ANALYSIS OF WATER-LEVEL FLUCTUATIONS OF THE

U.S. HIGHWAY 90 RETENTION POND, MADISON, FLORIDA

By Wayne C. Bridges

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ANALYSIS OF WATER-LEVEL FLUCTUATIONS OF THE U.S. HIGHWAY 90 RETENTION POND, MADISON, FLORIDA

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ABSTRACT

A closed basin stormwater retention pond, located 1 mile west of Madison, Florida, has a maximum storage capacity of 134.1 acre-feet at the overtopping altitude of 100.2 feet. The maximum observed altitude (July 1982 through March 1984) was 99.52 feet (126.7 acre-feet) on March 28, 1984.

This report provides a technique for simulating net monthly change in altitude in response to rainfall and evaporation. A regression equation was developed which relates net monthly change in altitude (dependent variable) to rainfall and evaporation (independent variables).

Rainfall frequency curves were developed using a log-Pearson Type III distribution of the annual, January through April, June through August, and July monthly rainfall totals for the years 1908-72, 1974, 1976-82. The altitude of the retention pond increased almost 7 feet during the 4-month period January through April 1983 when the rainfall total was 33.9 inches, and the recurrence interval exceeded the 100-year January-April rainfall.

INTRODUCTION

The Florida Department of Transportation (FDOT) constructed a 12-acre retention pond on the south side of U.S. Highway 90, 1 mile west of the downtown area of Madison. Stormwater from a 1-mile section of U.S. Highway 90 (4-lane curb and gutter with drop inlets) and a part of west Madison (106 acres) empty into the pond by way of a 54-inch storm drain. An 18-inch culvert drains a 35-acre farm south of the pond. Figure 1 is a map showing the contributing drainage area and location of the pond.

The town of Madison, population 3,487 in 1980, is situated on a hill (altitude of 191 feet at courthouse) and surface drainage is to low depressions surrounding the town. Stormwater flowing into the depressions is either evaporated or seeps laterally and downward into the ground. The average altitude of the depressions to the west of Madison is about 100 feet.

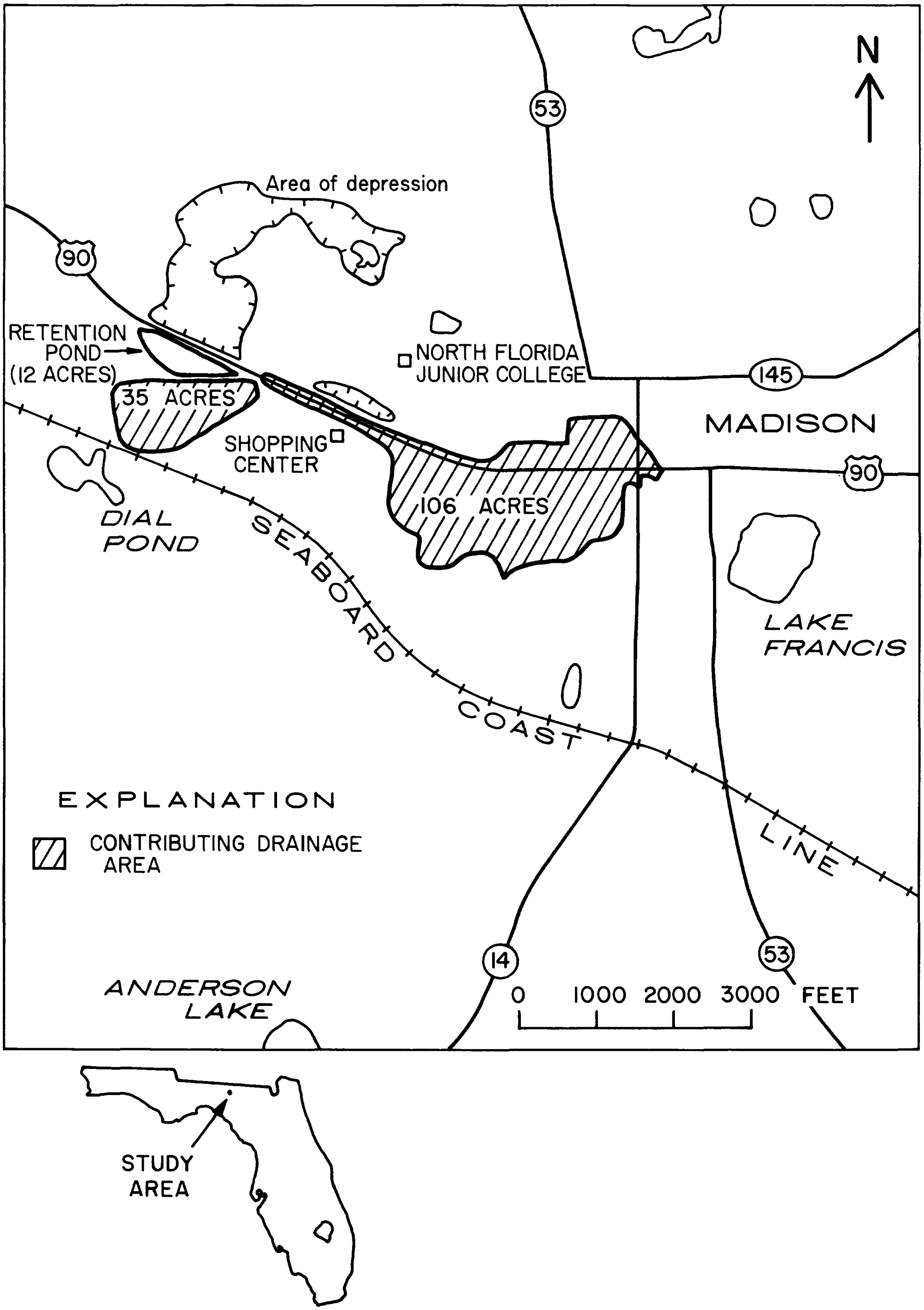

Figure 1.--Location of retention pond and contributing drainage area.

The rainfall total for January through April 1983 was 33.9 inches or 18.2 inches above normal. Because of the above normal rainfall, the altitude of the retention pond increased almost 7 feet. The FDOT expressed concern that, if above normal rainfall continued throughout 1983, the storage capacity of the retention pond might be exceeded. They were also concerned about the increase in pond altitude that would result from a 25-year recurrence interval rainfall.

The purpose of this report is to provide an analysis of the pond fluctuations and to demonstrate a technique for modeling pond reponse to stormwater runoff.

The U.S. Geological Survey, in cooperation with the FDOT, made an analysis of the pond fluctuations and the potential for the capacity of the pond to be exceeded for selected periods. Study considerations included:

- What effect would the maximum annual rainfall (83.34 inches, 1964) have on the pond, assuming a starting elevation of 88.0 feet?
- What is the initial altitude of the pond such that a 25-year frequency rainfall for January through April would cause the pond altitude to reach 99 feet?
- What is the initial altitude of the pond such that a 25-year frequency rainfall for the wet summer period, June through August, would cause the pond altitude to reach 99 feet?
- What is the initial altitude of the pond such that a 25-year frequency rainfall for the wettest month, July, would cause the altitude to reach 99 feet?
- What annual rainfall total would result in the gains and losses of the retention pond altitude being equal?

DATA AVAILABLE

The FDOT furnished data on rainfall and pond altitudes for the period July 1982 through March 1984. FDOT personnel read the pond and rain gages once daily except for weekends and holidays. Long-term daily rainfall for Madison, 1906-72, 1974, 1976-82, were available from National Weather Service records. Monthly mean evaporation data for Gainesville, 90 miles southeast of Madison, were available from the National Weather Service.

The Geological Survey collected water-level data on the drainage well (Madison well No. 18) located on the south side of the retention pond. Bimonthly observations are available from April 1952 to July 1954, recording gage from July 1954 to December 1964, bimonthly observations from January 1965 to September 1977, and one to four observations annually from November 1977 to July 1981. The Suwannee River Water Management District has operated a recording gage since March 1981 at Madison well No. 18.

WATERSHED CHARACTERISTICS

Prior to construction, the FDOT retention pond was an elongated depression located between the old Highway 90 and the new 4-lane Highway 90. This 12-acre area was excavated to an average altitude of 88 feet with the lowest point near the center being about 80 feet. The maximum capacity of the pond is 134.1 acre-feet at the overtopping altitude of 100.2 feet. Figure 2 shows a capacity curve for the retention pond. The maximum observed altitude (July 1982 through March 1984) was 99.52 feet (126.7 acre-feet) on March 28, 1984.

Inflow

The primary inflow to the pond is from: (1) a 54-inch diameter storm drain which conveys the stormwater from the 106 acres of west Madison and U.S. Highway 90, (2) an 18-inch diameter culvert that drains a small farm (35 acres) on the south side of the pond, (3) rainfall directly on the pond, and (4) bank seepage when the pond is low.

A large depression on the north side of U.S. Highway 90 is connected to the retention pond by a 36-inch diameter pipe (invert altitude 85.6 feet). A flap gate on the south end of the 36-inch pipe prevents outflow from the retention pond. Inflow to the retention pond is possible when the water level of the depression exceeds both the invert altitude of 85.6 feet and the altitude of the retention pond.

Inflow to the retention pond is also possible from a closed depression 1,500 feet east, located on the north side of U.S. Highway 90 at the community college. A 15-inch diameter pipe under U.S. Highway 90 connects to the 54-inch storm drain. The altitude of the invert is 102.6 feet.

A possible source of inflow and outflow is through a former outfall pipe under a shopping center parking lot (1,500 feet east of the retention pond). A weir was constructed in the former outfall pipe, at the junction with the 54-inch retention pond storm drain, at the elevation of the former culverts under U.S. Highway 90. Information from E. G. Ringe, FDOT, (written commun., 1984) indicates that little inflow or outflow occurred during the study period.

Outflow

Under present operating guidelines, discharge of excess stormwater runoff from the pond is limited to evaporation and seepage (laterally and downward). A drainage well is located on the south rim of the retention pond. The 4-inch diameter drilled artesian well is in the Upper Floridan aquifer. The well is 322 feet deep (cased to 307 feet) and is affected by pumping of a nearby city supply well. Although the well has an inlet altitude of 85.6 feet, the well was not used as a drainage well during the period June 1982 through March 1984, but was plugged to prevent water from the retention pond from discharging to the well.

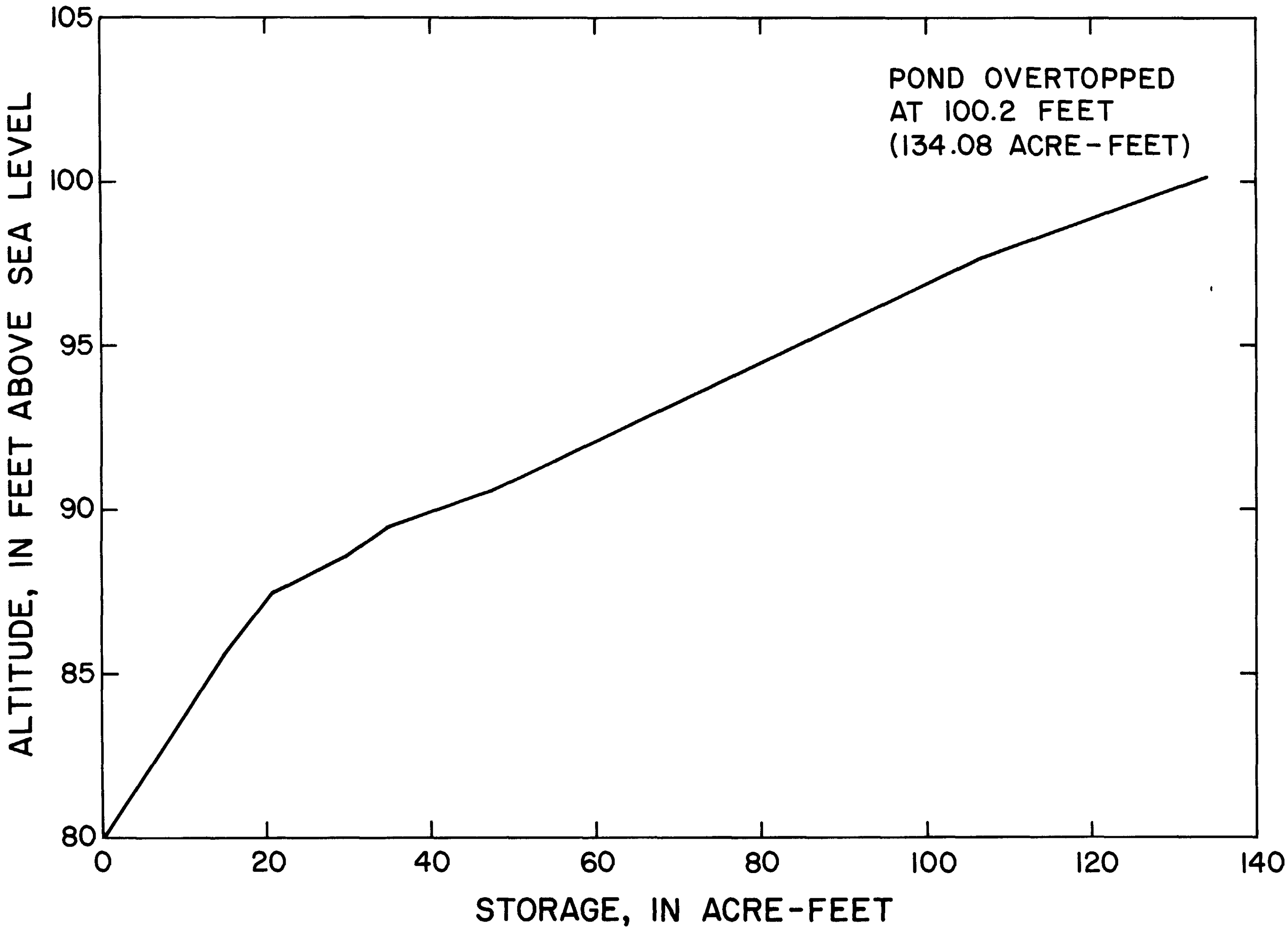

Figure 2.--Madison retention pond capacity curve. (Data furnished by Florida Department of Transportation.)

Figure 3 is a hydrograph of the month-end altitudes of the retention pond and the drainage well (Madison well No. 18) and monthly rainfall totals. Figure 3 illustrates the reponse of the pond and potentiometric surface to rainfall. When the head difference between the pond and the potentiometric surface of the Upper Floridan aquifer is at a minimum (example, April 1983), the downward leakage would be at a minimum.

REGRESSION MODEL

A multiple regression analysis was used to develop the relation between the net monthly change in water-surface altitude of the pond (dependent variable) and climatic characteristics (independent variables). The analysis was performed by means of the STEPWISE regression procedure with maximum R^2 improvement (SAS Institute, 1979).

Three climatic characteristics were tested for significance as independent variables in the regression analysis.

1. Rainfall (MORAIN), in inches: the monthly rainfall total measured at the retention pond.

2. Temperature (MMTEMP), in degrees Fahrenheit: monthly mean temperature for Madison from U.S. Weather Bureau publication Climatic Summary of the United States, Florida, supplement for 1951-60, No. 86-6.

3. Evaporation (PEVAP), in inches: observed monthly pan evaporation for Gainesville was converted to free water surface evaporation for Madison using NOAA Technical Report NWS 33 (U.S. Department of Commerce, 1982a). The pan coefficient used was 0.76.

4. Evaporation (TMEVAP), in inches: monthly pan evaporation for Gainesville was transferred to Madison and converted to free water surface (FWS) evaporation using NOAA Technical Reports NWS 33 and 34 (U.S. Department of Commerce, 1982a, b). Table 1 lists the average monthly FWS evaporation potential. TMEVAP was used in model simulation for periods other than the period of current record, July 1982 through March 1984.

Table 1.--Monthly potential evaporation (free water surface), long-term average rainfall, and 1983 rainfall at retention pond, for Madison, Fla.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Inches												
	2.07	2.58	3.96	4.97	5.57	5.29	4.97	4.69	4.00	3.45	2.53	1.98
	3.50	4.09	4.48	3.59	3.54	5.90	7.02	6.31	4.96	2.61	2.47	3.66
	7.10	8.40	9.20	9.20	2.10	5.85	5.30	4.08	4.10	1.90	7.30	8.50

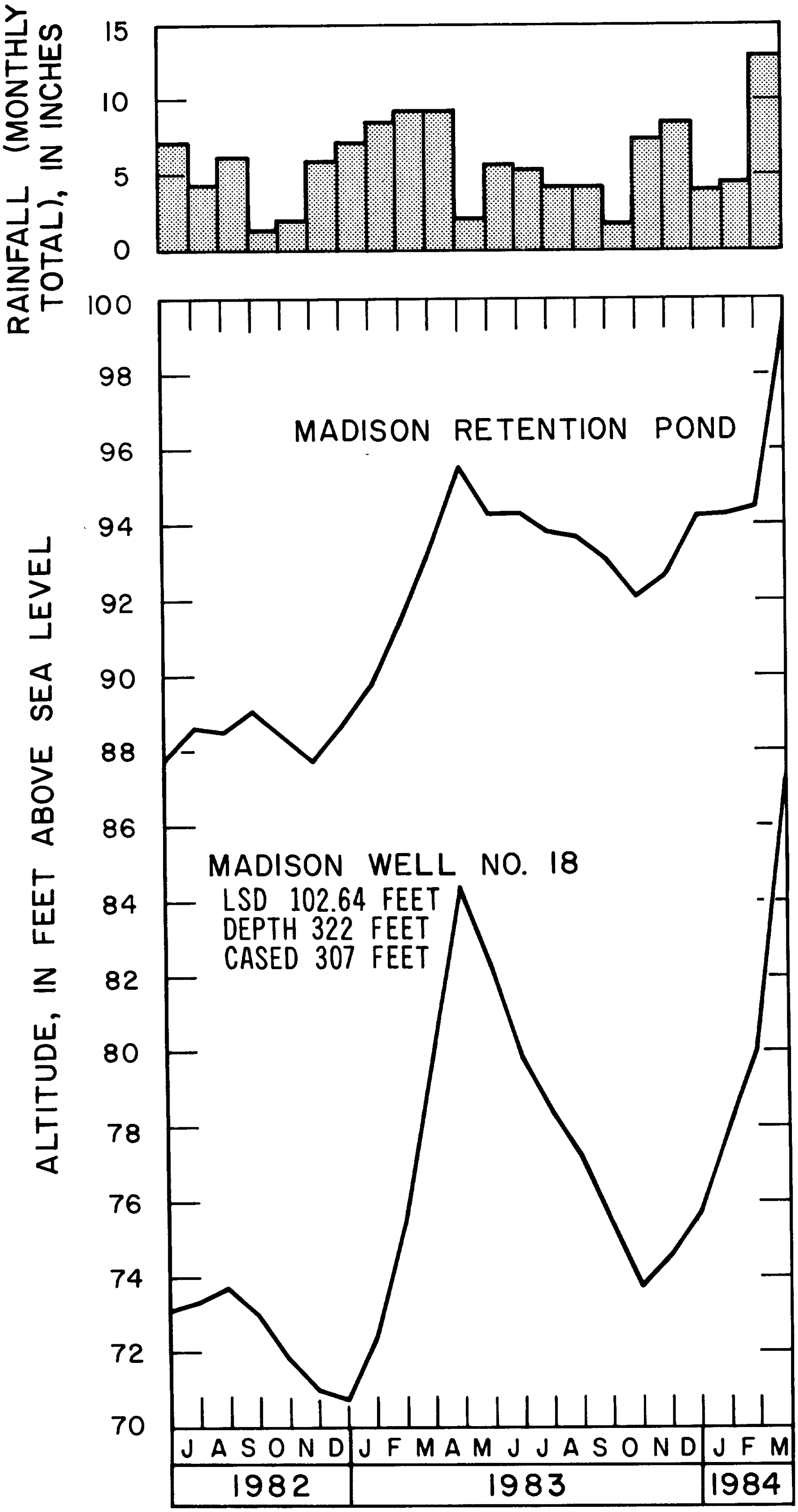

Figure 3.--Month-end altitudes of retention pond and Madison well No. 18, and monthly rainfall totals.

Analysis of Monthly Data

The significant independent variables were rainfall and evaporation. Monthly rainfall accounted for approximately 79 percent of the variance of the dependent variable. Rainfall and evaporation accounted for about 87 percent of the variance of the dependent variable. The standard error of the final regression model was 20.1 percent.

The equation for estimating the net monthly change in water-surface altitude, CNETCHG, has the form:

$$CNETCHG = 0.654(MORAIN)^{0.738}(5.7-PEVAP)^{0.137}-1.97 \qquad (1)$$

where

MORAIN is the total monthly rainfall, in inches; and
PEVAP is the estimated monthly evaporation (FWS), in inches.

To avoid problems associated with zero and negative numbers in the log transformations, a constant of 2.0 was added to the monthly change in water-surface altitude (NETCHG). The regression results indicate a bias, and, in order to reduce the net difference, a constant of -1.97 was used in equation 1.

The observed data from the pond, used in developing the regression equation, was for the period July 1982 through March 1984. Month-end pond altitudes ranged from 87.78 to 99.52 feet during the 21-month period.

Analysis of Weekly Data

An attempt was made to improve the regression model by analyzing weekly data. Weekly data for the pond altitude, water level of the Upper Floridan aquifer, rainfall, and evaporation were available from July 1, 1982 to December 28, 1983.

The independent variables, rainfall and evaporation, accounted for only 26 percent of the variation. The standard error was 68.3 percent. Other characteristics tested showed equally poor results, therefore, no further consideration will be given to weekly data in this report.

RAINFALL FREQUENCY

Rainfall frequency curves were developed using a log-Pearson Type III distribution of annual, January through April, June through August, and July rainfall totals for the years 1908-72, 1974, and 1976-82.

The rainfall-frequency curve shown in figure 4 is a log-Pearson Type III distribution of 73 years of annual rainfall totals for Madison.

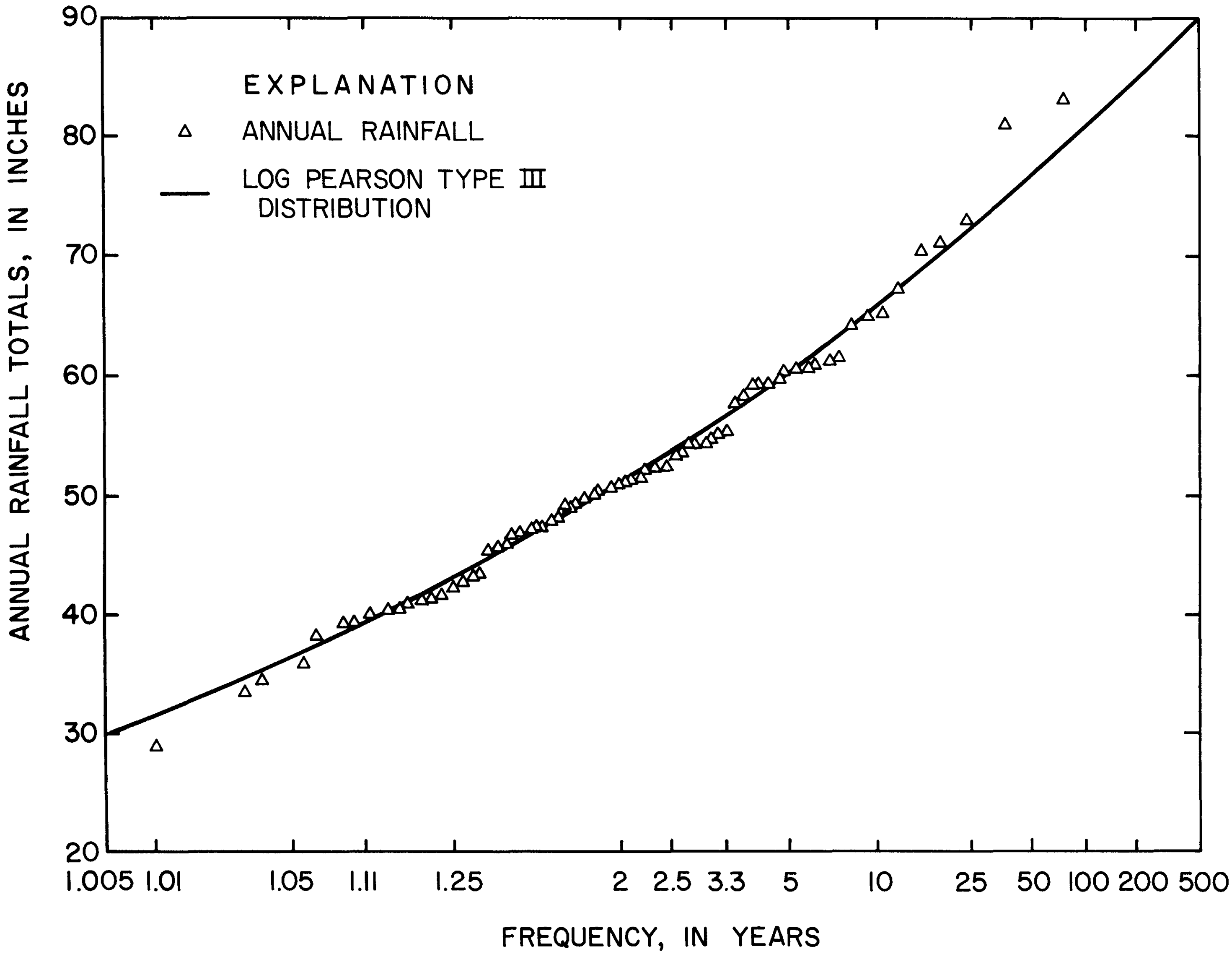

Figure 4.--Rainfall frequency curve of annual rainfall totals for Madison.

To determine the magnitude of the unusually wet period, January through April 1983, a rainfall-frequency curve was developed using 73 years of 4-month (January through April) rainfall totals (fig. 5).

The wettest 3 months of the year, based on a 73-year average, are June through August. Figure 6 represents the log-Pearson Type III distribution of the 3-month (June through August) totals. The hydrograph in figure 3 shows that June through August 1983 were not the 3 wettest months because 1983 was abnormally wet during the first 4 months of the year.

The month with the highest rainfall average, based on 73-years record, is July. Figure 7 is a log-Pearson Type III distribution of the July monthly rainfall totals. Although July 1983 (figure 3) was not the wettest month that year, 1983 was an exception as previously explained.

During the 21-month period of record, the month with the highest rainfall total was March 1984. The monthly total of 12.90 inches was equivalent to a 35-year recurrence interval.

The FDOT has set the 25-year recurrence interval rainfall as the design rainfall event. The magnitude of the 25-year recurrence interval annual rainfall (72.2 inches) is at Madison (fig. 4). Since 1908, only the 1948 (rainfall total, 81.29 inches), 1957 (rainfall total, 73.14 inches), and 1964 (rainfall total, 83.34 inches) rainfall totals have exceeded the magnitude of the 25-year recurrence interval rainfall.

SIMULATION

To demonstrate the simulation technique, the monthly rainfall measured at the retention pond, and evaporation (table 1) was input to the model to simulate the month-end pond altitude for the observed period. Table 2 and the graph in figure 8 show the observed and simulated pond altitudes for the period July 1982 through March 1984. The model tended to underestimate the observed altitudes except for the period of the sharp rise November 1983 through February 1984. The maximum difference between the observed and simulated month-end pond altitude was 1.55 feet in February 1984. The average difference for the 21 months was -0.043 feet.

Evaporation is one of the controlling factors affecting the net change of the water surface altitude of the retention pond. The seasonal effect of evaporation on the pond can be demonstrated by applying the regression model (equation 1) to the month with the highest (May) and lowest (December) evaporation. For example, to maintain the same altitude at the beginning and ending of the month, the rainfall total for May would require 6.5 inches, whereas only 3.5 inches would be needed in December to maintain that balance.

Having demonstrated that the model can be used to simulate the pond's response to rainfall-runoff, we can input historic rainfall data to the model and simulate what effect historic rainfall totals would have on the pond if the equivalent rainfall occurred under present (1984) operating conditions.

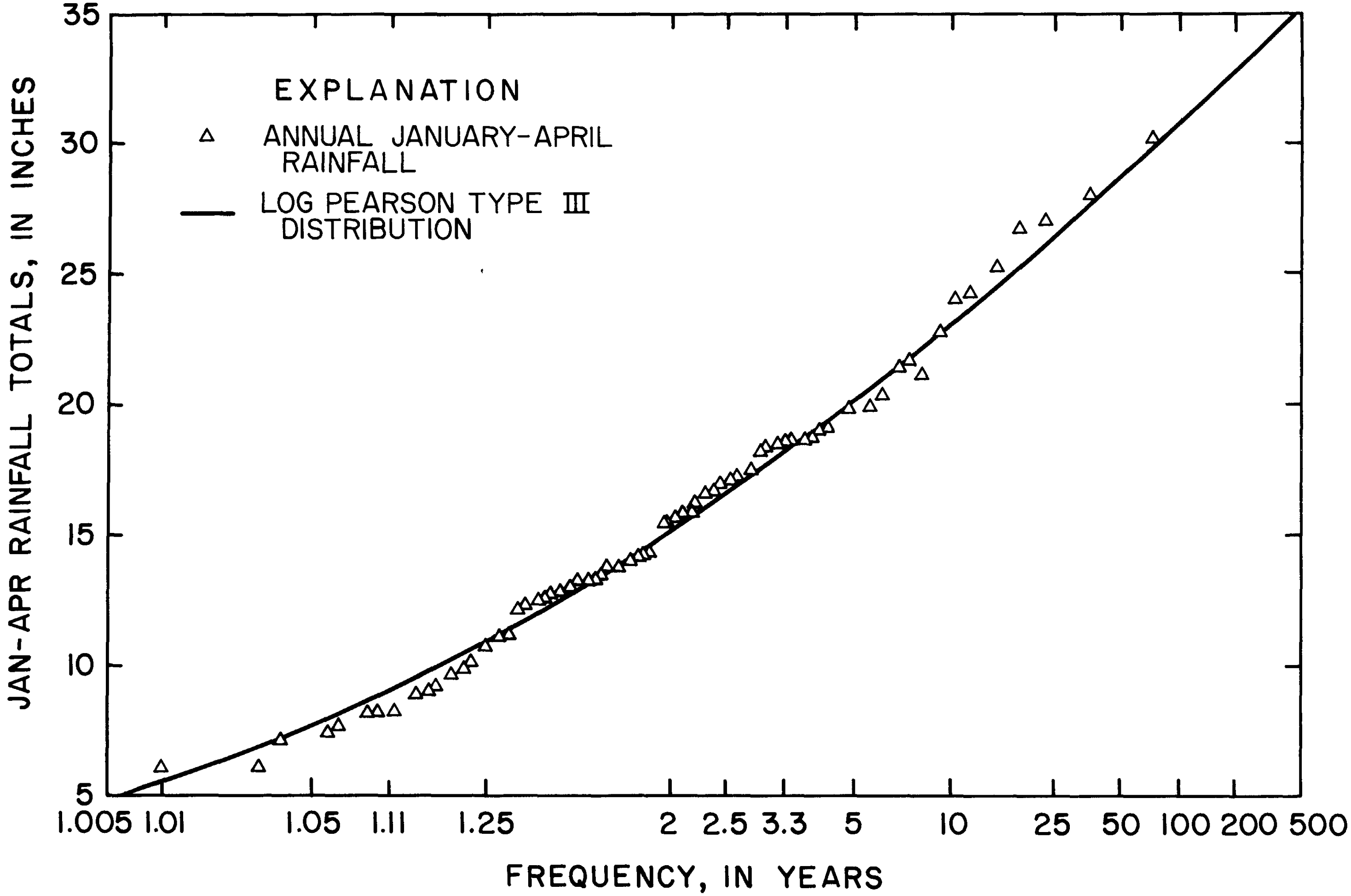

Figure 5.--Rainfall frequency curve of January through April rainfall totals for Madison.

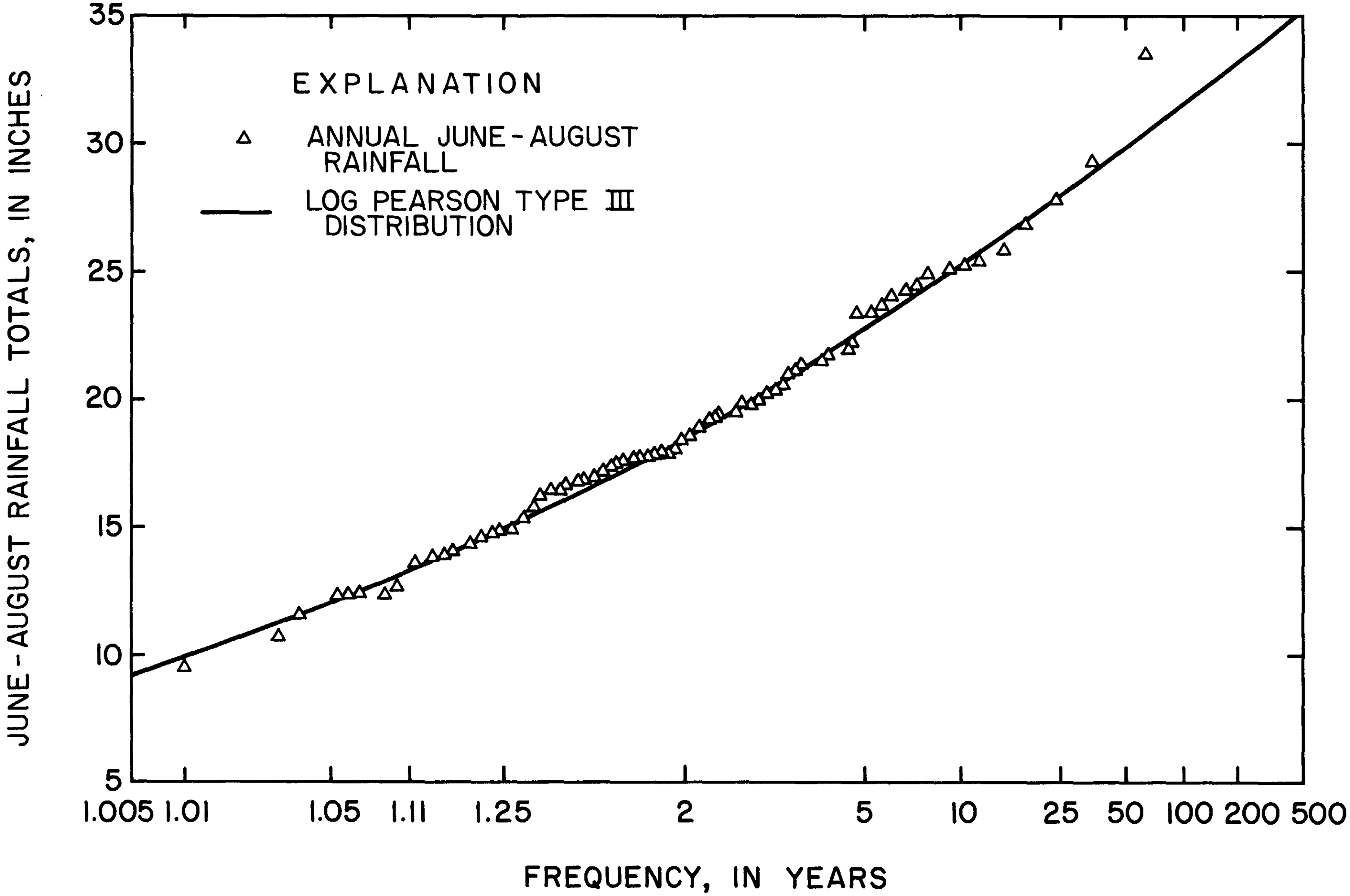

Figure 6.--Rainfall frequency curve of June through August rainfall totals for Madison.

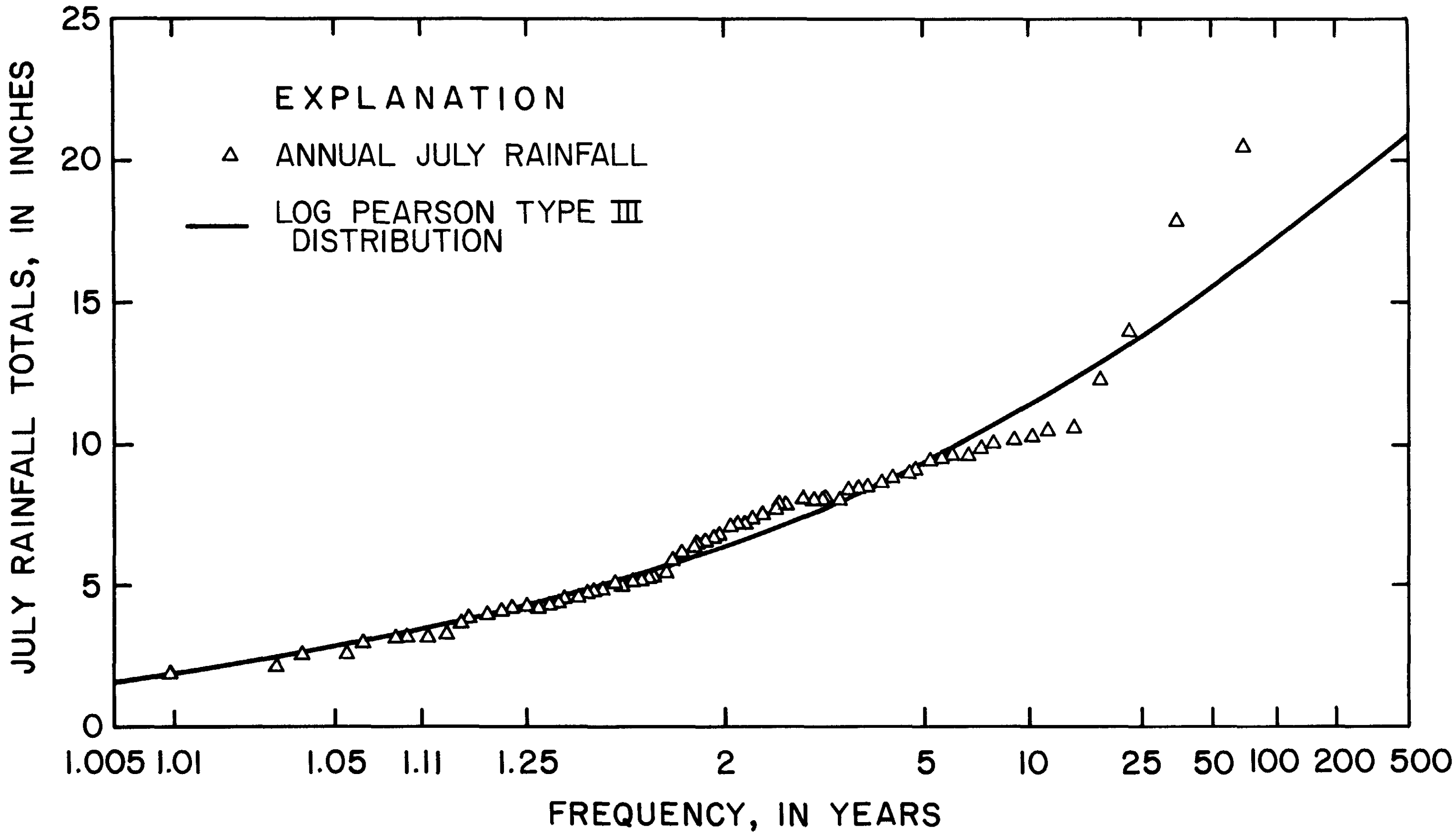

Figure 7.--Rainfall frequency curve of July rainfall totals for Madison.

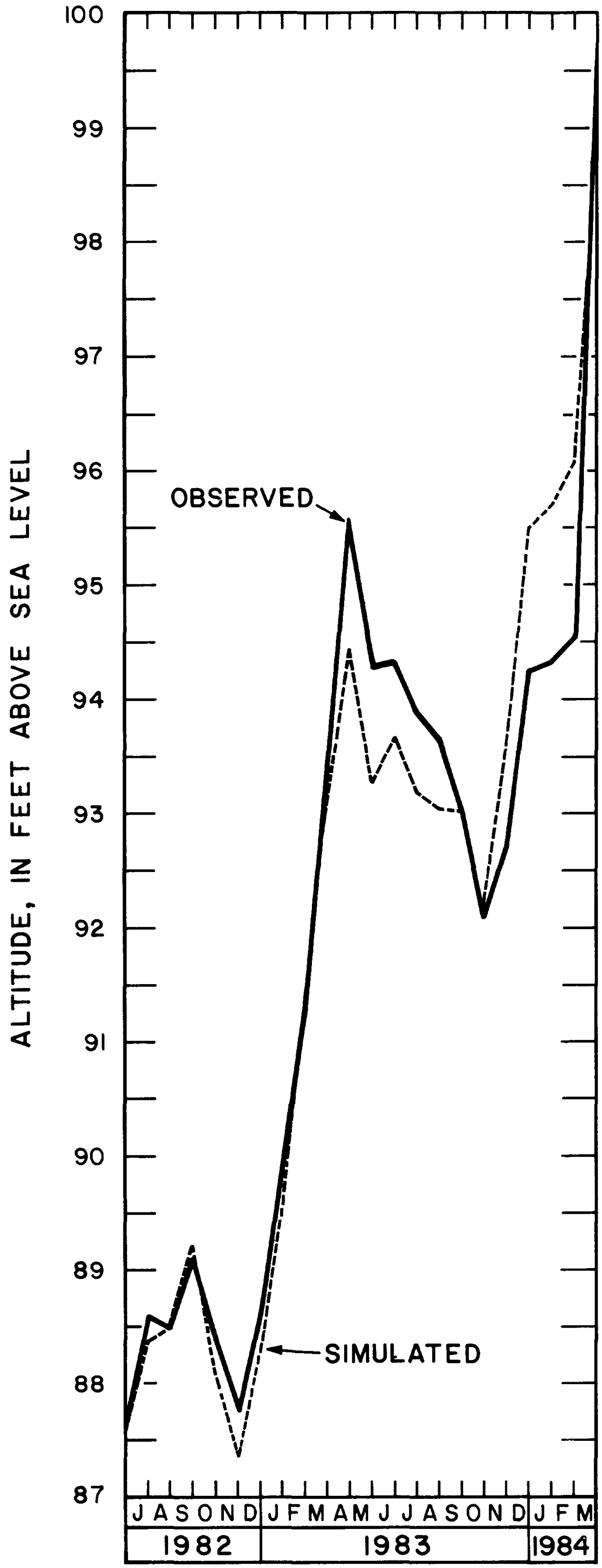

Figure 8.--Observed and simulated retention pond altitudes.

Table 2.--Observed and simulated data for the period July 1982 through March 1984

Year and month	Observed			Simulated	
	Month-end altitude	Net change	Rainfall	Net change in altitude	Pond altitude
1982					
June	87.70	-	-	-	87.70
July	88.60	+0.90	7.06	+0.69	88.39
Aug.	88.50	- .10	4.45	+ .10	88.49
Sept.	89.10	+ .60	6.00	+ .74	89.23
Oct.	88.41	- .69	1.20	-1.13	88.10
Nov.	87.78	- .63	1.95	- .71	87.39
Dec.	88.61	+ .83	5.90	+ .92	88.31
1983					
Jan.	89.83	+1.22	7.10	+1.37	89.68
Feb.	91.28	+1.45	8.40	+1.71	91.39
Mar.	93.25	+1.97	9.20	+1.71	93.10
Apr.	95.58	+2.33	9.20	+1.32	94.42
May	94.29	-1.29	2.10	-1.14	93.28
June	94.32	+ .03	5.85	+ .39	93.67
July	93.89	- .43	5.30	- .47	93.20
Aug.	93.64	- .25	4.08	- .16	93.04
Sept.	93.03	- .61	4.10	- .03	93.01
Oct.	92.09	- .94	1.90	- .81	92.20
Nov.	92.72	+ .63	7.30	+1.41	93.61
Dec.	94.22	+1.50	8.50	+1.89	95.50
1984					
Jan.	94.31	+ .09	4.00	+ .21	95.71
Feb.	94.54	+ .23	4.70	+ .38	96.09
Mar.	99.52	+4.98	12.90	+2.70	98.79

Change in Pond Altitude for Maximum Annual Rainfall

What would be the effect on the pond if the maximum annual rainfall (1964) of 83.34 inches occurred under present (1984) conditions? To project such an effect, one would most likely: (1) Determine the monthly rainfall totals for 1964 from the National Weather Service records, (2) determine the monthly FWS evaporation from table 1, and (3) simulate the net monthly change in altitude using equation 1. Assuming a starting altitude of 88 feet, the computed net change in the pond altitude would be +9.92 feet. Table 3 shows the input and output for the simulation model (equation 1). The recurrence interval of the 1964 rainfall total exceeded the 100-year rainfall total

(81 inches). A starting altitude of 89.08 feet would be required for the pond to reach a maximum altitude of 99.0 feet. If a maximum model error of 20 percent is assumed, the net change in pond altitude would be +11.90 feet.

Table 3.--Model input-output data for 1964

Year and month	Monthly rainfall (inches)	Monthly evaporation potential (inches)	Simulated net change (feet)	Estimated pond altitude (feet)
Dec.	-	-	-	88.00
1964				
Jan.	9.50	2.07	+2.14	90.14
Feb.	8.43	2.58	+1.72	91.86
Mar.	2.93	3.96	- .41	91.45
Apr.	6.46	4.97	+ .51	91.96
May	7.87	5.57	+ .30	92.26
June	4.98	5.29	- .08	92.18
July	12.46	4.97	+2.06	94.24
Aug.	6.34	4.69	+ .59	94.83
Sept.	9.61	4.00	+1.77	96.60
Oct.	5.07	3.45	+ .45	97.05
Nov.	2.03	2.53	- .68	96.37
Dec.	7.66	1.98	+1.55	97.92

Change in Pond Altitude for 25-Year Frequency Rainfall During January Through April

From January 1, 1983, through April 30, 1983, the range in altitude of the pond was about 7 feet (88.61 feet to 95.58 feet). The rainfall total for the 4 months was 33.9 inches. The January-April 1983 rainfall total exceeded the 100-year frequency (fig. 5). From figure 5, it can be determined that the 25-year frequency rainfall is 26.5 inches. From the historical rainfall record, the January-April 1928 rainfall total was 26.82 inches, and, for all practical purposes, could be called a 25-year frequency rainfall. The impact that the January-April 1928 rainfall would have on the retention pond if the rainfall occurred with the present conditions prevailing can be demonstrated. To use the simulation model (equation 1), the January-April 1928 monthly rainfall totals for Madison are needed. Table 1 provides the January-April monthly evaporation potential. Shown in table 4 are the input data and results from the simulation model. The net change would be +2.78 feet. The altitude of the pond on December 31 would have to be 96.22 feet in order to reach the maximum of 99.0 feet by the end of April. With a model error of 20 percent, the net change in altitude could be +3.34 feet.

Table 4.--Model input-output data for January-April 1928

Year and month	Monthly rainfall (inches)	Monthly evaporation potential (inches)	Simulated net change (feet)	Estimated pond altitude (feet)
Dec.	-	-	-	96.22
1928				
Jan.	0.86	2.07	-1.27	94.95
Feb.	4.90	2.58	+ .50	95.45
Mar.	8.72	3.96	+1.52	96.97
Apr.	12.34	4.97	+2.03	99.00

Change in Pond Altitude for 25-Year Frequency Rainfall During June Through August

The 3 months with the highest average rainfall are June through August. The 25-year frequency rainfall for June-August is 28.0 inches (fig. 6). The equivalent 25-year rainfall frequency occurred June-August 1909 when the total for the 3 months was 27.85 inches. Equation 1 was used to simulate the effect that the June-August 1909 rainfall would have on the retention pond. Table 5 shows the input data for equation 1 and the results from the simulation.

Table 5.--Model input-output data for June-August 1909

Year and month	Monthly rainfall (inches)	Monthly evaporation potential (inches)	Simulated net change (feet)	Estimated pond altitude (feet)
May	-	-	-	95.62
1909				
June	4.74	5.29	-0.15	95.47
July	18.04	4.97	+3.33	98.80
Aug.	5.07	4.69	+ .20	99.00

If the equivalent June-August 1909 rainfall had occurred under present conditions, the altitude of the pond on May 31 would have to be 95.62 feet in order to reach the maximum altitude of 99.0 feet by the end of August. The net change would be +3.38 feet, but the net change could be as great as +4.06 feet with a model error of 20 percent.

Change in Pond Altitude for 25-Year Frequency Rainfall During July

The month with the highest average rainfall is July. As portrayed in figure 7, the 25-year recurrence interval rainfall for July is 13.8 inches. According to equation 1, the net change corresponding to this rainfall would be +2.38 feet, and for a maximum model error of 20 percent, the net change could be +2.86 feet. The June 30 water-surface altitude would have to be 96.62 feet in order to reach 99.0 feet by July 31. The maximum observed July rainfall total was 20.68 inches in 1935, which is 6.88 inches greater than a 100-year recurrence interval rainfall. If the July 1935 rainfall is input into equation 1, the monthly net change would be +3.89 feet. The month-end water-surface altitude for June would have to be 95.11 feet in order to reach an altitude of 99.0 feet by the end of July.

Annual Rainfall Required for No Net Change in Pond Altitude

An annual rainfall total of 54 inches would be the approximate "break-even" total that would be necessary for net gains and losses at the retention pond to be about equal. The average annual rainfall (73 years) for Madison is 51.96 inches; therefore, years with average or below average rainfall would result in net losses of water from the pond.

CONCLUSION

The FDOT Madison retention pond has limited capacity (121 acre-feet at an altitude of 99 feet), and, under present (1984) conditions, has no outlet. The greatest potential for the capacity of the pond being exceeded would be in the winter months when evaporation potential is low and in early spring when ground-water levels are high.

The rainfall simulation model that was developed for this study was used as a tool to predict what would happen when selected historic rainfall record, or selected rainfall recurrence intervals, were simulated under 1984 conditions. Simulation of the 1964 rainfall record (83.34 inches), the year with the greatest rainfall total, showed that the capacity of the pond would not have been exceeded. This is assuming a starting altitude of less than 89.08 feet.

The pond is capable of handling the design 25-year annual rainfall (72.2 inches), the 25-year January through April rainfall (26.5 inches), the 25-year June through August rainfall (28.0 inches), and the 25-year July rainfall (13.8 inches).

The pond capacity was not exceeded during the unprecedented rainfall (33.9 inches) during January to April 1983 when the altitude of the pond increased almost 7 feet.

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