Chapter 23

Computerized Analysis of Rainfall Records to Determine Design Storm for CSO Abatement

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Design storms for control of discharges from storm or combined sewer systems are typically stated in terms of duration/recurrence-interval, e.g. the system must be designed for the 5-year 24-hour storm or the 1-year 6-hour storm. Selection of the design storm under these conditions normally means selecting it from standard curves or charts prepared by a government agency for the specific geographic area involved. When control requirements are stated in terms of allowable overflows or discharges, rather than in terms of containment

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or conveyance of a specific storm event, selection of the design storm or storms is not so easily determined. This chapter presents a methodology for selecting design storms to limit overflow from a combined sewer system to not more than a specified number of occurrences per year.

23.1 Background

The Metropolitan Government of Nashville and Davidson County Department of Water and Sewerage Services (MWS) must eliminate all unpermitted overflows from its Combined Sewer System by 1 July 2001. Elimination of unpermitted CSO's is one of several abatement actions dictated in an order issued in March 1990 by the Commissioner of the Tennessee Department of Environment and Conservation (TDEC). Overflows in excess of eight per year to the Cumberland River or in excess of one every fourteen months to its major tributaries will be considered as "unpermitted" under the terms of the Order (TDHE, 1990). Based upon a study conducted in 1988, the State determined this level of control for protecting water quality in the receiving streams.

The Nashville combined sewer system covers 8,975 acres (3632 hectares). These sewers were originally constructed to discharge directly into receiving streams or indirectly to trunk storm sewers. This system was modified in the 1950s by the addition of regulator structures and interceptors for conveyance of sewage to the Central Wastewater Treatment Plant (CWWTP). The intent of the design of the existing system was to provide for 100% treatment of the dry weather sanitary flow from the combined sewer area. The regulator devices were installed to divert part of the combined sewage to the receiving stream during rain events when the additional volume of storm water would cause the capacity of the treatment plant and the interceptors to be exceeded. The philosophy of design at the time of construction was that the overflow of diluted sewage to receiving streams, that were also swollen by rainfall, had a negligible environmental effect. Presently there are 30 active discharge points (regulated by mechanical float-operated gates, a combination of orifices and weirs, or simple "bleeder" type overflows) in the combined sewer system.

The firm of Consoer, Townsend & Associates (CTA), as the Manager of the Nashville Overflow Abatement Program (OAP), was tasked to develop appropriate design criteria and parameters for controlling overflows to the Cumberland River. A separate tasking was made for Brown's Creek. The earlier analysis and report (CTA, 1988) established the needed capacity improvements to the CWWTP, the receiving treatment facility for all combined sewer system flows from the MWS system. Upon completion of the current plant expansion in 1996 the peak pumping rate from the station receiving all combined sewer flow will be 160 MGD (1050 cu m/day).

To limit flow from the combined sewer system to a rate within the capacity of the central pumping station, excess flow will be temporarily stored

in detention facilities to be constructed by 2001 as part of the overall OAP. The required detention capacity is determined by routing runoff hydrographs generated by the HEC-1 model of the tributary combined sewer basins through an EXTRAN model of the proposed system with various detention basin/storage tunnel configurations. The key unknown parameter is selection of the intensity-duration relationship which would be exceeded eight times per year on average. Intensity-duration tables are not available for this return frequency, nor are they typically available for return frequencies of less than one year.

23.2 Design Storm Selection

In a typical design of facilities to convey and store runoff, a rainfall recurrence interval is selected. The recurrence interval is a statistical representation of the frequency at which an event will occur. For example, a one-year recurrence interval implies that an event will be equaled or exceeded at least once per year on average. Rainfall duration-intensity-frequency tables for Nashville for the period 1949 through 1985, are shown in *Nashville Stormwater Management Manual* (EDGe, 1988), where rainfall statistics are expressed either graphically as “intensity-duration-frequency” curves (Figure 23.1) or in tables of average intensity per hour for varying recurrence intervals and frequencies. The total depth (inches) of rainfall for a storm of a given duration is the product of average intensity (inches/hour) and duration (hours). For example, using tables in *Nashville Stormwater Management Manual*, it is projected that 3.39 inches (86.1 mm) of rain in 24 hours will occur on the average once every two years. In hydrologic terms, a 24-hour storm of 3.39 inches (86.1 mm) has a recurrence interval of two years. This does not mean that two such rainfalls will not occur in one year, but rather that over a reasonable number of years, 3.39 inches (86.1 mm) of rainfall in 24 hours can be expected to occur on average once every two years.

Because rainfall amounts vary from month-to-month (Figure 23.2), and the limitation has been established of an average of eight overflows per year, use of standard recurrence interval calculations, valid for recurrence intervals of one year or more, are not appropriate for this analysis. A technique is required that selects a rainfall depth that can be expected to be exceeded on average eight times per year. It was assumed that using actual rainstorm data from over 41 years of available records (September 1948 - December 1989) would provide valid data for rainfall selection. A computer model was developed to compute gross storage requirements using rainfall and assumptions of tributary area, imperviousness coefficient, and a pumping rate at the treatment plant. Rainfall was translated to runoff volume per hour. Hourly runoff volume in excess of the selected hourly pumped volume was assumed to be stored. The hourly storage amounts were accumulated. Pumping at the central wastewater treatment plant was assumed to increase with increasing flow until the maximum pumping rate

Figure 23.1
Standard intensity-duration-frequency curve for Metro Nashville and Davidson County, Tennessee (after *Nashville Stormwater Management Manual*).

Figure 23.2
Maximum, minimum and average monthly rainfall amounts at Nashville International Airport.

was reached, and remain at the maximum rate until the stored volume was reduced to zero.

23.2.1 Rainfall Analysis

The initial model analyzed all rainstorm events in the period from September 1948 through December 1989. Resulting storage amounts and their associated rainstorms were arranged in descending order. The rainstorm corresponding to the 330th largest storage volume requirement (Figure 23.3) was chosen as the initial design rainstorm [1.35 inches (34.3 mm) in 12 hours]. The 330th value was selected assuming that for the 41+ years of record, eight overflows per year would produce 330 overflow events. Two additional storms (Figure 23.4 and Figure 23.5) were modelled for comparative purposes. This analytical procedure was rejected when it was noted that differing pumping rates produced different design storms, depths and durations. Although pumping rates and storm patterns are significant for determining storage requirements, it was concluded that the design rainstorm selection procedure should be independent of man-made parameters. However, the 330th largest storage event rainstorm provided a benchmark against which other analytical techniques could be measured.

Hourly recorded rainfall amounts at the Nashville Airport were screened through a database program to develop records of total rainfall amounts for consecutive hourly periods from 1 to 72 hours in length. The program moved a window of a specific number of hours across the records in the data base and summed the total rainfall recorded during the period covered by the window to new records (storms). A second database program was used to order the resulting storms from largest (greatest amount of rainfall for the period) to smallest while ignoring any time overlap between records.

These storms were then reviewed to select the appropriate rainfall amounts for each duration, which should represent the total rainfall producing the runoff to be contained by the recommended system. This rough ordering yielded results inconsistent with standard depth-duration curves in published documents. Review of the storms generated by the rough ordering showed multiple occurrences of the same rainfall event in the records. For example, the magnitude of a single rainstorm in mid-September 1979 caused nine overlapping 24-hour periods covering portions of this single event to appear as the nine highest ranked (largest rainfall amounts) 24-hour storms. Further screening was necessary to eliminate the duplication of single events and permit accurate selection of the correct events to be contained by the recommended improvements.

A series of simple find/compare/delete database programs using the indexed storm records deleted duplicate records of the same storm event (defined as a record of the same length with a beginning time within a defined time

Figure 23.3
Flow and storage requirements for a natural, single-event 12-hour storm, total rainfall of 1.35" (34.3mm).

Figure 23.4
Flow and storage requirements for single-event 24-hour storm, total rainfall of 1.50" (38.1mm).

Figure 23.5
Flow and storage requirements for double-event 30-hour storm,
total rainfall of 2.10" (53.3).

interval either prior to or subsequent to the starting time of the storm initially selected for comparison). These programs started with the first (largest rainfall amount) storm of the selected duration (1, 2, 3, 6, 12 or 24 hours) in the indexed file and searched forward through the file for all events which started within the defined time interval. For screening purposes, the defined interval was selected as 12 hours either side of the starting time of the initially selected storm. Any record with a starting time within this interval was deleted from the file and the selector was moved forward to the next largest storm in the indexed file. The process was then repeated as many times as necessary to obtain the number of largest events desired. These data were sorted using database programs to rank each event by depth, duration and year to identify the nine largest events of each duration by year.

Prior to selecting 12 hours either side of the starting hour as the basis for elimination of duplicate events, both shorter and longer time intervals were evaluated and the results of their use compared, where possible, to standard intensity-duration-frequency curves and depth-duration data. Use of a 24-hour interval prior to and following 24-hour rainstorms produced results that were inconsistent with the published standard data. Telephone discussions with National Weather Service personnel supported the use of the 12-hour interval as a reasonably accurate delimiter. Typical interevent time definition (IETD)

values for urban catchments are reported (Li and Adams, 1992) as ranging from 1 to 6 hours. Analysis by the STATISTICS block of the SWMM program using the actual record data for Nashville defined the IETD for Nashville as 10 hours.

Rainfall records for January 1990 through February 1992 were obtained and added to the records used in the preliminary analyses. This shifted the critical event from the 330th to the 349th position ($43.5 \times 8 = 348$). A specially developed computer program searched the file of over 381,000 hourly rainfall records and created a database of naturally occurring rainfall events totaling more than 0.05 inches (1.27 mm) of rain separated by at least the 10 hour IETD. The computer program disregarded any group of hourly rainfall totals if the group included any missing record hour in either the period of the active rainstorm or in the 10 hour period of no rain. These storms were then considered as statistically independent storm events for further analysis and were ordered from largest to smallest by duration. Initial review indicated that further manipulation of the raw data making up the independent storm events was necessary to obtain results consistent with standard depth-duration data. For example, rainfall intensities produced for 6-hour duration events were significantly lower than expected for return frequencies of 2, 5, 10 and 25 years. This was corrected by adding the maximum 6-hour totals from storm events with longer durations to the tabulations of unique 6-hour events. This procedure was also followed for the other event durations.

An additional program was developed to extract shorter combinations of hourly data from longer duration individual storms and combine hourly data from more than one individual storm when the duration of interest was longer than the IETD between individual storms. The results obtained for the 24-hour depth duration from this process were manually compared to a tabulation of the results obtained from the earlier find/compare/delete screening process. Where differences between the two sets of results were encountered, the actual hourly rainfall data were reviewed to ascertain which set appeared to be valid. The program was modified and the process repeated several times in an iterative manner until it was considered debugged. The program was then used in its final (for the purpose of the Nashville study) form to produce rank ordered 1, 2, 3 and 6 through 72 hour (in 6 hour increments) depth-duration values (Table 23.1).

This procedure identified 3,184 naturally occurring storms ranging from 1 to 95 hours in length. Additional computer analyses were performed to identify the maximum depth produced by each natural storm for specific durations from 1 to 72 hours. The 10 hour IETD constraint was ignored for storm durations of 12 hours and greater in order to determine the maximum rainfall for the selected duration, whether produced by a single natural storm or by combinations of natural storms. While multiple shorter duration values are possible within a longer natural storm, only the largest value for a given duration for a given natural storm was used. For example, a natural storm lasting 13 hours could yield 13 one-hour duration periods, 12 two-hour duration periods, 11 three-hour

duration periods, etc., but only the largest value for each duration would be selected from this storm.

Table 23.1
Design Duration-Depth Values

Duration - Hours	Rainfall Depth - Inches*
1	0.51
2	0.70
3	0.82
6	1.00
12	1.20
18	1.32
24	1.36
30	1.41
36	1.45
42	1.47
48	1.51
54	1.56
60	1.59
66	1.64
72	1.67

* 349th ranked value (inches x 25.4 = mm)

23.2.2 Synthetic Design Storm Development and Testing

All rainfall/runoff analyses make certain assumptions regarding initial abstraction (the quantity of potential runoff detained by depression storage and initial wetting of the soil). These assumptions influence the total storage requirements by reducing the storage required for protracted rainstorms. For the analyses of the study, it was conservatively assumed that the soils should be wetted by an antecedent rainfall prior to the higher hourly intensity rainfall to maximize runoff. Total runoff from the tributary combined sewer systems was measured to develop specific basin characteristics.

One approach to designing a hyetograph is to create a balanced pattern. Figure 23.6 is an example of a balanced, 1.41" (35.8 mm), 30-hour storm that incorporates all the intensity-duration values identified in Table 23.1 for the eight per year recurrence (up to the 30-hour duration). The storage capacity for the proposed system using this storm was calculated by EXTRAN to be 78 million gallons (295,230 cu m).

To simulate a multiple-storm event to insure that the soil would be saturated, a 30-hour unbalanced synthetic hyetograph (Figure 23.7) with two

Figure 23.6
1.41-inch (35.8mm), 30-hour duration balanced rainfall hyetograph.

Figure 23.7
1.41-inch (35.8 mm), 30-hour duration design rainfall hyetograph.

rainfall periods was constructed. This hyetograph included a rainfall of 6 hours, an interval of 10 hours of no rain, and a second rainfall of 14 hours. The storage volume requirement resulting from this rainfall was 85 million gallons (321,725 cu m); thus the unbalanced hyetograph pattern was selected, because it resulted in a more conservative design.

Using a 30-hour design rainfall duration was, in part, a matter of judgement. The computer analysis of rainfall records determined intensity levels for up to 72 hours. Review of runoff hydrographs indicated that storage volume requirements were not increased by rainfall added after 30 hours. Additionally, analysis of the 12 largest storms in an average year (1949) discussed later in this section, indicated that the critical depth/durations occurred between 18 and 24 hours. Conservatively selecting 24 hours and adding a 6-hour antecedent rainfall resulted in selection of a 30-hour storm.

A significant aspect of the selected hyetograph is the time from the beginning of rainfall to the time of the maximum or peak hour rainfall rate. The selected storm represents historical data of sufficient duration to consider the potential occurrence of multiple events and forces the HEC-1 model to consider antecedent rainfall. Rather than using a balanced hyetograph, the soil was assumed to be saturated by a small storm early in the period, then the peak rainfall period was presented at the end of the storm. These conditions maximize soil moisture and assure maximum runoff.

The synthetic design storm hyetograph (Figure 23.7) was constructed so that no specific period of interest (i.e. 1 hour, 2 hours, 3 hours, 6 hours, 12 hours, and 24 hours) contained a total rainfall amount in excess of the 349th value for that particular duration. To test the validity of the storage volumes determined by use of the synthetic storm hyetograph, actual historical rainstorm patterns were modelled.

A tabulation (Table 23.2) of the estimated number of overflows which would have occurred over the 43.5 years of record had the recommended storage facilities been in place during those years was used as the starting point for selection of representative rainstorms to use in testing the model. The tabulation suggested that an average of eight overflows per year would have been caused by the largest recorded rainfall amounts for each of the six durations (1, 2, 3, 6, 12 and 24 hours) of interest over the period of record, with the annual number for each duration varying from a minimum of two to a maximum of sixteen. Each complete year (1949 through 1991) with rainfall data was reviewed to determine which year or years represented most closely an average year of rainfall.

Several factors were considered in selecting the average year. To adequately test the model, it was decided that the average year should be a year projecting as closely as possible to the 8 overflow average, and, given a choice between a year averaging slightly more or slightly less than 8 per year, the year averaging more than 8 would be preferred. An additional factor considered was

Table 23.2
Annual Events > 349th Ranked Event

Year	1Hr	2Hr	3Hr	6Hr	12Hr	24Hr	Total
1949	9	9	9	8	7	9	52.0
1950	11	12	16	13	12	13	64.3
1951	8	10	10	8	9	9	58.4
1952	7	6	4	6	7	7	39.6
1953	6	4	5	4	4	3	30.4
1954	4	7	6	9	9	10	42.4
1955	8	8	6	8	8	7	45.4
1956	3	5	5	6	6	7	43.9
1957	11	13	12	11	11	11	60.1
1958	7	8	6	6	7	7	40.9
1959	11	9	9	10	8	8	48.0
1960	5	6	7	6	5	5	42.4
1961	4	3	5	8	6	5	44.7
1962	7	9	7	10	10	13	57.6
1963	9	9	10	7	8	9	44.4
1964	5	6	6	5	6	7	45.0
1965	9	10	7	8	6	7	39.7
1966	5	8	8	6	7	6	41.1
1967	9	10	8	6	6	7	45.2
1968	10	9	9	9	7	7	43.9
1969	8	7	7	7	8	8	47.3
1970	8	8	9	7	9	10	46.9
1971	10	9	6	7	2	2	40.7
1972	9	7	7	8	8	6	54.4
1973	16	12	12	14	11	9	59.8
1974	8	8	8	9	9	9	60.7
1975	12	12	13	13	14	10	60.6
1976	8	9	10	9	10	9	49.6
1977	10	12	11	12	10	12	50.7
1978	13	9	9	9	9	9	53.4
1979	13	10	8	9	12	14	70.1
1980	4	4	7	6	6	5	34.9
1981	9	7	7	7	7	5	41.7
1982	9	6	7	8	7	8	49.4
1983	6	6	9	10	11	12	51.7
1984	12	11	10	12	12	13	56.5
1985	3	2	2	3	2	2	31.2
1986	5	4	4	4	5	6	31.5
1987	6	6	5	3	4	4	30.2
1988	2	3	5	5	5	4	31.4
1989	8	11	8	10	14	11	57.0
1990	10	9	9	9	10	10	45.8
1991	5	6	5	5	7	8	46.9
Max	16	13	16	14	14	14	70.1
Min	2	2	2	3	2	2	30.2
Avg	7.95	7.88	7.74	7.91	7.93	7.98	47.3

the variation from 8 overflows per year for each duration, with preference given to years with not less than 7 nor more than 9 overflows for any rainfall duration. Calendar year 1965 varied the least (0.17 in absolute terms) at 7.83 (mean value of all 6 durations) from meeting the 8 per year criteria, and 1967 was second with a variation of 0.33. Several years (1949, 1954-55, 1968-70, 1972, 1974, and 1982) varied ± 0.50 . These eleven years were all considered close enough to the average of 8 for further evaluation and were examined in more detail. Four of them (1949, 1968, 1970 and 1974) met the second criteria of having a mean value greater than 8 per year. The years 1949 and 1974 each met the third criteria of projecting between 7 and 9 overflows per year for each duration of interest. The year 1974 appeared to be nearer the average since 8 overflows for 1, 2 and 3-hour storms and 9 overflows for 6, 12 and 24-hour storms were projected. Seven overflows for the 12-hour storm, 8 for the 6-hour storm, and 9 for 1, 2, 3 and 24-hour storms were projected for 1949. However, when compared to the average annual total rainfall amount of 47.3 inches (based upon data from the 43 complete years of 1949 through 1991), 1949's total of 52.0 inches was significantly closer to the annual average than was 1974's 60.7 inches.

Additional tabulations were prepared listing the starting date, starting hour and total rainfall amount for the twelve largest rainfalls of each duration (1, 2, 3, 6, 12 and 24 hours) for calendar years 1949 and 1974. Totals of 18 (1949) and 19 (1974) separate rainfall events were identified as containing these 72 specific data points. Twelve of the 19 events of calendar year 1974 contained the largest 10 rainfalls of each duration with the exception of the 6th largest 1-hour rainfall and the 10th largest 24-hour rainfall. Fifteen of the 18 events of calendar 1949 were required to cover the largest 10 rainfalls of each duration. Hourly data for each of these events were extracted from the rainfall data base and used to construct input hyetographs for testing the model against real storms of record. The hyetographs for calendar year 1949 were selected as representative of an average year and the highest 12 ranked events (Table 23.3) were used for testing the model. The results obtained (Table 23.4) suggested that durations of less than 12 hours had little overall impact on the storage volume required and should not be given undue weight in sizing detention facilities for the Nashville system.

23.3 Future Applications of Methodology

At present, the State of Tennessee requires that Metro Nashville provide control to a level of not more than 8 overflows per year. The 10 hour interevent period established for the Metro Nashville area has been accepted (TDEC, 1990) by the state regulators as appropriate for definition of a rainfall "event" which must be evaluated for compliance with the terms of the order. Water quality studies of the receiving waters continue and it is reasonably anticipated that the "8 per year" criteria may change to either a stricter or more lenient requirement

Table 23.3
Top Ranked Storms for Calendar Year 1949

	Duration	1 Hour	2 Hours	3 Hours	6 Hours	12 Hours	24 Hours
1st Event	Date	04/12	04/12	04/12	04/12	06/14	06/14
	Total	1.43	1.59	1.63	1.86	2.60	3.39
2nd Event	Date	05/16	05/16	05/16	06/14	04/12	12/12
	Total	0.74	1.11	1.15	1.82	2.30	2.43
3rd Event	Date	07/25	07/13	06/14	03/26	12/11	04/12
	Total	0.74	1.01	1.07	1.47	1.80	2.37
4th Event	Date	07/13	06/14	12/12	12/12	10/30	10/30
	Total	0.71	1.00	1.07	1.46	1.61	2.02
5th Event	Date	05/22	08/19	07/13	03/17	03/26	03/26
	Total	0.60	0.88	1.02	1.24	1.59	1.59
6th Event	Date	08/19	05/22	03/26	05/16	03/17	01/04
	Total	0.60	0.85	1.01	1.20	1.47	1.57
7th Event	Date	03/26	03/26	05/22	10/30	02/18	03/17
	Total	0.58	0.78	1.00	1.04	1.25	1.56
8th Event	Date	05/20	07/25	03/17	07/13	05/16	02/18
	Total	0.58	0.74	0.91	1.02	1.20	1.50
9th Event	Date	06/14	12/12	08/19	05/22	05/20	05/20
	Total	0.58	0.72	0.90	1.00	1.17	1.37
10th Event	Date	08/05	08/05	05/20	08/19	07/13	05/16
	Total	0.51	0.70	0.76	0.97	1.14	1.34
11th Event	Date	03/17	03/17	08/05	05/20	01/02	01/26
	Total	0.46	0.69	0.75	0.94	1.09	1.32
12th Event	Date	07/10	05/20	07/25	02/19	08/19	07/13
	Total	0.42	0.59	0.74	0.87	1.02	1.23

when the studies are completed. The methodology can be used to establish design parameters similar to those established for the "8 per year" criteria for any other reasonable number of allowable overflows per year. Preliminary selection of design hyetographs for 4, 6, 12, 16 and 20 allowable overflows per year have been made and need only be routed through the HEC-1/EXTRAN system model to analyze required changes to detention and conveyance facilities. Figure 23.8 depicts the family of curves for 1 through 72 hour durations of rainfall that will apply to the Nashville system for those numbers of allowable overflows in addition to the 8 per year condition.

The analyses conducted to date have used rainfall data from the National Weather Service (NWS) rain gauge located at Nashville International Airport.

Table 23.4
Results of Modelling Calendar Year 1949 Actual Events

EVENT NO.	1HR	2HR	3HR	6HR	12HR	24HR	TOTAL	SYSTEM OVERFLOW
9	9	4	3	2	1	1	4.33	YES
14	*	9	4	4	3	2	2.72	YES
5	1	1	1	1	2	3	2.37	YES
13	*	*	*	7	4	4	2.09	YES
4	7	7	6	3	5	5	1.59	YES
1	*	*	*	*	*	6	1.57	YES**
3	11	11	8	5	6	7	1.57	YES
2	*	*	*	12	7	8	1.50	YES**
7	8	12	10	11	9	9	1.37	NO
6	2	2	2	6	8	10	1.34	NO
10	4	3	5	8	10	12	1.23	NO
12	6	5	9	10	12	*	1.02	NO
8	5	6	7	9	*	*	1.00	NO
11	3	8	12	*	*	*	0.74	NO

* Indicates Storm Not in 12 Largest Events of This Duration

** Extended Storm with Natural Antecedent Rainfall to Check Effect of Saturation

The MWS has installed a network of rain gauges throughout its service area to monitor variations in rainfall amounts and patterns and the impact on specific segments of the sewerage system. These gauges have not been in operation for a sufficient length of time to allow evaluation of historical trends to the extent possible with the NWS rainfall data. Continued collection and evaluation of data from all rain gauges in the MWS area will permit comparison between different rain gauge locations and possible modification of the operating permits based upon more refined analyses.

23.4 Summary

Rainfall data analyses established intensity/duration data for periods ranging from 1 to 72 hours against which the rainfall event causing an actual overflow can be compared to determine whether or not a violation has occurred. Without a means to confirm that a specific overflow was a violation or was one of the "8 per year" permitted under the terms of the order, measurement of actual compliance would be difficult at best. It could be argued that any overflows in

Figure 23.8
Rainfall amounts to be contained to limit overflows
to the indicated number per year.

Figure 23.9
Extended intensity-duration-frequency Metro Nashville
and Davidson County, Tennessee.

excess of 8 in one year, regardless of the rainfall pattern for the year, would constitute a violation. This same argument could permit up to 8 overflows without penalty even should no rainfall event during the year exceed the design criteria for which the system should capture all runoff without an overflow.

Finally, as seen in Figure 23.9, the methodology allows creation of intensity-duration-frequency curves for recurrence intervals of less than one year.

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