Precipitation and Runoff Patterns in Atlantic County, New Jersey 1945 - 1986

June 1987

New Jersey Pinelands Commission

PRECIPITATION AND RUNOFF PATTERNS IN ATLANTIC COUNTY, NEW JERSEY 1945 - 1986

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I. INTRODUCTION

The New Jersey Pinelands Comprehensive Management Plan[1] requires that the volume and rate of surface runoff generated from a given parcel of land by a fifty year storm of a 24-hour duration not increase as a result of any development of the parcel. Surface water runoff from impervious surfaces must be retained to facilitate infiltration into the ground water. Where practical, runoff should not be recharged where the depth to the water table is more than 20 feet below the surface nor should excessively and somewhat excessively drained soils be used for recharge of runoff.

The stormwater management program was designed to accommodate several major environmental objectives. These are: 1) maintain groundwater recharge patterns; 2) minimize changes in stream flow, including peak flow, base flow, and low flow; and 3) prevent ground water and surface water contamination associated with surface runoff.

The Atlantic County Department of Regional Planning and Development has raised several issues regarding the CMP standards. It is the department's opinion that the use of individual retention basins is excessively land consumptive, and it has expressed an interest in using regional storm water facilities to mitigate this suggested effect of the CMP program. The alternate use of detention basins rather than retention basins has also been suggested by Atlantic County.

At the request of Atlantic County, Pinelands Commission staff completed this assessment of the storm water runoff contribution made by 24-hr duration storms of varying intensities using different land cover assumptions. This assessment is a component of a broader proposal prepared by Pinelands Commission staff at the request of the Atlantic County Department of Planning and Regional Development. The more comprehensive study was intended to identify alternative stormwater management strategies and to assess the short term and long term environmental impact associated with those alternatives. The impacts to be studied included: 1) any potential localized and basin-wide lowering of the water table; 2) changes in the frequency and magnitude of peak flows in local and/or receiving streams; 3) alteration of base flows and low flows in local and/or receiving streams; and 4) associated local and watershed-wide groundwater and surface water quality changes.

Only volume is considered in this assessment. Other concerns, such as water quality issues, are not addressed. When relating the results of this study to the effectiveness of stormwater retention facilities, it must be assumed that retention basin operation is optimal.

II. DATA COLLECTION

There are three climatological observation stations within the Pinelands Area of Atlantic County. These stations are located at Hammonton, Mays Landing and Atlantic City Airport. The Atlantic City Airport station is located at the Federal Aviation Technical Center and is referred to as Atlantic City Airport-Pomona. The most readily available daily precipitation data for these stations are in computer data bases maintained by the National Climatic Data Center (NCDC) in Asheville, North Carolina. All available daily precipitation data for these three stations were obtained through NCDC on three microcomputer floppy diskettes. The data file was most complete for the Atlantic City Airport-Pomona station. The available period of record extends from February 1945 through 1986. Data gaps exist for 78 days in this period. The period of record for the Hammonton and Mays Landing Stations is 1945-1985. Data gaps exist for 631 days at Hammonton and 569 days at Mays Landing.

Frequency analysis of point rainfall values are used as the basis for defining the return period for precipitation events of varying magnitudes. Exteme events are infrequent. For example, in atlantic County the estimated average return period for a 24 hour event resulting in 6.8 inches for precipitation is 50 years. The precipitation records used in this analysis are limited because of the length of the period of record and because they do not include a large number of extreme events. In fact, no 50 year/24 hour storm event occurred during the 41 year period. They do, however, allow for an analysis of runoff patterns which would have occurred if the Pinelands stormwater program were in effect during this period and can be used to characterize typical conditions.

III. PRECIPITATION DISTRIBUTION

The daily precipitation data for each station were plotted. The data for Atlantic City Airport-Pomona are shown in Figure 1. Stations showed some variation in the magnitude of peaks on concurrent days indicating some geographic variation of precipitation. An analysis was done to determine whether the stations received different cumulative amounts of precipitation in storm events of increasing magnitude, and how these amounts were distributed.

For each station, non-zero daily precipitation values for the period of record were sorted in ascending order. Cumulative subtotals were then calculated for each .01 inch interval. The fraction of the total precipitation accounted for in each subtotal was also calculated. These cumulative subtotals are plotted vs. the corresponding daily magnitudes in Figures 2-4. The upper plot in each figure shows the full range of daily magnitudes, while the lower plot shows only the cumulative totals for magnitudes exceeding 2 inches. The lower plot of Figure 3, for example, shows that at the Atlantic City Airport-Pomona station, over 95% of precipitation fell in 24-hour events of 3 inches or less.

A comparison of these figures indicates that there is little difference between stations in the cumulative amount of precipitation that fell in daily events of increasing magnitude. This suggests that it is appropriate to carry out further analysis on data for only one of the stations. Considering both length and completeness of available records, the Atlantic City Airport-Pomona station was selected for this analysis.

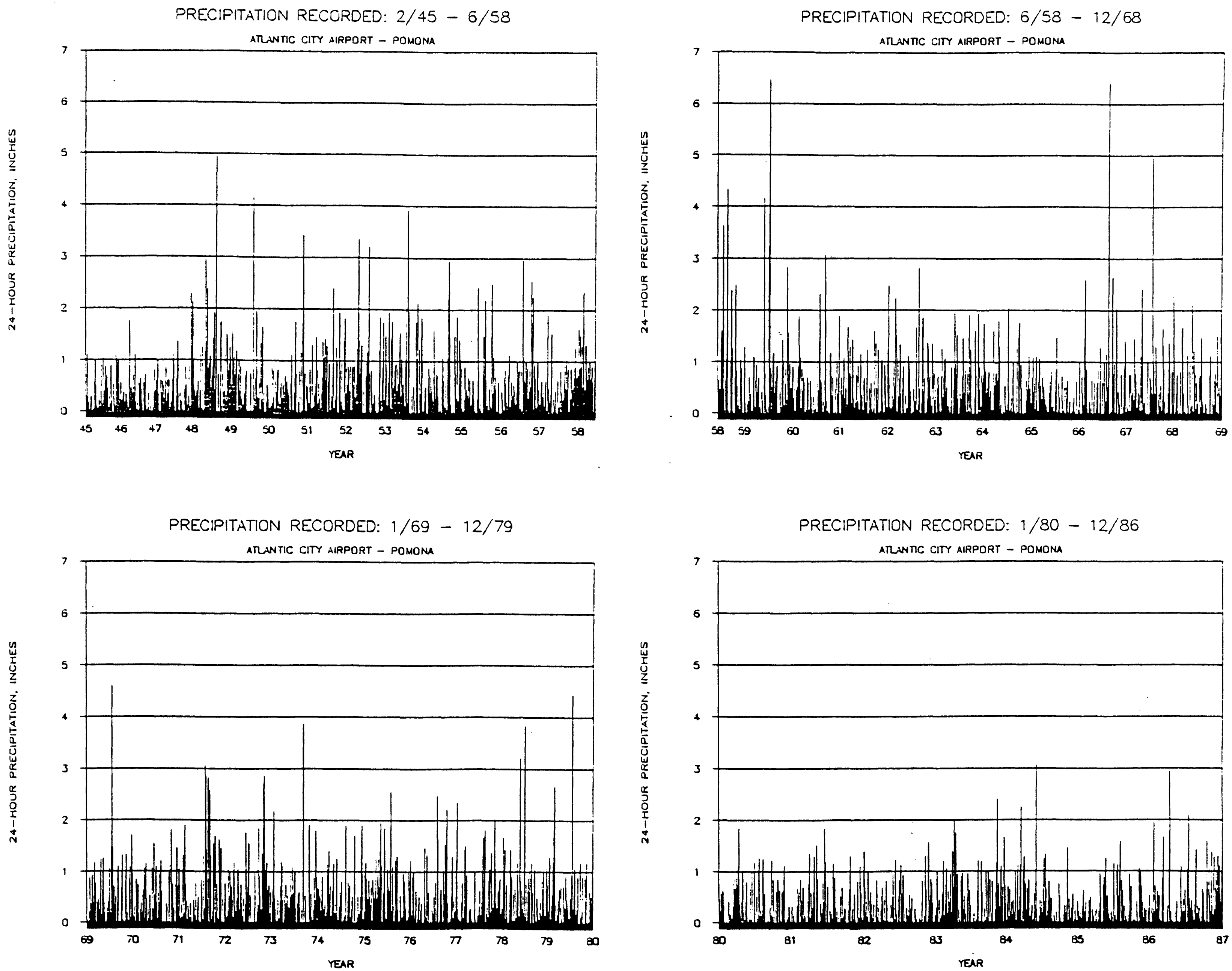
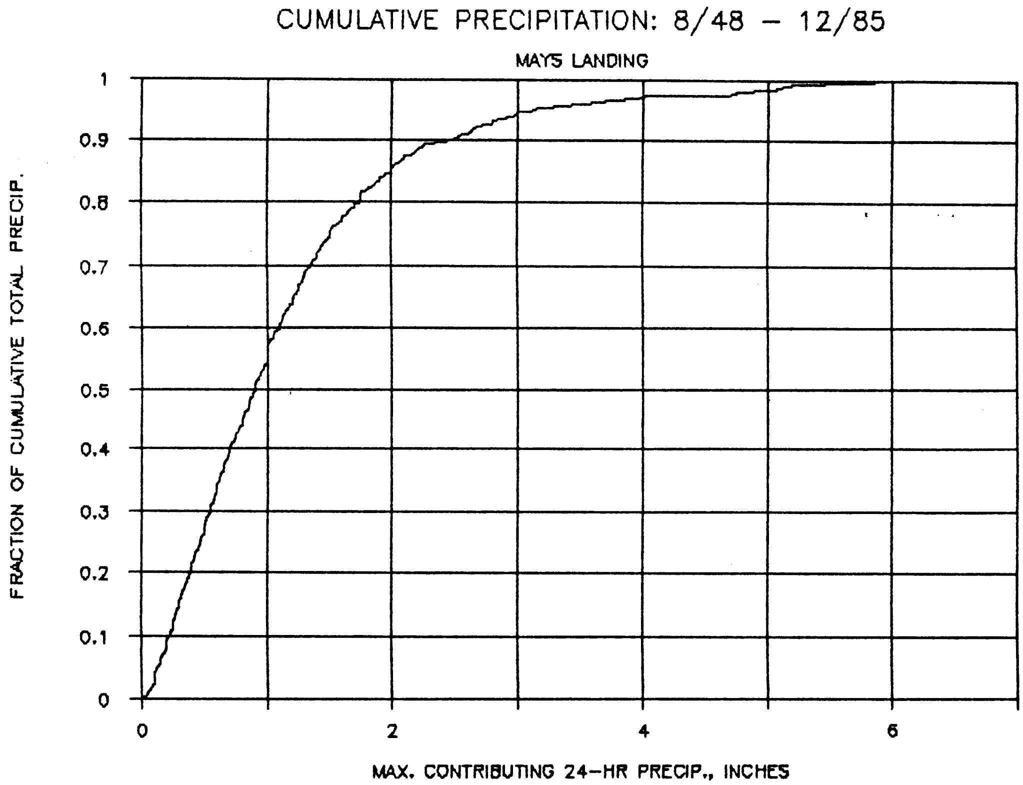


FIGURE 1. Precipitation Recorded At
Atlantic City Airport-Pomona: 1945-1986



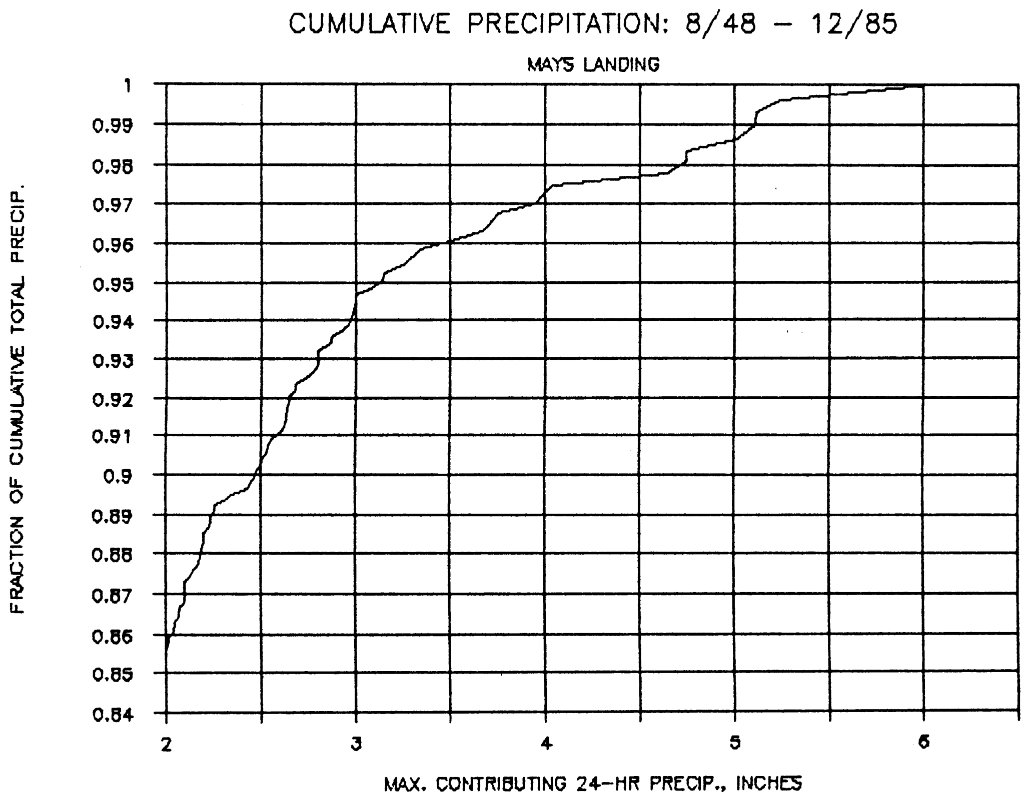
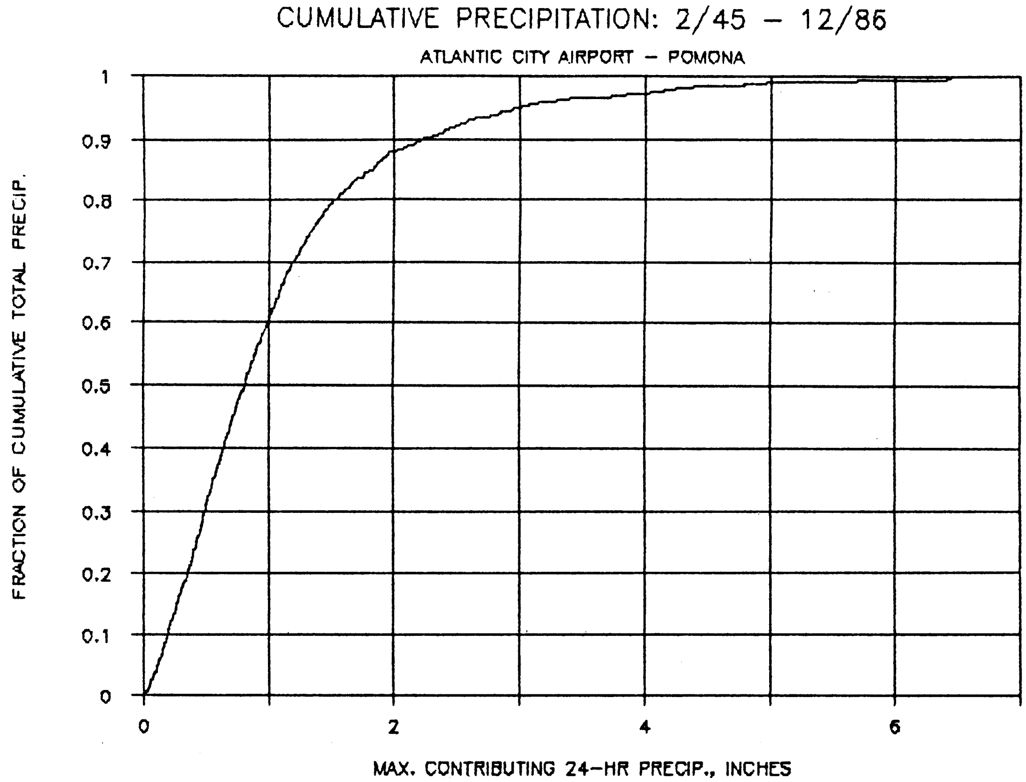


FIGURE 2. Cumulative Precipitation At Incremental Storm Magnitudes - Mays Landing



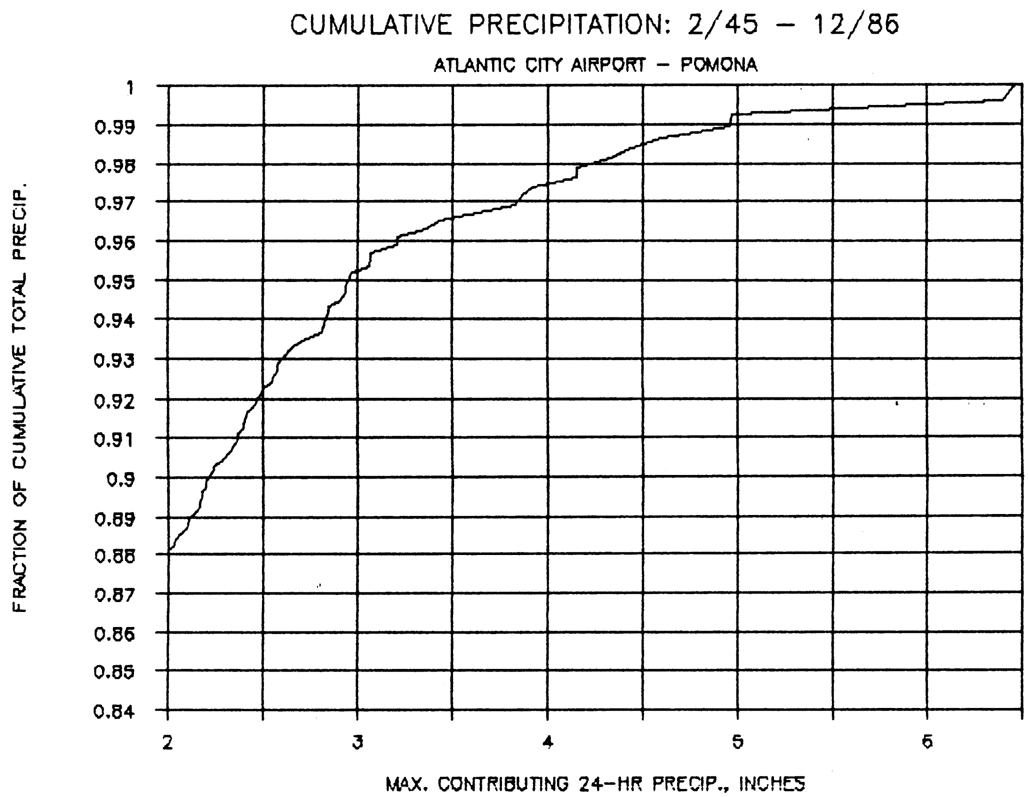
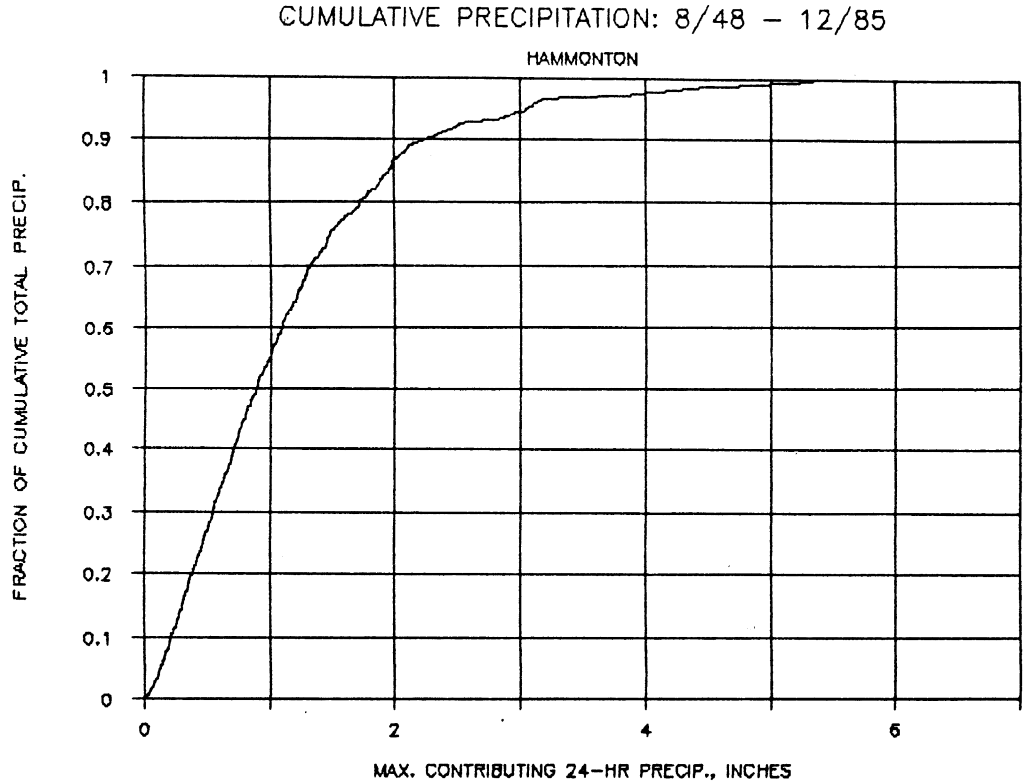


FIGURE 3. Cumulative Precipitation At Incremental Storm Magnitudes, Atlantic City Airport- Pomona



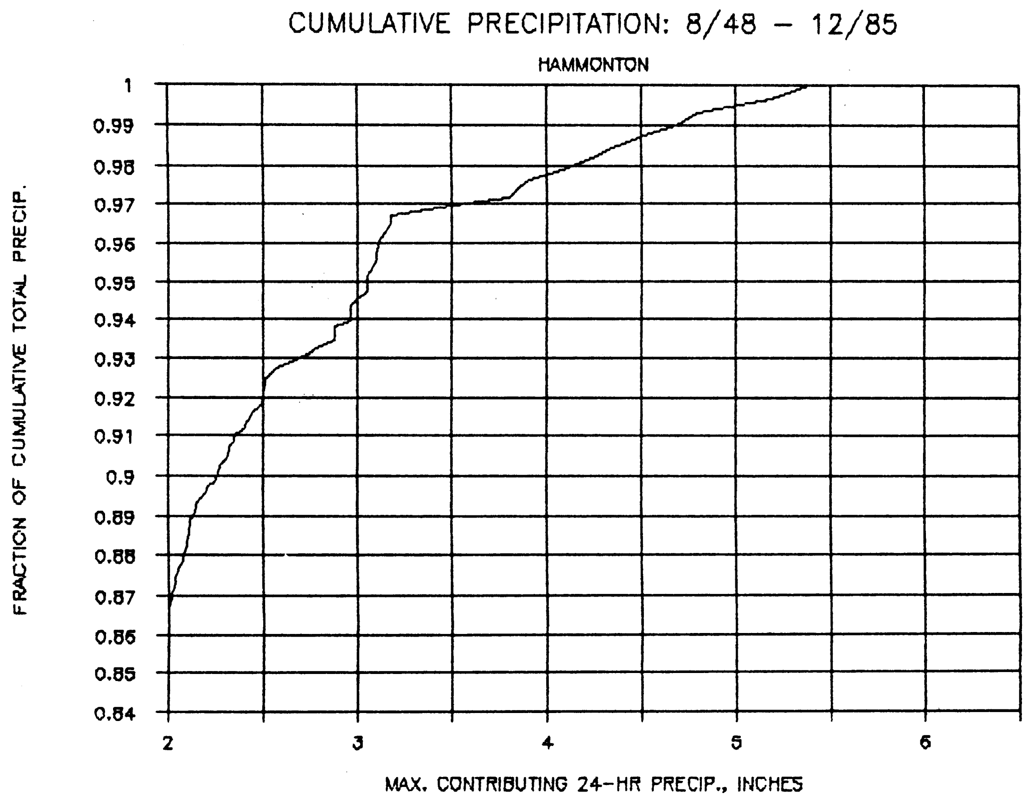


FIGURE 4. Cumulative Precipitation At Incremental Storm Magnitudes - Hammonton

IV. RUNOFF

A. Calculation of Stormwater Runoff: TR-55

A primary goal of the project is to quantify the cumulative volume of stormwater runoff which results from storm events of increasing magnitudes using different land cover characteristic assumptions. Several predictive runoff models have been developed for a variety of hydrological applications. The usefulness of predictive models is limited by a number of factors, including: 1) simplifying assumptions which may deviate from the real world; 2) availability of necessary input data; and 3) mathematical complexity.

The Soil Conservation Service (SCS) runoff curve number method for estimating storm runoff, as described in "Urban Hydrology for Small Watersheds" (TR-55),[2] provides a model which is useful for this analysis because it is not significantly limited by the above factors. Additionally, the Pinelands Commission requires that TR-55 be used in the design of stormwater retention basins.

The analysis completed in this study requires that runoff amounts of less than 0.5 inch be estimated. The SCS TR-55 manual indicates that the TR-55 methodology is less accurate in predicting such small amounts and recommends using an additional procedure to check against TR-55 estimates. However, given the comparative, general nature of this analysis, use of the additional procedure was not considered to be necessary.

The TR-55 method estimates runoff from rainfall and two parameters which are derived empirically from a runoff curve number (CN). The runoff curve number relates runoff to land use and is determined primarily from hydrologic soil group, cover type, agricultural practices, hydrologic condition, and antecedent runoff condition. CN values range from zero to 100. Generally speaking, runoff curve numbers increase with density and intensity of development. For this analysis, CN numbers of 40, 60, and 90 were selected as representative of undeveloped woodland, moderately developed land cover conditions, and more intensely developed land cover conditions, respectively.

B. Runoff Generated During Period of Record

For the period February 1945 through December 1986 15,231 daily precipitation measurements (not including trace amounts) totalled 1705 inches for the Atlantic City Airport at Pomona station. The total estimated runoff calculated for this period for the 40, 60 and 90 CN values was 2.5, 28, and 458 inches, respectively (Figure 5). Figure 5 shows the close relationship between cumulative runoff and land cover conditions.

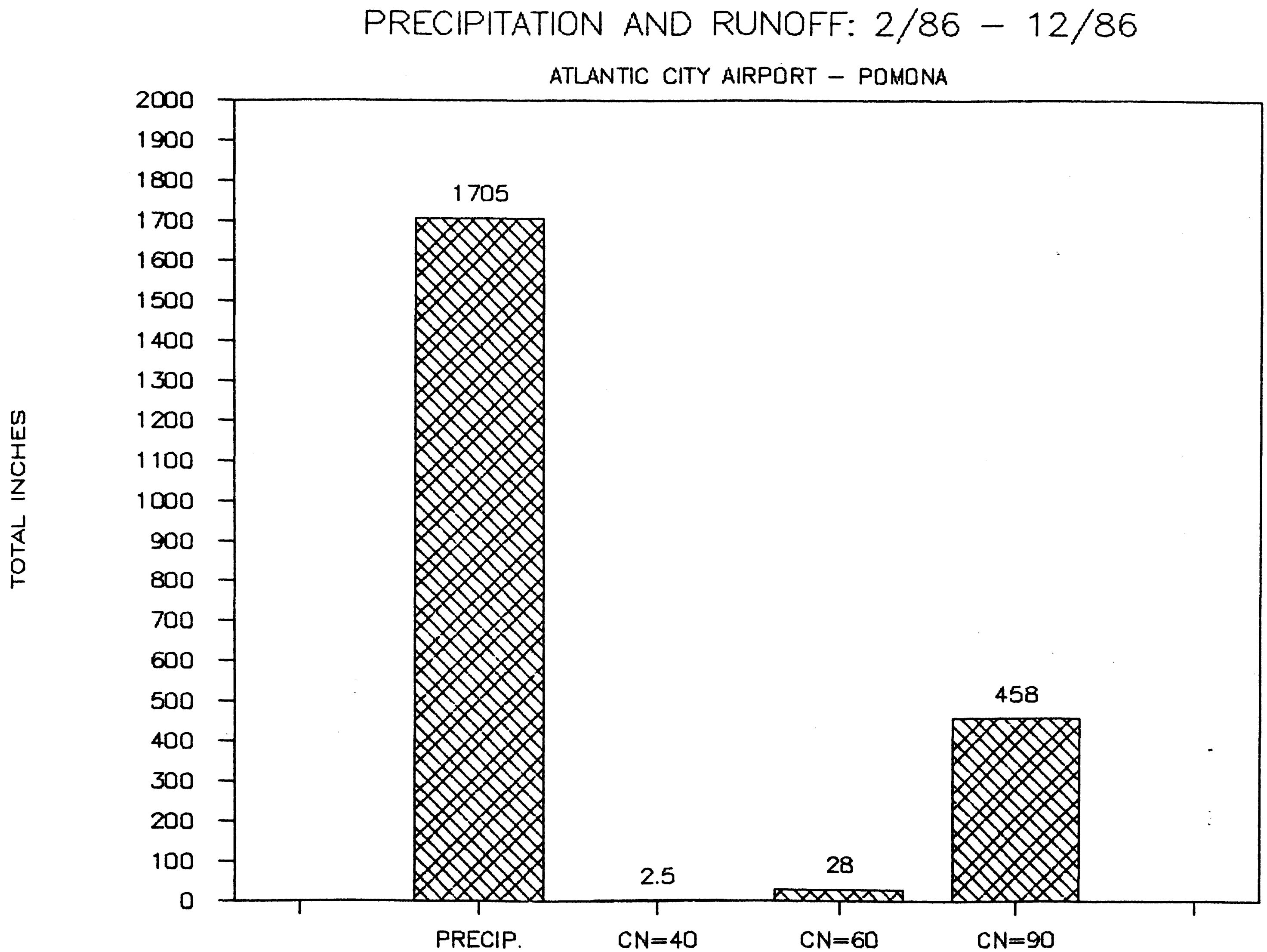


FIGURE 5. Cumulative Precipitation and Runoff: 1941-1986

Using a method similar to that used in the cumulative precipitation analysis, cumulative runoff was calculated for increasing storm magnitudes. Results are shown in Figure 6. Each line on the plot represents the simulated cumulative runoff resulting from a different land cover condition (CN number). For example, the graph shows that about 420 inches of runoff would have been generated from a parcel with CN = 90 from 24-hour storms of up to 4 inches in magnitude, and about 450 inches from 24-hour storms of up to 5 inches.

The vertical difference between any two lines at any point on the horizontal scale represents the increase in cumulative runoff which would have resulted from a change in land cover condition from storms of equal or lesser magnitude than that indicated at that point. Consider a hypothetical development. Assume that the land cover conditions of a parcel changed in 1945 from CN=60 to CN=90, and no retention facilities were constructed. Referring to Figure 6, it can be seen that the difference between the CN=60 curve and the CN=90 curve at the 4 inch storm point is about 400 inches for the period of record or about 10 inches per year. This represents the runoff that would have been generated from storm events of up to 4 inches through 1986. The same comparison can be made for any range of storm events. The flat slope at the top of the curves indicates that almost all of the increase in cumulative runoff resulted from 24-hour storms of less than 5 or 6 inches. Storms in excess of 5 inches were infrequent.

V. STORMWATER RETENTION

A. Retention Basin Design

The primary purpose of stormwater retention basins is to retain excess stormwater and allow it to infiltrate on-site rather than leave the site as runoff. In the Pinelands, basins are currently designed to retain the increase in runoff resulting from a 24-hour storm with a recurrence interval of 50 years (the 24-hour storm of a magnitude which occurs an average of once every 50 years). This means that the runoff from developed parcels with properly designed, constructed, and maintained retention facilities will, in theory, usually be no more than that occurring prior to development. A storm event of a magnitude exceeding the design storm would be the exception.

Although events of this magnitude are infrequent, they are expected to occur. Increases in runoff are expected to result on these occasions. If a storm of a shorter recurrence interval (and lesser magnitude) is used as a design criterion for retention basins, then post-development runoff volumes in excess of pre-development runoff would be expected to occur more frequently, and the cumulative post-development runoff leaving the site would increase.

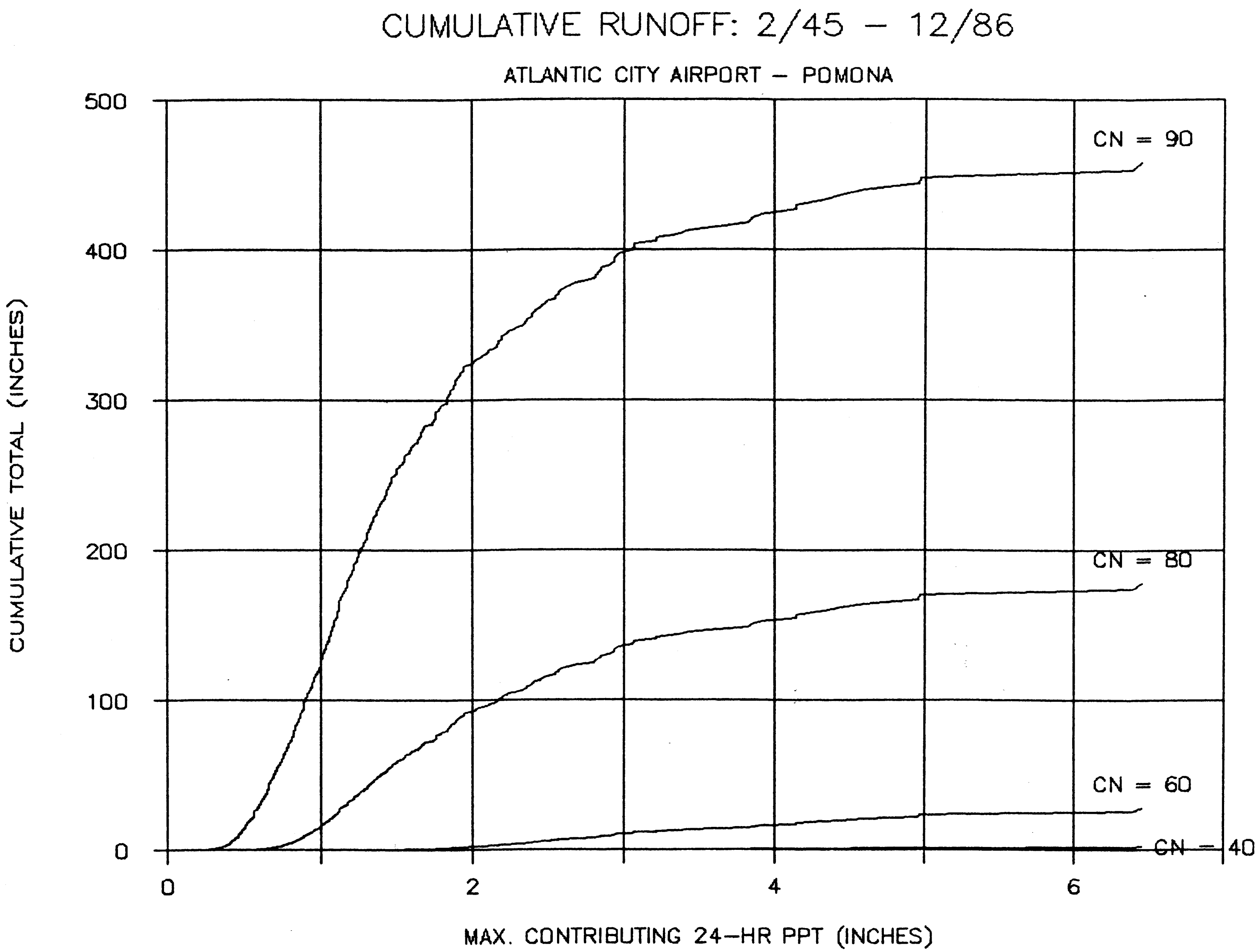


FIGURE 6. Cumulative Runoff At Incremental Storm Magnitudes: 1941-1986

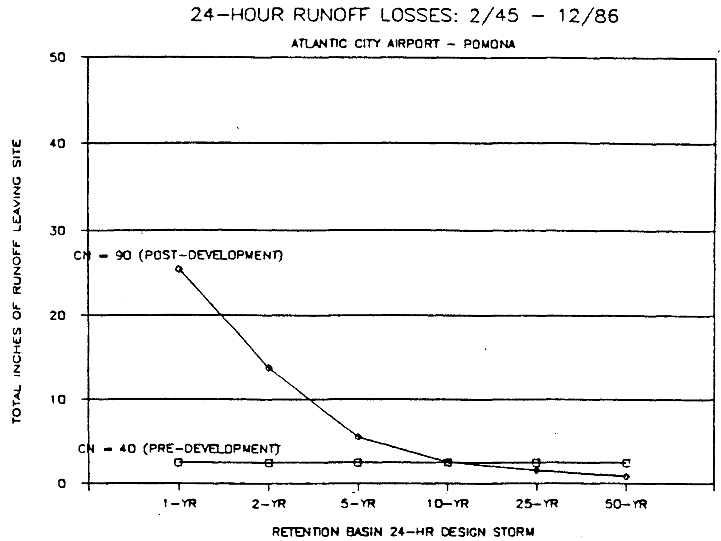
B. Runoff Volume Analysis

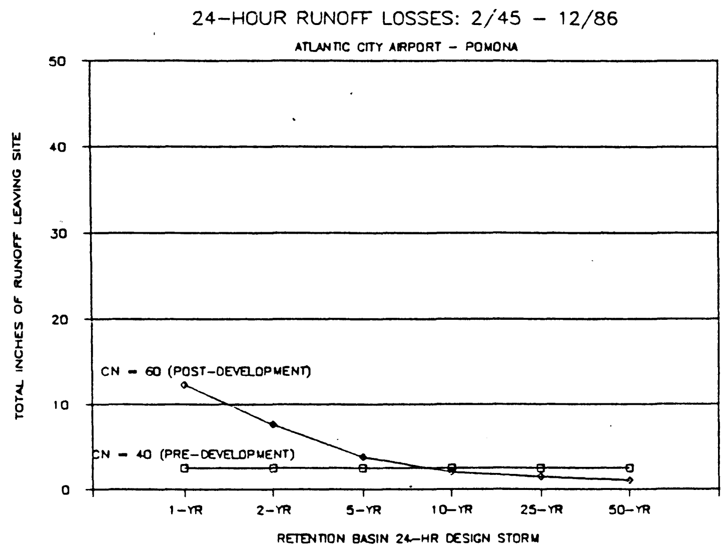
The purpose of the following analysis is to quantify the potential increase in cumulative off-site runoff volume resulting from a relaxed design storm standard and to determine the effects of such increases on the hydrologic budget under different design standard and development scenarios. The example given here details the methodology used to determine the cumulative depth of post-development runoff leaving a hypothetical parcel.

If it is assumed that the pre-development CN is equal to 40 and the post-development CN is equal to 90, then the retention basin capacity can be based on the magnitude of the design storm. For a 50-yr design storm, the basin capacity would be 4.86 inches. This represents the difference between pre-development and post-development runoff. It is assumed that only those 24-hour events generating more than 4.86 inches of runoff will result in volumes exceeding the capacity of the retention basin, and that the volume leaving the site as runoff in these instances equals the runoff minus the basin capacity. Using these assumptions, the daily precipitation events for the period of record were "routed" through the retention basin, and the cumulative volume of runoff leaving the site was totalled. For this scenario, the cumulative volume leaving the site as runoff was estimated to be about 0.8 inch, compared with 2.5 inches of pre-development, unretained runoff. The basin in this scenario actually resulted in less cumulative runoff leaving the site than prior to development. The approach used here does not address several site specific conditions such as infiltration rate, evaporation, distribution of rainfall, rainfall intensity and surface slopes. Discounting these factors should not, however, significantly effect the conclusions.

This analysis was repeated for a variety of scenarios with different pre- and post- development CN values, different design storm magnitudes, and different retention basin capacities. The results are plotted in Figure 7. Each point on the curved line of each figure represents the cumulative inches of runoff leaving a developed site for a particular design storm and development scenario.

These results indicate that on a long term basis a retention basin designed to accommodate a 25-yr/24 hr storm or a 10-yr/24 hr storm would not have resulted in excessive runoff leaving the development site. Smaller basins would have resulted in increased runoff leaving the site. The





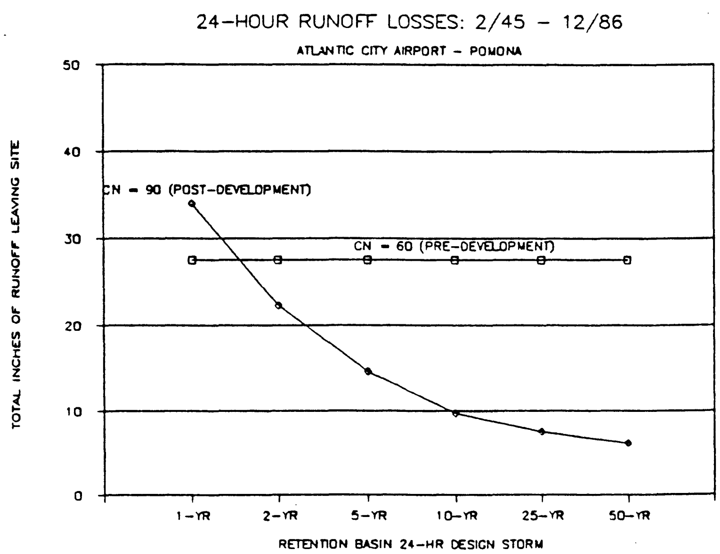


FIGURE 7. Pre- and Post- Development Off-Site Runoff From 24-Hour Events

analysis does not, however, address losses that may occur during shorter time periods (seasonal, annual, etc.) or losses that may result from storms occurring when basins have not emptied.

VI. EXTENDED DURATION PEAK EVENTS

The previous "routing" analysis is based on runoff estimated to result from storm events of 24-hour duration. An assumption of this analysis is that all 24-hour events are independent and do not influence the amount of runoff from subsequent events. In actuality, a storm in one 24-hour period may be followed by another storm at some later time (or it may continue), which could result in more runoff leaving the site than that estimated by the previous analysis, especially if the infiltration rate of the retention basin is low. An analysis was performed to quantify the significance of large amounts of precipitation occurring over periods longer than 24-hours.

Each continuous period of measurement (those with no missing data) for the Atlantic City Airport-Pomona station was processed to determine the total precipitation occurring in each 3-day and 7-day period. The periods overlapped to ensure that the maximum multi-day events would be identified. For 3-day totals, separate totals were calculated for days 1-3, 2-4, 3-5, etc. Similarly, for 7-day totals, separate totals were calculated for days 1-7, 2-8, 3-9, etc. Of these totals, those exceeding 5 inches of precipitation were identified for further analysis. Only the results of the 7-day period analyses are presented here. Five inches was chosen as the minimum value because storm events of lesser magnitude do not contribute significantly to off-site runoff from sites using retention facilities. The next step was to quantify the significance of these extended duration, peak events.

Twelve 7-day peak events were identified as shown in Figure 8. A notable maximum of 10.61 inches was recorded from July 10, 1959 through July 16, 1959. The runoff resulting from these peak events was estimated using the TR-55 method with the understanding that the TR-55 method is specific to 24-hour duration events. The consequence of this application of the method is that predicted runoff is probably overestimated and the estimates, therefore, represent a worst-case scenario. Runoff for 7-day totals were estimated as if the 7-day total occurred in 24 hours.

Off-site runoff was calculated for each of these peak events for different development scenarios and retention basin design storm criteria. The cumulative off-site runoff was determined and is compared with pre-development runoff in Figure 9. In interpreting these plots it should be noted that only the peak events are included. The top plot in figure 9 indicates that the total runoff from the peak events leaving the hypothetical parcel would be about the

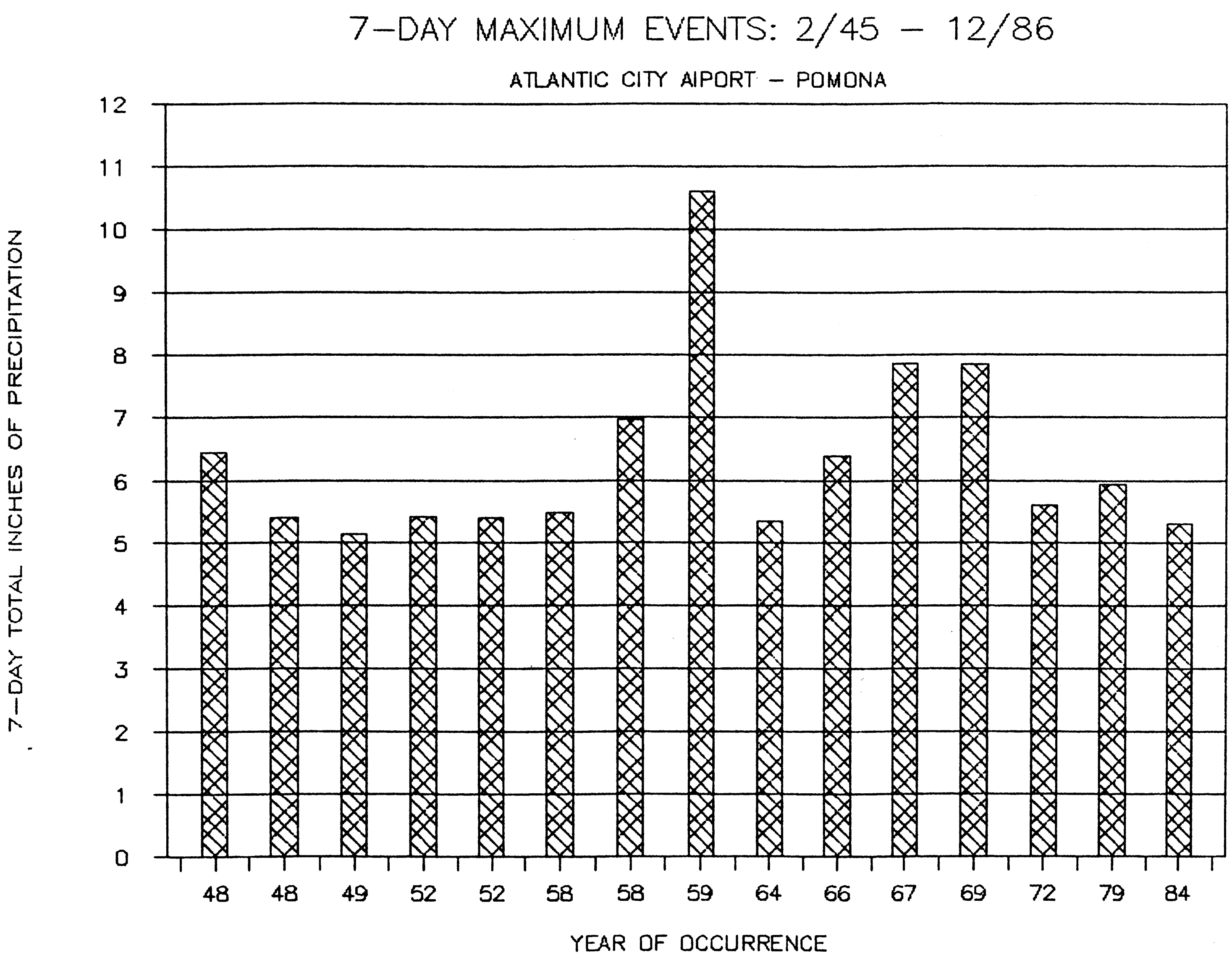
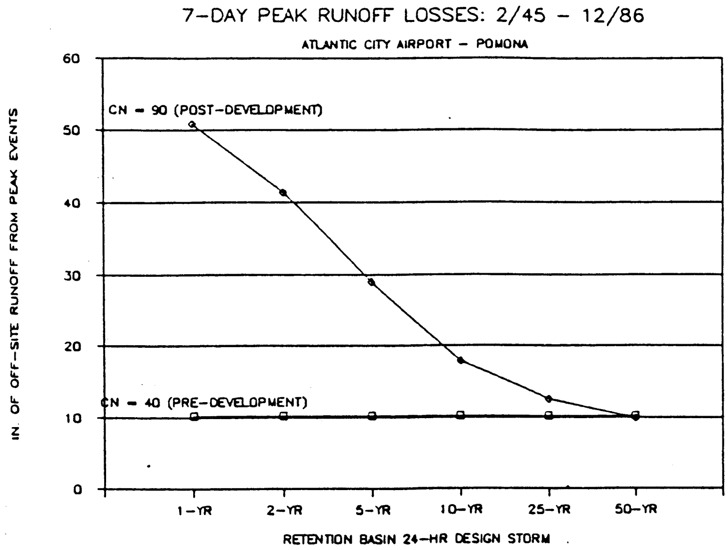
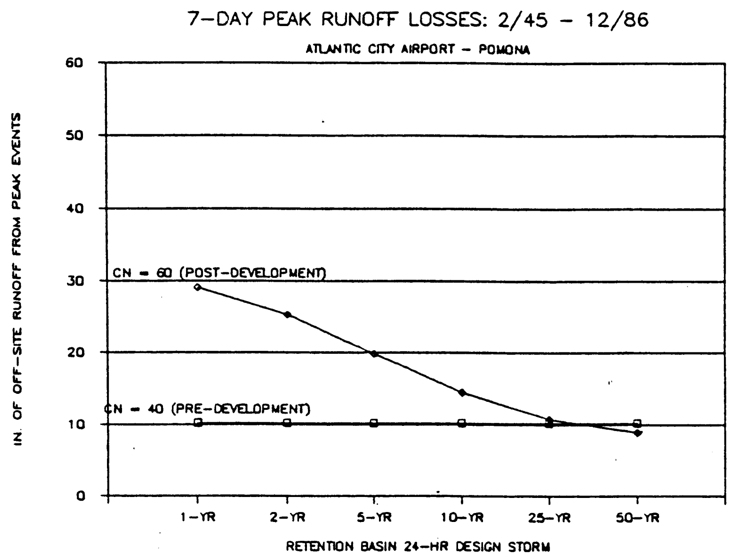


FIGURE 8. 7-Day Maximum Precipitation Events Exceeding 5 Inches





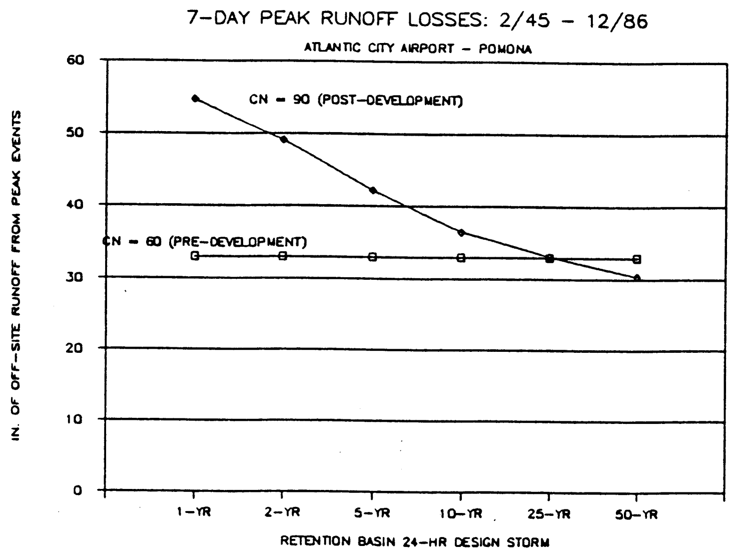


FIGURE 9. Pre- and Post- Development Off-Site Runoff From 7-Day Peak Events

same (10 inches) before and after development if the land cover CN changed from 40 to 90 with "50-yr" retention. A change in design standard from "50-yr" retention to "25-yr" or "10-yr" retention would result in an off-site runoff increase of about 2.5 or 7.8 inches, respectively, during the 41 year period of record.

For CN changes from 40 to 60 and from 60 to 90, the curves in the two lower plots in Figure 9 show that less runoff from peak events would leave the hypothetical parcel with "50-yr" retention after development than before, and that pre- and post-development off-site runoff would be about the same with "25-yr" retention. With less retention, more runoff leaves the site after development.

In summary the curves indicate that below 25-year retention, as basin size decreases, post-development runoff leaving the site from peak events exceeds pre-development runoff from the same events by an increasing margin.

Another analysis was conducted to assess the importance of these increases in relation to the annual and seasonal hydrologic budgets for the year and season in which the events occurred. This analysis considered peak 7-day events rather than events of other durations to provide an example of "worst-case" conditions. The seasons for this analysis are defined as May through October (growing season) and November through April (non-growing season). These are normally periods when net ground water storage is depleted and recharged, respectively. The hydrologic budget considered is represented here by the equation:

$$P = ET + DR + [GR + \Delta S]$$ where

P = precipitation
DR = direct runoff
ET = evapotranspiration
ΔS = change in storage
GR = ground water run off (baseflow)

In this analysis, the $[GR + \Delta S]$ term approximates the amount of net recharge for the time period (baseflow and storage components are not distinguished). In dry summer months this can be a negative value, when baseflow is low and ground water storage is depleted. The estimate of recharge was determined indirectly by the rearranged equation:

$$[\Delta S + GR] = P - ET - DR$$

P is the only measured value. DR is estimated using TR-55. "Actual" ET is estimated using Thornthwaite and Mather's climatic water budget method.[3] A computer spreadsheet program developed by Hughes and others was used to estimate ET.[4] This method estimates ET empirically from mean monthly temperature, monthly precipitation, available soil moisture capacity, and latitude data.

The extreme peak event in which 10.6 inches fell in July 1959 was considered. An annual budget estimate for Atlantic County using methods described above would be:

$$P = ET + DR + [GR + \Delta S]$$

$$47.8 = 23.2 + 0.7 + [23.9] \quad \text{(inches)}$$

Thus, of the 47.8 inches of precipitation recorded for 1959, about 23.2 inches were evapotranspired, about 0.7 inches became direct runoff, and about 23.9 inches were recharged. This recharge value is 3.9 inches higher than the 20 inches/yr value reported by Rhodehamel[5] as average for the Pinelands region. Thus, 1959 was a year with above average annual recharge.

If 1) the parcel CN is considered to be 40 before development and 90 following development and 2) a basin is designed to retain the increase in runoff resulting from a 50-yr/24-hour (6.8 inch) storm, the increase in runoff leaving the site as a result of this extreme event would have been about 2 inches. The "50-yr" basin represents the currently used Pinelands standards. The increase in runoff would represent about 8% of the estimated annual recharge for 1959. This analysis was repeated for basins sized for different design storms. The results, presented in Figure 10, show increasing losses of annual recharge with decreasing basin capacity. A "25-yr" and "10-yr" basin would result in a 2% and 4% increase, respectively, over the 8% loss resulting from the use of a "50-yr" basin.

A growing season budget (May - October) was also estimated as

$$P = ET + DR + [GR + \Delta S]$$

$$28.8 = 19.9 + 0.7 + [8.2] \quad \text{(inches)}$$

Increases in runoff leaving the site are shown in Figure 10 as percentages of the 8.2 inches of this seasonal recharge for the various retention basin design storms.

Figure 10 shows that if a "50-yr" basin was used, about 25% of the 1959 growing season recharge would have been lost due to increased off-site runoff occuring during this extreme event. The loss in this seasonal recharge would increase by 4% and 10% if a "25-yr" and "10-yr" retention basin, respectively, were used rather than a "50-yr" basin.

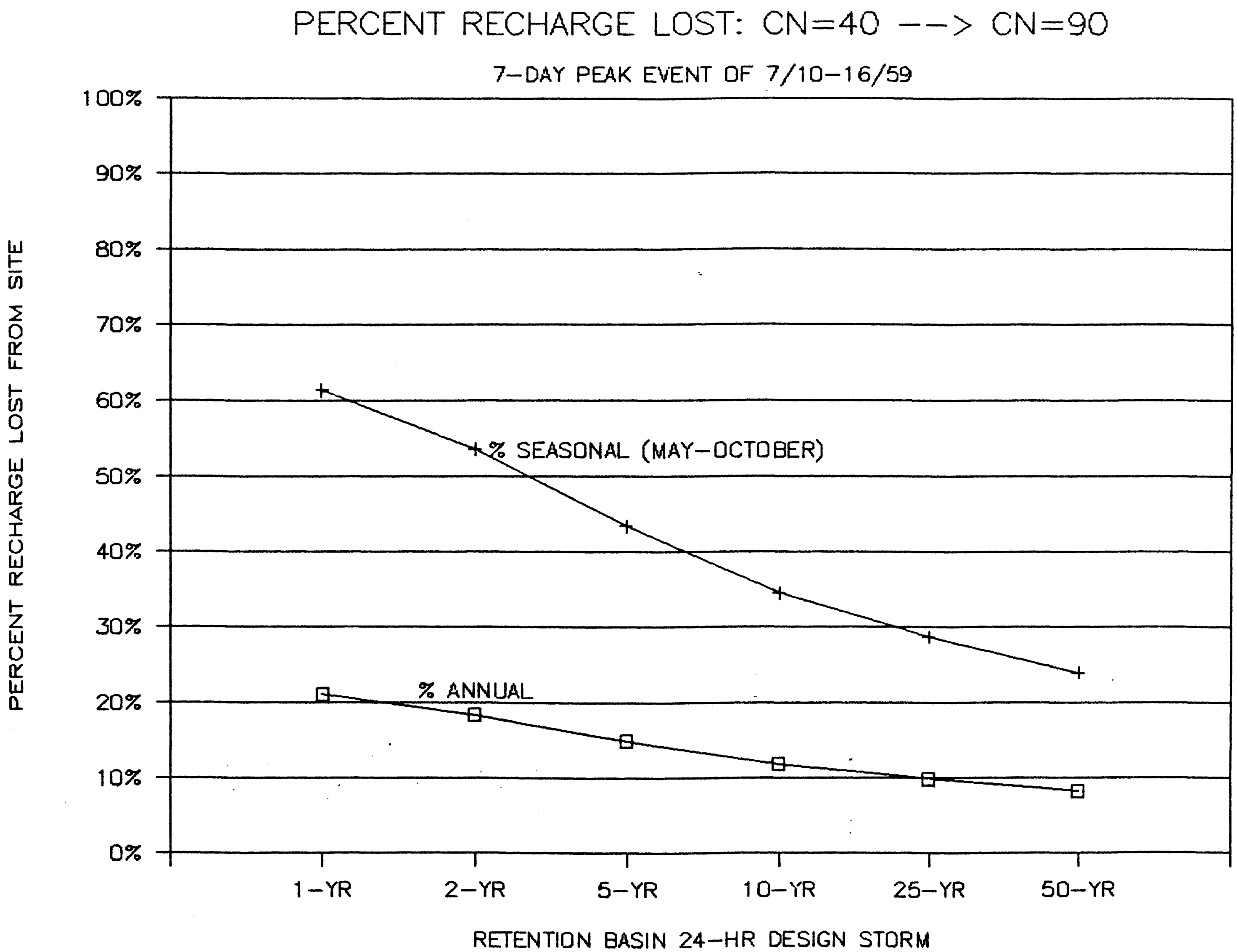


FIGURE 10. Increases In Off-Site Runoff As Percentage Of Seasonal and Annual Recharge: Peak Event of 7/59

Under the development scenario presented here, the extreme 7-day event of the period of record would result in increased off-site runoff and a loss of annual recharge and seasonal recharge. Recharge losses under these conditions are estimated to result from development regardless of the retention basin design storm criteria used. Permitting smaller retention basins could have the effect of increasing the loss of annual and seasonal recharge on relatively intensely developed parcels when infrequent, extreme events occur. These extreme events, however, will tend to occur during periods of above average annual and seasonal recharge.

VII. SUMMARY OF FINDINGS AND CONCLUSIONS

1. From February 1945 through December 1986 over 95 percent of all precipitation recorded at the National Weather Service station located at the Atlantic City Airport at Pomona occurred in 24-hour events of 3 inches or less.

2. A total of 1705 inches of precipitation was measured during the 41 year study period. Using the Soil Conservation Service TR-55 method, it was estimated that the total runoff generated during the same period was 2.5 inches, 28 inches, and 458 inches for undeveloped (CN=40), low density development (CN=60), and high density development (CN=90) scenarios, respectively.

3. The total amount of runoff leaving a developed site during the period of record was shown to be less than or equal to pre-development runoff when a "50-yr" or "25-yr" retention basin was used. A retention basin designed to accommodate a 10-yr/24 hr storm would have resulted in about the same amount of off-site runoff occurring prior to development. Smaller basins would have resulted in increased runoff leaving a development site.

4. Twelve 7-day cumulative precipitation events in excess of 5 inches were identified through the analysis. These represent events that may result in significant runoff leaving a developed site with retention facilities. Use of a "50-yr" basin would have resulted in less total runoff leaving the site under all development scenarios. Pre-development and post-development runoff would have been the same or slightly higher if a "25-yr" basin was used. Increasingly greater amounts of runoff would have resulted from smaller basins.

5. The loss of annual and seasonal recharge occurring on a relatively intensely developed parcel during the most extreme precipitation event of the study period was simulated. Substantial losses resulted regardless of

retention basin design capacity. Differences resulting from the use of a "50-yr", "25-yr", or "10-yr" retention basin were relatively minor.

6. The analyses performed do not address water quality impacts associated with runoff leaving a developed site. Such an assessment would require an understanding of the water quality characteristics of stormwater in the Pinelands and the fate of any pollutants entering retention basins during storm events.

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