric Association stations are included on the disc, along with the required processing and interaction software.

The availability of such a large amount of rainfall data on Compact Disc eliminated hours of manual input, along with the corresponding chance for human error. Through the use of Climatedata, rainfall data for each storm event for the desired station was transferred directly into a spreadsheet for manipulation. QUARTTRO-PRO (1991), a spreadsheet program from

Borland International, Inc., was used for the management and statistical analysis of the rainfall data. The use of computers for the retrieval, manipulation, and ultimate analysis of the very large databases minimized possibility for human error and increased the accuracy of this study.

Geographical Distribution

Rainfall stations were chosen based on geographical location, as well as the reliability and completeness of the data obtained. It was desired for the analysis to adequately encompass the State, and therefore stations selected were well distributed over the varying geographic regions. Invariably all of the stations experience some incompleteness with regard to data collection, possibly a result of either mechanical or power failure. The completeness of record is available through Climatedata (1988) and is represented by the percent coverage value which is a value equal to the number of days in which observations were reported divided by the number of all possible days of the record.

Based on the previously described criteria for selection of rainfall stations, seventeen stations were chosen for analysis. These stations are listed in Table 3-1 along with their percent coverage value. All of the stations selected exhibited a recovery of 92 percent or greater.

Fifteen years of data were used in the analysis of each station and evaluation of the most recent rainfall records was

Station	Mean Annual Rainfall (inches)		Coverage Value (%)
	Database* Record	Complete** Record	
Apalachicola	55.49	54.42	97
Daytona Beach	48.69	49.23	99
Fort Myers	50.55	52.82	95
Gainesville	43.23	52.32	92
Inglis	49.43	50.00	96
Jacksonville	48.85	51.95	97
Key West	38.51	40.24	95
Lakeland	49.58	48.94	98
Melbourne	40.82	46.15	94
Miami	54.51	57.60	97
Moore Haven	43.18	45.25	98
Niceville	65.69	60.36	93
Orlando	48.20	48.21	94
Parrish	51.01	52.00	92
Tallahassee	64.31	64.51	97
Tampa	44.56	46.30	95
West Palm Beach	61.51	60.91	99

* Most recently reported 15 years.
** Total number of years rain gauge was operational (greater than or equal to 15 years).

Table 3-1 Listing of Selected Rainfall Stations Used in Analysis and Rainfall Record Characteristics.

desired. Of the seventeen stations selected, Orlando was the only station which did not have a complete 15 year database. The Orlando rainfall station records began on May 1, 1974, and therefore the analysis is based on 176 months of data rather than the preferred 180 months.

The geographic distribution of the seventeen rainfall stations is shown in Figure 3-1. It is apparent that the selected rainfall stations are representative of the various regions in the State.

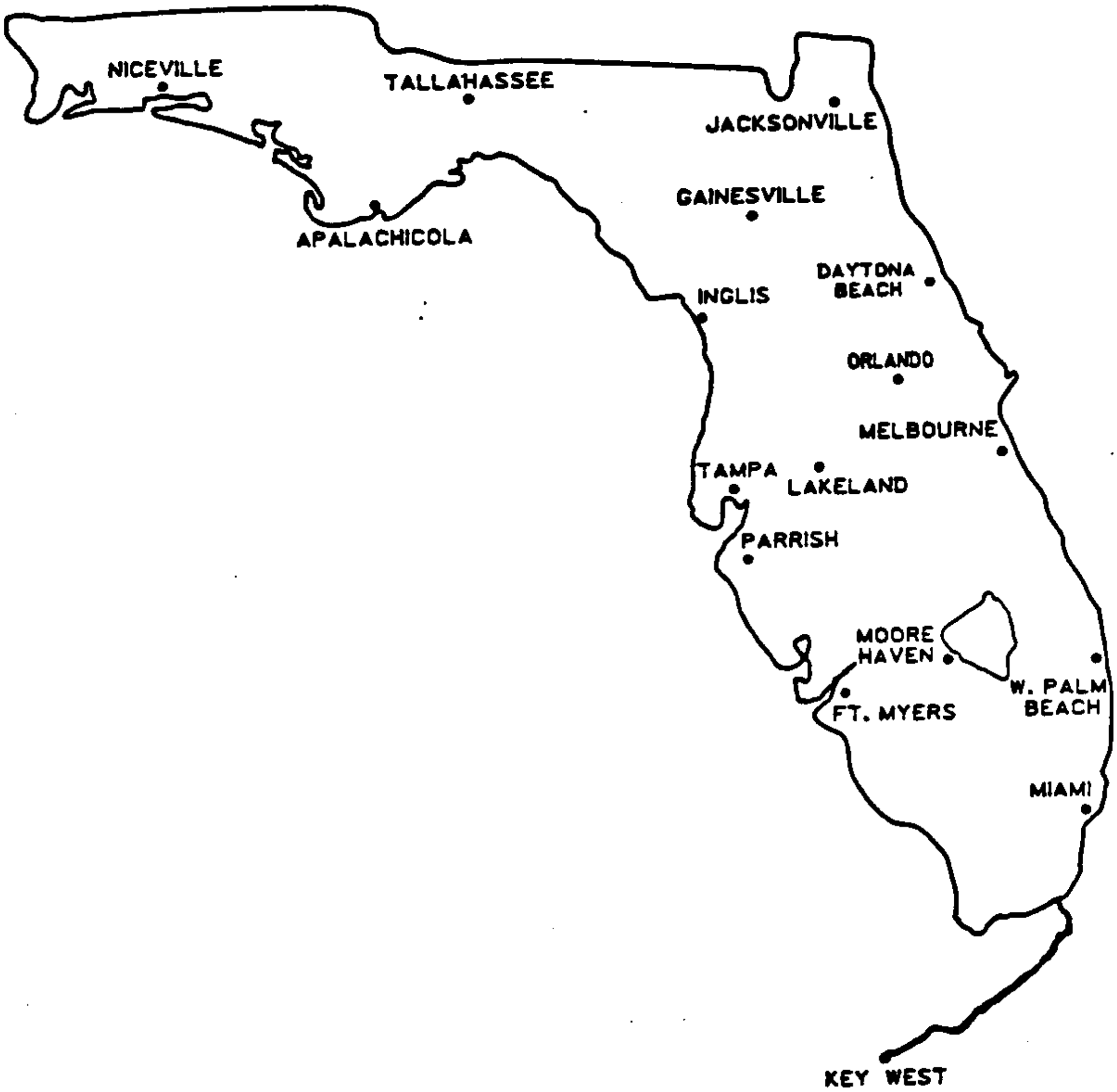

Figure 3-1 Geographic Location of the Seventeen Rainfall Stations Used in Analysis.

CHAPTER FOUR

DATA ANALYSES AND RESULTS

Introduction

A procedure to estimate rainfall volumes given an inter-event dry period and risk of failure is required. A conditional probability distribution is developed and the rainfall volume is obtained, from the distribution, as related to a risk of failure (exceedence probability).

For illustrative purposes, the Orlando Rainfall Station (94% recovery) has been selected as a model. The same procedure was used for the other rainfall data files. The Orlando Rainfall Station began operation on May 1, 1974, and therefore the statistical analysis, for this station only, is based on 176 months of data (typical is 180 months).

Selecting the Length of the Database

Subroutines and equations were written for the spreadsheet software QUATTRO PRO (1991) to combine hourly rainfall data readings and define storm events on the basis of inter-event dry period. The method is to "group" hourly precipitation readings into a set of separate "storm events" on the basis of an inter-event dry period. This technique generates an individual fifteen year rainfall record for each

specific inter-event dry period. The rainfall volume in a particular hour is assigned to an event in progress if it is less than the inter-event dry period from the previous reading, else it is recognized as the start of a subsequent independent event.

At first, two years of rainfall data were used and a frequency distribution was developed. Another year was added and the resulting frequency distribution was compared to the previous one using graphical means. Beyond five cumulative years, there was little graphical differences and thus another graphical comparison procedure was performed to determine the effects on the 72 Hour - 3 Month volume with additional years of data. This was done to determine how many years of data to use for the frequency distributions. The precipitation volume associated with a 72 hour inter-event dry period and a 3 month return period was determined for 6 years through 15 years of data, using the most recent record years. The 72 Hour - 3 Month Volume for Orlando is found in Figure 4-1. From this Figure, it is seen that the fluctuation in volume decreases as the number of years of data increase (a "leveling off effect" is demonstrated). This indicates that fifteen years of data should be adequate. This same result occurred for fifteen of the other rainfall stations, and the data used for the analysis of these stations represents rainfall records for the years 1974 through 1988.

Review of the 72 Hour - 3 Month Volumes for the Niceville

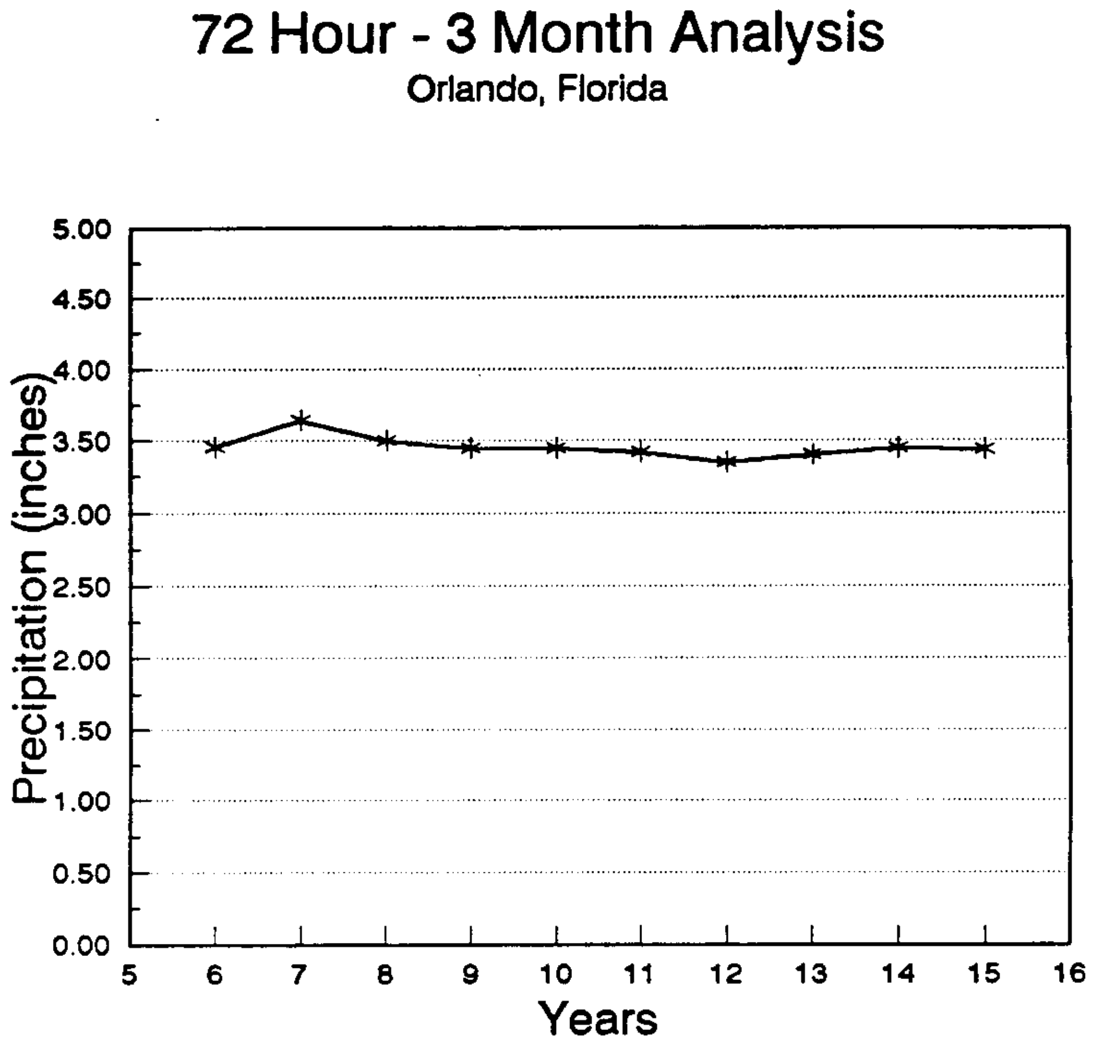

Figure 4-1 Sensitivity analysis for precipitation volume for a 72 hour Inter-event Dry Period and a 3 month Return Period for Orlando, as a function of the number of years of data.

Rainfall Station revealed significant oscillations from year to year with an upward trend in the volume as the number of years of data increased. Upon investigation, it was discovered that the rainfall record had considerable stretches of incomplete data for the years used in the analysis. For this case, the data was adjusted to include only complete years and substitutions of prior years were made. The final years used in the analysis were 1970, 1971, 1973-1981, and 1985-1988, inclusive. This fifteen year record was re-analyzed and produced acceptable results for the 72 Hour - 3 Month Analysis. Appendix A contains the 72 Hour - 3 Month graphical presentations for each rainfall station.

Procedure for Developing Frequency Distributions

Fifteen years of data were analyzed for each station and rainfall events were defined for inter-event dry periods of 4-hour, 12-hour, 24-hour, 48-hour, 72-hour, 96-hour, and 120-hour. A rainfall event associated with any inter-event dry period that had less than 0.04 inches of rainfall recorded was considered to not generate runoff, as was the case reported in the Orlando area (Stutler, 1989). Schueler (1987), reported no runoff from rainfalls less than 0.08 inches to 0.12 inches. The rainfall producing runoff will be variable from one location to another. Statistical information on precipitation volume and storm duration for the rainfall events, as a function of inter-event dry period, can be found in Appendix D and Appendix E of this report, respectively. The mean,

maximum, and minimum precipitation volumes for each inter-event dry period, as well as, the standard deviation, variance, coefficient of variation, and number of events used in analysis, can be found in Appendix D. The mean and maximum storm durations for each inter-event dry period, along with the standard deviation, variance, coefficient of variation and number of events analyzed, can be found in Appendix E.

The exponential distribution, a special case of the gamma distribution, results when the coefficient of variation is 1. Rainfall statistics for rainfall events separated by at least 4 dry hours can be represented by a gamma distribution (Hydroscience, 1979). The independence of storm events can be indicated by a coefficient of variation of about 1 (Driscoll, 1989). The duration tables in Appendix E show a coefficient of variation very near 1 for an inter-event dry period of 4-hours indicating the independence of this parameter, however for other minimum inter-event dry periods, the coefficient is greater than one.

For a design exceedence level, the precipitation volume for a specific return period is determined from the exceedence probability distributions (Wanielista, 1990):

$$Pr(P>P_T) = 1-F(P_T|\Delta) = 1-\sum Pr(P|\Delta) \qquad (13)$$

where: P = precipitation volume, depth
P_T= design precipitation volume, depth
Δ = inter-event dry period, time

Using the exceedence probability distribution allows the direct calculation of the return period for which a specific

precipitation volume can be expected to exceed. The recurrence interval, or return period, is the inverse of the exceedence probability, or (Wanielista, 1990):

$$T_r = \frac{\frac{M}{N}}{1 - P_r(X \le x)} \tag{14}$$

where: T_r = return period, months
$Pr(X \le x)$ = probability of occurrences
M = number of months in the record
N = number of rainfall events

The exceedence probability distribution for a 4-hour inter-event dry period and the associated return periods for the Orlando Rainfall Station are shown in Table 4-1. For the purpose of generating the **P-I-F** curves, precipitation volumes for return periods of 2-month, 3-month, 4-month, and 6-month were determined from the exceedence probability analysis using linear interpolation when required (refer to Table 4-1). The **P-I-F** curves found in Appendix B were created for each of the seventeen rainfall stations using the previously described procedure. The **P-I-F** curve for Orlando is shown in Figure 4-2. Precipitation volumes can be read directly from the **P-I-F** curves for a desired inter-event dry period and return period.

The number and percentage of yearly storms exceeding the precipitation volume which is associated with a specific return period and inter-event dry period has been tabulated in Appendix F and is shown for the Orlando Rainfall Station in Table 4-2. These percentages are calculated using the number of storms per year from Appendix D. For a 4-hour inter-event

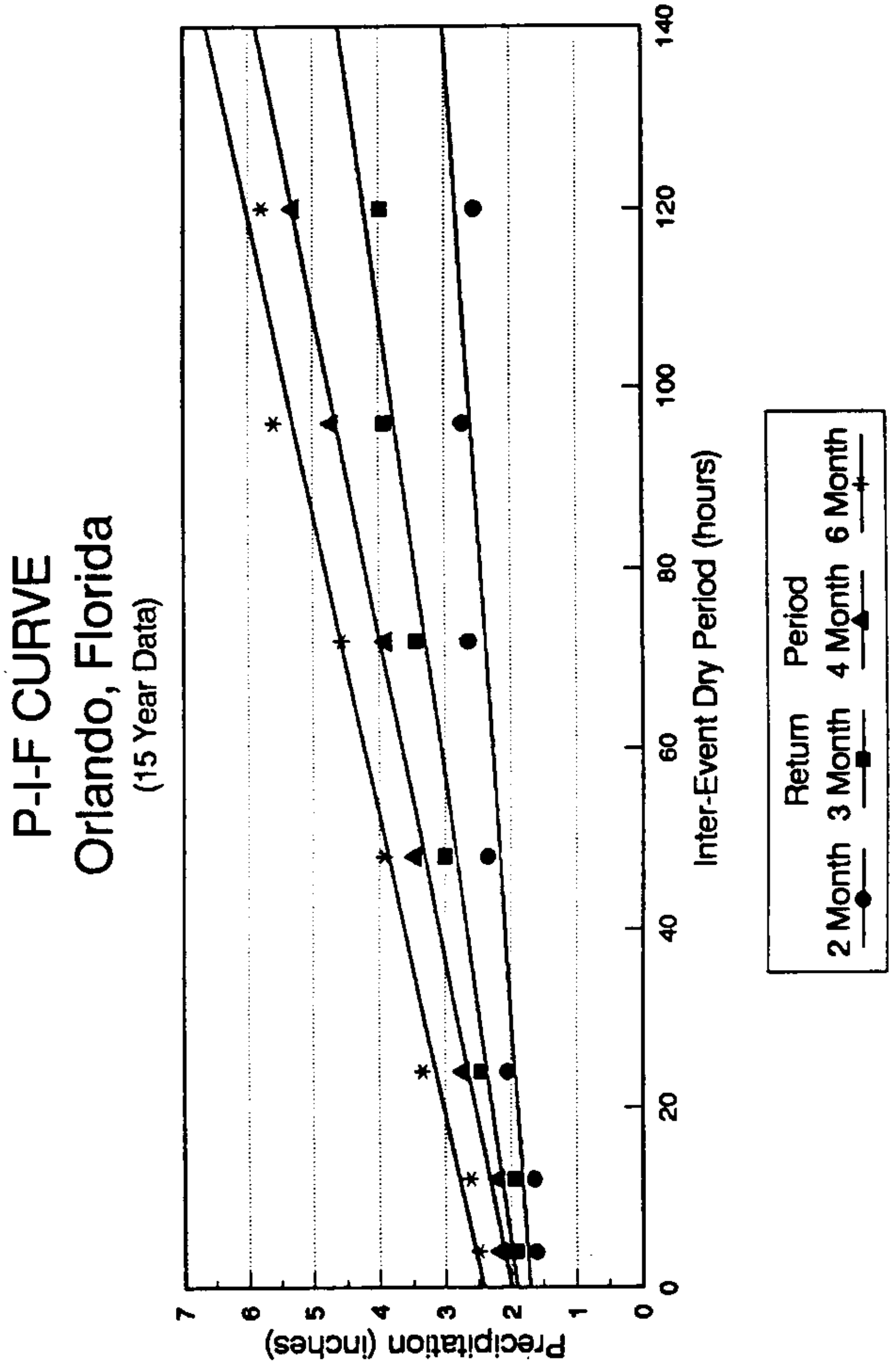

Figure 4-2 P-I-F Curve For Orlando, Florida.

P (in.)	X	X/N	Sum X/N	$(1-P_r)$[b]	T_r(mo.)[c]
0	0	0.0000	0.0000	1.0000	******
1.50	[a]1350	0.9323	0.9323	0.0677	1.7959
1.55	5	0.0035	0.9358	0.0642	1.8925
1.60	4	0.0028	0.9385	0.0615	1.9775
1.65	6	0.0041	0.9427	0.0573	2.1205
1.70	9	0.0062	0.9489	0.0511	2.3784
1.75	6	0.0041	0.9530	0.0470	2.5882
1.80	3	0.0021	0.9551	0.0449	2.7077
1.85	4	0.0028	0.9579	0.0421	2.8852
1.90	0	0.0000	0.9579	0.0421	2.8852
1.95	5	0.0035	0.9613	0.0387	3.1429
2.00	5	0.0035	0.9648	0.0352	3.4510
2.10	6	0.0041	0.9689	0.0311	3.9111
2.20	4	0.0028	0.9717	0.0283	4.2927
2.30	2	0.0014	0.9731	0.0269	4.5128
2.40	6	0.0041	0.9772	0.0228	5.3333
2.50	4	0.0028	0.9800	0.0200	6.0690
>2.50	29	0.0200	1.0000	0.0000	******
N=	1448				

Return Period	Precipitation (inches)
2 Month	1.61
3 Month	1.92
4 Month	2.15
6 Month	2.48

[a] X = number of rainfall events in the interval 0 to 1.50 i
[b] $(1 - P_r) = 1 - \text{Sum}(X / N)$
[c] T_r = (176 months / 1448 storms) / $(1 - P_r)$

Table 4-1 Exceedence Probability and Return Peri
Calculations For Orlando, Florida; Using 176 Mont
Of Data And An Inter-Event Dry Period of 4 Hours

Return Period (Months)		2	3	4	6
Number Per Year Exceeding		6	4	3	2
4 Hour Δ	Orlando	6.1	4.1	3.0	2.0
	Statewide	6.4	4.2	3.2	3.1
12 Hour Δ	Orlando	6.8	4.5	3.4	2.3
	Statewide	7.6	5.1	3.8	2.5
24 Hour Δ	Orlando	9.8	6.5	4.9	3.3
	Statewide	10.2	6.8	5.1	3.4
48 Hour Δ	Orlando	13.6	9.0	6.8	4.5
	Statewide	13.9	9.3	6.9	4.6
72 Hour Δ	Orlando	17.5	11.7	8.8	5.8
	Statewide	17.1	11.8	8.9	5.9
96 Hour Δ	Orlando	23.0	15.3	11.5	7.7
	Statewide	22.5	15.0	11.2	7.5
120 Hour Δ	Orlando	27.6	18.4	13.8	9.2
	Statewide	27.9	18.6	14.0	9.3

Note: The percentage of storm events with cumulative volume less than or equal to the design volume given a minimum inter-event dry period is equal to 100 minus the percentage exceeding.

Table 4-2 Percentage Of Yearly Storms Exceeding The Precipitation Volume Associated With A Given Return Period And Inter-Event Dry Period For Orlando, Florida, and the Statewide Florida average.

dry period and 2 month return period, the percent of storms exceeding equals 6 / 96.53 * 100 % = 6.2 %. This information can be particularly useful when special considerations must be given to discharges made to environmentally sensitive receiving water bodies. For example, a design which would be exceeded (fail) three times annually, with proper treatment achieved at least 90 percent of the time, would correspond to a precipitation volume representative of a 72 hour inter-event dry period and a 4 month return period for the Orlando Rainfall Station.

Sensitivity Analysis for Type of Rain Gauge

There are two types of rain gauges in use at the seventeen rainfall stations. Ten of the stations utilize the Universal Rain Gauge, which yields precipitation readings to a hundredth of an inch accuracy. The remaining seven stations operate a Fisher-Porter Rain Gauge, which records rainfall data to one-tenth of an inch precision. An analysis was performed to discover if there was a significant difference in the results obtained from the varying degrees of accuracy. Three stations participated in this analysis; Daytona Beach, Jacksonville, and Orlando. The rainfall data from these stations, which was recorded in hundredths of an inch, was rounded to tenths of an inch. This eliminated rainfall events which did not total 0.10 inches for an inter-event dry period of 4-hours. The exceedence probability distribution was executed and the precipitation volumes were determined for

each specified inter-event dry period and return period. The results for the Orlando Rainfall Station are displayed in Table 4-3. A percent difference was calculated as a comparison, and when comparing the two rain gauge types, the Universal Rain Gauge usually yields a more conservative or greater value. Therefore, it is concluded that the results should reflect data that are as accurate as the instruments will allow. The sensitivity analysis for rain gauge accuracy for the three station sites tested are found in Appendix G of this report.

Inter-Event Dry Periods

The inter-event dry period characteristics of each of the rainfall stations analyzed showed several degrees of variance. For rainfall events with a minimum dry period of 4 hours between successive readings, statistical information including the mean, standard deviation, variance, coefficient of variation, and number of events used in analysis, were determined for inter-event dry periods at each rainfall station. The results of this analysis are shown in Table 4-4. The average inter-event dry periods range from 70 hours to 114 hours. The station with the most diverse inter-event dry periods is Key West, which could be expected as a result of the varying influence of the island's surrounding waters.

Water quality enhancement is achieved in wet detention ponds through sedimentation, chemical interactions, and biological processes. Stormwater detention for a period of 24

I/E Dry Period	Minimum Storm Reading For Gauge And Percent Difference	Mean Precipitation (in.) For Return Periods (Mo.)			
		2	3	4	6
4 Hour	0.04 / Universal	1.61	1.92	2.15	2.48
	0.10 / Fisher-Porter	1.61	1.89	2.15	2.48
	% Difference	0.00	1.56	0.00	0.00
12 Hour	0.04 / Universal	1.64	1.94	2.18	2.61
	0.10 / Fisher-Porter	1.64	1.94	2.17	2.58
	% Difference	0.00	0.00	0.46	1.15
24 Hour	0.04 / Universal	2.05	2.46	2.72	3.34
	0.10 / Fisher-Porter	2.02	2.43	2.67	3.18
	% Difference	1.46	1.22	1.84	4.79
48 Hour	0.04 / Universal	2.34	3.00	3.45	3.92
	0.10 / Fisher-Porter	2.20	2.72	3.20	3.74
	% Difference	5.98	9.33	7.25	4.59
72 Hour	0.04 / Universal	2.63	3.44	3.90	4.57
	0.10 / Fisher-Porter	2.48	3.24	3.76	4.37
	% Difference	5.70	5.81	3.59	4.38
96 Hour	0.04 / Universal	2.72	3.91	4.70	5.59
	0.10 / Fisher-Porter	2.72	3.76	4.20	5.17
	% Difference	0.00	3.84	10.64	7.51
120 Hour	0.04 / Universal	2.54	3.98	5.30	5.79
	0.10 / Fisher-Porter	2.70	3.98	5.00	5.87
	% Difference	-6.30	0.00	5.66	-1.38

Table 4-3 Sensitivity Analysis For Rain Gauge Accuracy For Orlando, Florida

Station	Mean (Hrs.)	Standard Deviation	Variance	Coeff. of Var.	Count
Apalachicola	94.44	123.26	15192.6	1.31	1311
Daytona	89.74	114.11	13021.7	1.27	1384
Ft. Myers	91.89	167.39	28019.1	1.82	1386
Gainesville	97.14	178.77	31958.7	1.84	1305
Inglis	94.16	164.50	27061.4	1.75	1342
Jacksonville	88.35	106.16	11270.6	1.20	1400
Key West	113.72	512.82	262987.7	4.51	1265
Lakeland	85.10	125.38	15721.1	1.47	1480
Melbourne	95.99	144.22	20798.7	1.50	1326
Miami	70.33	108.83	11844.7	1.55	1768
Moore Haven	99.74	151.88	23069.0	1.52	1261
Niceville	84.70	246.65	60838.5	2.91	1576
Orlando	84.50	113.51	12885.3	1.34	1450
Parrish	85.31	120.25	14459.6	1.41	1465
Tallahassee	85.08	104.46	10911.9	1.23	1451
Tampa	96.29	130.55	17044.0	1.36	1301
West Palm	70.82	95.63	9145.1	1.35	1749

Table 4-4 Inter-Event Dry Period Statistics For Each Rainfall Station Using A Minimum 4-Hour Dry Period Between Successive Storms.

hours or more may result in greater than 90 percent removal of suspended solids and associated pollutants carried by runoff water (Gizzard et al., 1986). Removal of soluble fractions, colloidal fractions and small size suspended solids concentrations in urban runoff may be improved by increasing detention times in a wet detention pond (Yousef et at., 1985 and Hartigan and Quasebarth, 1985). A recent study using model detention ponds (Yousef, 1988) concluded that a minimum detention time of at least 72 hours is needed to remove more than 95 percent of suspended solids and 30 to 70 percent of nutrients and heavy metals. Therefore, it may be desirable to design these ponds based on an inter-event dry period consistent with desired pollutant removal effectiveness. If design storm events are based on a minimum of 72 or 96 hour inter-event dry period, sufficient time may be available for treatment of runoff events (Hvitved-Jacobsen, Yousef, and Wanielista, 1988). A minimum inter-event dry period of 72 hours has been specified as a time period during which the majority of contaminants are removed by natural purification in wet detention ponds (Wanielista, Yousef, and Harper, 1990).

Using P-I-F Curves in Design

Utilizing the procedure detailed in Chapter Two of this report to determine the Equivalent Impervious Area (EIA), the P-I-F curves can be employed to determine the volume of storage required for water quality enhancement, treatment volume. The precipitation volume for the desired inter-event

dry period and return period is read from the P-I-F curve and multiplied by the EIA to calculate the volume required for treatment.

$$\textit{Treatment Volume} = \frac{(EIA \times P)}{12} \qquad (15)$$

where: Treatment Volume = storage volume, acre feet
EIA = equivalent impervious area, acres
P = precipitation volume, inches
12 = conversion factor, inches/foot

For Orlando, Florida, a 72 Hour - 3 Month design storm will have a precipitation volume of 3.4 inches (Figure 4-2). A pond with a watershed consisting of an equivalent impervious area of 5 acres would have a treatment volume of 1.42 acre feet. The linear lines of Figure 4-2 were developed using linear regression and represent trend lines as the relationship between rainfall event volume and inter-event dry periods.

CHAPTER FIVE

DIVERSION VOLUME ANALYSIS

Methodology And Criteria

Retention facilities built in accordance with Chapter 17-25, Florida Administrative Code, must have the capacity to store and infiltrate either the runoff from the first inch of rainfall or (a minimum of) the first one-half inch of runoff with 72 hours. Small watershed areas (100 acres or less) are only required by the Department of Environmental Regulation to provide for the minimum first one-half inch level of retention (F.D.E.R., 1988). The use of a off-line retention facility for the diversion of the treatment volume is usually controlled by hydraulic techniques, thus requiring no electrical energy. Since retention depends on soil and cover infiltration rates, testing must be performed at the site in the vicinity of the pond to determine infiltration rates and the location of the water table.

The Florida Department of Environmental Regulation ha reported, for fixed diversion volumes, estimated averag yearly pollutant removal efficiencies considering first flus conditions (small watersheds). The diversion efficiencies t achieve desired treatment levels are shown in Table 5-1 These efficiencies were developed for a 4.6 acre commercia

area that was 83% impervious by M.P. Wanielista (1977) and reported by the East Central Florida Regional Planning Council (1983). From Table 5-1, for a small watershed, a design diversion depth of 0.5 inches should divert 90 percent of the average annual runoff mass of pollutants.

% Efficiency / Retention	Diversion Depth[a]
99	1.25
97	1.00
95	0.75
90	0.50
80	0.25

[a] For a 100 % impervious watershed

Table 5-1 Efficiency Percent Vs. Retention Volume (F.D.E.R., 1988)

For larger projects with a runoff coefficient greater than 0.5, the storage volume would be calculated using Equation 16 (F.D.E.R., 1988, pg. 6-207).

$$V_m = \frac{CAP}{12} \tag{16}$$

where: V_m = required volume of basin (ac-ft)
C = rational runoff coefficient (dimensionless)
A = contributing drainage area (ac.)
P = total rainfall (in.)
12 = constant for inches/foot

To meet State Stormwater Rule requirements, the value of P is equal to one inch.

In reference to the above described criteria, the Florida

Department of Environmental Regulation makes the following statement: "The two sizing procedures discussed above are simplistic, easy to use procedures. They provide the engineer with the minimum basin volume that is required to satisfy the intentions of state stormwater treatment standards. However, it should be noted that the procedures were developed quite sometime ago (1977-1978) during the initial phases of the state nonpoint source pollution control program. The initial evaluation of pollutant removal efficiency and diversion volume required to achieve water quality objectives was based primarily on statistical analyses of rainfall event magnitude and duration. The results, summarized and illustrated in Table 6-11, (Table 5-1), were viewed as a first indication that high efficiencies of pollutant removal were possible by diversion and retention of the first one-half inch of runoff or the runoff from the first inch of rainfall." (F.D.E.R., 1988, pg. 6-207).

It should be further noted that the original field measurements of water quantity and quality data were done on a diversion pond with an average infiltration rate of 8 to 10 inches per hour with a maximum pond depth of 2.5 feet. Thus, the pond would infiltrate the stored maximum volume in about four hours, or less. Therefore, an inter-event dry period of 4 hours, or less, would be sufficient to insure the pond was empty before the beginning of the next rainfall event. The efficiencies, as reported, were specific for short inter-event

dry periods and first flush events.

The Florida Department of Environment Regulation also employs an additional technique for the determination of diversion storage volumes for 80 and 90 percent efficiency. These equations, termed the Wanielista Design Equations, were developed based on water quality and quantity research actually conducted in the field subsequent to the adoption of the previously described criteria (East Central Florida Regional Planning Council, 1983). These design equations were developed for shallow basins (less than or equal to 5 feet) and are suitable to estimate storage volumes needed to achieve 80 to 90 percent pollutant removal for a wider range of watershed sizes and conditions (F.D.E.R., 1988, pg. 6-208).

For Type A Soils:

80% Efficiency = $V_I = 0.016\ A^{1.28}$ for impervious watershed

90% Efficiency = $V_I = 0.046\ A^{1.18}$ for impervious watershed

$V_5 = V_I\ (0.59 + 0.37\ CN / 100)$ for composite land use

where: A = watershed area (acres)
V_I = storage volume for impervious watershed and a 5 foot deep pond (acre feet)
V_5 = storage volume at a depth of 5 feet (acre feet)
CN = composite curve number

The watershed areas used to develop these equations were between 2 and 500 acres. Other equations are used to adjust volumes when the pond diversion volume is less than 5 feet.

A high degree of treatment can be ensured by simply diverting the corresponding percentage of runoff, however this

criteria is only valid to the extent that all storms equal to or less than the diverted amount will be stored and treated (infiltrated). A number of factors including the method of calculating runoff, antecedent moisture conditions, the infiltration rate, the time variability between rainfall events, the size of the watershed and the depth of the basin (deeper basins require a longer time to recover) affect the actual treatment efficiency and thus the storage volume required for a basin to actually achieve 80 percent treatment (F.D.E.R., 1988, Chapter 6). The inter-event dry period has not been considered in the current regulations, but will be evaluated in this work as it affects diversion volume given an annual removal efficiency.

Calculation of the Diversion Volume

A cumulative distribution function was generated from the fifteen year database for inter-event rainfall records of 4-hour, 24-hour, and 72-hour, at each rainfall station to develop diversion volume curves. Equation (17) is the basic equation for the diversion volume analysis (Wanielista,1990, pg. 340).

$$F(Vol.|DiversionVol.) = \sum_{i=0}^{DiversionVol.} P(i)_i \overline{x_i} n + \sum_{i=DiversionVol.}^{\infty} P(i)_i \, DiversionVol.\, n \quad (17)$$

where: $\bar{x}$ = average precipitation for interval
Vol. = volume of rainfall per year
n = number of events in interval
P(i) = frequency of the event interval
Diversion Volume = maximum volume diverted per storm event (in.)

An example calculations format for a diversion volume analysis using the Orlando Rainfall Station is shown in Table 5-2. An illustrative example of the calculations used to determine the percent of average yearly volume diverted for the first several precipitation volumes is as follows:

1) 19.8 + 0.10 (1448 - 396) = 125
125 / 695.3 * 100% = 18 %

2) 62.4 + 0.20 (1448 - 396 - 284) = 216
216 / 695.3 * 100% = 31.1 %

3) 95.7 + 0.30 (1448 - 396 - 284 - 133) = 286.2
286.2 / 695.3 * 100% = 41.2 %

These mathematical manipulations are performed quickly and effortlessly through the use of a microcomputer and spreadsheet software. QUATTRO PRO (1991) was used to perform the necessary mathematics in this analysis. The diversion volume is the sum of rainfall up to the diversion volume plus the sum of the diversion volume and the frequency of exceedence. From Table 5-2, an off-line system which diverts 1.00 inch of rainfall over the watershed area in the Orlando Region has an efficiency of 78.3 percent (about 80 percent) for a 4-hour inter-event dry period.

Prec.	n_i	$\bar{x}_i$	Sum n_i	$n_i*\bar{x}_i$	Sum $n_i*\bar{x}_i$	Vol. (in.)	Vol. (%)
0.10	396	0.05	396	19.8	19.8	125.0	18.0
0.20	284	0.15	680	42.6	62.4	216.0	31.1
0.30	133	0.25	813	33.3	95.7	286.2	41.2
0.40	107	0.35	920	37.5	133.1	344.3	49.5
0.50	93	0.45	1013	41.9	175.0	392.5	56.4
0.60	70	0.55	1083	38.5	213.5	432.5	62.2
0.70	46	0.65	1129	29.9	243.4	466.7	67.1
0.80	43	0.75	1172	32.3	275.6	496.4	71.4
0.90	36	0.85	1208	30.6	306.2	522.2	75.1
1.00	36	0.95	1244	34.2	340.4	544.4	78.3
1.10	35	1.05	1279	36.8	377.2	563.1	81.0
1.20	23	1.15	1302	26.5	403.6	578.8	83.2
1.30	18	1.25	1320	22.5	426.1	592.5	85.2
1.40	13	1.35	1333	17.6	443.7	604.7	87.0
1.50	17	1.45	1350	24.7	468.3	615.3	88.5
2.00	47	1.75	1397	82.3	550.6	652.6	93.9
2.50	22	2.25	1419	49.5	600.1	672.6	96.7
3.00	11	2.75	1430	30.3	630.3	684.3	98.4
3.50	8	3.25	1438	26.0	656.3	691.3	99.4
4.00	4	3.75	1442	15.0	671.3	695.3	100.0
>4.00	6	4	1448	24.0	695.3	695.3	100.0
	1448						

Table 5-2 Example Diversion Volume Calculations For Orlando, Florida (15 Years of Data, 4 Hour Inter-Event Dry Period).

Diversion Volumes As A Basis For Infiltration Pond Design

Diversion Volume Curves have been generated using the previously described technique for the seventeen rainfall stations in this study. The curves are representative of 4-hour, 24-hour, and 72-hour inter-event dry periods (and can be found in Appendix C of this report. The diversion volume method of water quality treatment is directed specifically towards use in off-line retention systems. The desired efficiency of pollutant removal is assured through the diversion of the corresponding precipitation volume into the retention basin for infiltration. The inter-event dry period selected for the design diversion volume should correspond to the anticipated recovery time for the retention system.

To determine the storage volume for the infiltration pond, a runoff coefficient representative of the watershed area is used with Equation (16). The value of R = 1.00 inch, as currently specified by the Florida Department of Environmental Regulation, would now be a variable precipitation volume which is determined from the Diversion Volume Curves (rather than a constant value).

Example Problem

A 120 acre watershed, in the Orlando area, with a runoff coefficient of 0.5 must have an off-line retention pond to control 80 % of the average annual pollution mass in the runoff water. The off-line retention site has a limiting infiltration rate of 0.21 ft/hour and a 5 foot deep basin is

established for design. Therefore, an inter-event dry period of 24 hours would be appropriate (5 feet / 0.21 feet per hour = 24 hours). Based on the size of the watershed (>100 Acres) and moderate amount of impervious area, a first flush probably does not exist, thus Figure 5-1 diversion volume curve can be used. For 80 percent efficiency and a 24-hour inter-event dry period, the diversion volume is 1.6 inches (Figure 5-1) from the equivalent impervious area . The storage volume of the pond is calculated by Equation (16) to be 8 acre-feet.

Use of Diversion Volume Curves

The effect of any "first flush" events is not considere in the Diversion Volume Curves. A constant concentration o pollutants in the runoff for each storm event is assumed i this analysis. If a "first flush" effect does exist, th design would be conservative in that the percent efficiency o the system would be increased for the removal of pollutant

An off-line retention system incorporating the use o Diversion Volume Curves would be cost effective for wat quality control of large watersheds with a minimum first flu effect. The infiltration systems may also be used to redu the volume of stormwater discharge and thus may meet t intent of the State Stormwater Policy for reuse. In additio off-line stormwater management systems may be designed sediment control, chemical treatment using alum, or selec filtration material to remove solids and dissolved materia

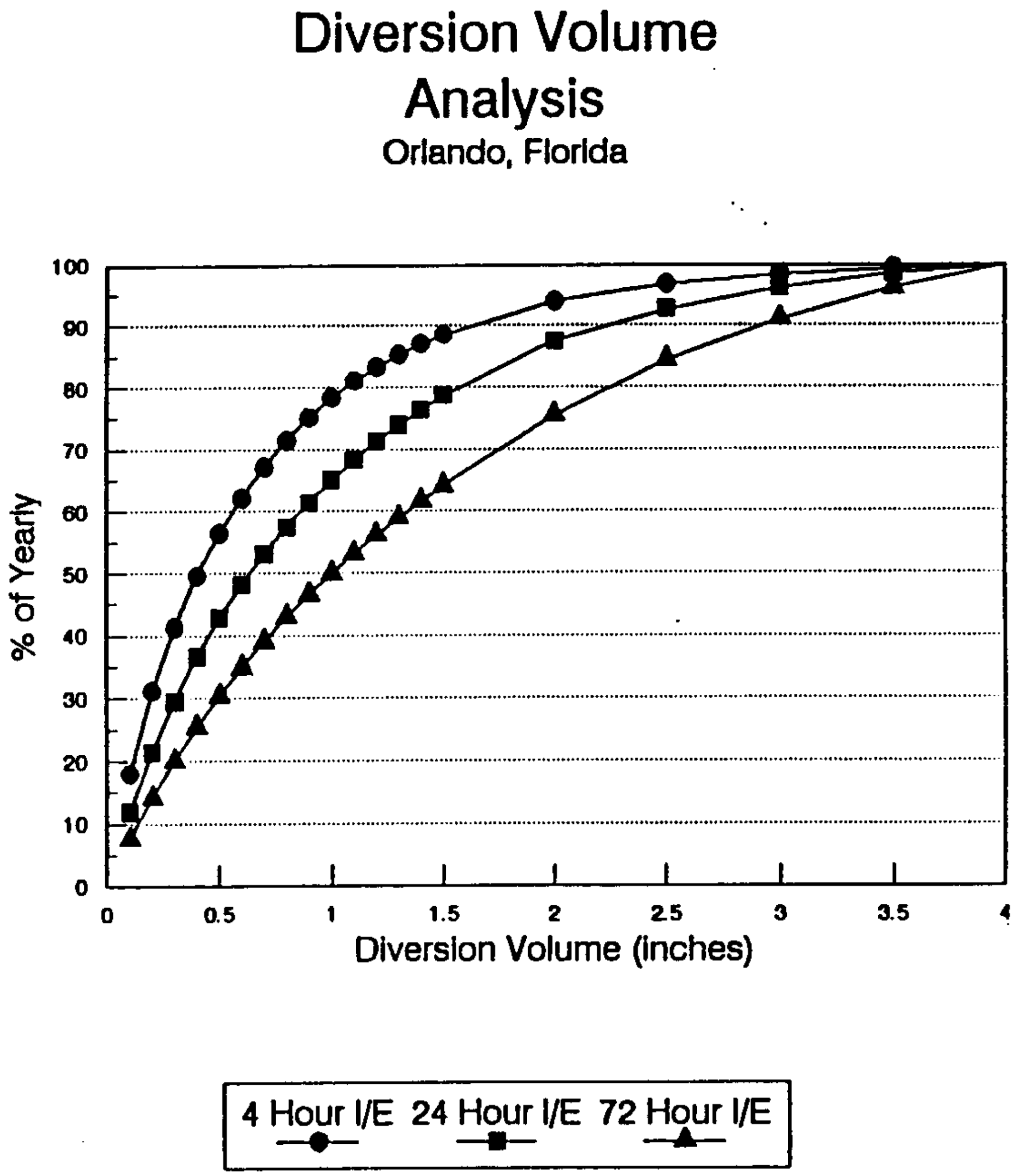

Figure 5-1 Percentage of Yearly Volume Diverted for Treatment based on 15 Years of Data for Orlando, Florida.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Overview

This work is based on the use of a minimum inter-event dry period which is the minimum time of no rainfall between two rainfall events. It is proposed to use a minimum inter-event dry period as a basis for the design of stormwater management systems for water quality control. The inter-event dry period allows for the consideration of wet detention times for pollutant removal, as well as, the recovery time for systems designed for infiltration, chemical treatment, sediment control, or off-line retention. Use of the inter-event dry period in design gives the designer the ability to achieve varying levels of water quality improvement based on individual system detention or process times.

Conditional frequency distributions on rainfall volumes given a minimum inter-event dry period were developed for 17 regions in Florida. For specifed exceedence frequencies (levels of risk), curves were developed that relate precipitation volume to minimum inter-event dry periods, and were called Precipitation - Inter-event Dry Period - Frequency curves, or P-I-F curves.

Geographic Variability of P-I-F Curves

The P-I-F Curves can be used to determine treatment volumes for watersheds of various sizes and land uses by utilizing the runoff coefficient along with precipitation volumes that correspond to specific inter-event dry periods and exceedence frequencies. As is inherent with all design, there exists a risk of failure associated with that design.

The mean volumes for the 4-hour, 12-hour, 24-hour, 72-hour, and 120-hour inter-event dry periods, and three month return periods are shown in Table 6-1 for each geographic region in Florida. This comparison shows a standard deviation from the mean precipitation volume, for the statewide results, ranging from 0.2 inches to 0.5 inches. This low deviation indicates that it would be conceivable for a statewide rule to be set forth and applied to each region of the state.

Based on the results from each site, the 72 Hour - 3 Month precipitation volume has an average exceedence of 11.8 percent. This means that, based on a statewide average, utilization of the P-I-F curves will achieve the desired level of treatment approximately 90 percent of the time for a design based on the 72 Hour - 3 Month precipitation volume.

Geographic Variability of Diversion Volume Curves

A comparison of the precipitation volumes associated with average annual diversion volumes of 80 percent and 90 percent are shown in Table 6-2 and Table 6-3, respectively. Each region analyzed, for both 80 percent and 90 percent diversion

volumes, had only a 0.1 inch standard deviation from the statewide mean volume associated with each inter-event dry period. This demonstrated a close correlation in the percent of annual diverted volume, inter-event dry period, and the associated precipitation volume for each rainfall station throughout the State. Furthermore, the comparison of these results, strengthens the concept that statewide criteria could be developed based on this research.

Geographic Variability of Statistical Data

The geographic variability in average volume and duration data for the 4-hour and 72-hour minimum inter-event dry periods are shown in Table 6-5. For the 4-hour minimum inter-event dry period, the statewide mean precipitation volume is 0.53 inches and the corresponding storm duration is 3.9 hours. The statewide mean precipitation volume for the 72-hour minimum inter-event dry period is 1.48 inches with a mean storm duration of 57.3 hours.

Recommendations

Based on a comparison of this study's data and findings, it can be concluded that the geographic variability throughout the State is minimal. If state-wide design volumes are required for practical application based on this research, it is recommended that the average of all geographic locations be used.

Region	Minimum Inter-Event Dry Period (Hours)				
	4	12	24	72	120
Apalachicola	1.8	2.0	2.2	2.6	3.2
Daytona Beach	1.7	1.8	2.0	2.5	2.8
Fort Myers	2.0	2.1	2.2	2.4	2.5
Gainesville	1.4	1.5	1.8	2.2	2.5
Inglis	1.7	1.9	2.1	2.4	2.6
Jacksonville	1.7	1.7	2.0	2.6	3.0
Key West	1.3	1.5	1.6	1.8	2.0
Lakeland	1.7	1.8	2.0	2.4	2.5
Melbourne	1.3	1.5	1.7	2.1	2.3
Miami	1.7	1.9	2.0	2.6	2.9
Moore Haven	1.5	1.6	1.8	1.9	2.0
Niceville	2.1	2.3	2.5	3.1	3.6
Orlando	1.6	1.7	2.0	2.5	2.8
Parrish	1.8	1.9	2.0	2.3	2.5
Tallahassee	2.1	2.2	2.5	3.3	3.9
Tampa	1.5	1.6	1.9	2.0	2.2
West Palm Beach	2.1	2.2	2.5	3.0	3.3
Comparison of Precipitation Volumes (inches)					
Minimum	1.3	1.5	1.6	1.8	2.0
Maximum	2.1	2.3	2.5	3.3	3.9
Average	1.7	1.8	2.0	2.5	2.7
Standard Deviation	0.3	0.3	0.3	0.4	0.5

Table 6-1 Comparison of *Precipitation Volumes (inches) By Geographic Regions For Selected Minimum Inter-Event Dry Periods And Two-Month Return Periods.

* From Trend Lines In Appendix B

Region	Minimum Inter-Event Dry Period (Hours)				
	4	12	24	72	120
Apalachicola	2.2	2.3	2.5	3.4	4.2
Daytona Beach	2.2	2.3	2.5	3.4	4.1
Fort Myers	2.2	2.3	2.6	3.4	4.3
Gainesville	1.8	2.0	2.2	2.9	3.6
Inglis	2.2	2.3	2.6	3.4	4.1
Jacksonville	2.1	2.2	2.4	3.2	3.9
Key West	1.8	1.9	2.0	2.4	3.0
Lakeland	2.1	2.2	2.4	3.0	3.8
Melbourne	1.8	1.9	2.1	2.9	3.6
Miami	2.2	2.3	2.5	3.4	4.2
Moore Haven	1.9	2.0	2.2	2.9	3.4
Niceville	2.3	2.6	2.9	4.0	5.0
Orlando	2.0	2.1	2.4	3.4	4.2
Parrish	2.1	2.2	2.5	3.3	4.1
Tallahassee	2.5	2.6	3.0	4.0	5.0
Tampa	1.9	2.0	2.1	2.8	3.4
West Palm Beach	2.4	2.5	3.0	4.0	5.0
Comparison of Precipitation Volumes (inches)					
Minimum	1.8	1.9	2.0	2.4	3.0
Maximum	2.5	2.6	3.0	4.0	5.0
Average	2.1	2.2	2.5	3.3	4.0
Standard Deviation	0.2	0.2	0.3	0.4	0.5

Table 6-2 Comparison of *Precipitation Volumes (inches) By Geographic Regions For Selected Minimum Inter-Event Dry Periods And Three-Month Return Periods.

* From Trend Lines In Appendix B

Region	Minimum Inter-Event Dry Period (hours)		
	4	24	72
Apalachicola	1.3	1.7	2.2
Daytona Beach	1.2	1.7	2.2
Fort Myers	1.2	1.8	2.5
Gainesville	1.1	1.5	2.1
Inglis	1.3	1.8	2.3
Jacksonville	1.1	1.6	2.1
Key West	1.1	1.5	2.0
Lakeland	1.1	1.6	2.2
Melbourne	1.1	1.6	2.2
Miami	1.1	1.7	2.4
Moore Haven	1.1	1.6	2.2
Niceville	1.3	1.9	2.4
Orlando	1.1	1.6	2.3
Parrish	1.1	1.6	2.3
Tallahassee	1.3	1.8	2.3
Tampa	1.1	1.5	2.2
West Palm Beach	1.3	1.8	2.4
Comparison Of 80 Percent Diversion Volumes (inches)			
Minimum	1.1	1.5	2.0
Maximum	1.3	1.9	2.5
Average	1.2	1.7	2.3
Standard Deviation	0.1	0.1	0.1

Table 6-3 Comparison Of 80 Percent *Diversion Volumes (inches) By Geographic Regions For Selected Minimum Inter-Event Dry Periods And Three-Month Return Periods.

* From Curves In Appendix C

Region	Minimum Inter-Event Dry Period (hours)		
	4	24	72
Apalachicola	2.0	2.4	2.9
Daytona Beach	1.8	2.5	2.9
Fort Myers	1.8	2.5	3.1
Gainesville	1.7	2.1	2.8
Inglis	1.8	2.5	3.0
Jacksonville	1.8	2.3	2.8
Key West	1.8	2.3	2.8
Lakeland	1.7	2.3	3.0
Melbourne	1.7	2.3	2.9
Miami	1.7	2.5	3.1
Moore Haven	1.6	2.3	2.9
Niceville	2.0	2.5	3.0
Orlando	1.6	2.2	2.9
Parrish	1.6	2.3	3.0
Tallahassee	2.0	2.5	3.0
Tampa	1.6	2.1	2.9
West Palm Beach	2.0	2.5	3.0
Comparison Of 90 Percent Diversion Volumes (inches)			
Minimum	1.6	2.1	2.8
Maximum	2.0	2.5	3.1
Average	1.8	2.4	2.9
Standard Deviation	0.1	0.1	0.1

Table 6-4 Comparison Of 90 Percent *Diversion Volumes (inches) By Geographic Regions For Selected Minimum Inter-Event Dry Periods And Three-Month Return Periods.

* From Curves in Appendix C

Region	4-Hour Minimum Inter-Event Dry Period		72-Hour Minimum Inter-Event Dry Period	
	Mean Volume (inches)	Mean Duration (hours)	Mean Volume (inches)	Mean Duration (hours)
Apalachicola	0.63	5.5	1.54	49.9
Daytona Beach	0.53	4.8	1.34	51.0
Fort Myers	0.54	2.6	1.82	70.3
Gainesville	0.50	2.9	1.34	51.8
Inglis	0.55	3.0	1.45	47.2
Jacksonville	0.52	5.3	1.34	56.7
Key West	0.45	3.8	1.13	45.8
Lakeland	0.50	3.1	1.52	61.3
Melbourne	0.46	2.7	1.25	46.5
Miami	0.46	3.9	1.71	83.1
Moore Haven	0.49	4.1	1.35	58.4
Niceville	0.62	3.8	1.70	51.7
Orlando	0.49	4.1	1.41	64.0
Parrish	0.52	2.6	1.49	55.6
Tallahassee	0.67	5.2	1.74	56.5
Tampa	0.54	4.4	1.32	54.7
West Palm Beach	0.53	4.3	1.71	68.9
Average	0.53	3.9	1.48	57.3

Table 6-5 Comparison of Rainfall Statistics For 4-Hour and 72-Hour Minimum Inter-Event Dry Periods By Geographic Region.

APPENDIX A

LENGTH OF DATA ANALYSIS

72 Hour - 3 Month Analysis

Apalachicola, Florida

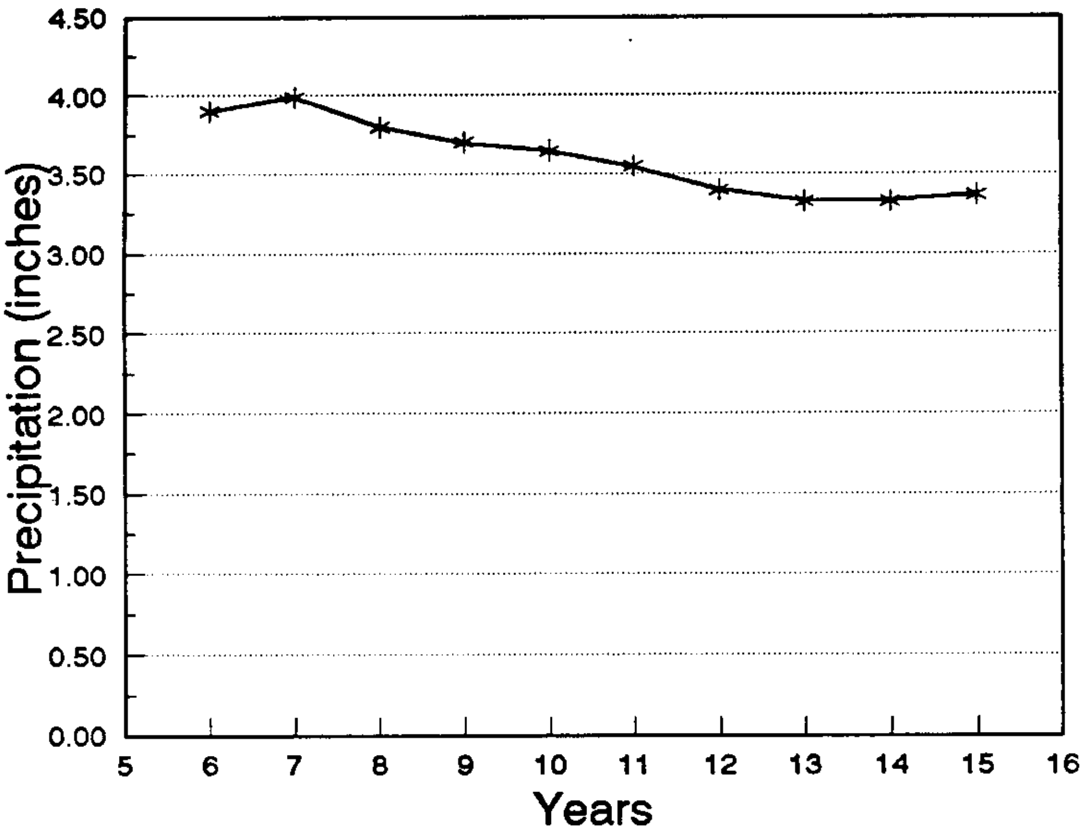

Figure A.1
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Apalachicola as a function of the number of years of data.

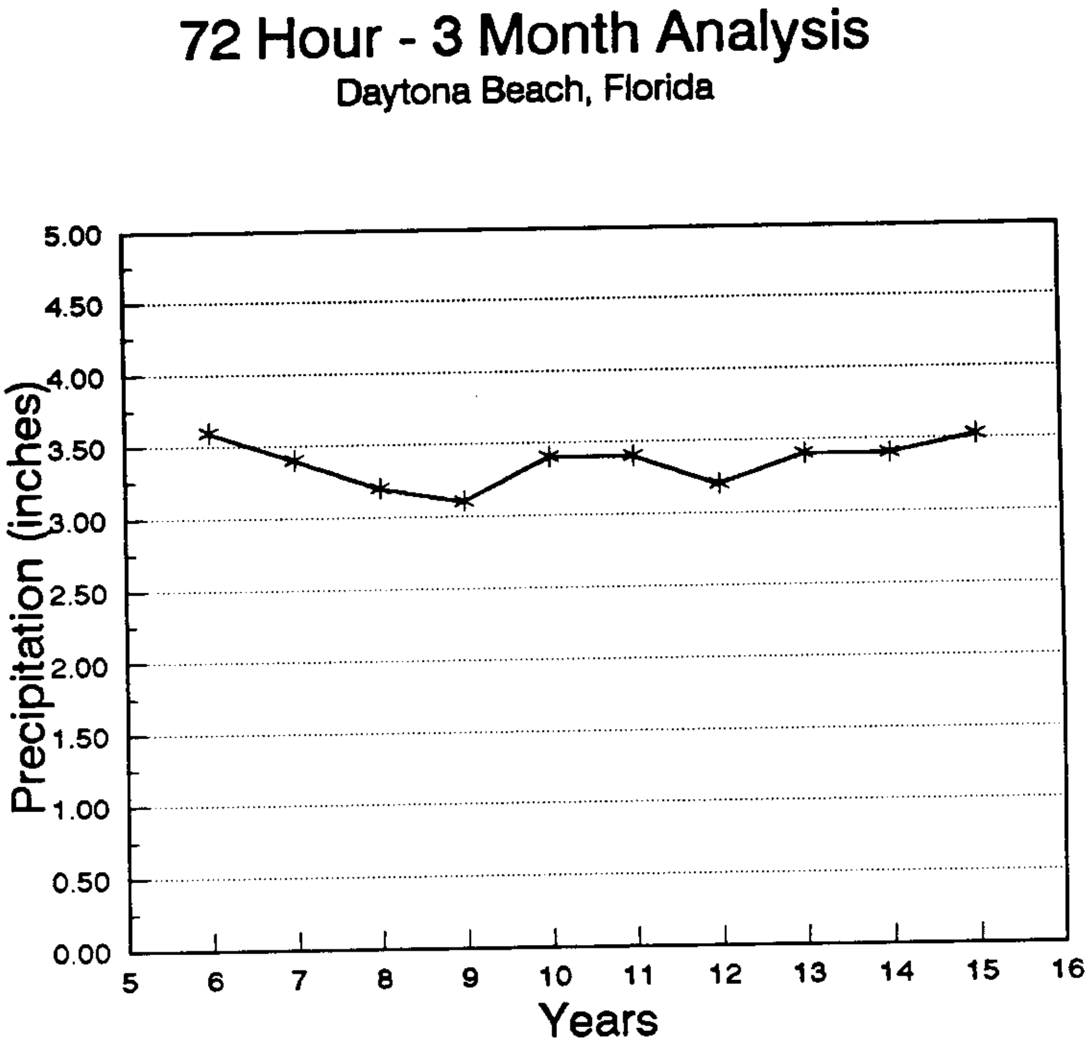

Figure A.2
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Daytona Beach as a function of the number of years of data.

72 Hour - 3 Month Analysis
Ft. Myers, Florida

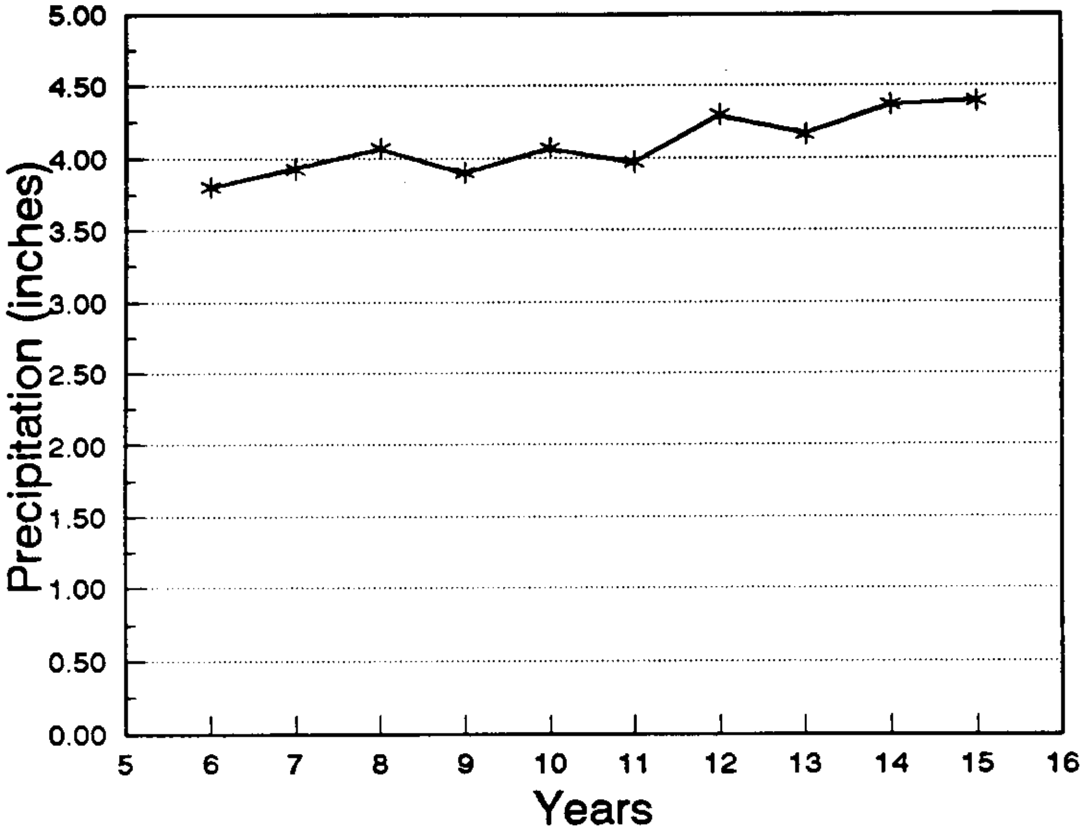

Figure A.3
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Ft. Myers as a function of the number of years of data.

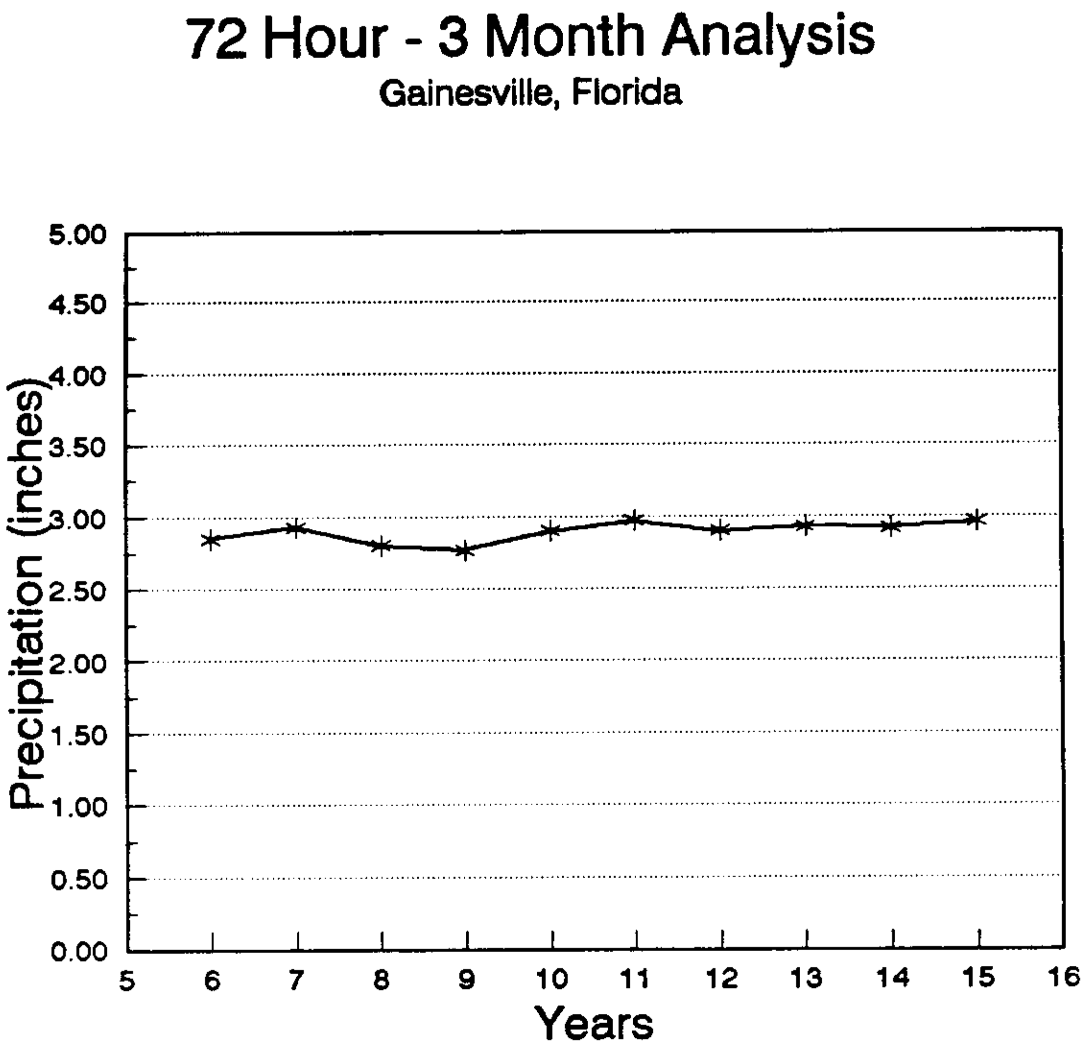

Figure A.4
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Gainesville as a function of the number of years of data.

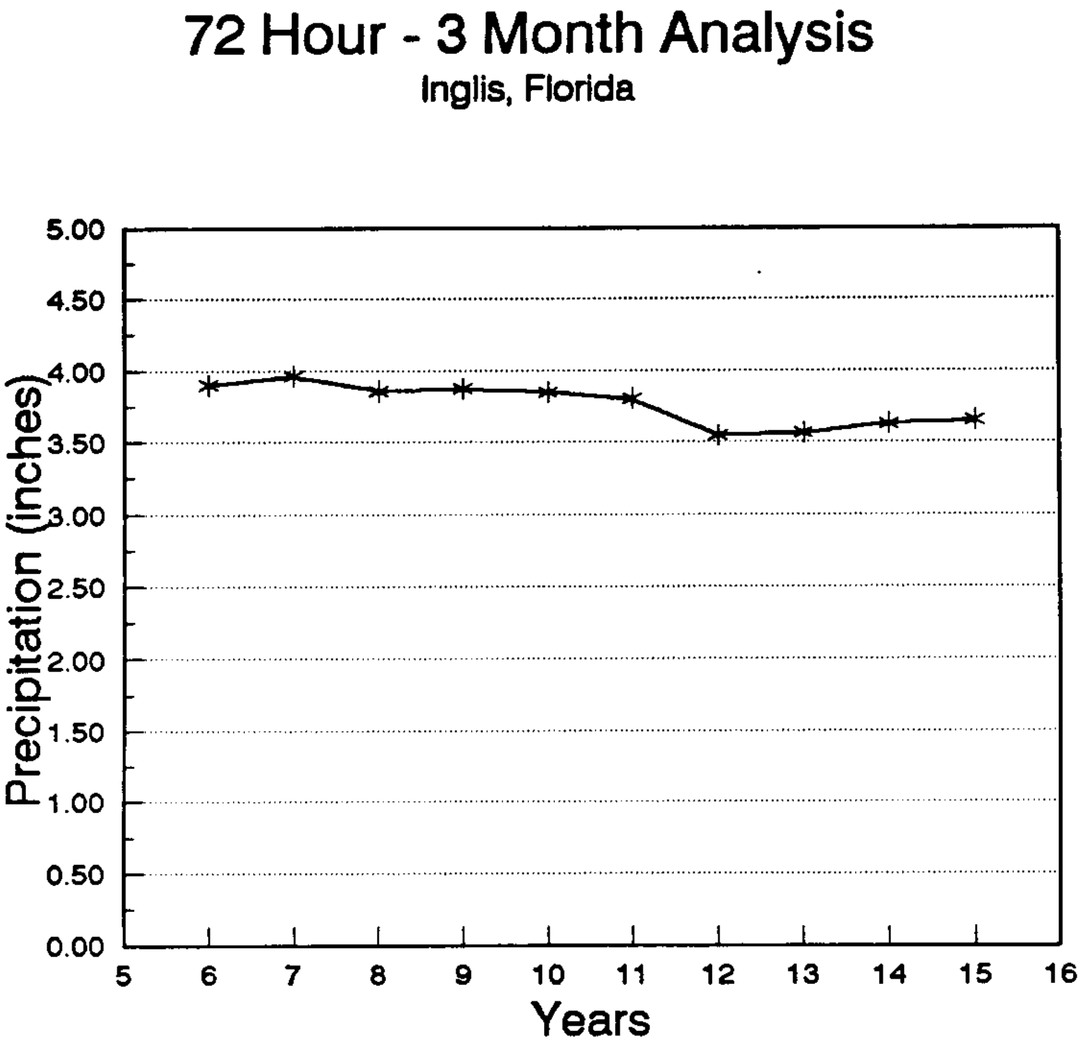

Figure A.5
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Inglis as a function of the number of years of data.

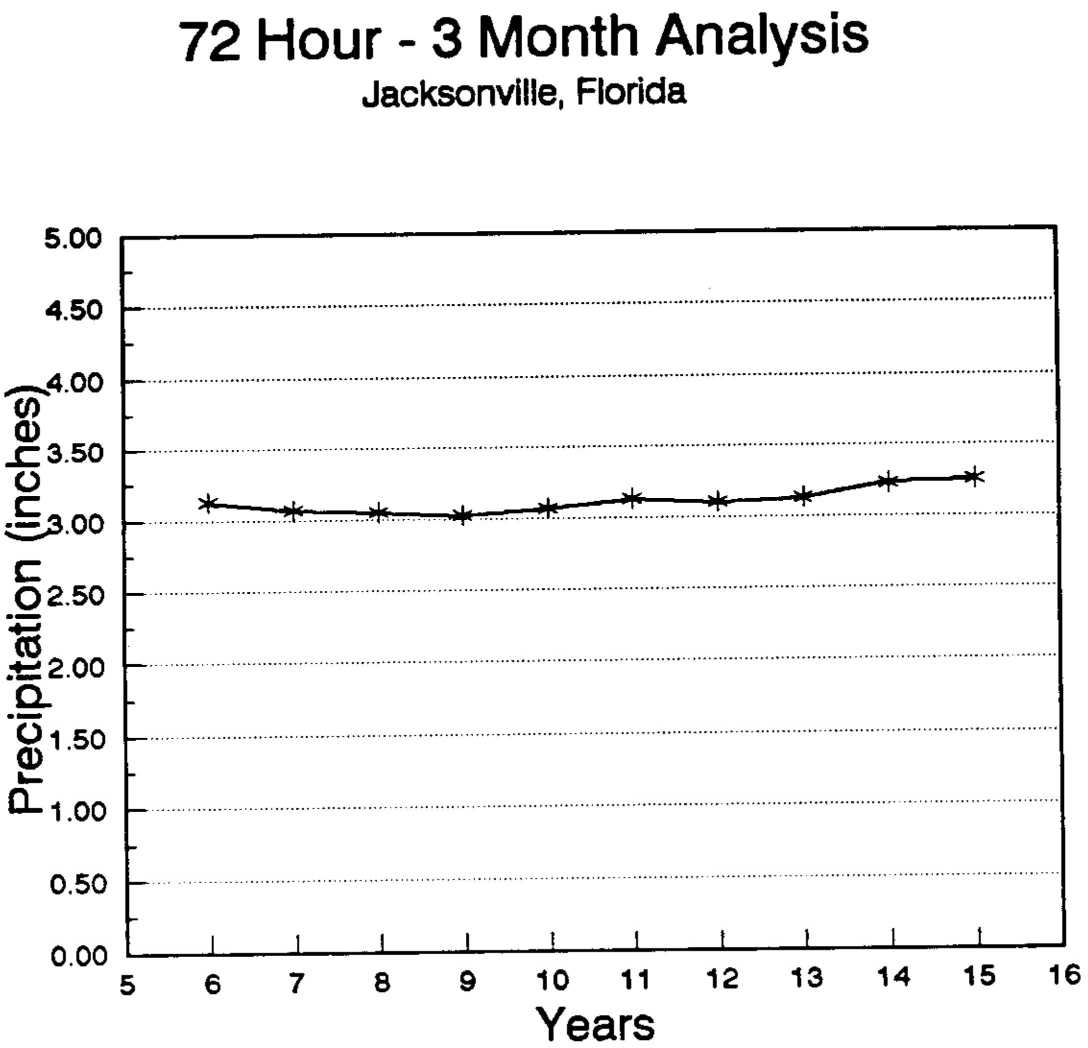

Figure A.6
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Jacksonville as a function of the number of years of data.

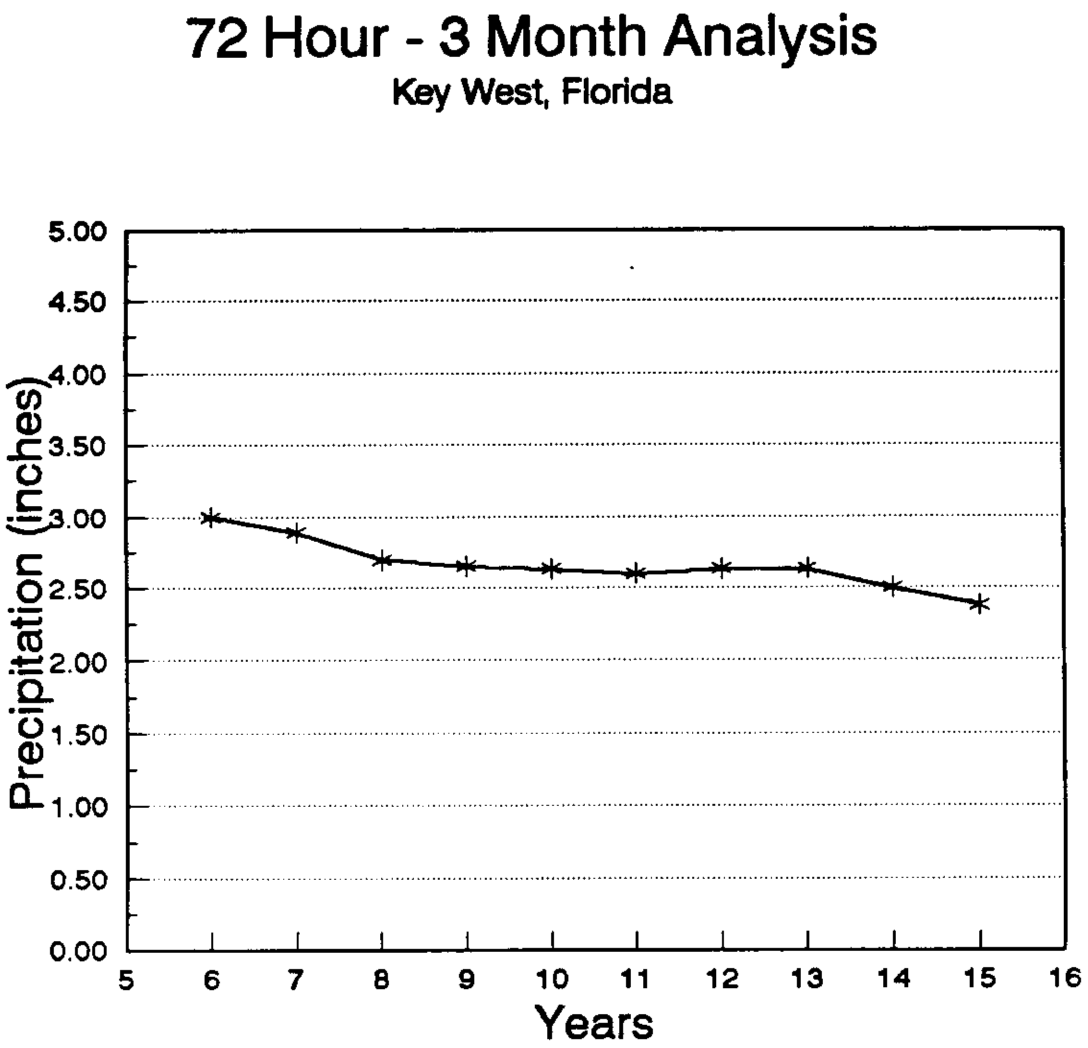

Figure A.7
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Key West as a function of the number of years of data.

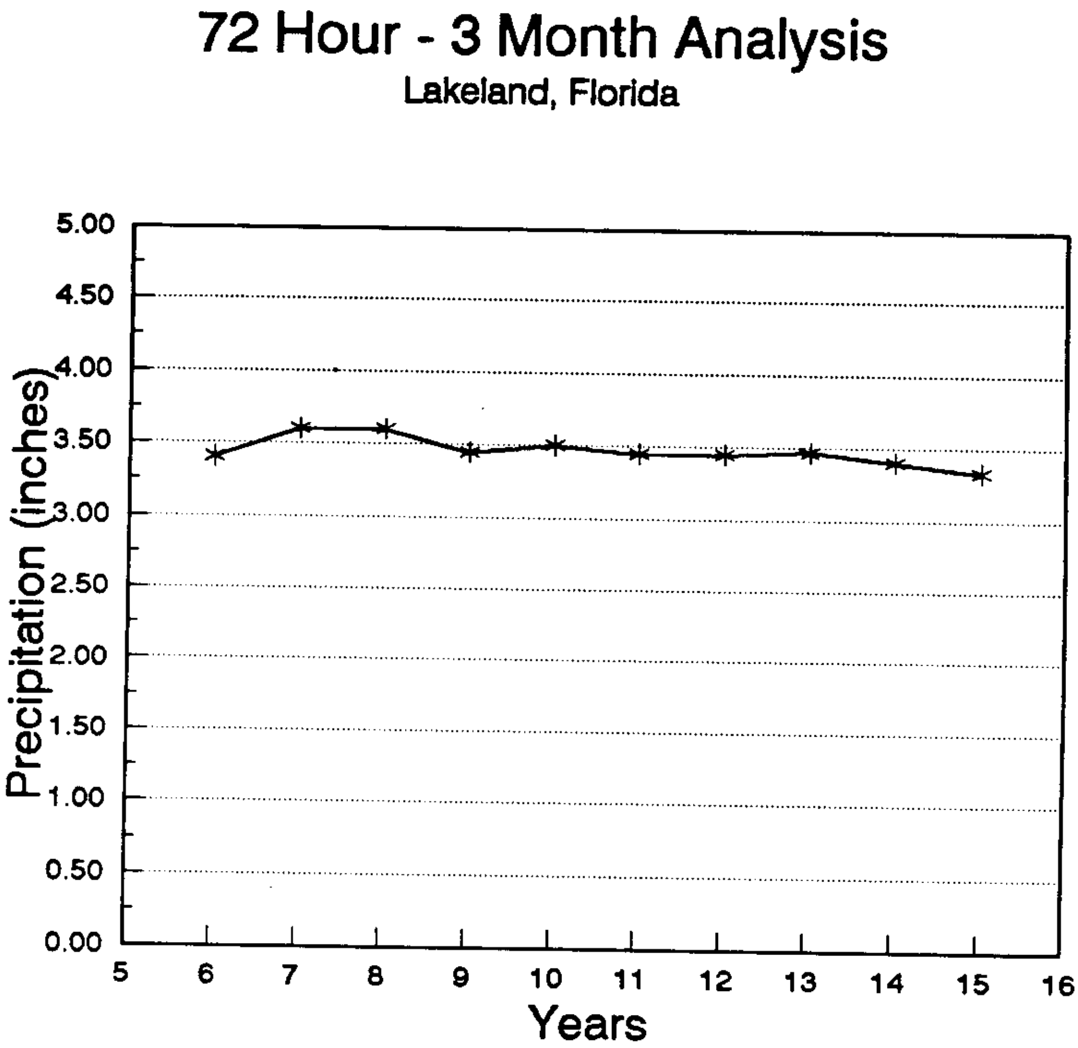

Figure A.8
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Lakeland as a function of the number of years of data.

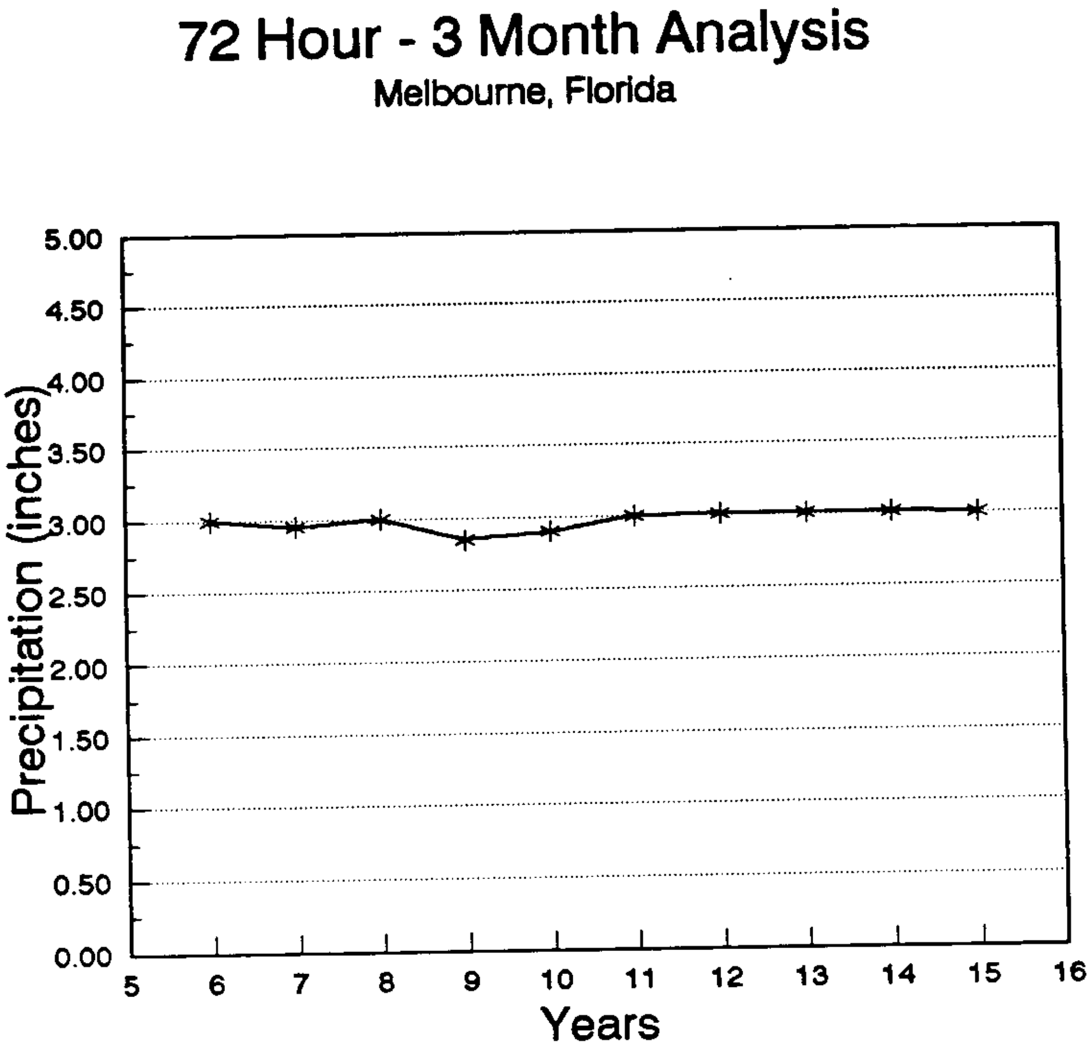

Figure A.9
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Melbourne as a function of the number of years of data.

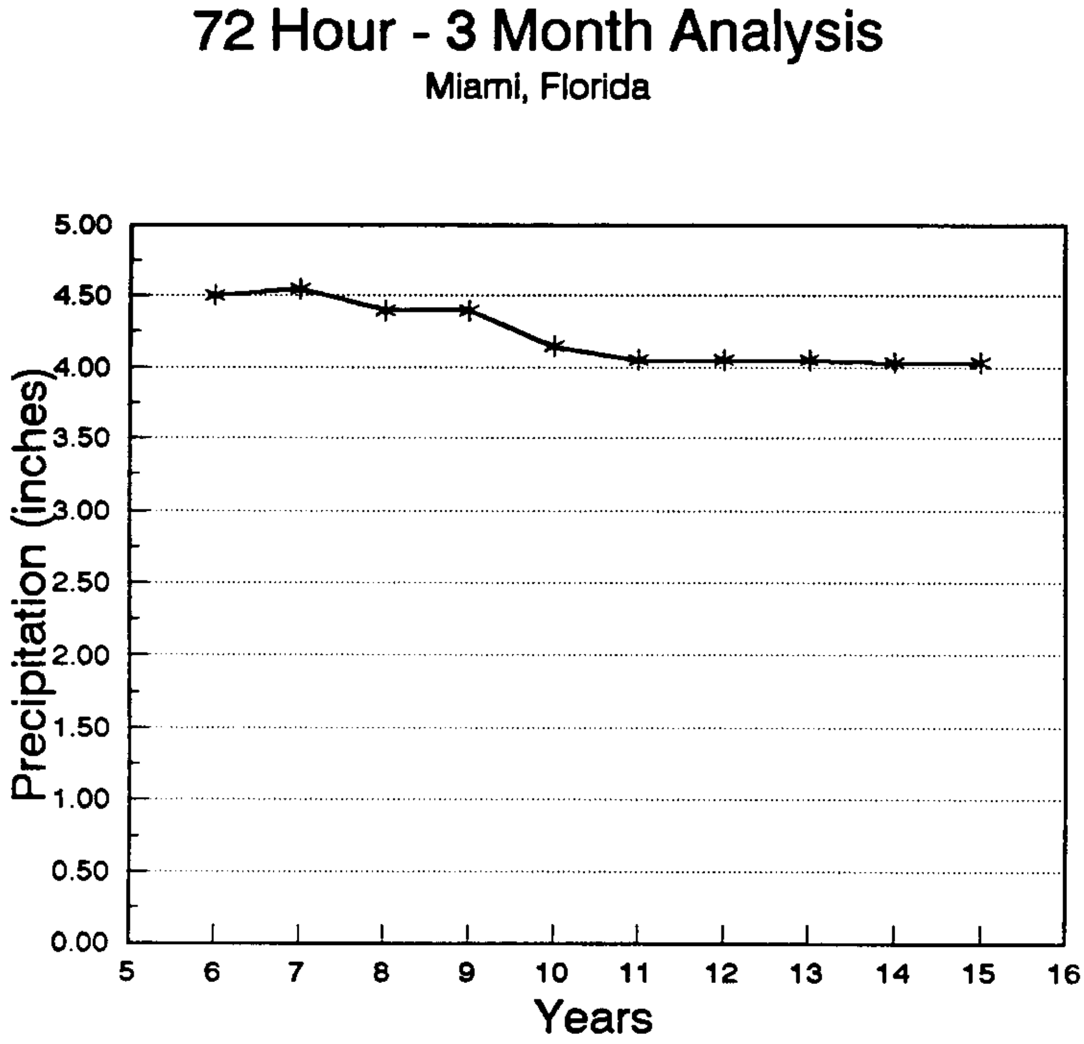

Figure A.10
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Miami as a function of the number of years of data.

72 Hour - 3 Month Analysis

Moore Haven, Florida

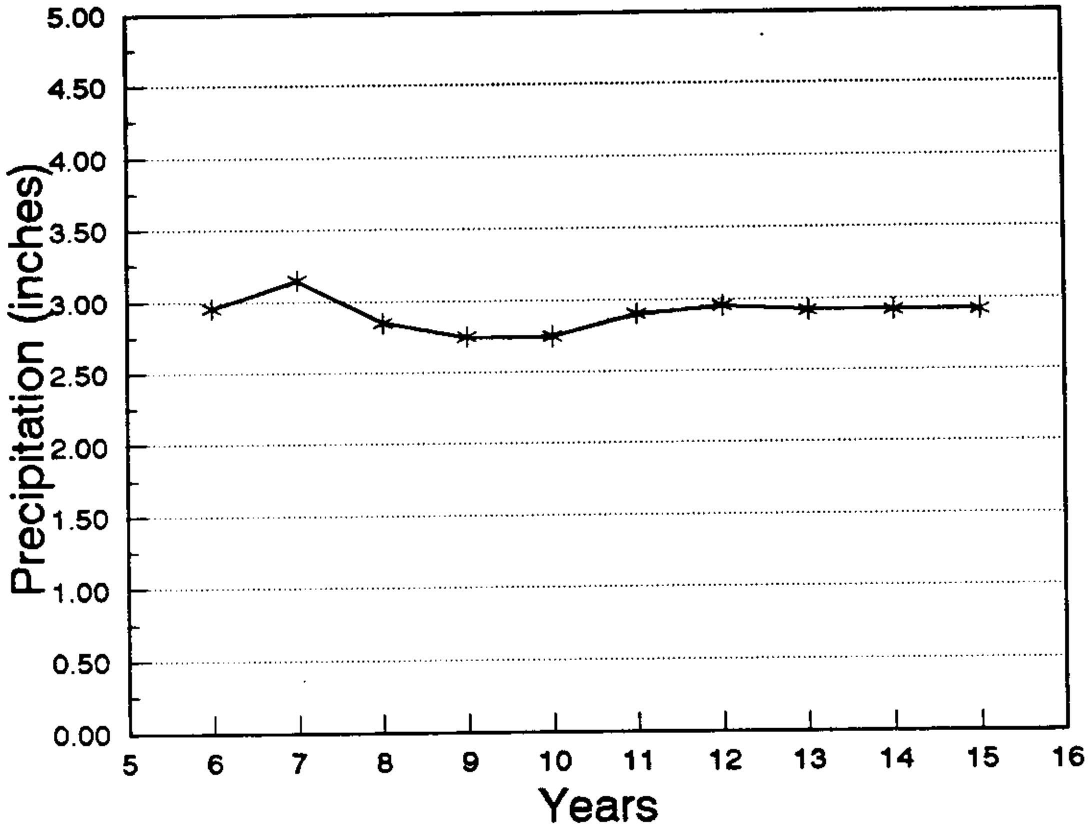

Figure A.11
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Moore Haven as a function of the number of years of data.

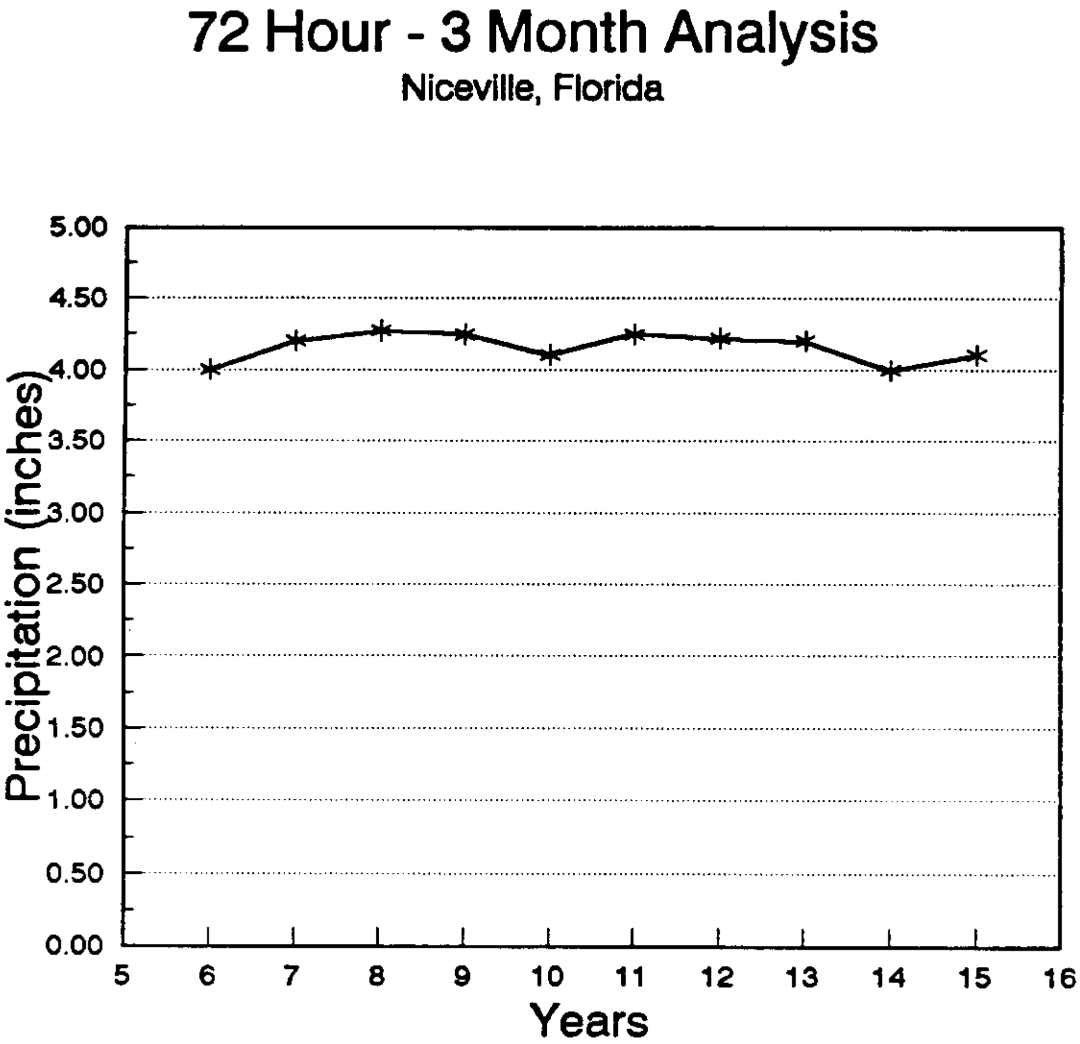

Figure A.12
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Niceville as a function of the number of years of data.

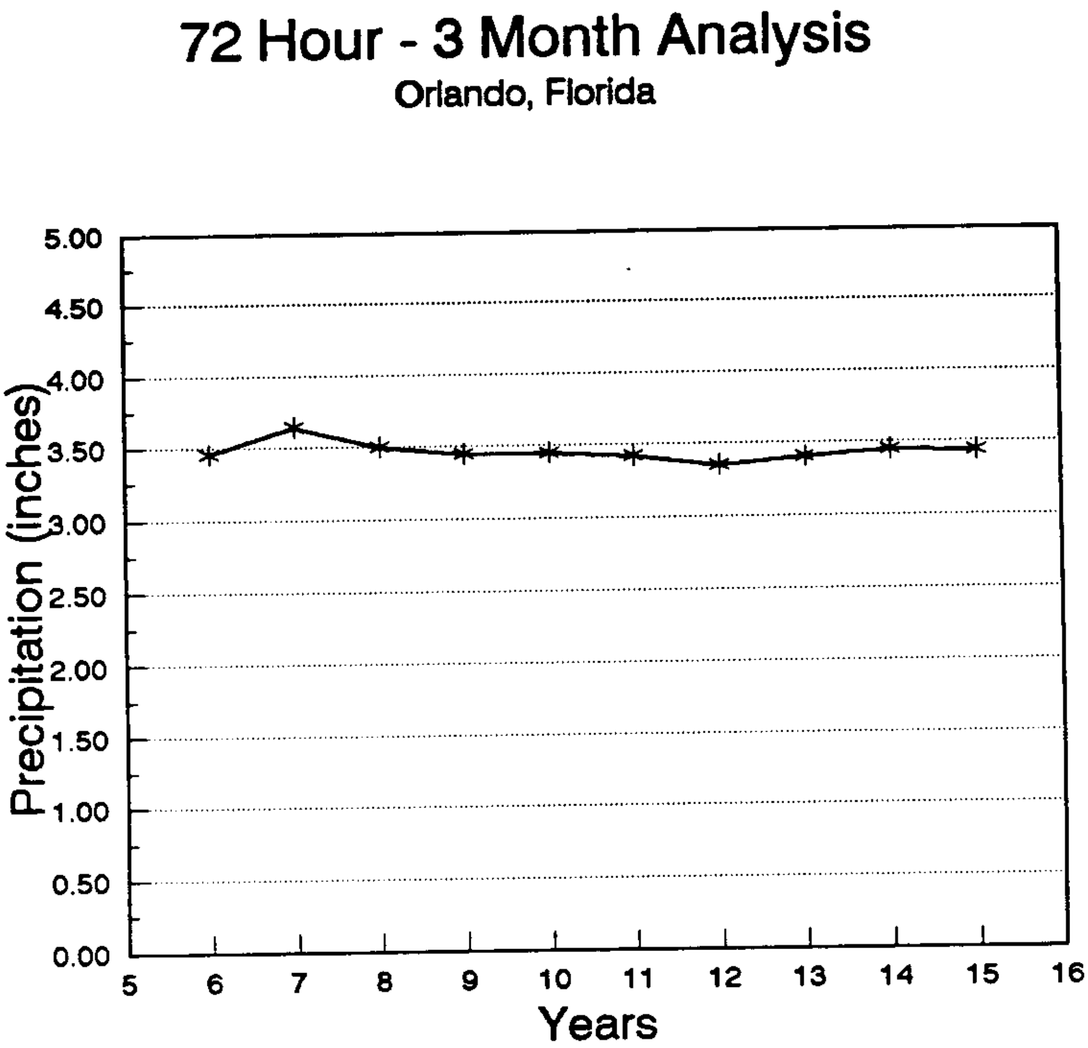

Figure A.13
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Orlando as a function of the number of years of data.

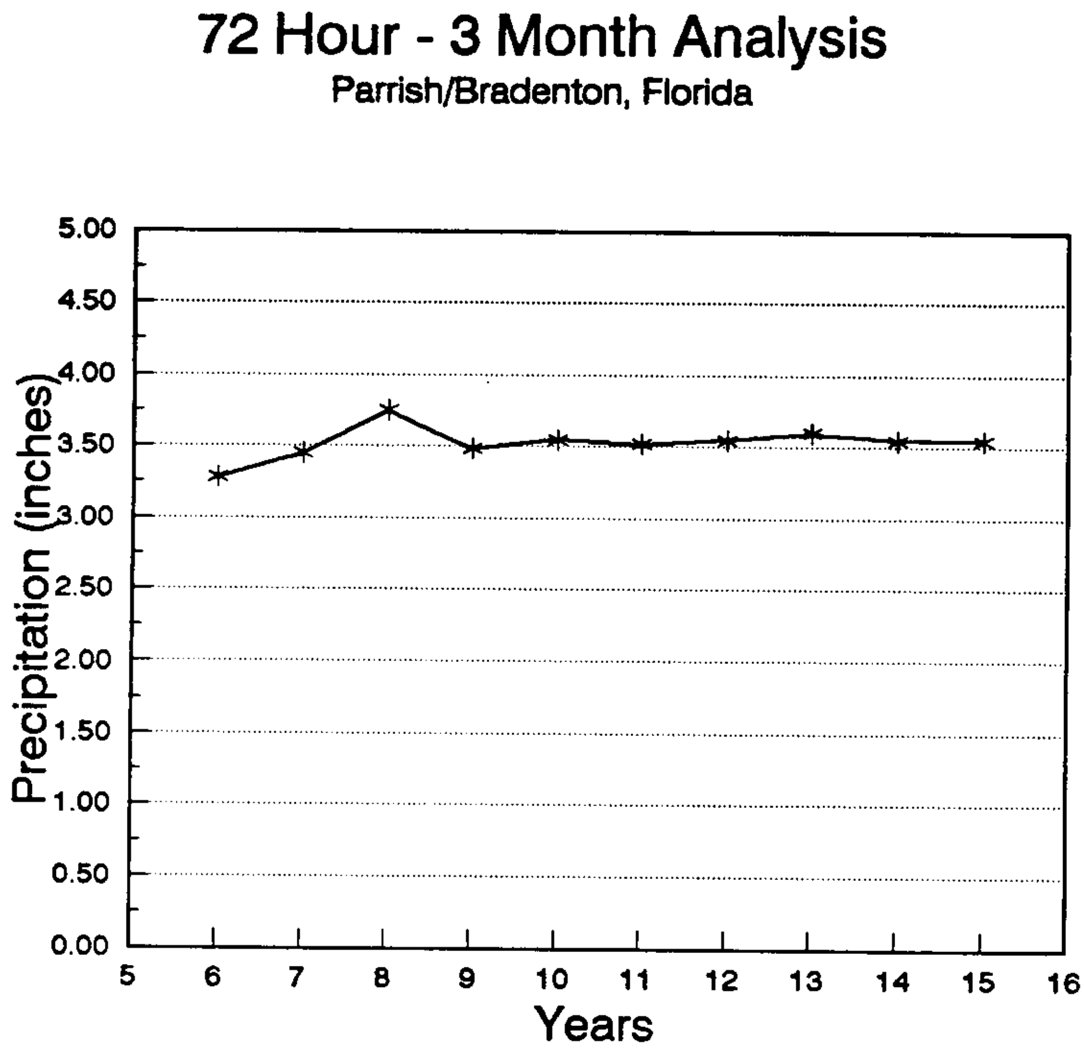

Figure A.14
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Parrish/Bradenton as a function of the number of years of data.

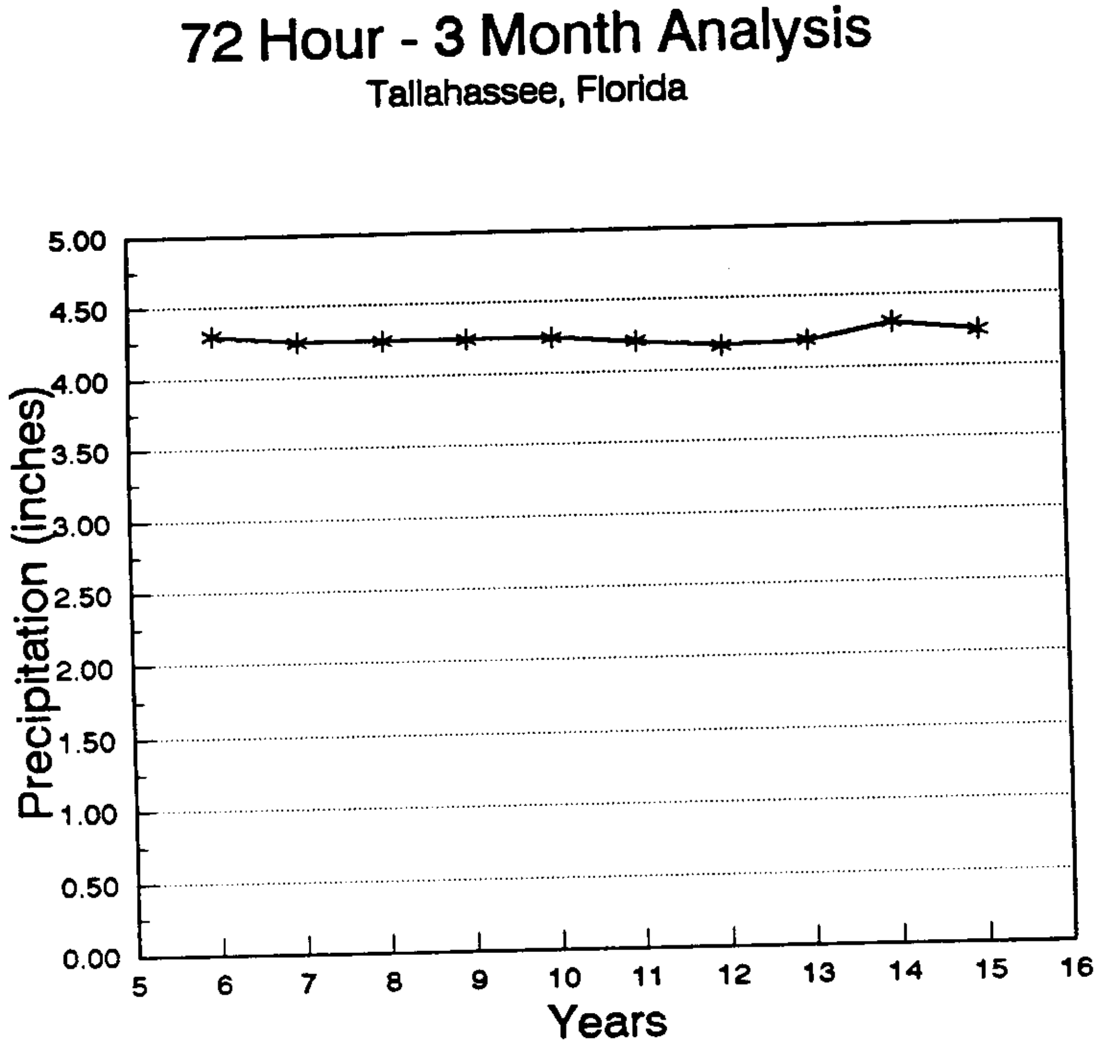

Figure A.15
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Tallahassee as a function of the number of years of data.

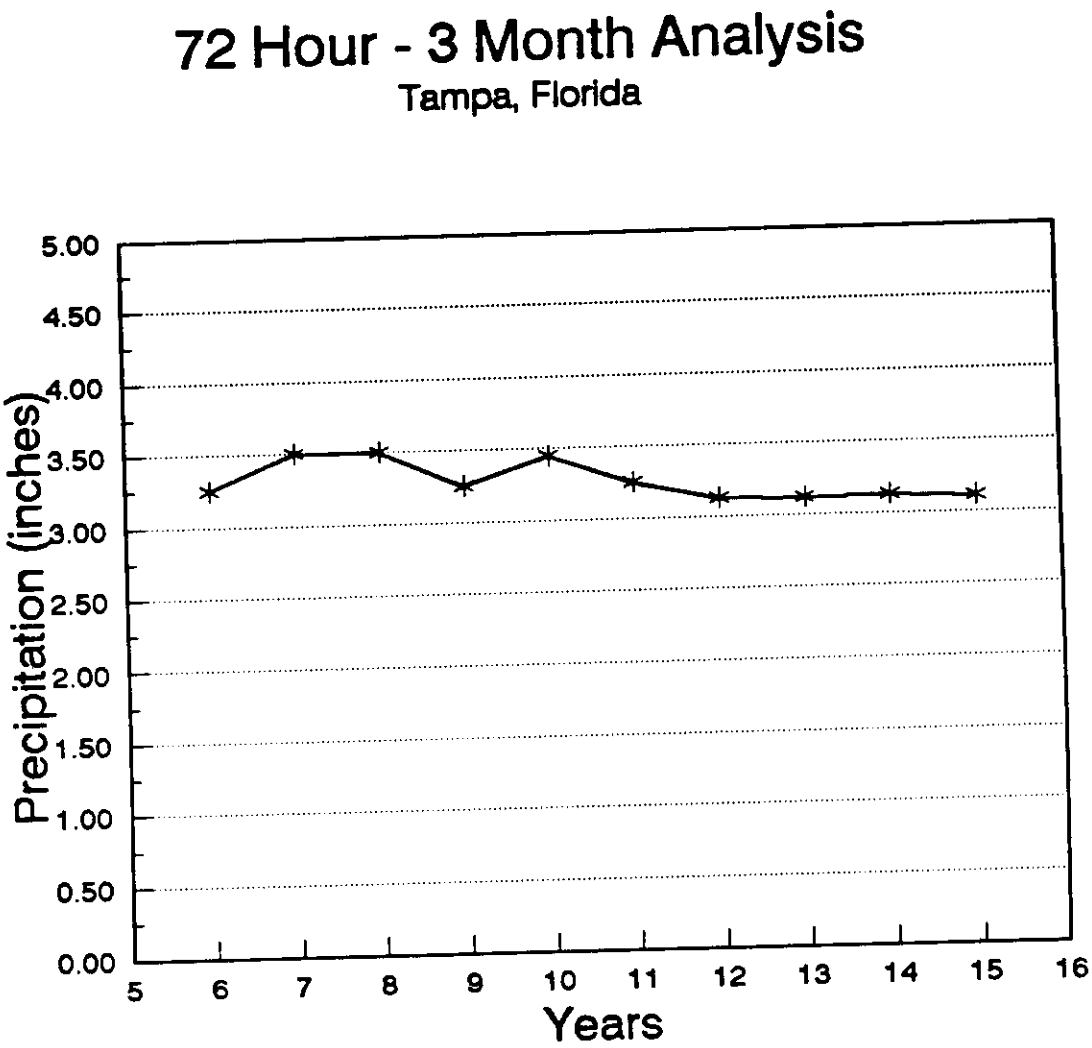

Figure A.16
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for Tampa as a function of the number of years of data.

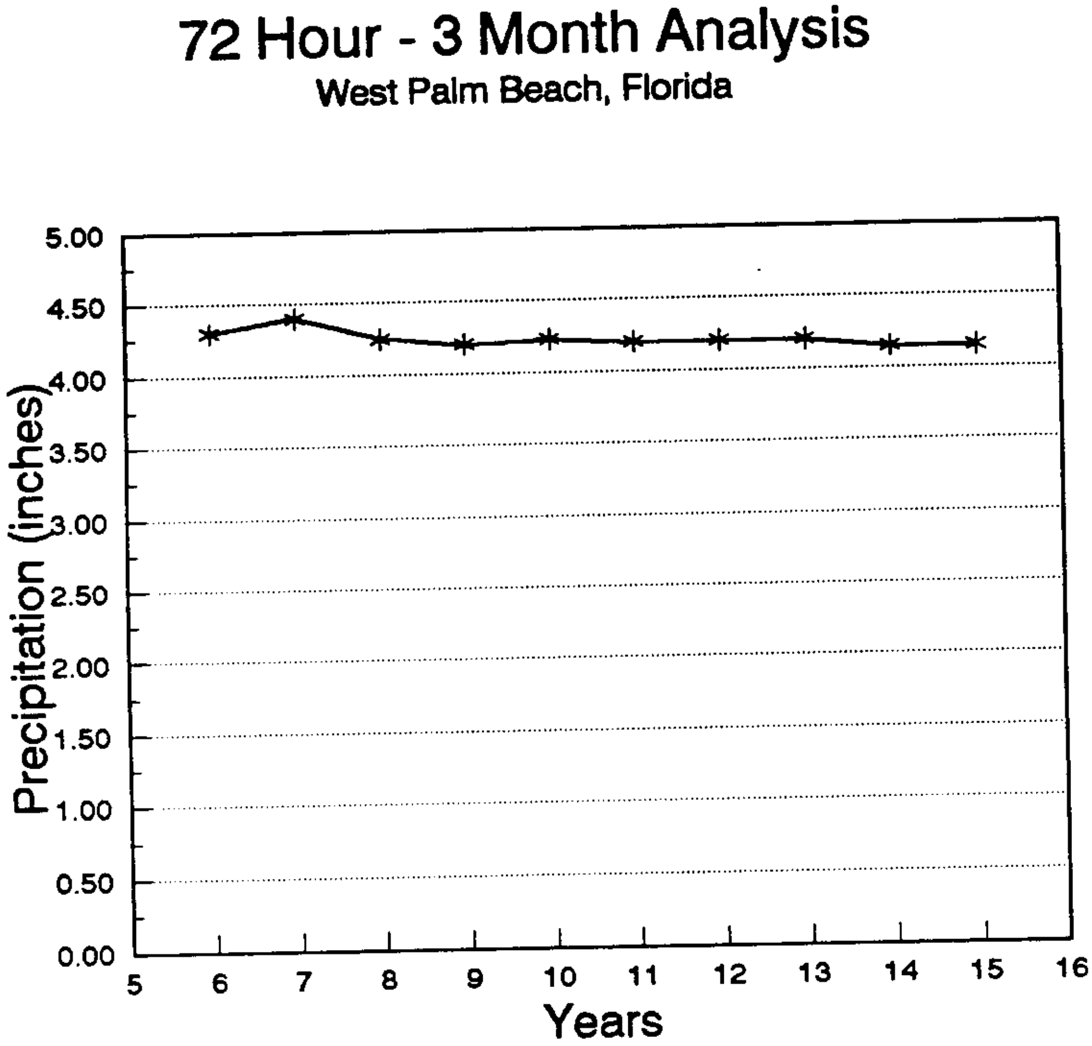

Figure A.17
Sensitivity analysis for precipitation volume given a 72 hour Inter-Event Dry Period and a 3 month Return Period for West Palm Beach as a function of the number of years of data.

APPENDIX B

P-I-F CURVES

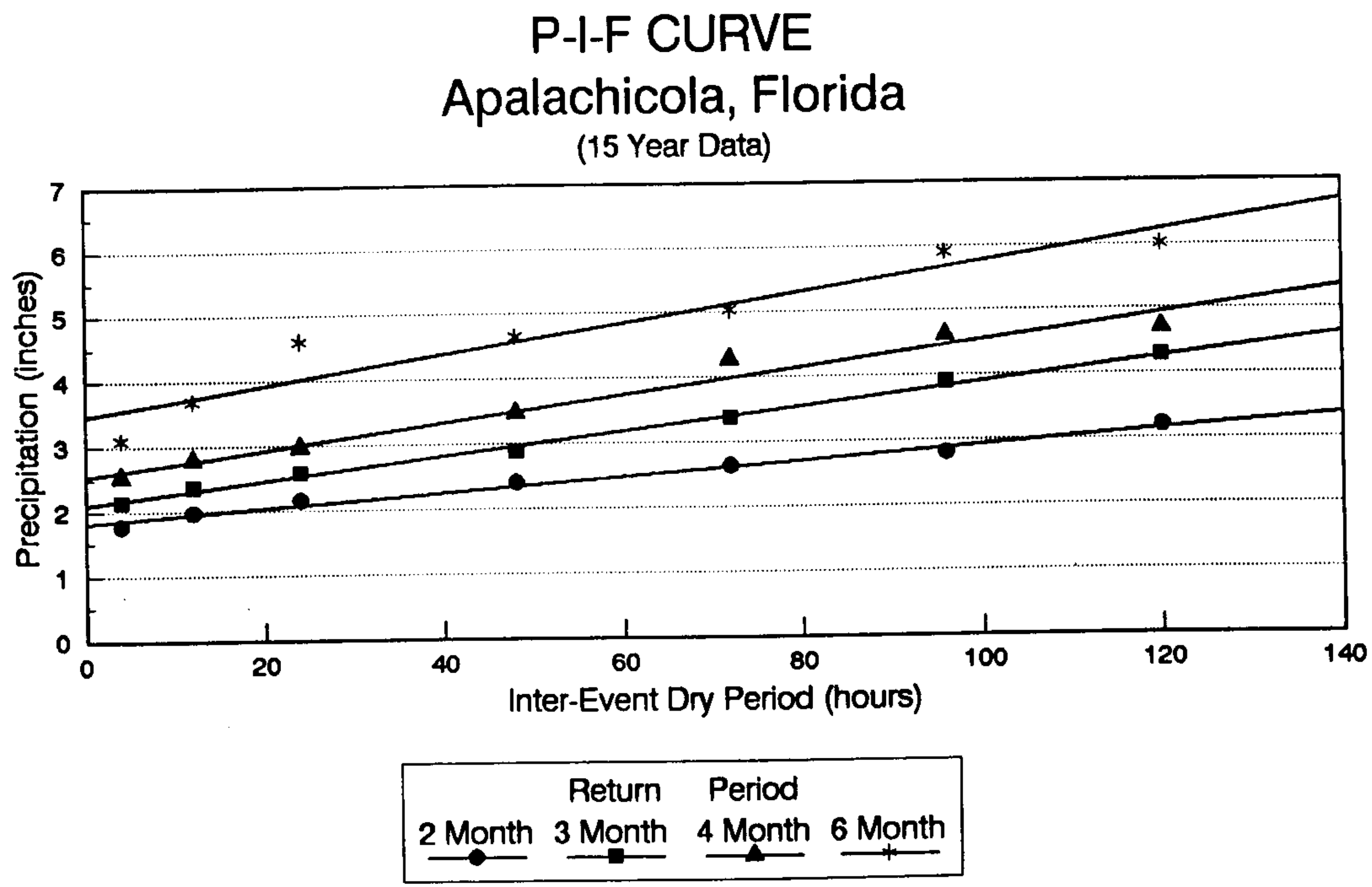

Figure B.1 P-I-F Curve for Apalachicola, Florida; Precipitation >= 0.04 inches.

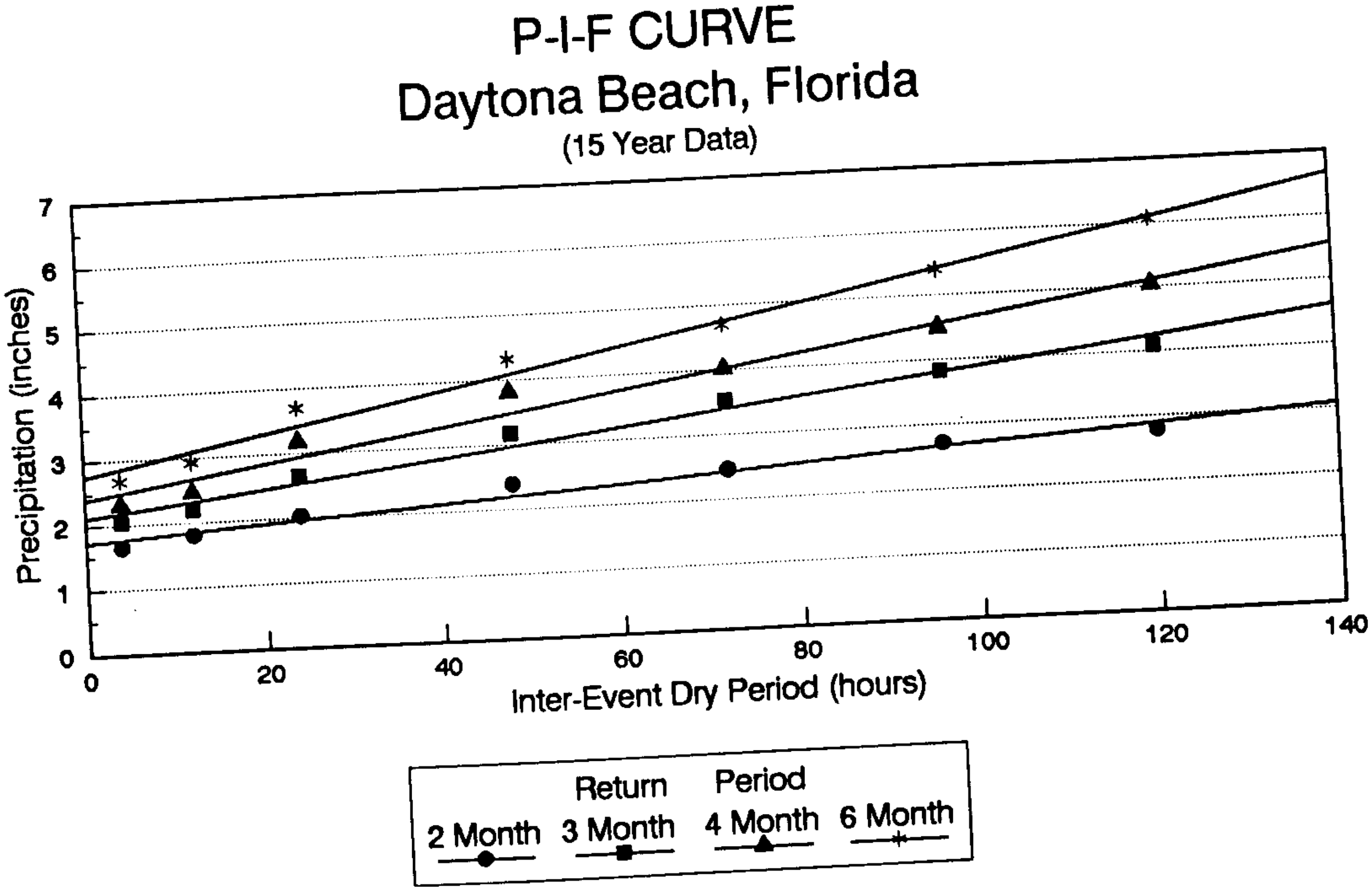

Figure B.2 P-I-F Curve for Daytona Beach, Florida; Precipitation >= 0.04 inches

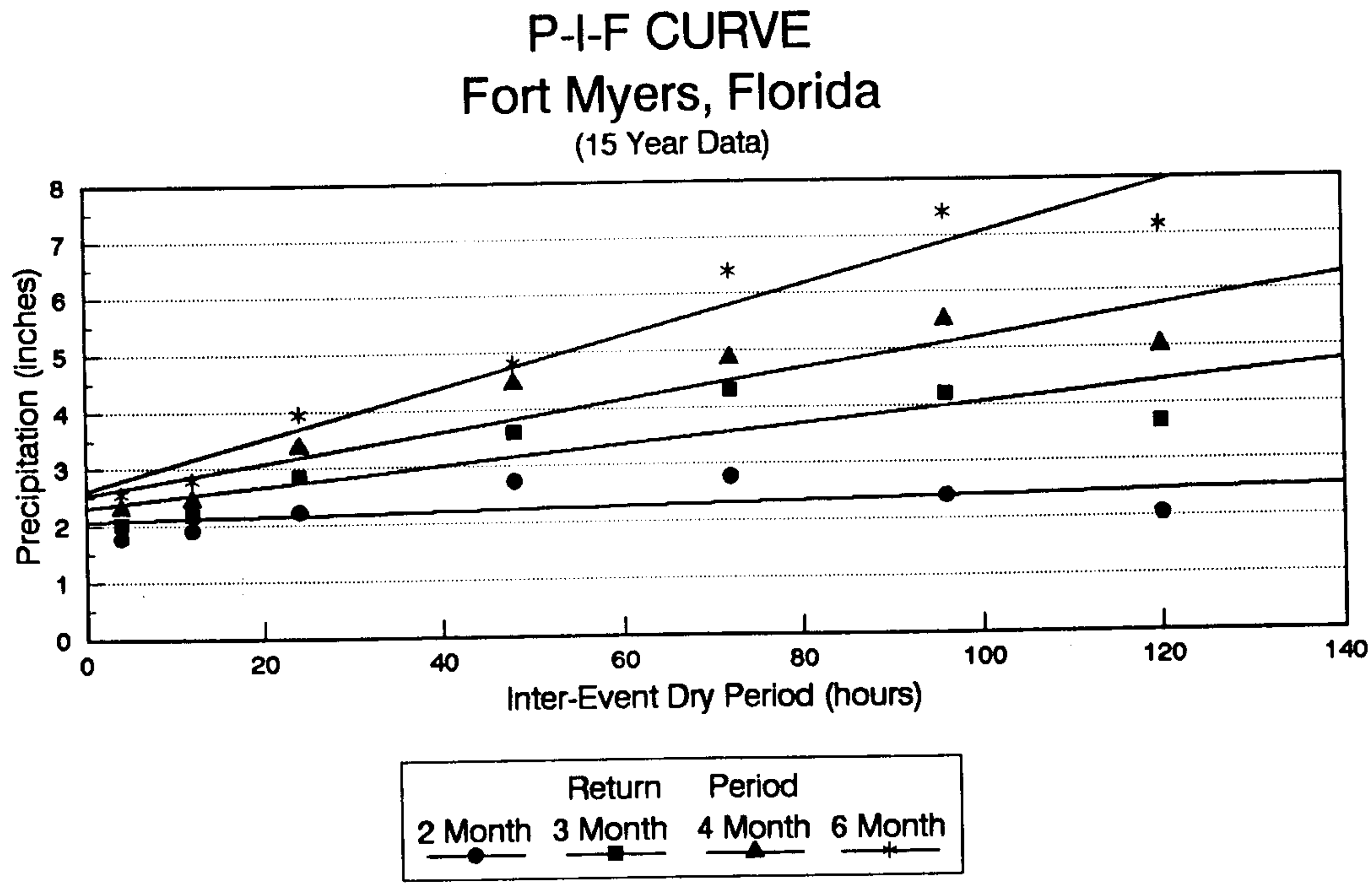

Figure B.3 P-I-F Curve for Ft. Myers, Florida; Precipitation >= 0.04 inches.

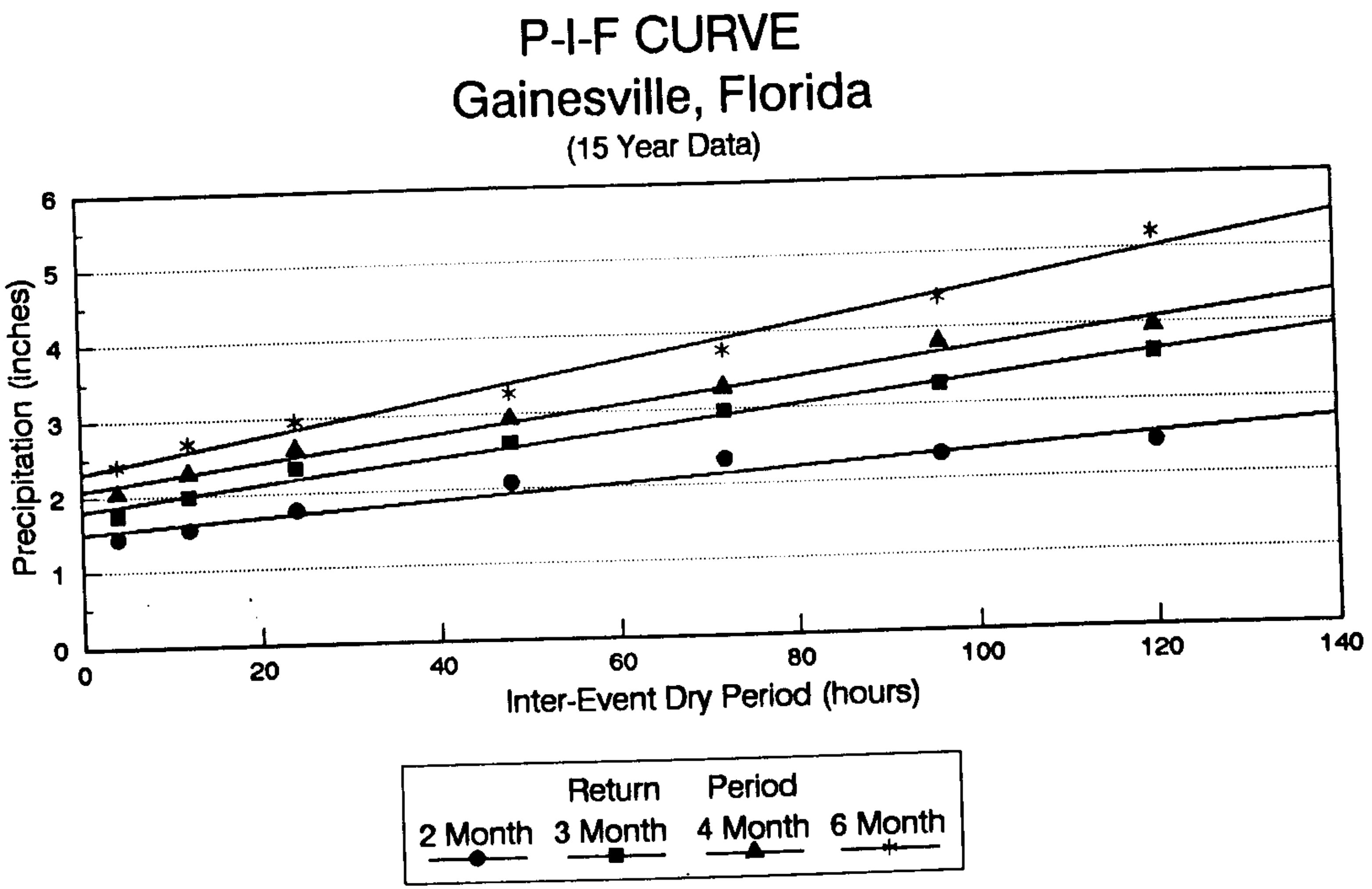

Figure B.4 P-I-F Curve for Gainesville, Florida; Precipitation >= 0.04 inches.

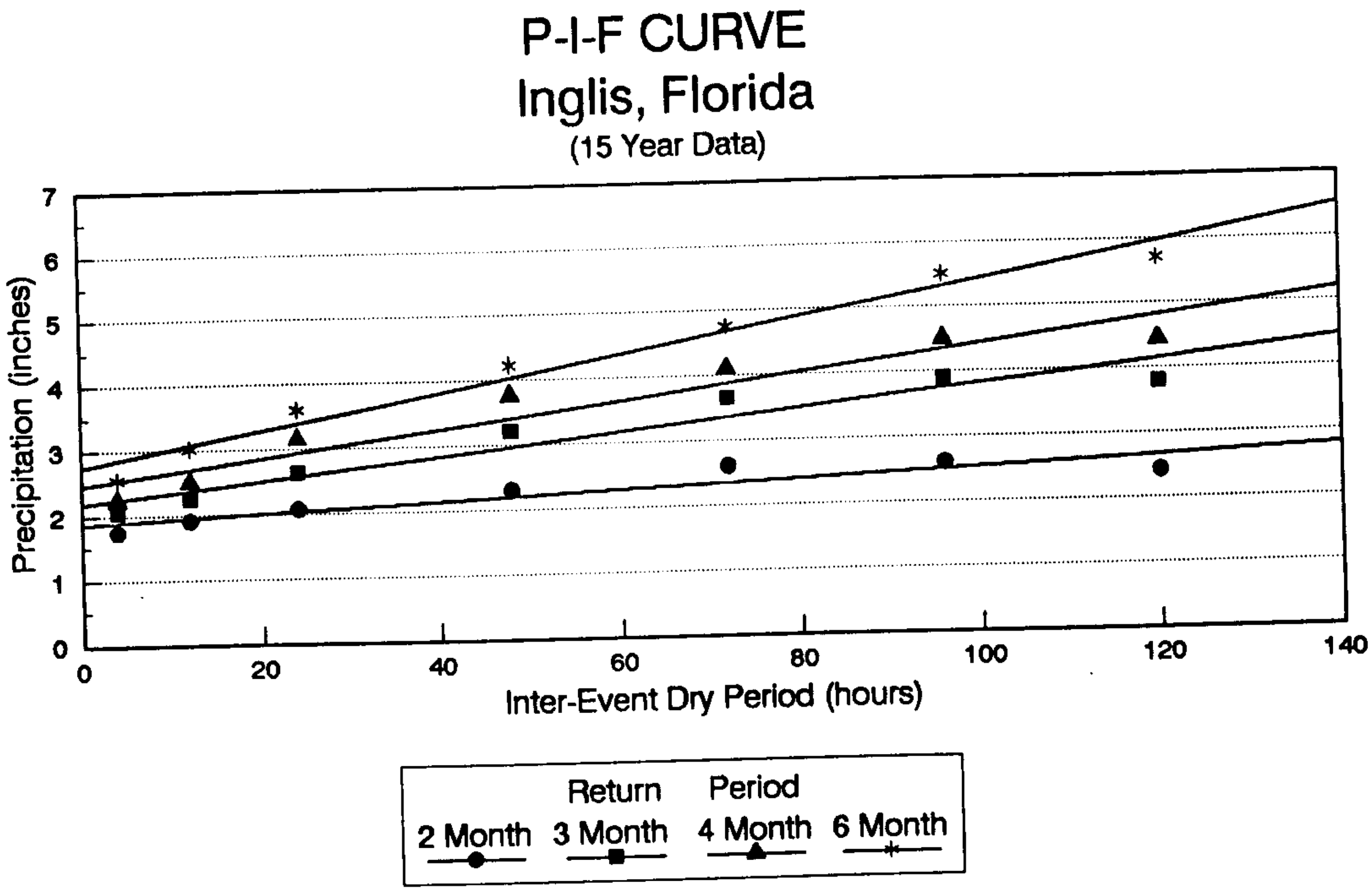

Figure B.5 P-I-F Curve for Gainesville, Florida; Precipitation >= 0.04 inches.

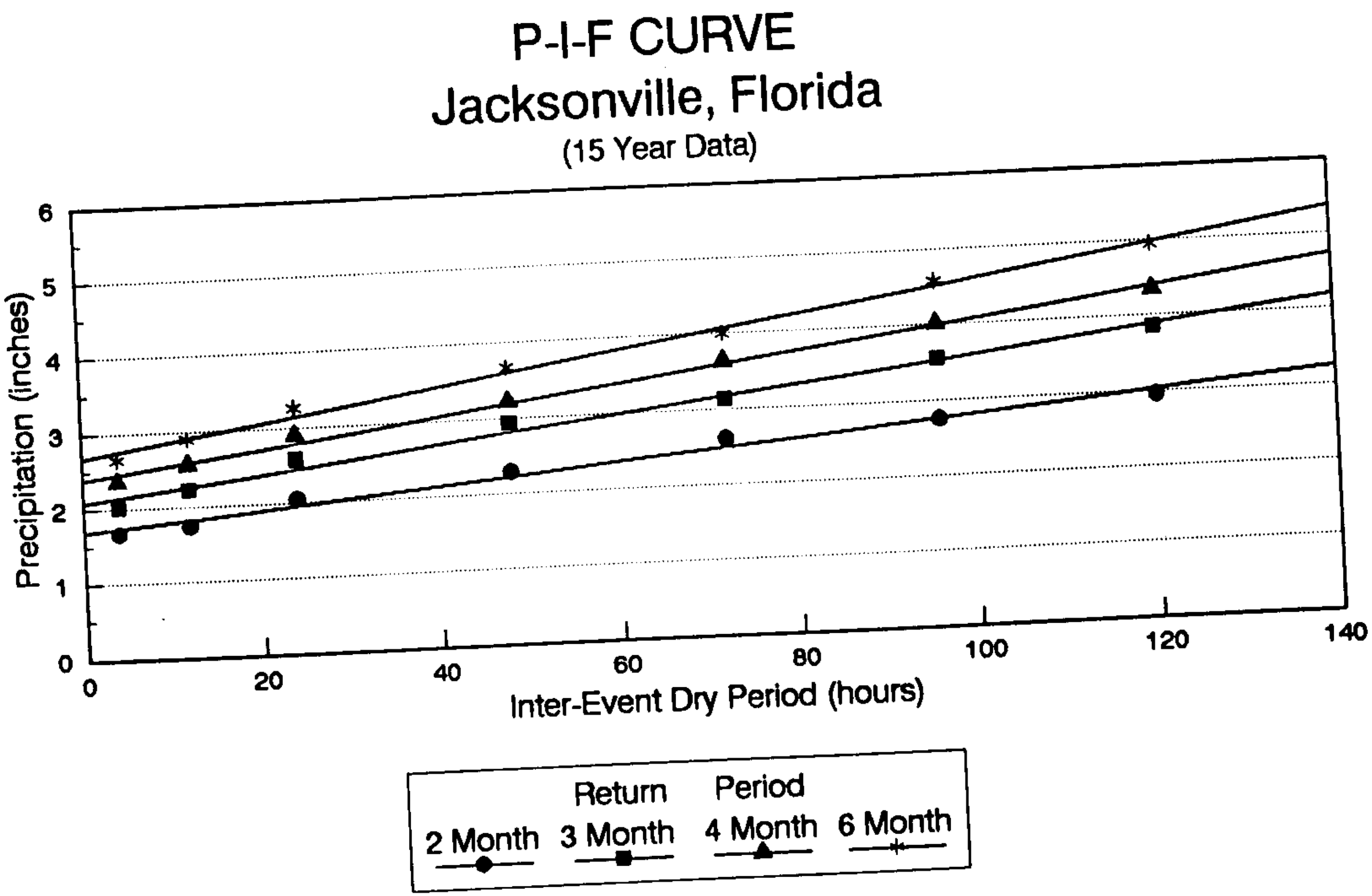

Figure B.6 P-I-F Curve for Jacksonville, Florida; Precipitation >= 0.04 inches.

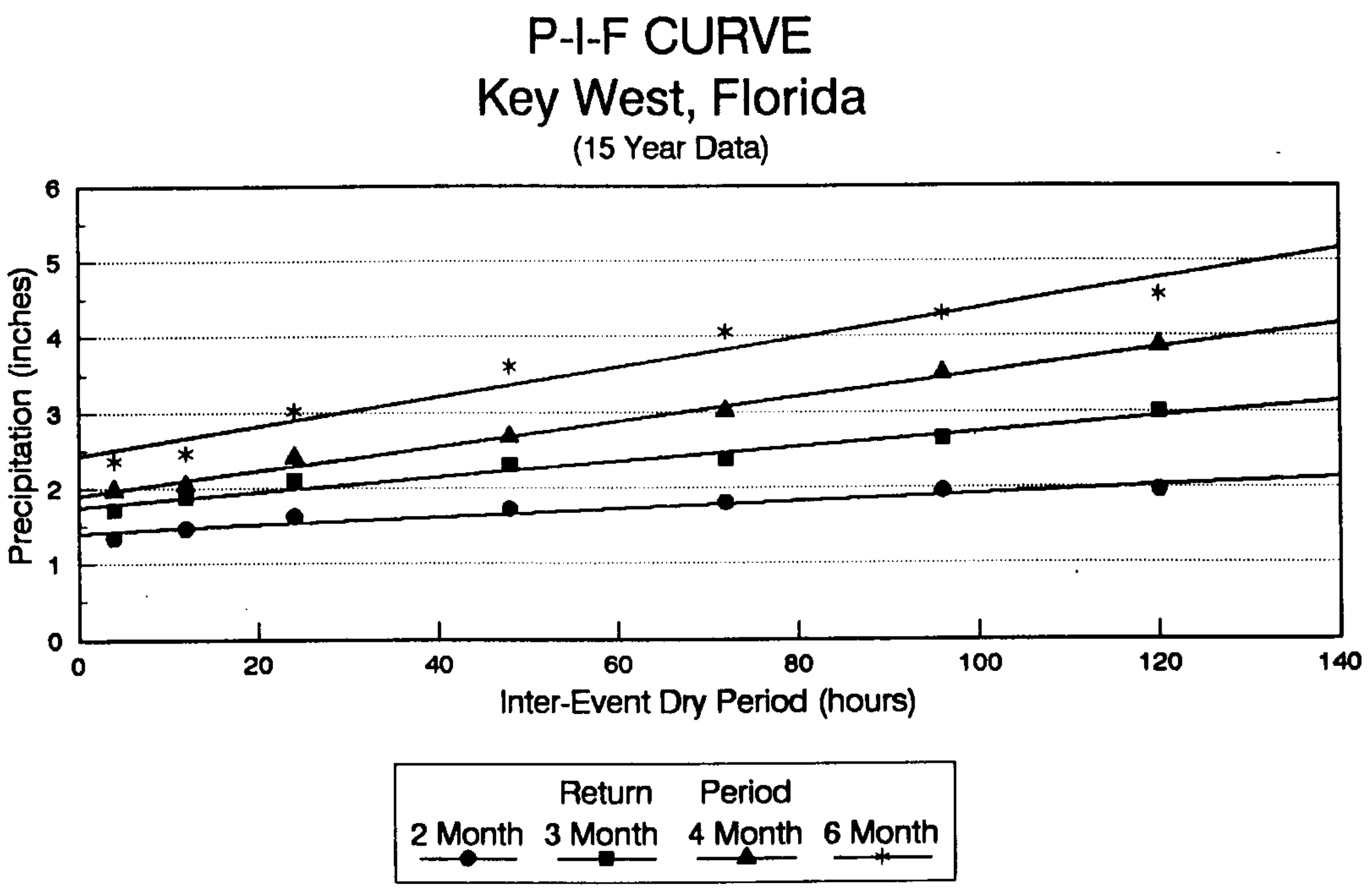

Figure B.7 P-I-F Curve for Key West, Florida; Precipitation >= 0.04 inches.

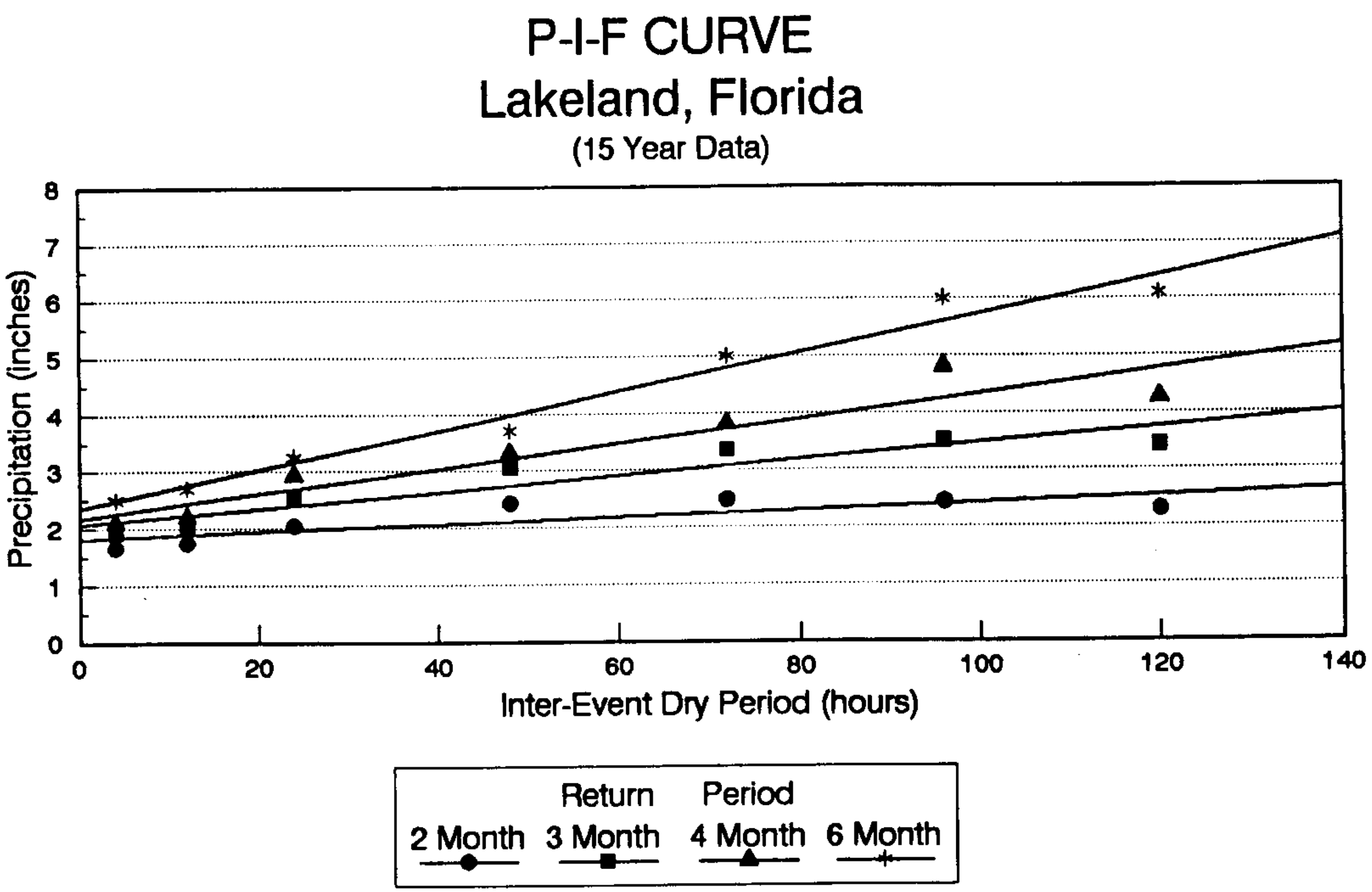

Figure B.8 P-I-F Curve for Lakeland, Florida; Precipitation >= 0.04 inches.

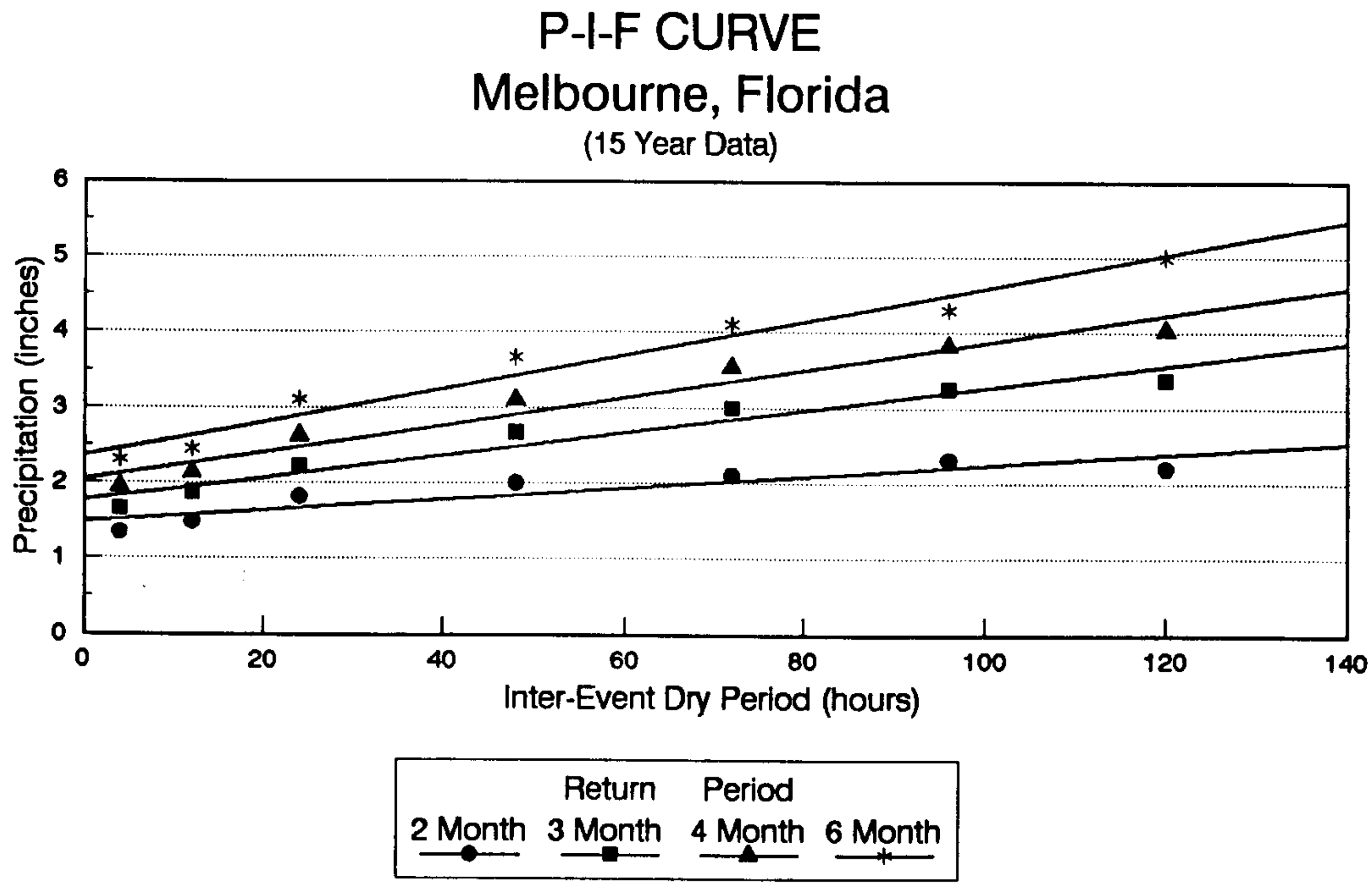

Figure B.9 P-I-F Curve for Melbourne, Florida; Precipitation >= 0.04 inches.

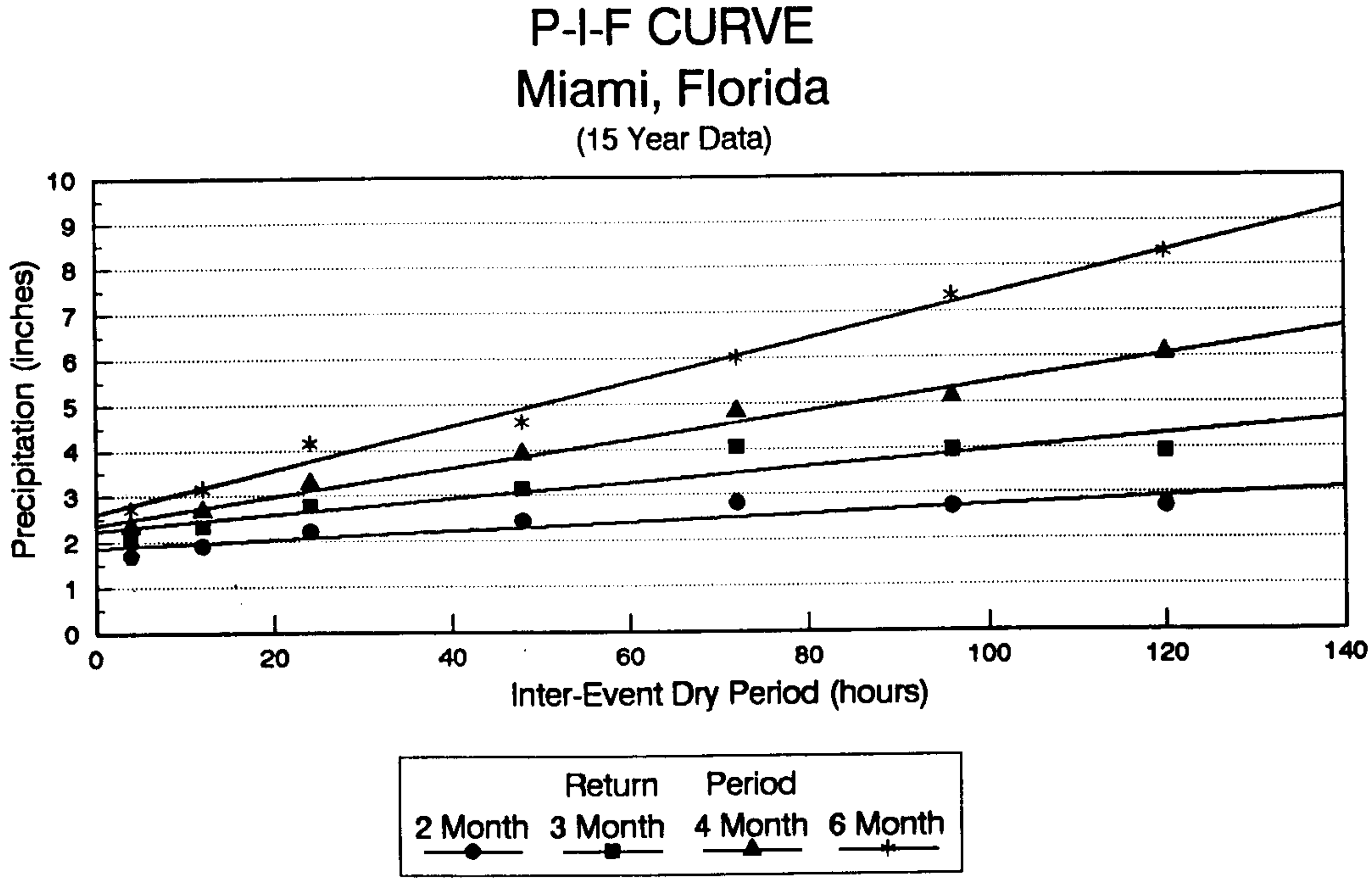

Figure B.10 P-I-F Curve for Miami, Florida; Precipitation >= 0.04 inches.

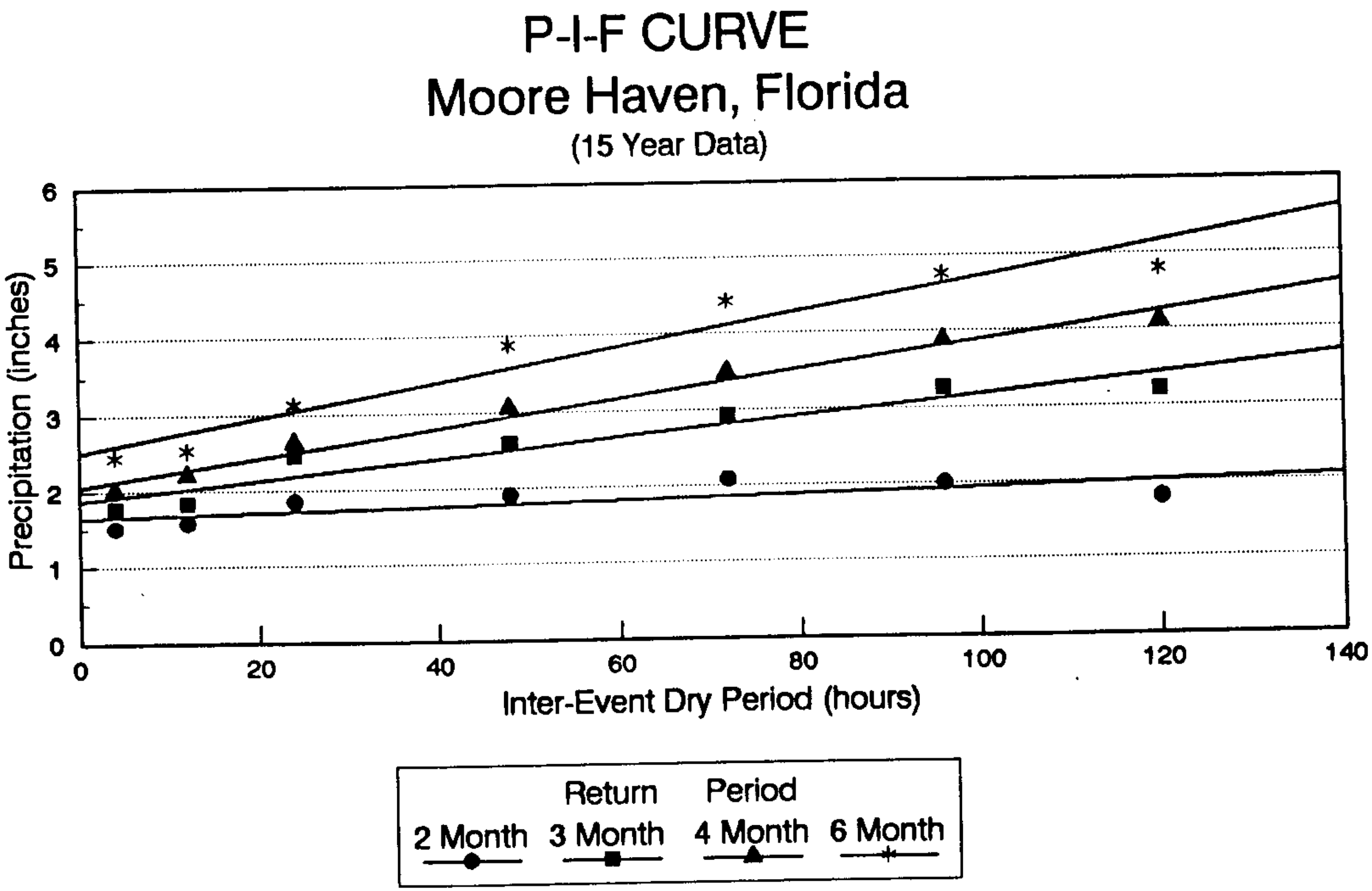

Figure B.11 P-I-F Curve for Moore Haven, Florida; Prec. >= 0.04 inches.

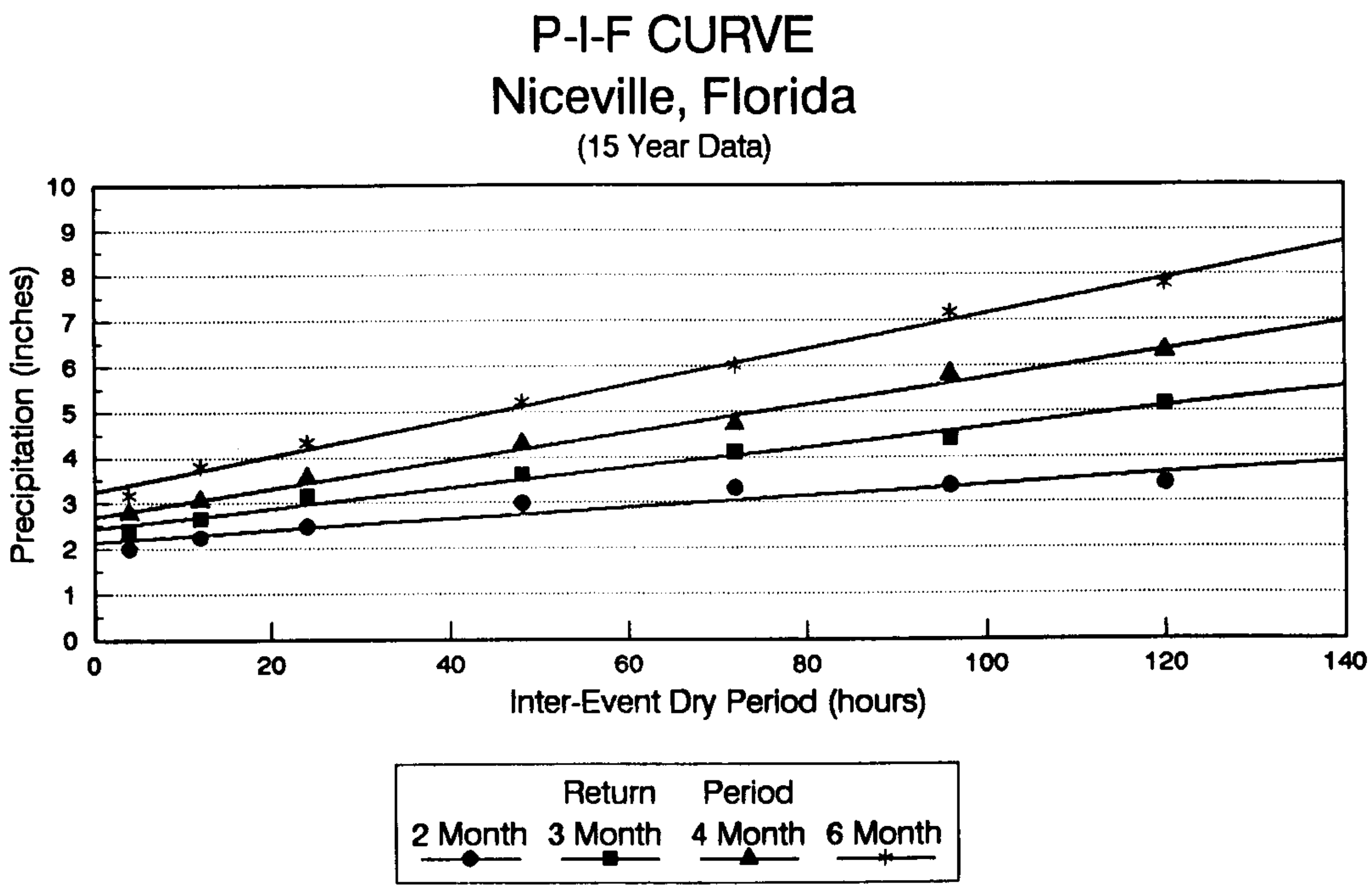

Figure B.12 P-I-F Curve for Niceville, Florida; Precipitation >= 0.04 inches.

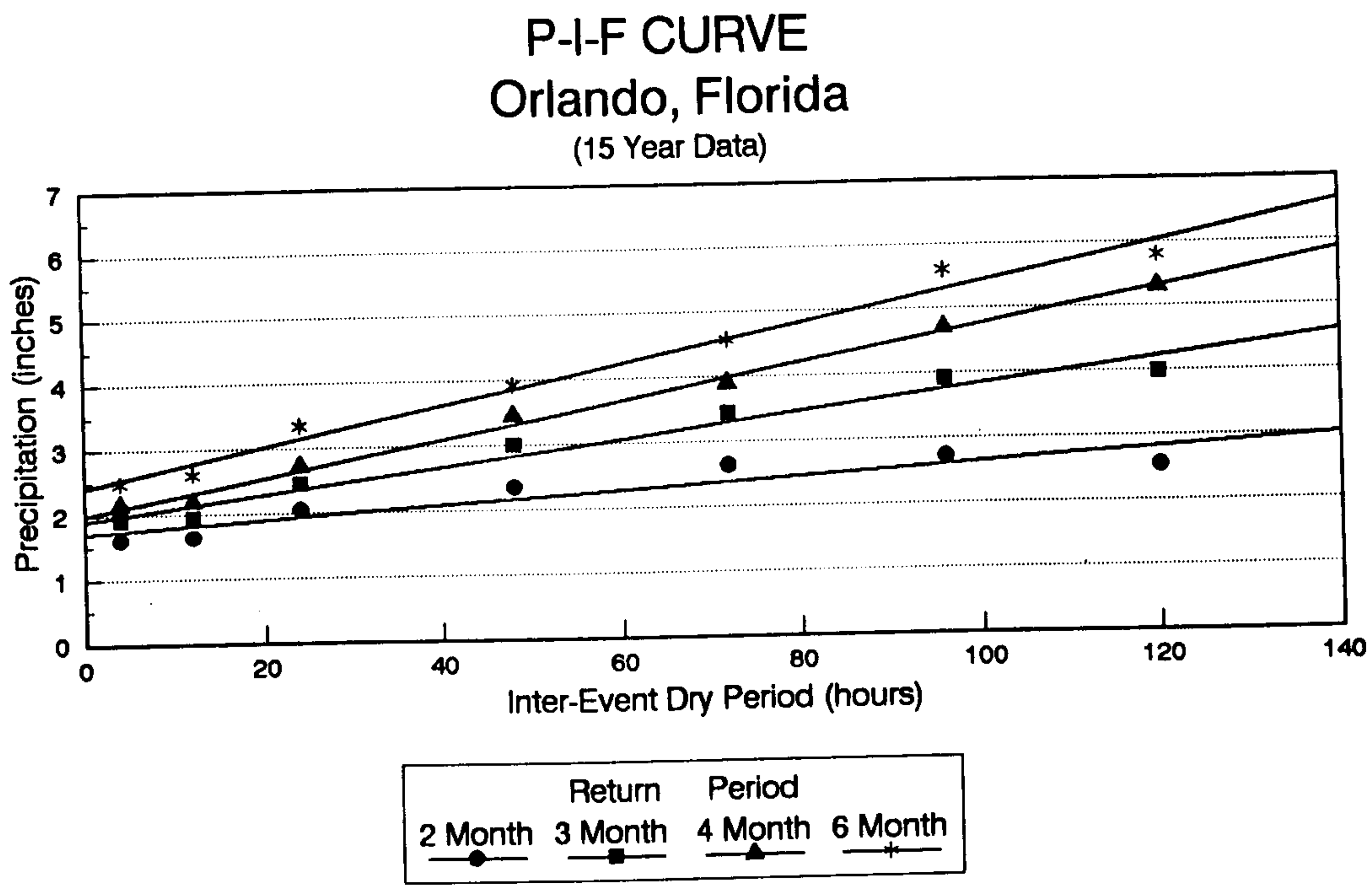

Figure B.13 P-I-F Curve for Orlando, Florida; Precipitation >= 0.04 inches.

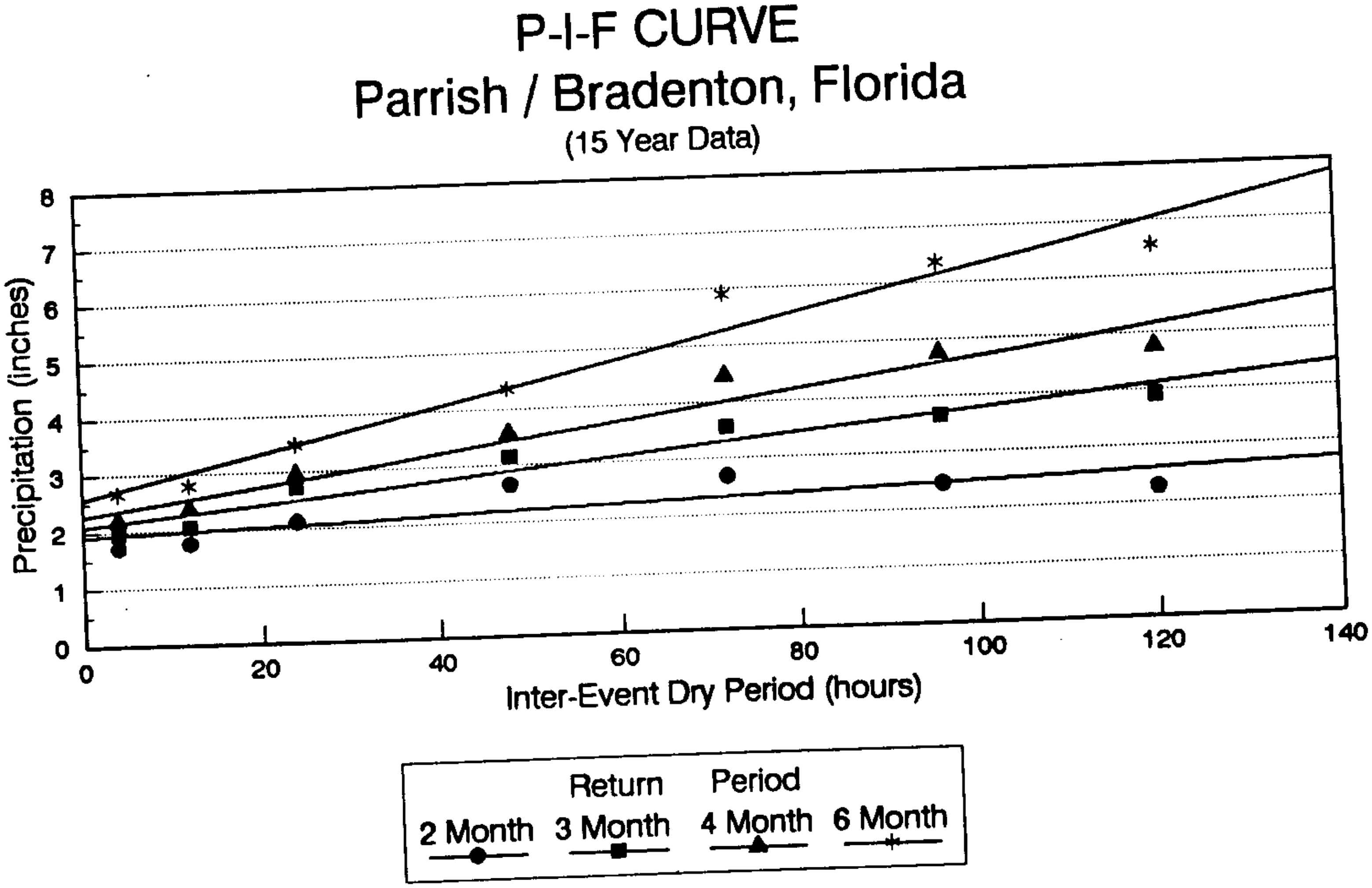

Figure B.14 P-I-F Curve for Parrish / Bradenton, Florida; Prec. >= 0.04 inches.

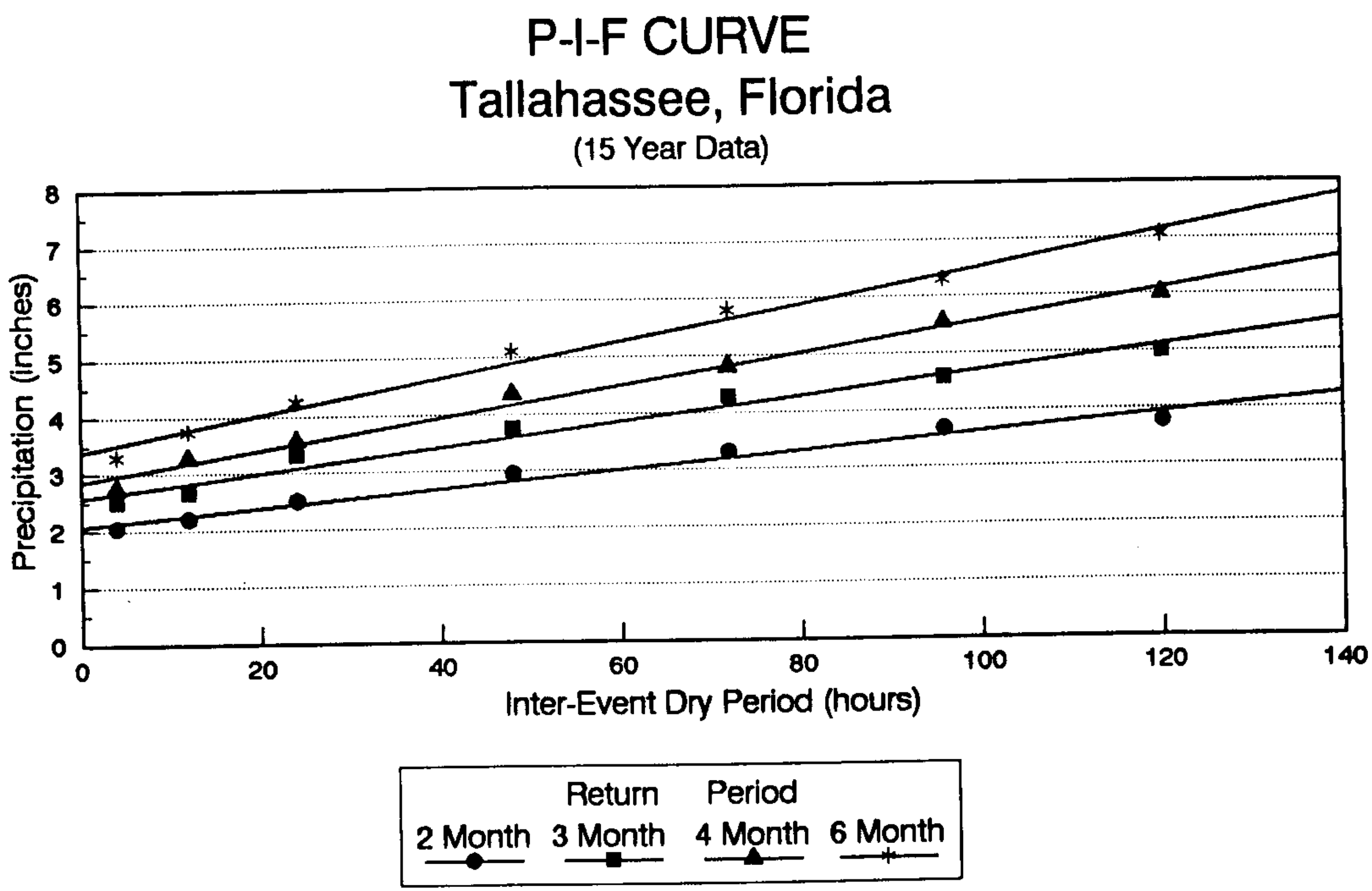

Figure B.15 P-I-F Curve for Tallahassee, Florida; Precipitation >= 0.04 inches.

P-I-F CURVE
Tampa, Florida
(15 Year Data)

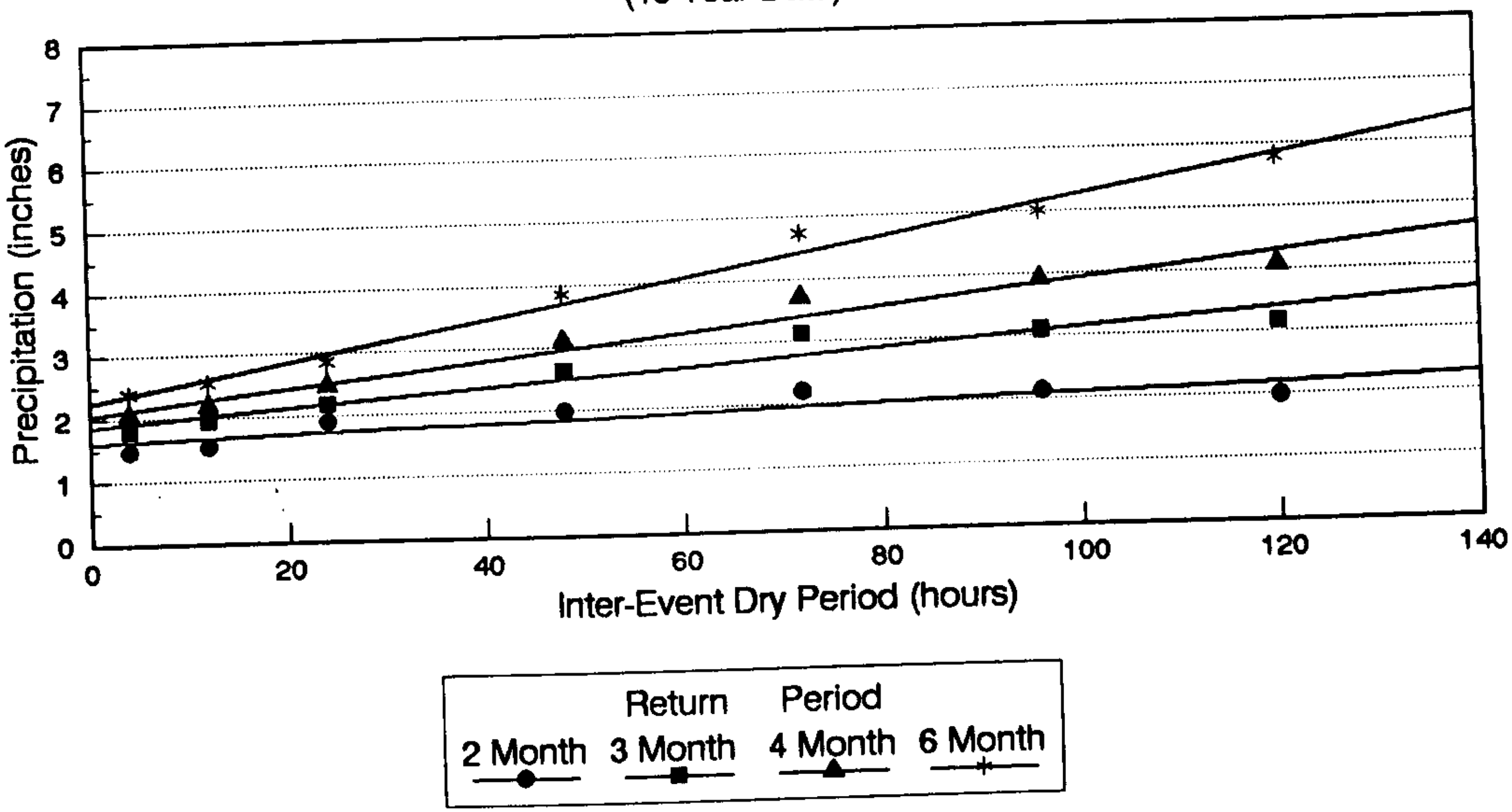

Figure B.16 P-I-F Curve for Tampa, Florida; Precipitation >= 0.04 inches.

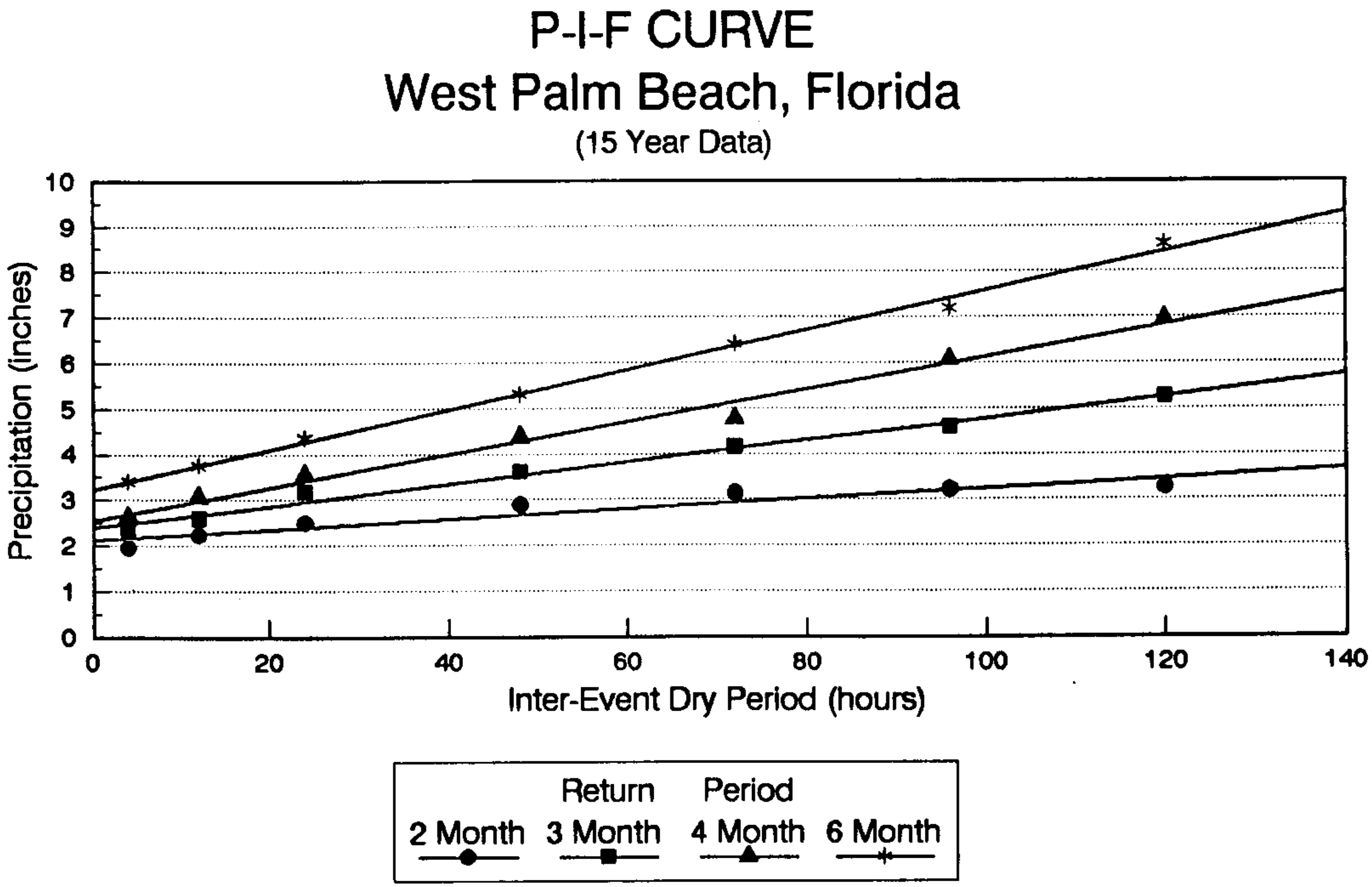

Figure B.17 P-I-F Curve for West Palm Beach, Florida; Prec. >= 0.04 inches.

APPENDIX C

DIVERSION VOLUME ANALYSIS

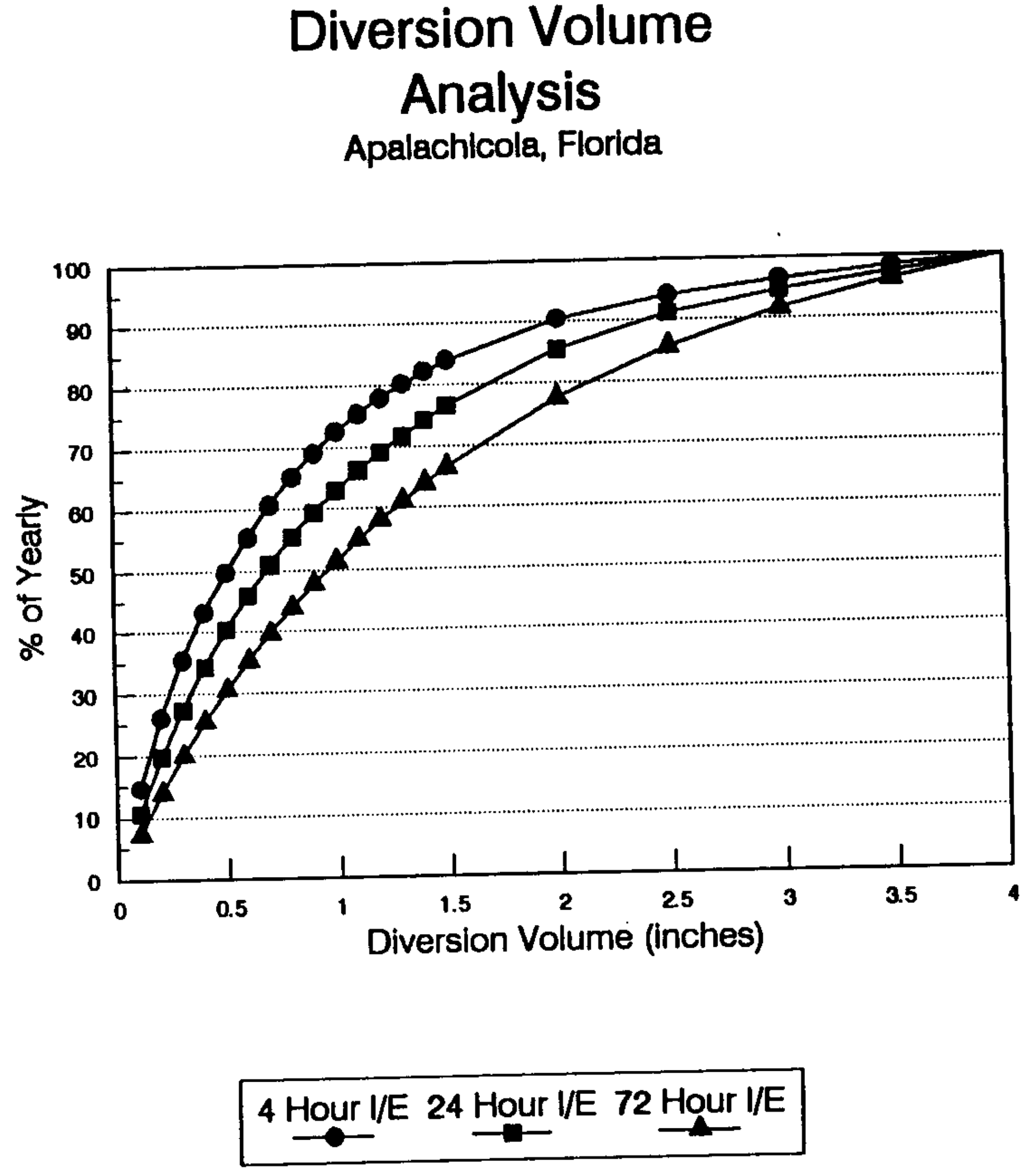

Figure C.1
Percentage of yearly volume diverted for treatment based on 15 years of data for Apalachicola, Florida.

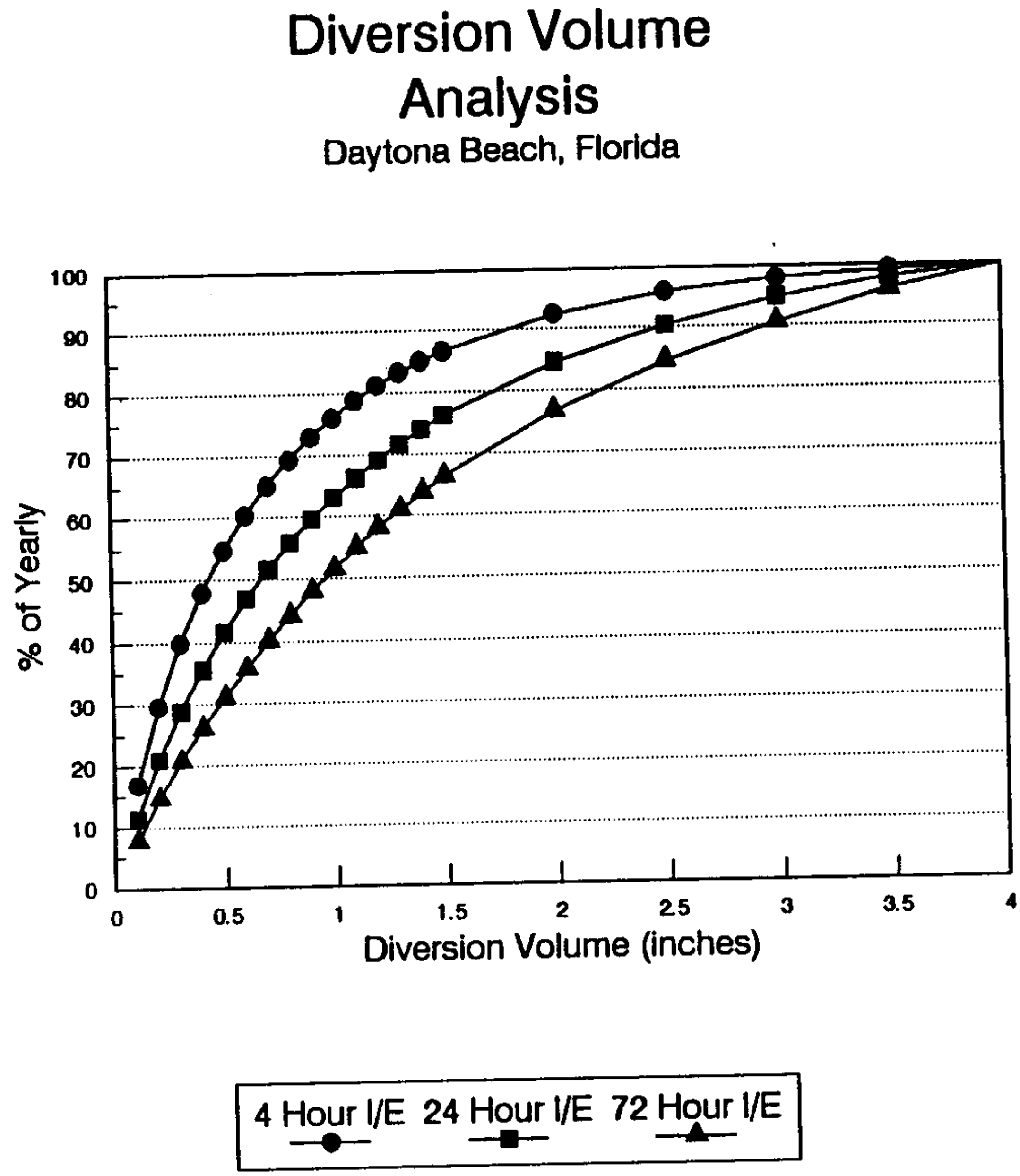

Figure C.2
Percentage of yearly volume diverted for treatment based on 15 years of data for Daytona Beach, Florida.

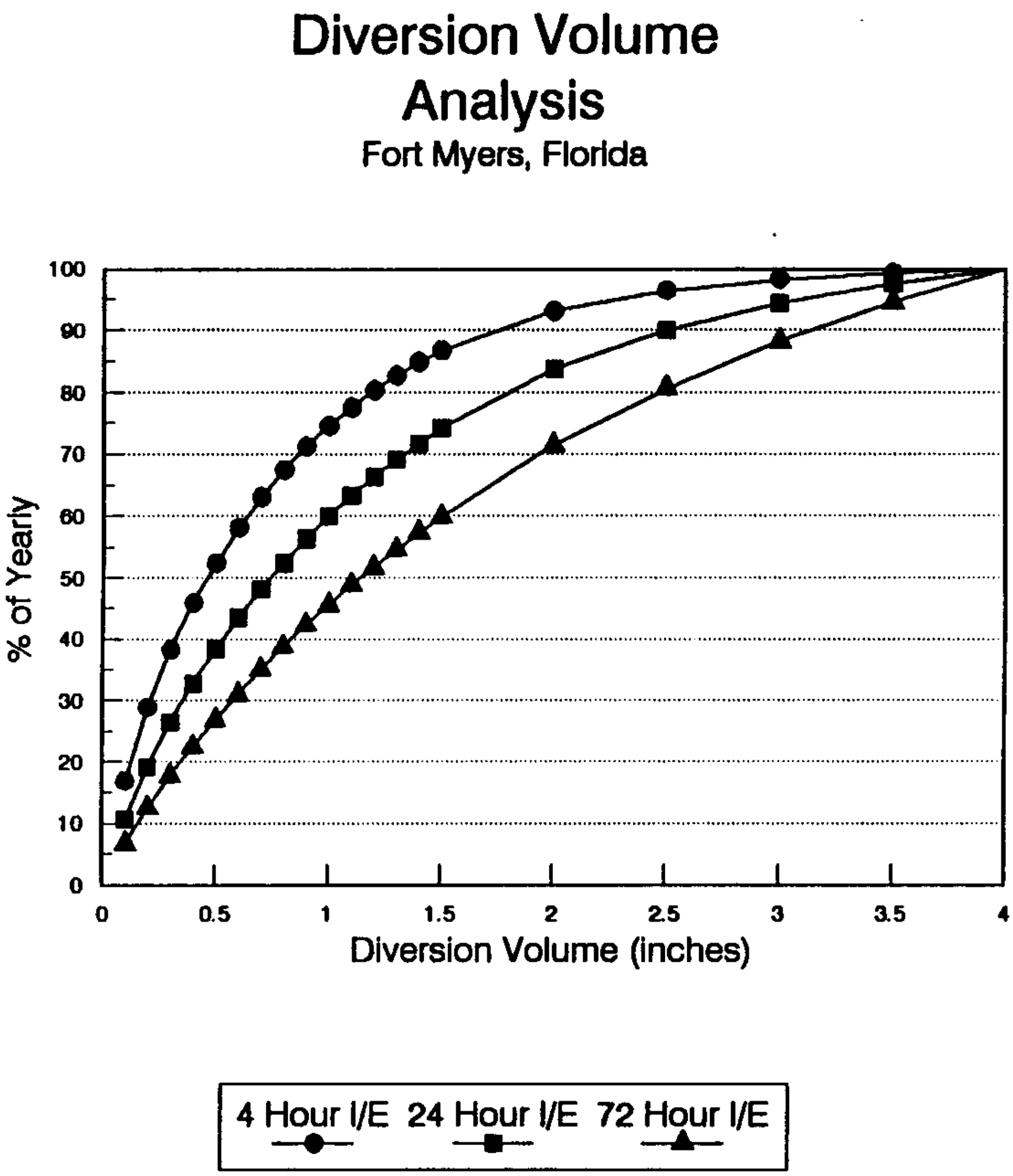

Figure C.3
Percentage of yearly volume diverted for treatment based on 15 years of data for Fort Myers, Florida.

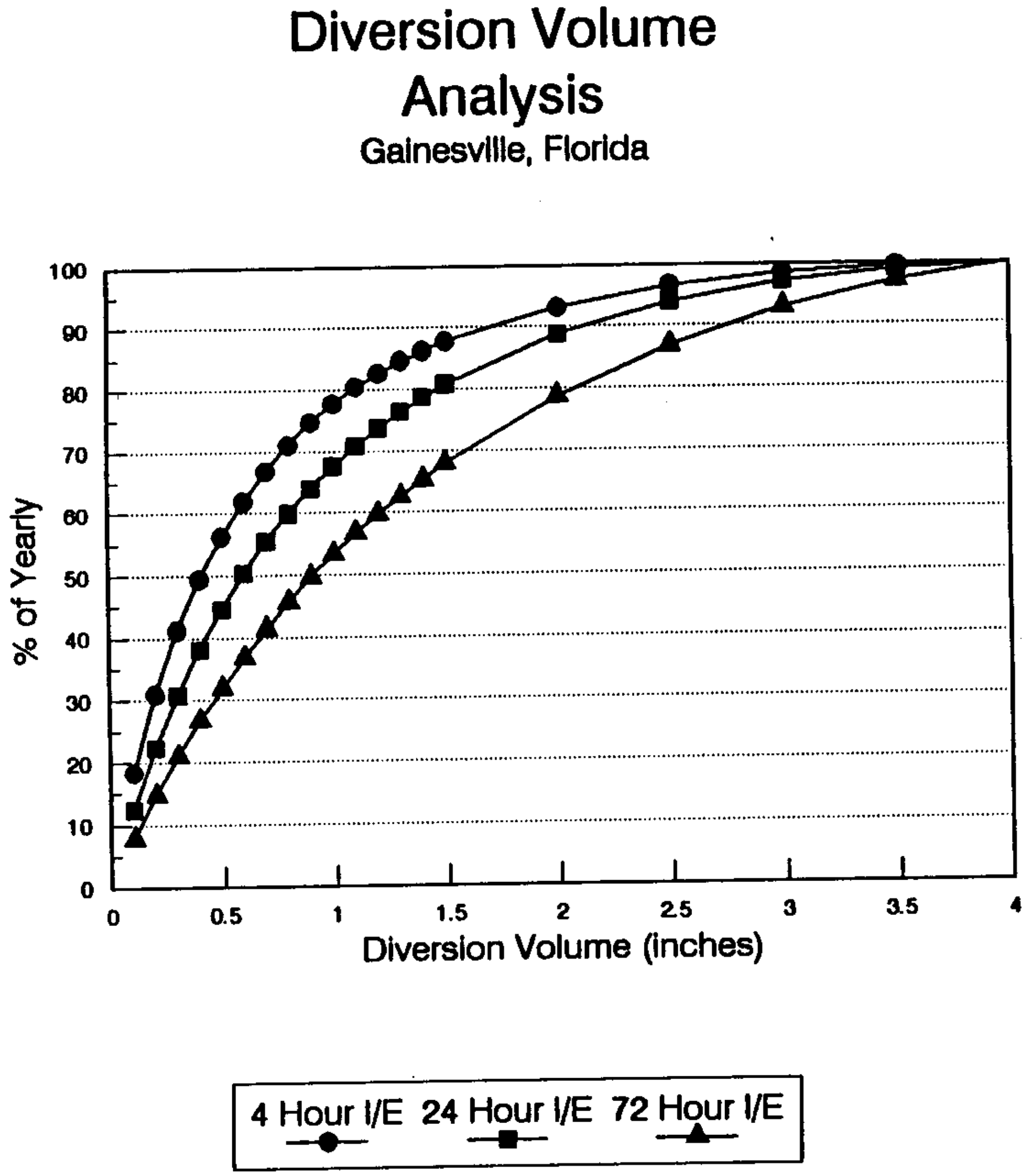

Figure C.4
Percentage of yearly volume diverted for treatment based on 15 years of data for Gainesville, Florida.

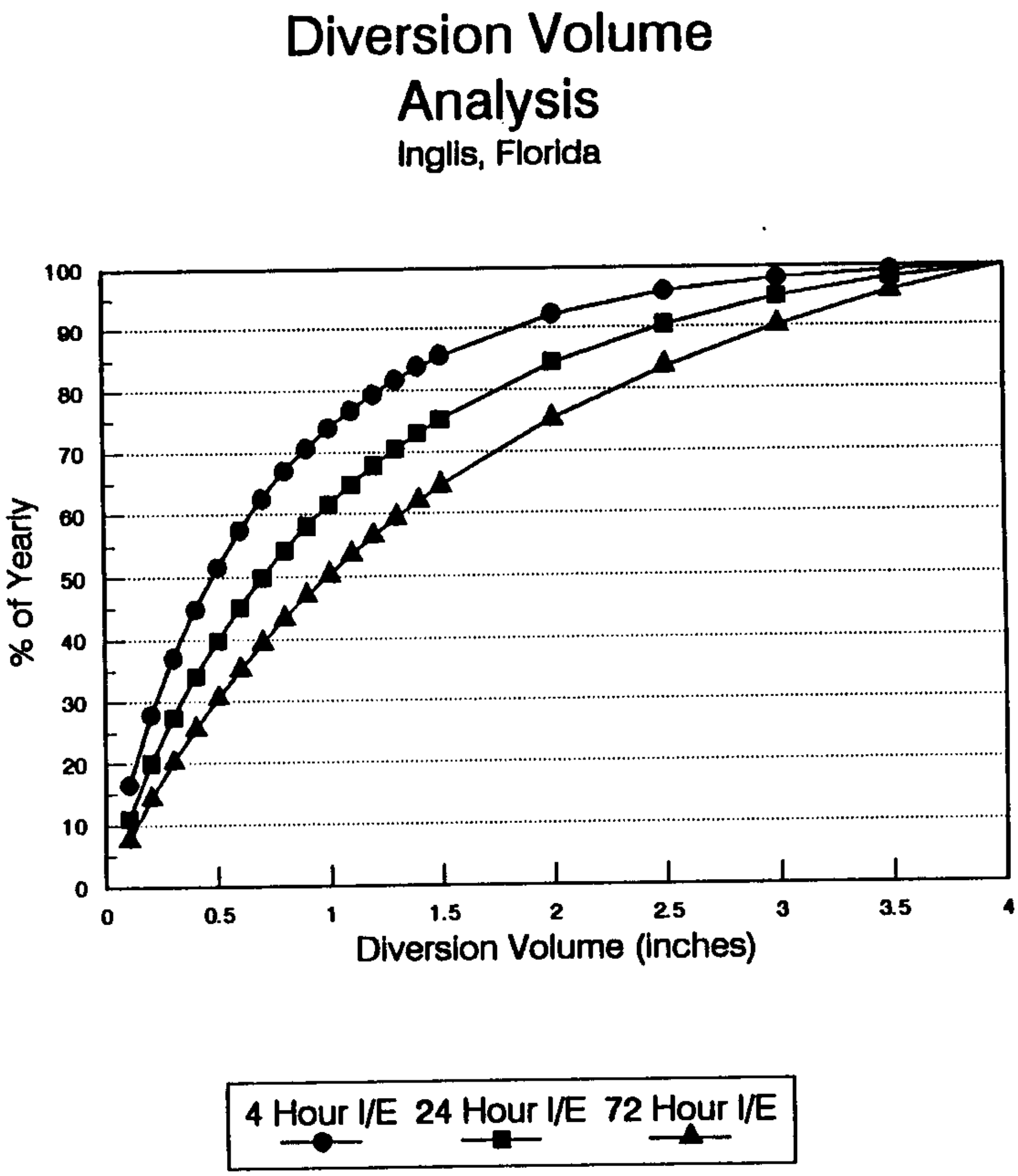

Figure C.5
Percentage of yearly volume diverted for treatment based on 15 years of data for Inglis, Florida.

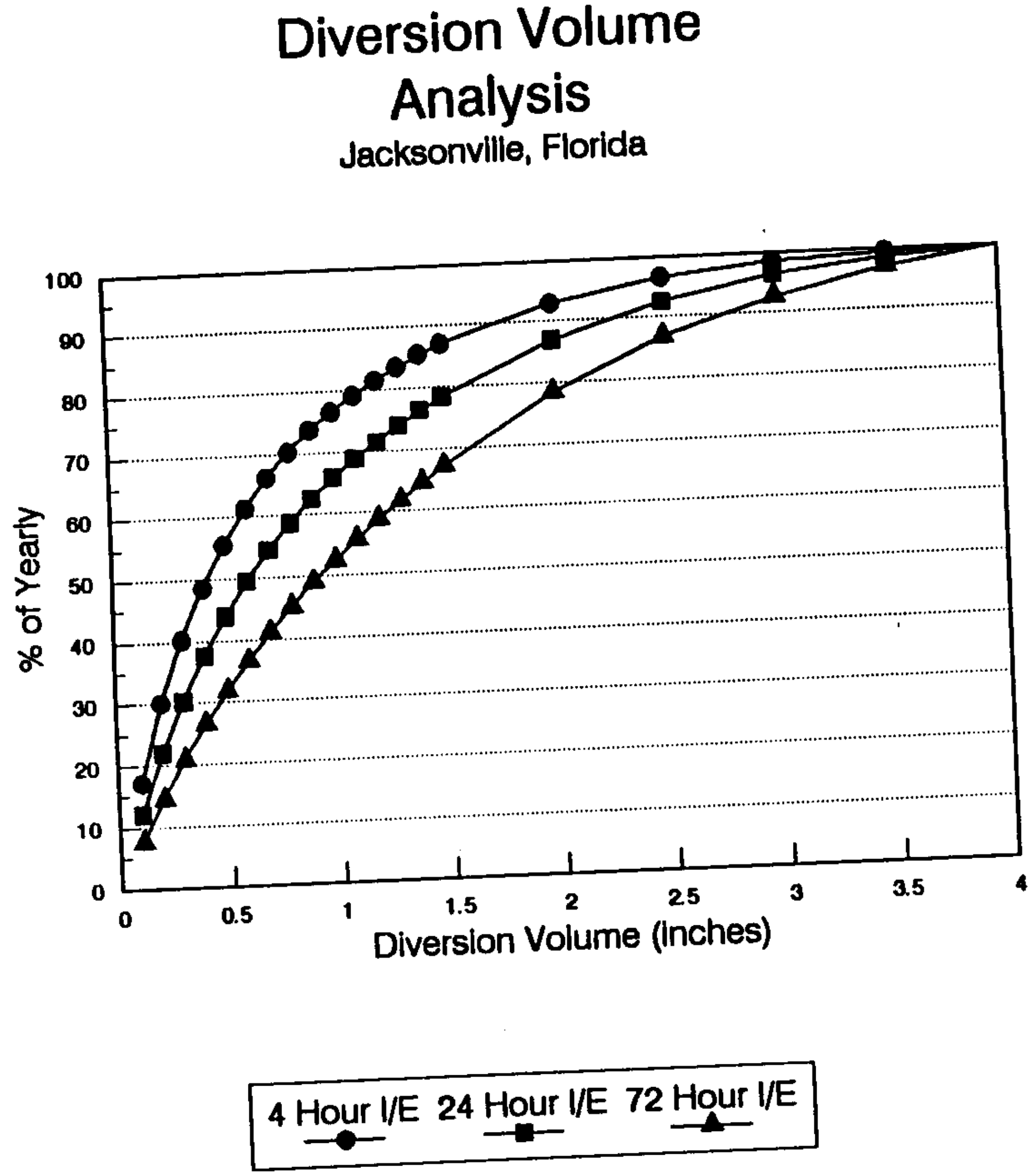

Figure C.6
Percentage of yearly volume diverted for treatment based on 15 years of data for Jacksonville, Florida.

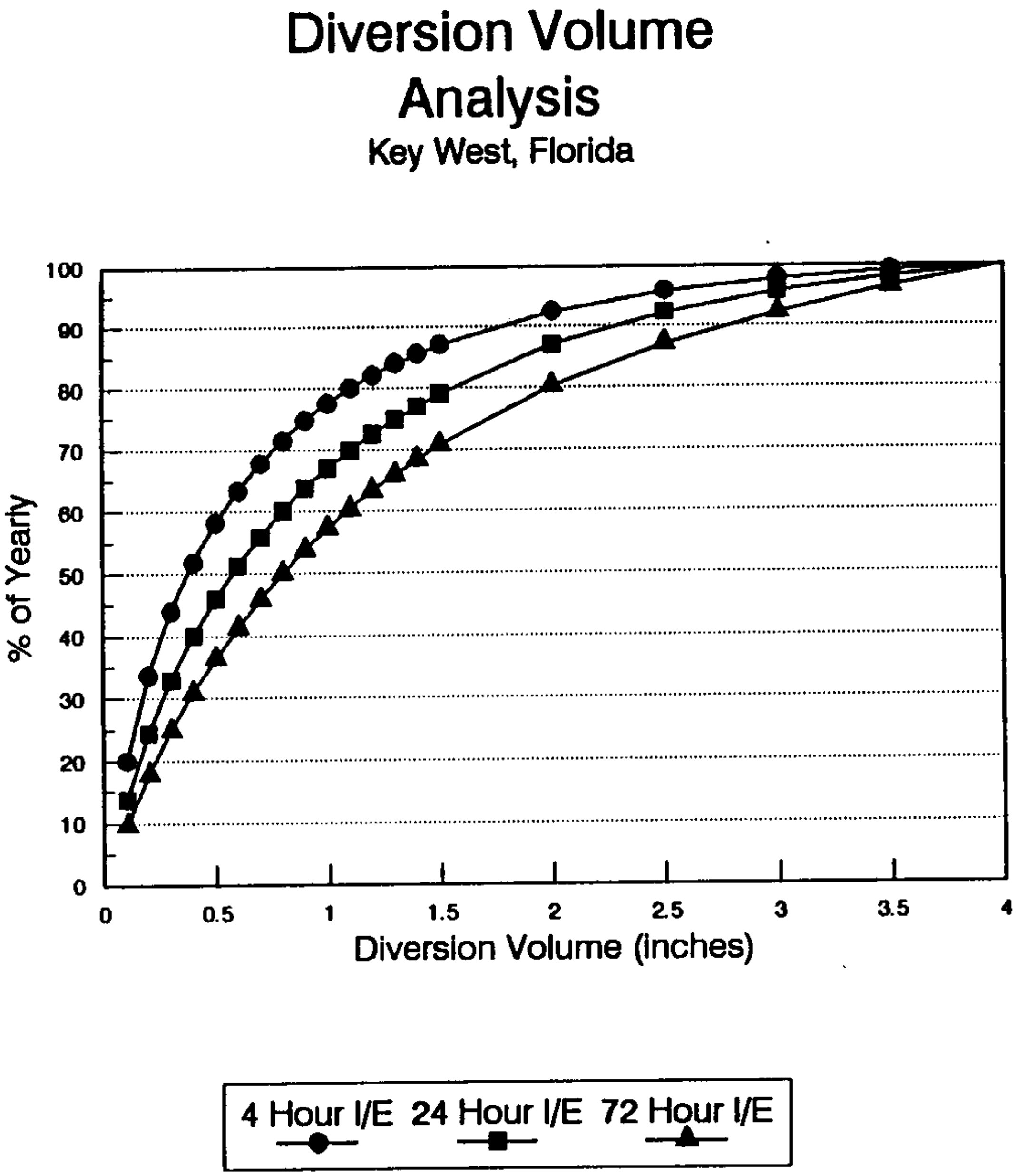

Figure C.7
Percentage of yearly volume diverted for treatment based on 15 years of data for Key West, Florida.

Diversion Volume Analysis

Lakeland, Florida

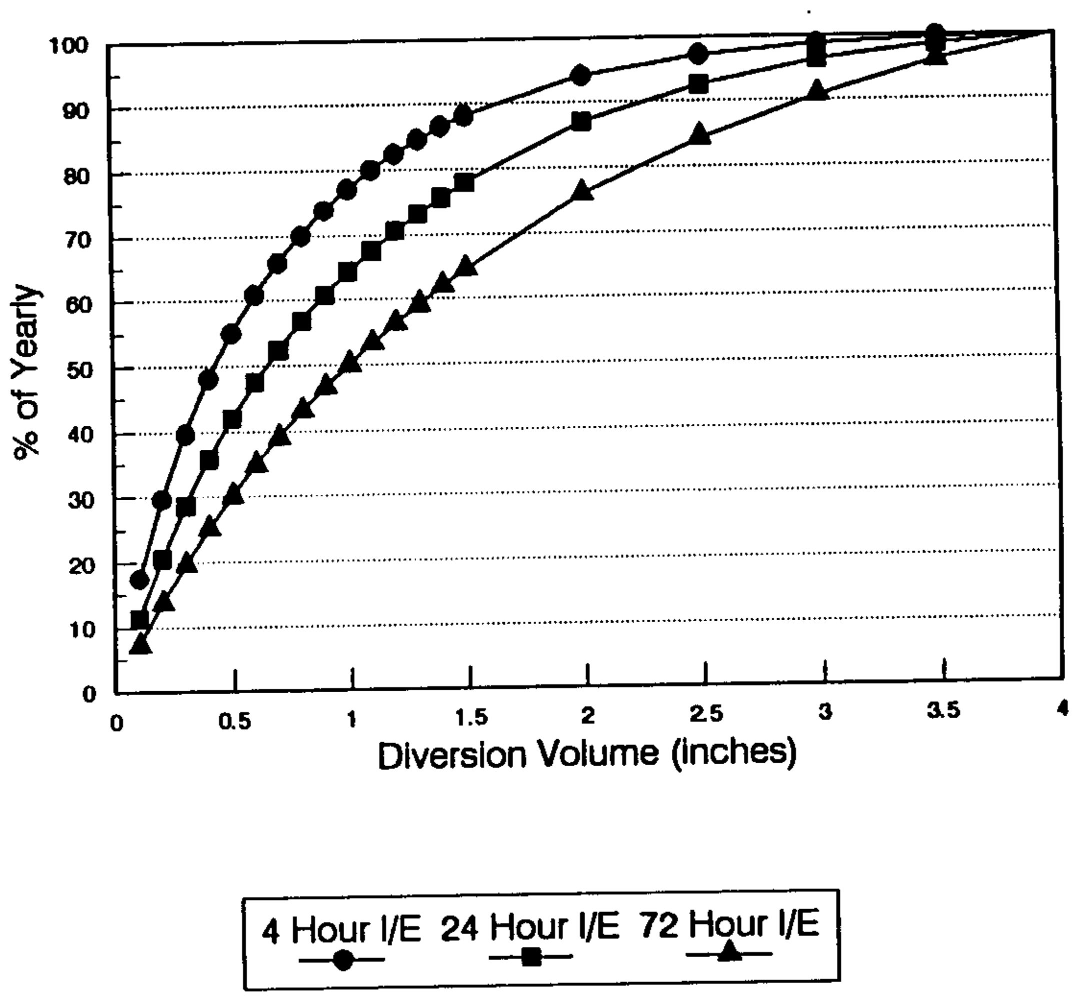

Figure C.8
Percentage of yearly volume diverted for treatment based on 15 years of data for Lakeland, Florida.

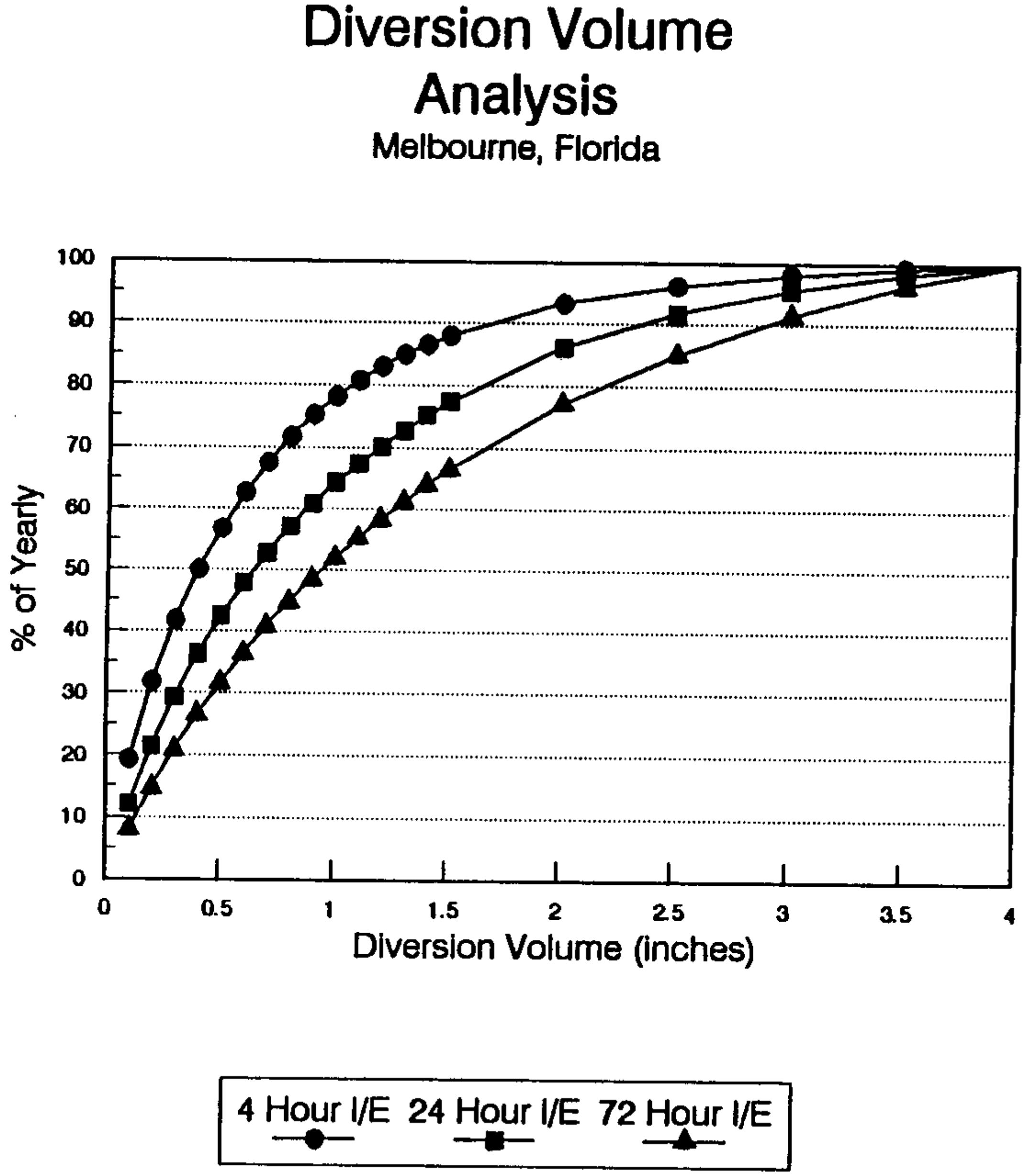

Figure C.9
Percentage of yearly volume diverted for treatment based on 15 years of data for Melbourne, Florida.

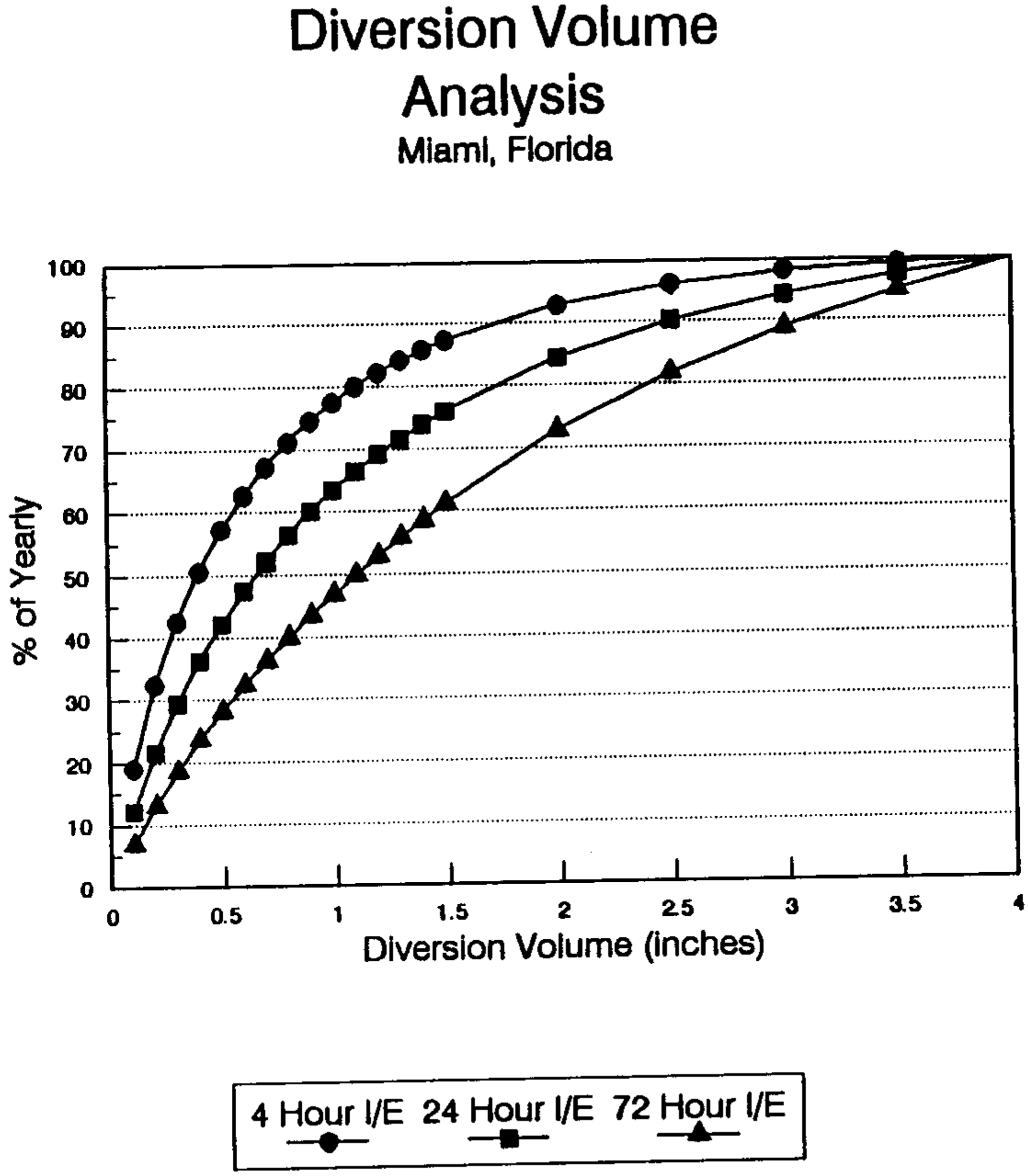

Figure C.10
Percentage of yearly volume diverted for treatment based on 15 years of data for Miami, Florida.

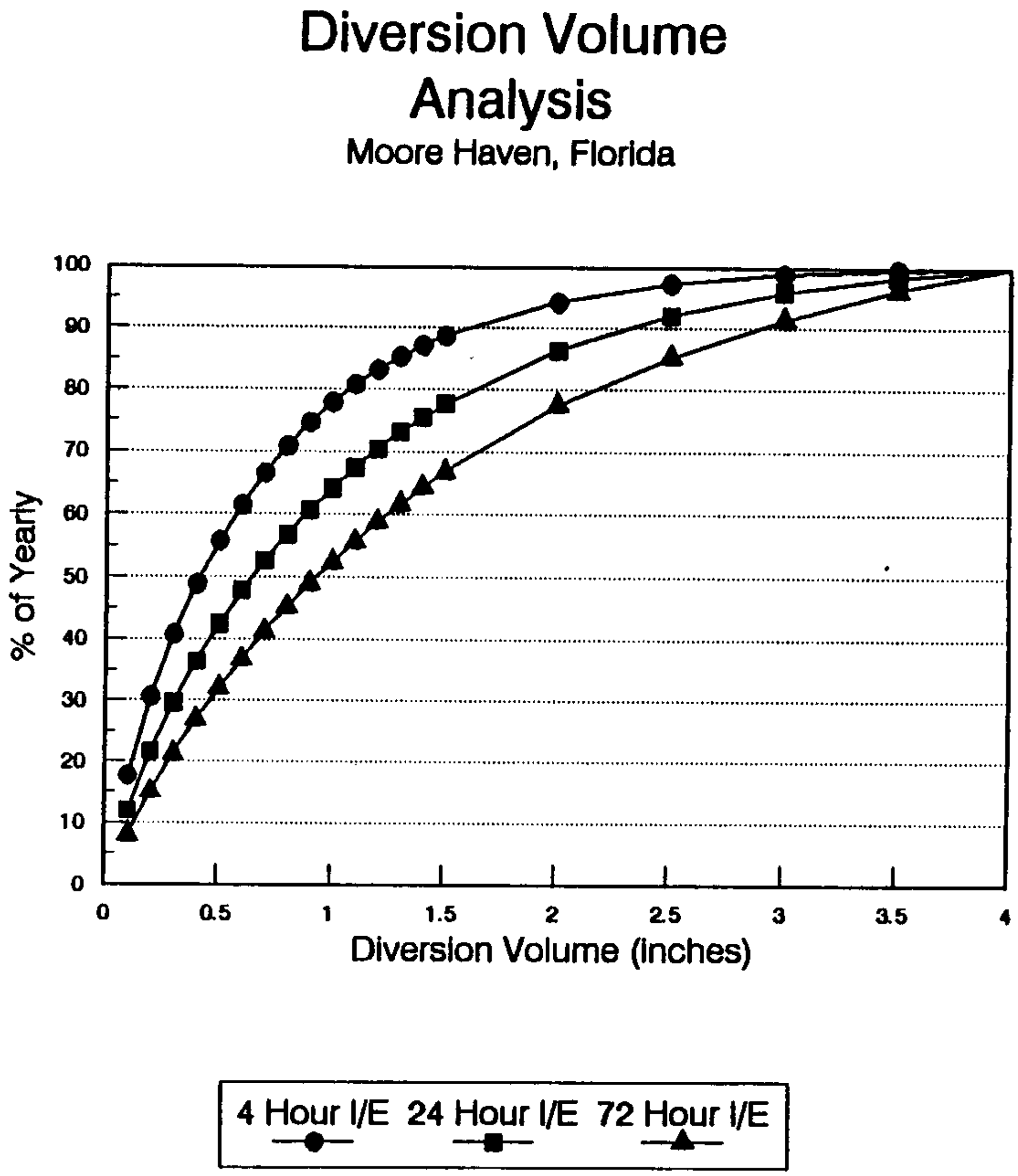

Figure C.11
Percentage of yearly volume diverted for treatment based on 15 years of data for Moore Haven, Florida.

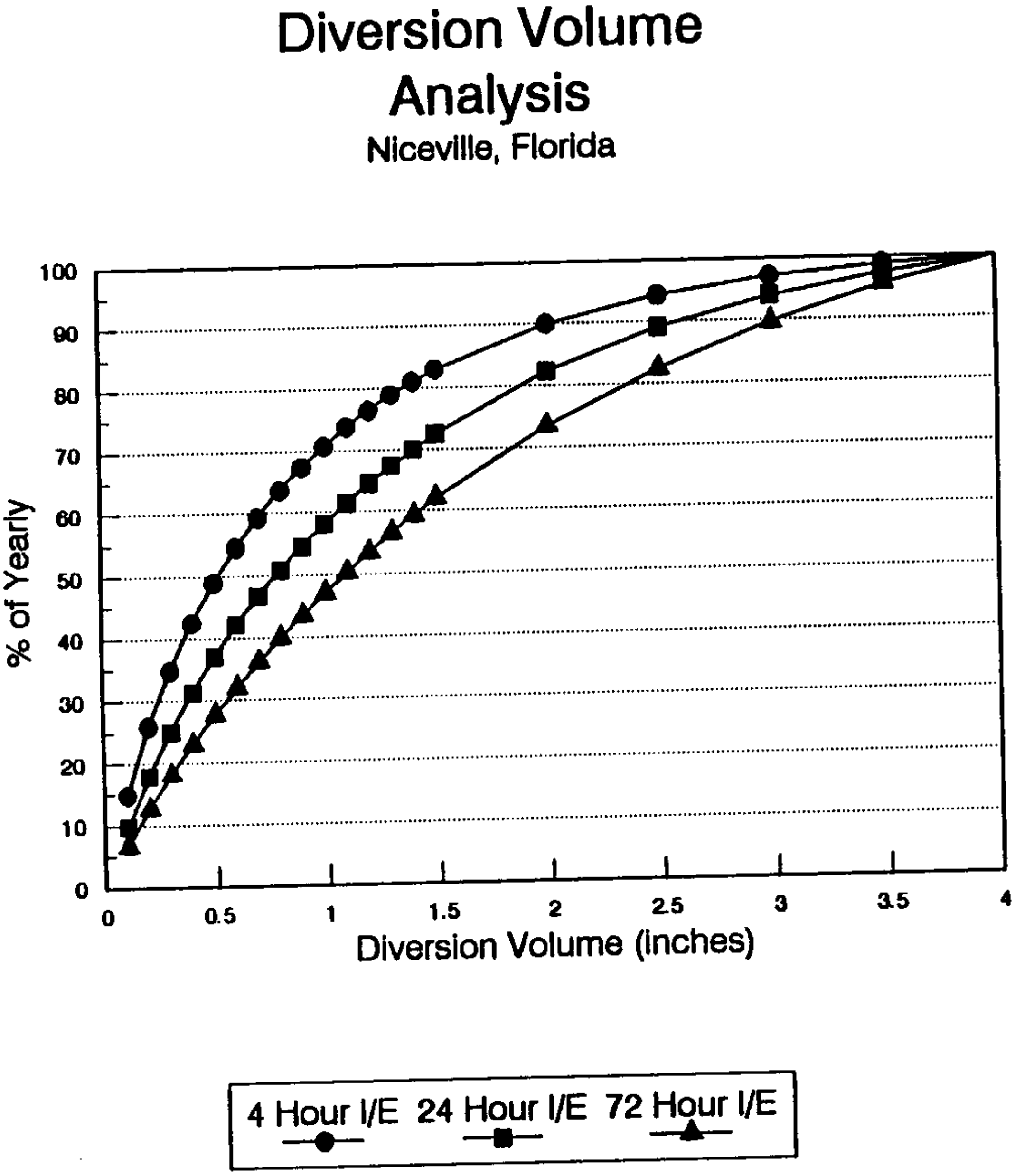

Figure C.12
Percentage of yearly volume diverted for treatment based on 15 years of data for Niceville, Florida.

Diversion Volume Analysis

Orlando, Florida

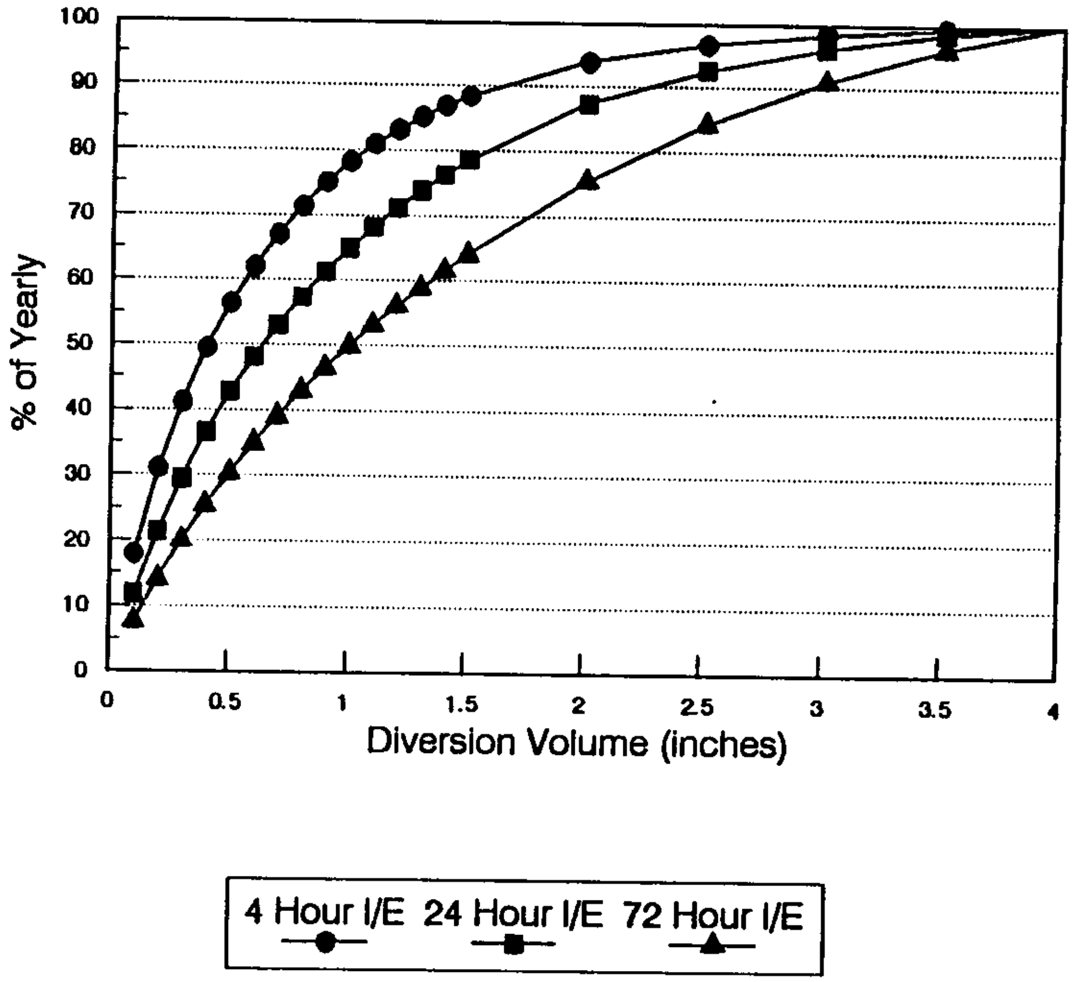

Figure C.13
Percentage of yearly volume diverted for treatment based on 15 years of data for Orlando, Florida.

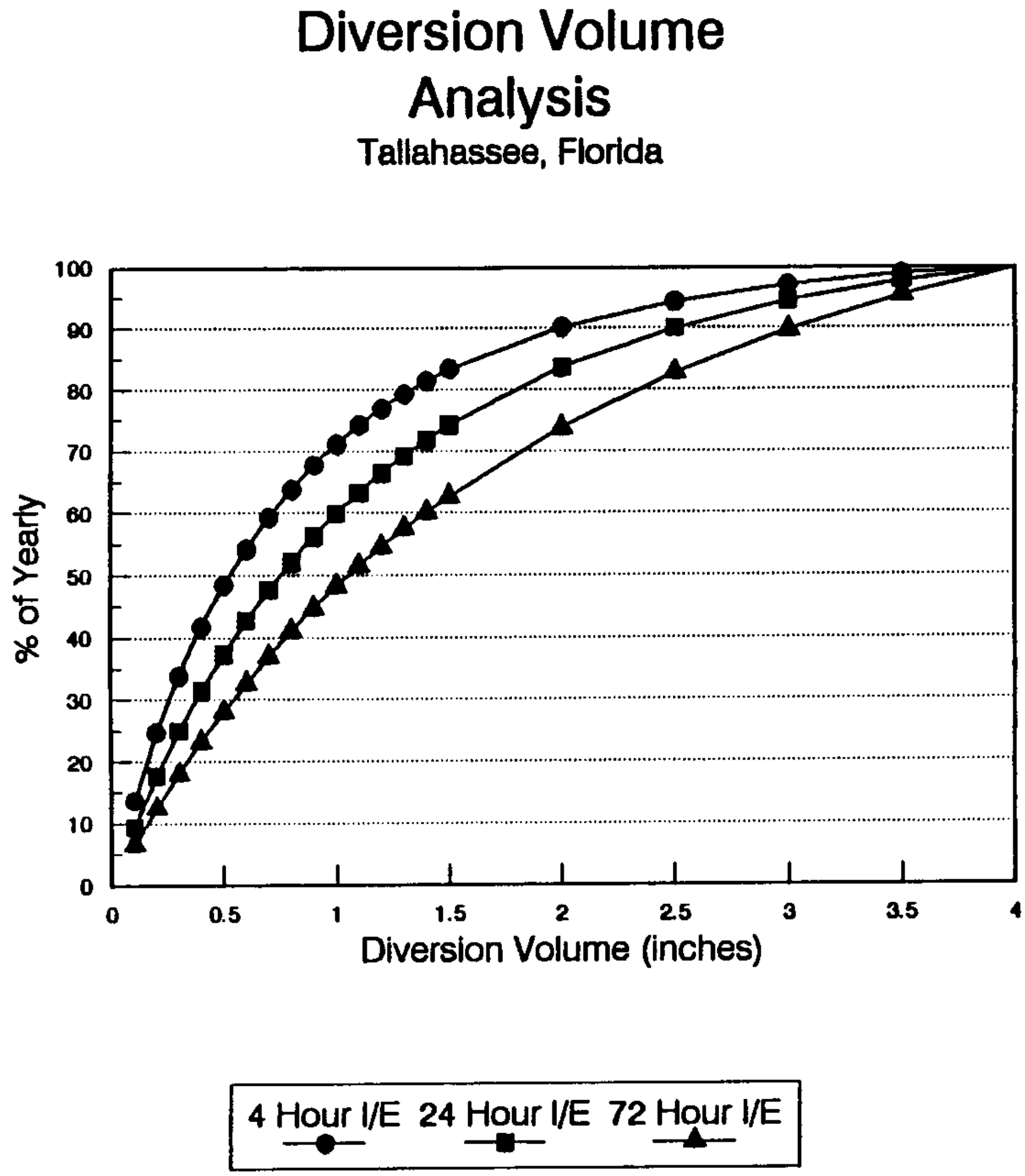

Figure C.15
Percentage of yearly volume diverted for treatment based on 15 years of data for Tallahassee, Florida.

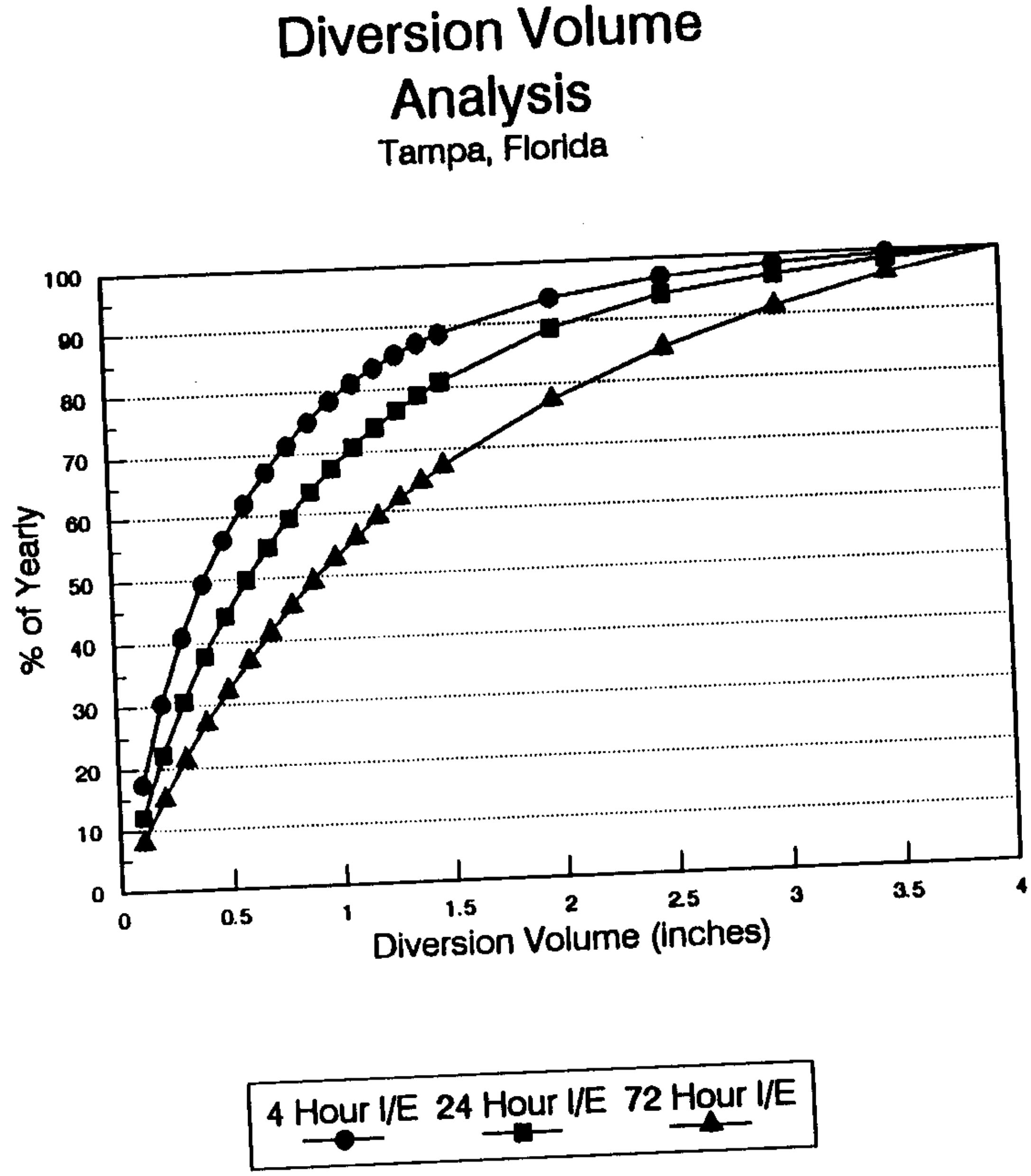

Figure C.16
Percentage of yearly volume diverted for treatment based on 15 years of data for Tampa, Florida.

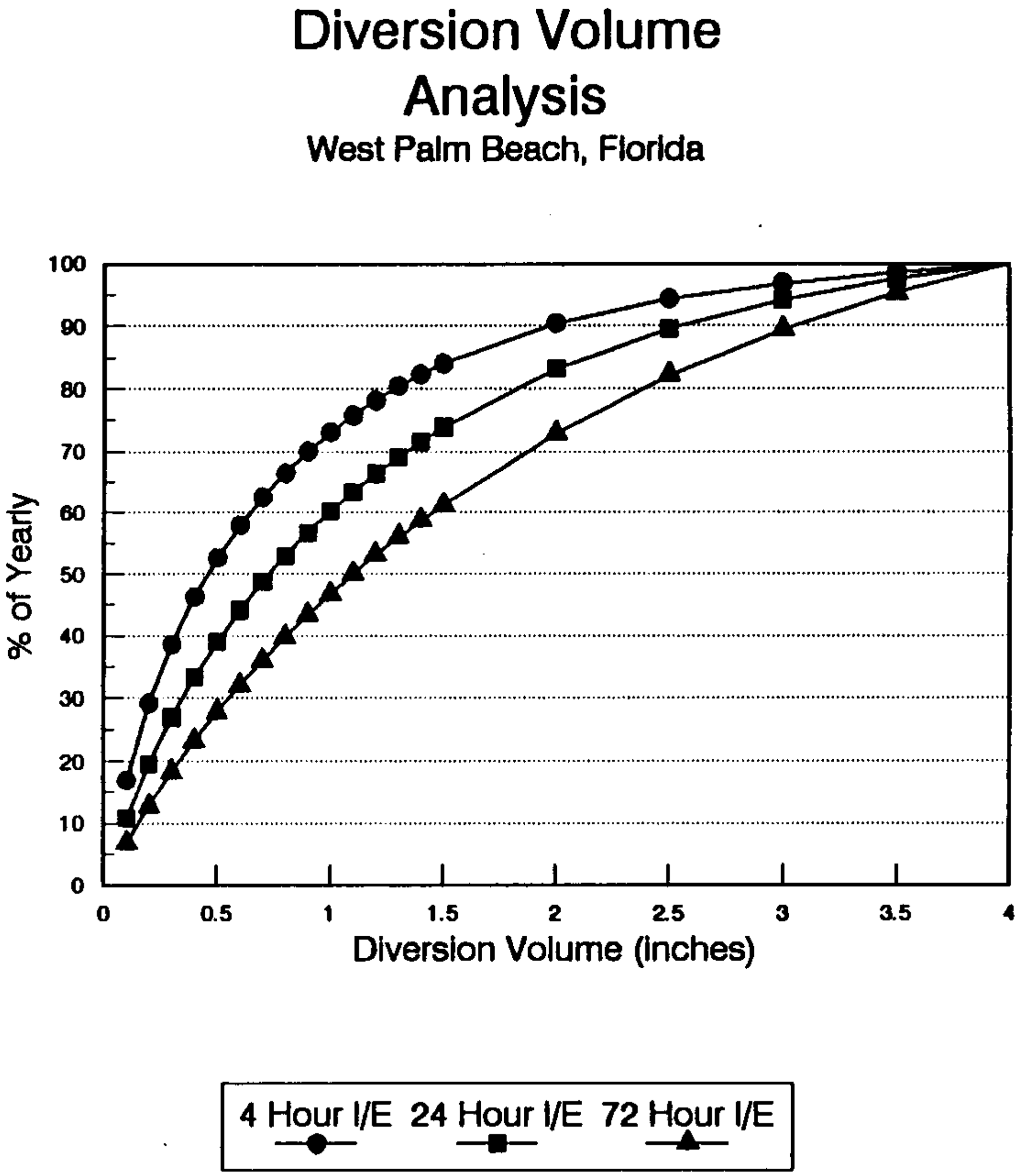

Figure C.17
Percentage of yearly volume diverted for treatment based on 15 years of data for West Palm Beach, Florida.

APPENDIX D

PRECIPITATION VOLUME STATISTICS

Table D.1 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Apalachicola, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.63	0.77	0.96	1.23	1.54	1.93	2.43
Maximum Precipitation Volume (inches)	9.86	10.25	12.43	15.12	15.12	16.00	30.57
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.93	1.10	1.36	1.65	1.98	2.46	3.23
Variance	0.86	1.22	1.86	2.71	3.93	6.07	10.46
Coefficient of Variation	1.46	1.43	1.42	1.34	1.28	1.27	1.33
Total Number of Storms	1,311.00	1,081.00	867.00	675.00	539.00	430.00	342.00
Number of Storms Per Year	87.40	72.07	57.80	45.00	35.93	28.67	22.80

Precipitation >= 0.04 inches

Table D.2 Precipitation Volume Statistical Information As a Function of Minimun Inter-Event Time Period For Daytona Beach, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.53	0.61	0.83	1.10	1.34	1.70	2.13
Maximum Precipitation Volume (inches)	5.88	6.49	8.50	8.86	10.42	14.27	15.85
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.70	0.80	1.09	1.38	1.66	2.15	2.54
Variance	0.49	0.65	1.19	1.90	2.76	4.60	6.47
Coefficient of Variation	1.33	0.32	1.31	1.25	1.24	1.26	1.19
Total Number of Storms	1,384.00	1,191.00	876.00	662.00	544.00	428.00	342.00
Number of Storms Per Year	92.27	79.40	58.40	44.13	36.27	28.53	22.80

Precipitation >= 0.04 inches

Table D.3 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Ft. Myers, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.54	0.64	0.92	1.36	1.82	2.36	2.81
Maximum Precipitation Volume (inches)	8.36	8.63	9.61	13.10	15.75	46.74	46.74
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.75	0.87	1.23	1.76	2.50	4.20	5.36
Variance	0.56	0.75	1.52	3.10	6.25	17.61	28.76
Coefficient of Variation	1.38	1.35	1.33	1.30	1.37	1.78	1.91
Total Number of Storms	1,386.00	1,172.00	817.00	557.00	415.00	320.00	269.00
Number of Storms Per Year	92.40	78.13	54.47	37.13	27.67	21.33	17.93

Precipitation >= 0.04 inches

Table D.4 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Gainesville, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.50	0.60	0.77	1.05	1.34	1.74	2.13
Maximum Precipitation Volume (inches)	6.80	8.00	8.00	10.80	14.90	20.00	20.00
Minimum Precipitation Volume (inches)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Standard Deviation (inches)	0.65	0.76	0.93	1.28	1.62	2.22	2.73
Variance	0.42	0.57	0.87	1.63	2.64	4.93	7.43
Coefficient of Variation	1.31	1.26	1.21	1.21	1.21	1.28	1.28
Total Number of Storms	1,305.00	1,084.00	848.00	617.00	484.00	374.00	306.00
Number of Storms Per Year	87.00	72.27	56.53	41.13	32.27	24.93	20.40

Precipitation >= 0.10 inches

Table D.5 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Inglis, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.55	0.69	0.89	1.15	1.45	1.83	2.27
Maximum Precipitation Volume (inches)	10.90	15.10	15.10	15.10	15.10	21.80	32.00
Minimum Precipitation Volume (inches)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Standard Deviation (inches)	0.79	0.97	1.23	1.50	1.80	2.33	3.39
Variance	0.62	0.94	1.51	2.25	3.24	5.44	11.52
Coefficient of Variation	1.42	1.41	1.38	1.30	1.24	1.27	1.50
Total Number of Storms	1,342.00	1,080.00	834.00	645.00	512.00	405.00	327.00
Number of Storms Per Year	89.47	72.00	55.60	43.00	34.13	27.00	21.80

Precipitation >= 0.10 inches

Table D.6 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Jacksonville, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.52	0.62	0.79	1.04	1.34	1.65	2.05
Maximum Precipitation Volume (inches)	10.57	10.57	10.57	12.48	16.50	16.50	17.96
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.71	0.84	1.03	1.33	1.64	1.97	2.50
Variance	0.50	0.71	1.06	1.78	2.68	3.88	6.24
Coefficient of Variation	1.36	1.36	1.30	1.28	1.22	1.20	1.22
Total Number of Storms	1,399.00	1,178.00	926.00	701.00	545.00	444.00	356.00
Number of Storms Per Year	93.27	78.53	61.73	46.73	36.33	29.60	23.73

Precipitation >= 0.04 inches

Table D.7 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Key West, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.45	0.56	0.71	0.92	1.13	1.38	1.70
Maximum Precipitation Volume (inches)	23.28	24.39	24.39	24.96	27.41	27.41	27.41
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.96	1.14	1.38	1.68	2.00	2.22	2.55
Variance	0.93	1.29	1.90	2.81	3.99	4.94	6.51
Coefficient of Variation	2.12	2.04	1.95	1.81	1.77	1.61	1.50
Total Number of Storms	1,265.00	1,032.00	812.00	622.00	510.00	417.00	338.00
Number of Storms Per Year	84.33	68.80	54.13	41.47	34.00	27.80	22.53

Precipitation >= 0.04 inches

Table D.8 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Lakeland, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.50	0.60	0.83	1.17	1.52	1.97	2.43
Maximum Precipitation Volume (inches)	5.50	6.60	7.61	11.94	16.00	22.40	33.00
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.05
Standard Deviation (inches)	0.64	0.76	1.02	1.46	1.99	2.74	3.71
Variance	0.41	0.57	1.03	2.14	3.97	7.50	13.79
Coefficient of Variation	1.27	1.27	1.22	1.25	1.31	1.39	1.53
Total Number of Storms	1,481.00	1,249.00	898.00	640.00	491.00	380.00	308.00
Number of Storms Per Year	98.73	83.27	59.87	42.67	32.73	25.33	20.53

Precipitation >= 0.04 inches

Table D.9 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Melbourne, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.46	0.58	0.78	1.04	1.25	1.53	1.79
Maximum Precipitation Volume (inches)	7.10	8.50	8.80	8.80	12.70	12.80	16.40
Minimum Precipitation Volume (inches)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Standard Deviation (inches)	0.64	0.80	1.05	1.31	1.60	1.85	2.20
Variance	0.41	0.63	1.11	1.71	2.57	3.43	4.86
Coefficient of Variation	1.39	1.38	1.35	1.25	1.28	1.21	1.23
Total Number of Storms	1,326.00	1,059.00	787.00	586.00	488.00	401.00	342.00
Number of Storms Per Year	88.40	70.60	52.47	39.07	32.53	26.73	22.80

Precipitation >= 0.10 inches

Table D.10 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Miami, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.46	0.58	0.80	1.20	1.71	2.13	2.64
Maximum Precipitation Volume (inches)	16.21	16.21	16.21	16.21	16.21	24.60	24.60
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.79	0.98	1.31	1.73	2.40	3.05	3.72
Variance	0.63	0.96	1.71	2.99	5.74	9.33	13.81
Coefficient of Variation	1.72	1.68	1.63	1.45	1.40	1.43	1.41
Total Number of Storms	1,768.00	1,399.00	1,014.00	681.00	476.00	382.00	308.00
Number of Storms Per Year	117.87	93.27	67.60	45.40	31.73	25.47	20.53

Precipitation >=0.04 inches

Table D.11 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Moore Haven, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.49	0.55	0.77	1.07	1.35	1.71	2.13
Maximum Precipitation Volume (inches)	4.70	5.25	6.18	9.87	17.11	21.05	32.61
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.63	0.69	0.98	1.41	1.89	2.45	3.31
Variance	0.39	0.47	0.96	1.99	3.57	6.00	10.99
Coefficient of Variation	1.27	1.24	1.27	1.32	1.40	1.43	1.56
Total Number of Storms	1,258.00	1,124.00	802.00	581.00	461.00	363.00	292.00
Number of Storms Per Year	85.77	76.64	54.68	39.61	31.43	24.75	19.91

Precipitation >=0.04 inches

Table D.12 Precipitation Volume Statistical Information As a Function of Minimum Inter- Event Time Period For Niceville, Florida, 15 Years of Data (1970,1971,1973-1981,1985-1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.62	0.81	1.03	1.34	1.70	2.27	2.99
Maximum Precipitation Volume (inches)	12.30	15.60	15.60	15.80	15.80	18.90	26.60
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.91	1.15	1.35	1.64	2.02	2.73	3.60
Variance	0.82	1.32	1.81	2.71	4.09	7.47	12.96
Coefficient of Variation	1.45	1.42	1.31	1.23	1.19	1.20	1.20
Total Number of Storms	1,577.00	1,212.00	958.00	734.00	578.00	430.00	326.00
Number of Storms Per Year	105.10	80.80	63.90	48.90	38.50	28.70	21.70

Precipitation >=0.04 inches

Table D.13 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Orlando, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.49	0.55	0.78	1.09	1.41	1.85	2.22
Maximum Precipitation Volume (inches)	5.87	10.74	10.74	10.74	13.32	16.88	22.46
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.64	0.74	1.00	1.36	1.82	2.41	3.11
Variance	0.41	0.55	1.00	1.85	3.30	5.83	9.70
Coefficient of Variation	1.31	1.36	1.28	1.25	1.29	1.31	1.40
Total Number of Storms	1,448.00	1,296.00	903.00	649.00	502.00	383.00	318.00
Number of Storms Per Year	96.53	86.40	60.20	43.27	33.47	25.53	21.20

Precipitation >=0.04 inches

Table D.14 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Parrish/Bradenton, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.52	0.63	0.85	1.16	1.49	1.90	2.33
Maximum Precipitation Volume (inches)	4.80	11.70	11.70	12.00	13.70	21.60	24.80
Minimum Precipitation Volume (inches)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Standard Deviation (inches)	0.63	0.80	1.05	1.43	2.15	2.84	3.61
Variance	0.40	0.65	1.11	2.06	4.60	8.08	13.01
Coefficient of Variation	1.23	1.29	1.24	1.23	1.44	1.50	1.55
Total Number of Storms	1,462.00	1,209.00	892.00	651.00	508.00	398.00	324.00
Number of Storms Per Year	98.58	81.52	60.15	43.90	34.25	26.84	21.85

Precipitation >= 0.10 inches

Table D.15 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Tallahassee, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.67	0.79	1.03	1.37	1.74	2.18	2.82
Maximum Precipitation Volume (inches)	8.84	8.94	9.60	10.72	20.04	20.49	23.63
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.86	1.02	1.27	1.58	2.18	2.60	3.52
Variance	0.74	1.03	1.60	2.50	4.75	6.74	12.42
Coefficient of Variation	1.29	1.29	1.23	1.15	1.25	1.19	1.25
Total Number of Storms	1,449.00	1,223.00	936.00	701.00	554.00	440.00	339.00
Number of Storms Per Year	96.60	81.53	62.40	46.73	36.93	29.33	22.60

Precipitation >= 0.04 inches

Table D.16 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For Tampa, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.54	0.58	0.78	1.06	1.32	1.63	1.97
Maximum Precipitation Volume (inches)	11.45	12.98	12.98	13.65	14.57	17.58	18.02
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.70	0.85	1.07	1.47	1.79	2.34	2.96
Variance	0.49	0.73	1.14	2.17	3.20	5.46	8.78
Coefficient of Variation	1.38	1.46	1.36	1.39	1.35	1.44	1.50
Total Number of Storms	1,300.00	1,141.00	847.00	628.00	501.00	408.00	336.00
Number of Storms Per Year	86.67	76.07	56.47	41.87	33.40	27.20	22.40

Precipitation >= 0.04 inches

Table D.17 Precipitation Volume Statistical Information As a Function of Minimum Inter-Event Time Period For West Palm Beach, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Precipitation Volume (inches)	0.53	0.65	0.91	1.30	1.71	2.19	2.91
Maximum Precipitation Volume (inches)	8.78	11.34	11.34	12.65	15.19	20.30	21.89
Minimum Precipitation Volume (inches)	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Standard Deviation (inches)	0.81	0.99	1.31	1.77	2.29	2.93	3.80
Variance	0.66	0.97	1.72	3.13	5.22	8.57	14.42
Coefficient of Variation	1.54	1.53	1.44	1.36	1.34	1.34	1.31
Total Number of Storms	1,749.00	1,425.00	1,011.00	707.00	538.00	420.00	316.00
Number of Storms Per Year	116.60	95.00	67.40	47.13	35.87	28.00	21.07

Precipitation >= 0.04 inches

APPENDIX E

STORM DURATION STATISTICS

Table E.1 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Apalachicola, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	5.5	8.0	14.2	28.0	49.9	83.6	133.2
Total Number of Storm Events	1,311.0	1,081.0	867.0	675.0	539.0	430.0	342.0
Maximum Storm Duration (hours)	45.0	72.0	147.0	273.0	455.0	911.0	1,802.0
Standard Deviation (hours)	5.3	9.3	19.0	36.9	67.1	118.2	182.7
Variance	27.9	87.1	361.8	1,363.6	4,504.1	13,974.0	33,359.8
Coefficient of Variation	1.0	1.2	1.3	1.3	1.3	1.4	1.4
Number of Storms Per Year	87.4	72.1	57.8	45.0	35.9	28.7	22.8

Precipitation >= 0.04 inches

Table E.2 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Daytona Beach, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	4.8	6.7	15.4	31.2	51.0	87.1	135.9
Total Number of Storm Events	1,384.0	1,191.0	876.0	662.0	544.0	428.0	342.0
fMaximum Storm Duration (hours)	47.0	72.0	127.0	277.0	619.0	859.0	1,052.0
Standard Deviation (hours)	4.9	8.4	19.8	44.4	73.1	122.5	175.8
Variance	23.6	70.4	390.3	1,974.9	5,348.9	15,000.7	30,903.3
Coefficient of Variation	1.0	1.3	1.3	1.4	1.4	1.4	1.3
Number of Storms Per Year	92.3	79.4	58.4	44.1	36.3	28.5	22.8

Precipitation >= 0.04 inches

Table E.3 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Ft. Myers, Florida, 15 Years of Data (1974.- 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	2.6	4.4	14.2	37.3	70.3	115.8	158.0
Total Number of Storm Events	1,386.0	1,172.0	817.0	557.0	415.0	320.0	269.0
Maximum Storm Duration (hours)	41.0	52.0	315.0	362.0	745.0	2,715.0	2,715.0
Standard Deviation (hours)	2.8	6.0	23.5	54.9	113.5	234.0	315.7
Variance	7.9	36.5	552.1	3,011.2	12,876.2	54,741.7	99,658.4
Coefficient of Variation	1.1	1.4	1.7	1.5	1.6	2.0	2.0
Number of Storms Per Year	92.4	78.1	54.5	37.1	27.7	21.3	17.9

Precipitation >= 0.10 inches

Table E.4 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Gainesville, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	2.9	4.9	11.2	27.9	51.8	91.4	135.5
Total Number of Storm Events	1,305.0	1,084.0	848.0	617.0	484.0	374.0	306.0
Maximum Storm Duration (hours)	30.0	54.0	116.0	356.0	674.0	1,092.0	1,723.0
Standard Deviation (hours)	3.2	6.6	15.6	40.6	80.5	139.2	207.8
Variance	10.3	43.0	243.4	1,650.8	6,475.1	19,362.0	43,188.0
Coefficient of Variation	1.1	1.4	1.4	1.5	1.6	1.5	1.5
Number of Storms Per Year	87.0	72.3	56.5	41.1	32.3	24.9	20.4

Precipitation >= 0.10 inches

Table E.5 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Inglis, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	3.0	5.4	12.1	25.3	47.2	81.6	126.8
Total Number of Storm Events	1,342.0	1,080.0	834.0	645.0	512.0	405.0	327.0
Maximum Storm Duration (hours)	46.0	88.0	163.0	216.0	713.0	808.0	1,828.0
Standard Deviation (hours)	3.5	7.5	17.6	36.4	76.1	125.7	214.6
Variance	12.1	55.9	309.8	1,325.5	5,785.2	15,810.1	46,036.9
Coefficient of Variation	1.2	1.4	1.5	1.4	1.6	1.5	1.7
Number of Storms Per Year	89.5	72.0	55.6	43.0	34.1	27.0	21.8

Precipitation >= 0.10 inches

Table E.6 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Jacksonville, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	5.3	7.5	14.3	30.6	56.7	88.8	137.2
Total Number of Storm Events	1,399.0	1,178.0	926.0	701.0	545.0	444.0	356.0
Maximum Storm Duration (hours)	53.0	69.0	147.0	243.0	490.0	621.0	1,298.0
Standard Deviation (hours)	5.2	9.0	18.7	41.6	71.9	113.5	175.0
Variance	26.7	81.0	349.3	1,728.0	5,164.3	12,891.3	30,632.4
Coefficient of Variation	1.0	1.2	1.3	1.4	1.3	1.3	1.3
Number of Storms Per Year	93.3	78.5	61.7	46.7	36.3	29.6	23.7

Precipitation >= 0.04 inches

Table E.7 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Key West, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	3.8	6.1	12.5	26.9	45.8	74.7	117.1
Total Number of Storm Events	1,265.0	1,032.0	812.0	622.0	510.0	417.0	338.0
Maximum Storm Duration (hours)	35.0	77.0	104.0	233.0	489.0	697.0	1,232.0
Standard Deviation (hours)	4.0	8.0	17.1	40.1	67.0	103.3	166.2
Variance	15.7	64.7	292.2	1,604.4	4,482.1	10,673.1	27,605.0
Coefficient of Variation	1.1	1.3	1.4	1.5	1.5	1.4	1.4
Number of Storms Per Year	84.3	68.8	54.1	41.5	34.0	27.8	22.5

Precipitation >= 0.04 inches

Table E.8 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Lakeland, Florida 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	3.1	5.0	14.0	33.1	61.3	104.3	154.2
Total Number of Storm Events	1,481.0	1,249.0	898.0	640.0	491.0	380.0	308.0
Maximum Storm Duration (hours)	28.0	58.0	156.0	372.0	866.0	1,050.0	1,684.0
Standard Deviation (hours)	3.3	6.8	20.1	49.6	99.0	165.8	250.8
Variance	11.0	45.7	404.0	2,457.6	9,803.5	27,503.2	62,903.5
Coefficient of Variation	1.1	1.4	1.4	1.5	1.6	1.6	1.6
Number of Storms Per Year	98.7	83.3	59.9	42.7	32.7	25.3	20.5

Precipitation >= 0.04 inches

Table E.9 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Melbourne, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	2.7	5.0	12.8	28.6	46.5	74.4	105.5
Total Number of Storm Events	1,326.0	1,059.0	787.0	586.0	488.0	401.0	342.0
Maximum Storm Duration (hours)	37.0	100.0	127.0	330.0	444.0	557.0	822.0
Standard Deviation (hours)	3.1	7.7	18.8	41.2	66.4	102.0	142.1
Variance	9.4	58.9	353.6	1,694.7	4,411.4	10,402.4	20,197.3
Coefficient of Variation	1.2	1.5	1.5	1.4	1.4	1.4	1.4
Number of Storms Per Year	88.4	70.6	52.5	39.1	32.5	26.7	22.8

Precipitation >= 0.10 inches

Table E.10 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Miami, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	3.9	6.8	16.1	40.5	83.1	123.6	178.7
Total Number of Storm Events	1,768.0	1,399.0	1,014.0	681.0	476.0	382.0	308.0
Maximum Storm Duration (hours)	42.0	119.0	160.0	340.0	687.0	1,253.0	1,668.0
Standard Deviation (hours)	4.1	10.0	23.8	56.5	121.8	180.1	250.9
Variance	16.9	100.9	566.6	3,195.7	14,845.6	32,429.8	62,948.8
Coefficient of Variation	1.0	1.5	1.5	1.4	1.5	1.5	1.4
Number of Storms Per Year	117.9	93.3	67.6	45.4	31.7	25.5	20.5

Precipitation >= 0.04 inches

Table E.11 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Moore Haven, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	4.1	5.4	15.0	33.9	58.4	96.1	146.1
Total Number of Storm Events	1,258.0	1,124.0	802.0	581.0	461.0	363.0	292.0
Maximum Storm Duration (hours)	35.0	74.0	167.0	361.0	631.0	1,511.0	1,762.0
Standard Deviation (hours)	3.6	6.2	21.2	49.5	88.0	148.6	224.0
Variance	13.1	38.4	447.2	2,449.4	7,738.8	22,086.3	50,164.3
Coefficient of Variation	0.9	1.2	1.4	1.5	1.5	1.6	1.5
Number of Storms Per Year	85.8	76.6	54.7	39.6	31.4	24.8	19.9

Precipitation >= 0.04 inches

Table E.12 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Niceville, Florida, 15 Years of Data.

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	3.8	6.9	13.3	27.9	51.7	98.4	164.3
Total Number of Storm Events	1,577.0	1,212.0	958.0	734.0	578.0	430.0	326.0
Maximum Storm Duration (hours)	37.0	74.0	120.0	315.0	588.0	973.0	1,188.0
Standard Deviation (hours)	4.0	9.1	17.8	39.9	72.7	129.0	206.2
Variance	15.8	83.1	314.9	1,590.2	5,289.0	16,645.6	42,536.6
Coefficient of Variation	1.1	1.3	1.3	1.4	1.4	1.3	1.3
Number of Storms Per Year	105.1	80.8	63.9	48.9	38.5	28.7	21.7

Precipitation >= 0.04 inches

Table E.14 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Parrish/Bradenton, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	2.6	4.6	12.8	30.2	55.6	93.9	139.4
Total Number of Storm Events	1,462.0	1,209.0	892.0	651.0	508.0	398.0	324.0
Maximum Storm Duration (hours)	28.0	91.0	100.0	362.0	801.0	1,073.0	1,471.0
Standard Deviation (hours)	2.9	7.1	18.4	45.3	100.3	155.6	226.7
Variance	8.4	50.6	337.2	2,050.0	10,050.7	24,225.2	51,387.9
Coefficient of Variation	1.1	1.5	1.4	1.5	1.8	1.7	1.6
Number of Storms Per Year	98.6	81.5	60.2	43.9	34.3	26.8	21.9

Precipitation >= 0.10 inches

Table E.15 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Tallahassee, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	5.2	7.4	15.2	32.3	56.5	92.7	152.1
Total Number of Storm Events	1,449.0	1,223.0	936.0	701.0	554.0	440.0	339.0
Maximum Storm Duration (hours)	53.0	76.0	120.0	240.0	887.0	982.0	1,223.0
Standard Deviation (hours)	5.1	9.4	18.8	42.2	92.8	132.7	209.7
Variance	26.3	87.5	354.2	1,776.4	8,605.4	17,596.9	43,959.0
Coefficient of Variation	1.0	1.3	1.2	1.3	1.6	1.4	1.4
Number of Storms Per Year	96.6	81.5	62.4	46.7	36.9	29.3	22.6

Precipitation >= 0.04 inches

Table E.16 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For Tampa, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	4.4	6.0	14.5	31.8	54.7	86.3	127.7
Total Number of Storm Events	1,300.0	1,141.0	847.0	628.0	501.0	408.0	336.0
Maximum Storm Duration (hours)	35.0	91.0	121.0	442.0	571.0	1,324.0	1,324.0
Standard Deviation (hours)	4.2	7.7	19.1	50.8	87.4	146.5	213.0
Variance	17.9	59.1	364.3	2,575.4	7,636.8	21,455.8	45,356.0
Coefficient of Variation	1.0	1.3	1.3	1.6	1.6	1.7	1.7
Number of Storms Per Year	86.7	76.1	56.5	41.9	33.4	27.2	22.4

Precipitation >= 0.04 inches

Table E.17 Storm Duration Statistical Information As a Function of Minimum Inter-Event Dry Period For West Palm Beach, Florida, 15 Years of Data (1974 - 1988).

Minimum Dry Period, Δ (hours)	4	12	24	48	72	96	120
Mean Storm Duration (hours)	4.3	6.9	16.8	38.6	68.9	111.6	183.6
Total Number of Storm Events	1,749.0	1,425.0	1,011.0	707.0	538.0	420.0	316.0
Maximum Storm Duration (hours)	48.0	95.0	177.0	392.0	752.0	1,080.0	1,539.0
Standard Deviation (hours)	4.3	8.8	23.0	54.5	98.1	161.4	244.6
Variance	18.1	76.8	528.1	2,969.8	9,625.6	26,032.9	59,825.1
Coefficient of Variation	1.0	1.3	1.4	1.4	1.4	1.5	1.3
Number of Storms Per Year	116.6	95.0	67.4	47.1	35.9	28.0	21.1

Precipitation >= 0.04 inches

APPENDIX F

EXCEEDENCE STATISTICS

Table F.1 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Apalachicola, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.9	8.3	10.4	13.3	16.7	20.9	26.3
3	4	4.6	5.6	6.9	8.9	11.1	14.0	17.5
4	3	3.4	4.2	5.2	6.7	8.3	10.5	13.2
6	2	2.3	2.8	3.5	4.4	5.6	7.0	8.8

Table F.2 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Daytona Beach, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.5	7.6	10.3	13.6	16.5	21.0	26.3
3	4	4.3	5.0	6.8	9.1	11.0	14.0	17.5
4	3	3.3	3.8	5.1	6.8	8.3	10.5	13.2
6	2	2.2	2.5	3.4	4.5	5.5	7.0	8.8

Table F.4 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Gainesville, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.9	8.3	10.6	14.6	18.6	24.1	29.4
3	4	4.6	5.5	7.1	9.7	12.4	16.0	19.6
4	3	3.4	4.2	5.3	7.3	9.3	12.0	14.7
6	2	2.3	2.8	3.5	4.9	6.2	8.0	9.8

Table F.5 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Inglis, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.7	8.3	10.8	14.0	17.6	22.2	27.5
3	4	4.5	5.6	7.2	9.3	11.7	14.8	18.3
4	3	3.4	4.2	5.4	7.0	8.8	11.1	13.8
6	2	2.2	2.8	3.6	4.7	5.9	7.4	9.2

Table F.6 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Jacksonville, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.4	7.6	9.7	12.8	16.5	20.3	25.3
3	4	4.3	5.1	6.5	8.6	11.0	13.5	16.9
4	3	3.2	3.8	4.9	6.4	8.3	10.1	12.6
6	2	2.1	2.5	3.2	4.3	5.5	6.8	8.4

Table F.7 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Key West, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	7.1	8.7	11.1	14.5	17.6	21.6	26.6
3	4	4.7	5.8	7.4	9.6	11.8	14.4	17.8
4	3	3.6	4.4	5.5	7.2	8.8	10.8	13.3
6	2	2.4	2.9	3.7	4.8	5.9	7.2	8.9

Table F.8 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Lakeland, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.1	7.2	10.0	14.1	18.3	23.7	29.2
3	4	4.1	4.8	6.7	9.4	12.2	15.8	19.5
4	3	3.0	3.6	5.0	7.0	9.2	11.8	14.6
6	2	2.0	2.4	3.3	4.7	6.1	7.9	9.7

Table F.9 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Melbourne, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.8	8.5	11.4	15.4	18.4	22.4	26.3
3	4	4.5	5.7	7.6	10.2	12.3	15.0	17.5
4	3	3.4	4.2	5.7	7.7	9.2	11.2	13.2
6	2	2.3	2.8	3.8	5.1	6.1	7.5	8.8

Table F.10 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Miami, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	5.1	6.4	8.9	13.2	18.9	23.6	29.2
3	4	3.4	4.3	5.9	8.8	12.6	15.7	19.5
4	3	2.5	3.2	4.4	6.6	9.5	11.8	14.6
6	2	1.7	2.1	3.0	4.4	6.3	7.9	9.7

Table F.11 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Moore Haven, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	7.0	7.8	11.0	15.1	19.1	24.2	30.1
3	4	4.7	5.2	7.3	10.1	12.7	16.2	20.1
4	3	3.5	3.9	5.5	7.6	9.5	12.1	15.1
6	2	2.3	2.6	3.7	5.0	6.4	8.1	10.0

Table F.12 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Niceville, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	5.7	7.4	9.4	12.3	15.6	20.9	27.6
3	4	3.8	5.0	6.3	8.2	10.4	14.0	18.4
4	3	2.9	3.7	4.7	6.1	7.8	10.5	13.8
6	2	1.9	2.5	3.1	4.1	5.2	7.0	9.2

Table F.13 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Orlando, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.2	6.9	10.0	13.9	17.9	23.5	28.3
3	4	4.1	4.6	6.6	9.2	12.0	15.7	18.9
4	3	3.1	3.5	5.0	6.9	9.0	11.7	14.2
6	2	2.1	2.3	3.3	4.6	6.0	7.8	9.4

Table F.14 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Parrish / Bradenton, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.1	7.4	10.0	13.7	17.5	22.4	27.5
3	4	4.1	4.9	6.7	9.1	11.7	14.9	18.3
4	3	3.0	3.7	5.0	6.8	8.8	11.2	13.7
6	2	2.0	2.5	3.3	4.6	5.8	7.5	9.2

Table F.15 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Tallahassee, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.2	7.4	9.6	12.8	16.2	20.5	26.5
3	4	4.1	4.9	6.4	8.6	10.8	13.6	17.7
4	3	3.1	3.7	4.8	6.4	8.1	10.2	13.3
6	2	2.1	2.5	3.2	4.3	5.4	6.8	8.8

Table F.16 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period Tampa, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	6.9	7.9	10.6	14.3	18	22.1	26.8
3	4	4.6	5.3	7.1	9.6	12	14.7	17.9
4	3	3.5	3.9	5.3	7.2	9	11.0	13.4
6	2	2.3	2.6	3.5	4.8	6	7.4	8.9

Table F.17 Number and percentage of yearly storms exceeding the precipitation volume associated with a given Return Period and Minimum Inter-Event Dry Period West Palm Beach, Florida.

Return Period (Months)	No. / Year Exceeding	4 Hour Δ %	12 Hour Δ %	24 Hour Δ %	48 Hour Δ %	72 Hour Δ %	96 Hour Δ %	120 Hour Δ %
2	6	5.1	6.3	8.9	12.7	16.7	21.4	28.5
3	4	3.4	4.2	5.9	8.5	11.2	14.3	19.0
4	3	2.6	3.2	4.5	6.4	8.4	10.7	14.2
6	2	1.7	2.1	3.0	4.2	5.6	7.1	9.5

APPENDIX G

SENSITIVITY ANALYSIS FOR RAIN GAUGE ACCURACY

Sensitivity Analysis For Daytona Beach, Florida					
I/E Dry Period	Minimum Storm Reading For Gauge And Percent Difference	Mean Precipitation (in.) For Return Periods (Mo.)			
		2	3	4	6
4 Hour	0.04 / Universal	1.65	2.04	2.31	2.68
	0.10 / Fisher-Porter	1.65	2.04	2.31	2.58
	% Difference	0.00	0.00	0.00	3.73
12 Hour	0.04 / Universal	1.80	2.20	2.47	2.93
	0.10 / Fisher-Porter	1.81	2.16	2.40	2.86
	% Difference	-0.56	1.82	2.83	2.39
24 Hour	0.04 / Universal	2.03	2.65	3.18	3.70
	0.10 / Fisher-Porter	1.98	2.62	3.15	3.70
	% Difference	2.46	1.13	0.94	0.00
48 Hour	0.04 / Universal	2.38	3.17	3.81	4.32
	0.10 / Fisher-Porter	2.28	2.95	3.57	4.06
	% Difference	4.20	6.94	6.30	6.02
72 Hour	0.04 / Universal	2.46	3.53	4.02	4.70
	0.10 / Fisher-Porter	2.36	3.35	3.90	4.40
	% Difference	4.07	5.10	2.99	6.38
96 Hour	0.04 / Universal	2.71	3.83	4.50	5.40
	0.10 / Fisher-Porter	2.60	3.67	4.30	5.20
	% Difference	4.06	4.18	4.44	3.70
120 Hour	0.04 / Universal	2.78	4.10	5.04	6.05
	0.10 / Fisher-Porter	2.76	3.90	4.63	5.30
	% Difference	0.72	4.88	8.13	12.40

Table G-1 Sensitivity Analysis For Rain Gauge Accuracy For Daytona Beach, Florida

Sensitivity Analysis For Orlando, Florida					
I/E Dry Period	Minimum Storm Reading For Gauge And Percent Difference	Mean Precipitation (in.) For Return Periods (Mo.)			
		2	3	4	6
4 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.61 1.61 0.00	1.92 1.89 1.56	2.15 2.15 0.00	2.48 2.48 0.00
12 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.64 1.64 0.00	1.94 1.94 0.00	2.18 2.17 0.46	2.61 2.58 1.15
24 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	2.05 2.02 1.46	2.46 2.43 1.22	2.72 2.67 1.84	3.34 3.18 4.79
48 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	2.34 2.20 5.98	3.00 2.72 9.33	3.45 3.20 7.25	3.92 3.74 4.59
72 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	2.63 2.48 5.70	3.44 3.24 5.81	3.90 3.76 3.59	4.57 4.37 4.38
96 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	2.72 2.72 0.00	3.91 3.76 3.84	4.70 4.20 10.64	5.59 5.17 7.51
120 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	2.54 2.70 -6.30	3.98 3.98 0.00	5.30 5.00 5.66	5.79 5.87 -1.38

Table G-2 Sensitivity Analysis For Rain Gauge Accuracy For Orlando, Florida

Sensitivity Analysis For Key West, Florida					
I/E Dry Period	Minimum Storm Reading For Gauge And Percent Difference	Mean Precipitation (in.) For Return Periods (Mo.)			
		2	3	4	6
4 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.34 1.34 0.00	1.72 1.72 0.00	1.97 1.97 0.00	2.36 2.36 0.00
12 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.46 1.44 1.37	1.88 1.88 0.00	2.04 2.04 0.00	2.46 2.46 0.00
24 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.62 1.58 2.47	2.10 2.06 1.90	2.40 2.38 0.83	3.02 2.90 3.97
48 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.72 1.70 1.16	2.30 2.22 3.48	2.67 2.48 7.12	3.60 3.30 8.33
72 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.80 1.73 3.89	2.38 2.30 3.36	3.00 2.65 11.67	4.06 3.46 14.78
96 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.95 1.79 8.21	2.65 2.38 10.19	3.50 3.03 13.43	4.30 4.04 6.05
120 Hour	0.04 / Universal 0.10 / Fisher-Porter % Difference	1.96 1.83 6.63	3.00 2.73 9.00	3.86 3.30 14.51	4.55 4.15 8.79

Table G-3 Sensitivity Analysis For Rain Gauge Accuracy For Key West, Florida

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