CALIBRATION OF FEDERAL AGENCY STORM WATER RUNOFF QUANTITY MODELS FOR OKLAHOMA CITY

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Six discrete event urban rainfall-runoff quantity models used by Federal agencies were calibrated on twenty-three events recorded by the U. S. Geological Survey (USGS) on three urban basins during 1974-1975 in Oklahoma City. The models were the Rational Method, used by the Department of Housing and Urban Development (HUD); TR-20, used by the U. S. Soil Conservation Service (SCS): HEC-1, used by the U. S. Corps of Engineers (COE); Urban Flood Hydrograph Synthesis Model (G824), used by the USGS: SWMM, developed for the U. S. Environmental Protection Agency (EPA): and MINICAT, under consideration for use by the National Weather Service, River Forecast Center (RFC). The models were calibrated for peak discharge on the recorded floods, and all except the Rational Method were calibrated for runoff volume.

INTRODUCTION

Urban surface water hydrology has a wide range of applications toward water quality, soil erosion and sedimentation, urban land use planning, flood plain zoning, and engineering projects, such as the design of storm sewer conduits and channels, flood control levees and detention lakes, and bridges and culverts for streams. The USGS presently operates about ten recording flood gages and about two dozen nonrecording crest gages in the metropolitan Oklahoma City area, and the Oklahoma City municipal government operates an additional few, but almost all have been installed in the last few years, and do not have long periods of record. Therefore, owing to the shortage of observed data, most persons wanting estimates of surface water quantity at a particular location in the Oklahoma City metro area must use models to generate synthetic data, or use published figures which were probably generated from synthetic models. Because of the recency of availability of the observed data, there has been little report of calibrations of the models (which were all developed outside of Oklahoma) for local Oklahoma City conditions. The previous calibrations known to this author using the data available for this study are in Thomas (1), Beard (2), Black and Veatch (3), and these calibrated only one model each. Therefore, almost all the model users have input into their models parameter values that were assumed, or at best, validated for other localities. That is not a very desirable state of affairs, because then no one has any idea how well the model outputs relate to figures that would be available if a stream gage were operating at the model user's point of interest. The purpose of this report is to add more data to the few calibration results now available in an effort to bring our synthetic models more in conformity to the real world.

DATA REDUCTION

The rainfall and flood gage data used in this study were collected and tabulated by hydrologists of the Oklahoma City office of the Water Resources Division of the USGS during 1974-1975 at three sites in Oklahoma City. Twenty-three runoff events resulting from rainfalls of 0.98 to 4.9 inches (24.9 to 124.5 mm) were used in this calibration. Table 1 gives the location of the sites and some facts describing the drainage basin upstream of each. Drainage area, percentage impervious cover, and slope of main water course were available from the USGS in Thomas (1). Percentage of basin urbanized and length of main water course were available from Mr. Dale Reynolds of the Tulsa District of the COE. Mean surface slope was determined by averaging values determined at grid points as described in Viessman *et al.* (4, p. 95). Percent of main water course concrete-lined includes length in storm sewers and curbed streets, and in the case of Deep Fork Creek at Eastern Avenue, some earth channel realignment and widening. Percent of basin upstream of ponds is im-

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portant because ponds usually lengthen and flatten the outflow hydrograph.

The process of calibrating the models to the data varied from model to model because of their nature. The USGS model is self-calibrating with inbuilt optimization subroutines in the computer model described in Carrigan *et al.* (5), and Carrigan (6). The general process followed for the other models (except the Rational Method) was first to calibrate the rainfall loss rates for each model for each basin until the mean of the ratios of synthetic volume of runoff to observed volume of runoff for the individual basin's storm events was well within one standard deviation of unity. The exact process for calibrating HEC-1 is described in its users' manual (7, addendum 1, pp. 7-8). TR-20 was calibrated for volume of runoff by averaging the "curve number" as calculated in Mockus (8, Chapter 10) for each storm event by basin. SWMM and MINICAT use Horton's equation for infiltration (9, p. 59; 10) and they were calibrated for volume of runoff by trial-and-error adjustment of Horton's parameters. Percentage of impervious cover was also treated as a variable to be calibrated in working with SWMM, MINICAT, and the USGS urban model, because some of the rooftops and sidewalks, for example, may shed the rain water onto the previous ground, and thus act as a pervious surface instead of an impervious surface. Such estimation of the effective impervious area has been reported in studies of other cities in Dempster (11) and Jewell (12). The Rational Method was not calibrated for runoff volume because in its traditional usage it predicts only flood peak discharge.

After consideration of runoff volume, the models were calibrated for peak discharge by adjusting the model's hydrograph shape parameters until the mean of the ratios of observed peak discharge to synthetic peak discharge for each storm event as well within one standard deviation of unity. That was done on a basin-by-basin basis, because each basin has its own parameter values. As in the case of runoff volume, the USGS model calibrates the unit hydrograph parameters for shape by an inbuilt optimization subroutine, and HEC-1 was calibrated for the basins' unit hydrographs by the procedure in its users' manual as previously mentioned. TR-20 was calibrated on both Deep Fork basins by assuming the standard shape factor as described in the SCS references, and adjusting time of concentration by trial and error until the synthetic peak discharges approached the real time of observed peak discharges. However, that process did not work on the Bluff Creek basin, because calibrating to match synthetic peaks to observed peaks gave poor agreement of synthetic time of peak to real-time observed peak. Thus, Bluff Creek's unit hydrograph for TR-20 was adjusted to resemble HEC-1's unit hydrograph for that basin by placing more of the hydrograph volume on the descending limb after the peak than is found in the standard shape SCS unit hydrograph. In calibrating MINICAT, the sheet flow length across each subcatchment was shortened by a ratio of the physical length so as to induce a travel time yielding hydrograph times matching as nearly as reasonably possible the observed hydrograph times. In SWMM, the user has the option of putting all the subcatchment flow into the head of the channel going through the

TABLE 1. *Basin physical characteristics*

	Deep Fork Creek at Portland Ave.	Deep Fork Creek at Eastern Ave.	Bluff Creek at Northwest Highway
Drainage area, sq. mi. (km^2)	2.98 (7.72)	28.2 (73.0)	1.64 (4.25)
Length of main watercourse, mi. (km)	2.88 (4.63)	11.4 (18.35)	2.18 (3.51)
Slope of main watercourse, ft/mi (m/km)	44 (8.3)	19.9 3.76)	65.7 (12.4)
Mean surface slope, percent	3.3	3.0	3.5
Impervious cover, percent	45	35	42
Main water-course concrete lined, percent	50	35	45
Basin urbanization, percent	100	60	100
Basin upstream of ponds, percent	0	15	30

subcatchment, or of putting all the subcatchment outflow into the outflow channel downstream of the subcatchment. In order to evaluate the impact of one option against the other, Deep Fork Creek at Portland Avenue was modeled without the channels through the upstream catchments, while Deep Fork Creek at Eastern Avenue and Bluff Creek were modeled with the upstream channels. Then as with MINICAT, the lengths of the subcatchments parallel to the sheet flow were adjusted during the calibration as a ratio of actual ground lengths until satisfactory approximation of the observed hydrograph times and shapes was achieved.

The ponds in the basins Bluff Creek and Deep Fork Creek at Eastern Avenue were modeled as wide low sloping channels in SWMM and MINICAT.

In calibrating the Rational Method, each basin's time of concentration was fixed as that determined earlier in the study during the calibration of HEC-1, and rainfall intensity for each storm for use in the Rational Equation was determined as the maximum of the average intensities that occurred during the time of concentration. The "runoff coefficient" for each storm was then determined by dividing that event's peak discharge by the storm’s intensity found as described above and dividing by the basin's area in acres. The runoff coefficient "C" for each basin was finally found by averaging the coefficients for storms used in this calibration that occurred over the basin.

RESULTS

Table 2 displays the results of the calibrations, and Figures 1, 2, and 3 show the unit hydrographs derived by the three models using unit hydrographs. For each of the twenty-three storms used in this study, for each of the six models, the calibrated peak discharges, volumes of runoff, and graphs of the synthetic hydrographs may be found in K. Williams (13, 14) along with the observed peak discharges, runoff volumes, and runoff hydrographs plus the observed rainfall hyetographs that produced the floods.

An interesting result of the calibration process was that antecedent soil moisture conditions (ground wetness resulting from recent rains and/or low evaporation rates)

TABLE 2. *Calibration results*

	Model and Parameter	Deep Fork Creek at Portland Avenue	Deep Fork Creek at Eastern Avenue	Bluff Creek
	Rational Method Runoff Coefficient "C"	0.38	0.38	0.22
TR-20	Time of concentration, hr	0.70	2.83	0.46
TR-20	IUH shape factor, K	484	484	205
TR-20	Curve number, CN	88	86	85
HEC-1	Snyder's lag, hr	0.42	2.55	0.47
HEC-1	Snyder's CP	0.78	0.62	0.39
HEC-1	Clark's time of concentration, hr	0.58	2.82	0.46
HEC-1	Clark's storage coefficient, hr	0.20	2.40	0.89
HEC-1	STRKR, in/hr (mm/hr)	0.39 (9.9)	0.42 (10.7)	0.68 (17.3)
HEC-1	DLTKR, inches (mm)	1.69 (42.9)	0.83 (21)	3.58 (91)
HEC-1	RTIOL, dimensionless	11.0	1.28	2.16
HEC-1	ERAIN, dimensionless	0.57	0.63	0.53
USGS Urban Runoff Model	Time of concentration, hr	0.42	3.5	0.42
USGS Urban Runoff Model	Storage coefficient, hr	0.73	2.8	1.2
USGS Urban Runoff Model	Effective impervious cover, percent	25	25	25
USGS Urban Runoff Model	PSP, inches (mm)	2.12 (53.8)	1.71 (43.4)	1.98 (50.3)
USGS Urban Runoff Model	KSAT, in/hr (mm/hr)	0.12 (3)	0.10 (2.5)	0.16 (4.1)
USGS Urban Runoff Model	RGF, dimensionless	6.3	9.1	14.6
USGS Urban Runoff Model	BMSM, inches (mm)	16.2 (411)	39 (991)	39 (991)
USGS Urban Runoff Model	EVC, dimensionless	0.6	1.4	1.1
USGS Urban Runoff Model	RR, dimensionless	0.7	0.8	1.3

were not a statistically significant influence on runoff volume. An attempt to reduce the standard error of the estimate during calibrating TR-20 by using J. Williams and LaSeur's method of accounting water yield (15) was unsuccessful. Then a sign test was run of antecedent rainfall against the observed runoff curve number by storm event, and it was found that variations in observed curve number were independent of the antecedent rainfall.

A Mann-Whitney U-test was made to determine if infiltration was influenced by peak rainfall intensity. It was found on Deep Fork Creek at Portland Avenue that infiltration rate tended to decrease as rainfall intensified, but the opposite took place on Bluff Creek, and the relationship was random on Deep Fork at Eastern Avenue. Therefore the test was judged inconclusive and on each basin the infiltration rate was not changed from storm to storm for any model except the USGS Urban Model, which automatically accounts for soil moisture between storms by its inbuilt subroutines. Likewise for the Rational Method an attempt to relate the runoff coefficient "C" to rainfall intensity proved unsuccessful.

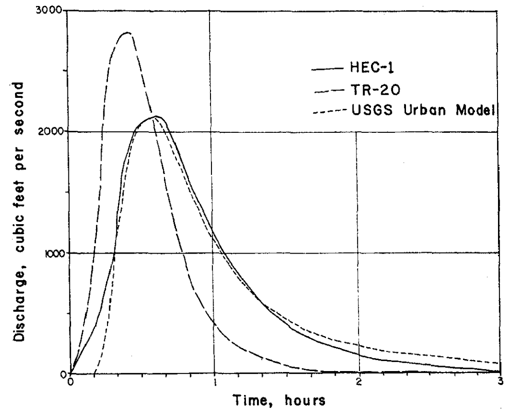

FIGURE 1. Unit hydrographs for Deep Fork Creek at Portland Avenue

DISCUSSION

Both Deep Fork Creek basins have unit hydrographs of a typical shape; about one-

TABLE 2 — CONTINUED

	Model and Parameter	Deep Fork Creek at Portland Avenue	Deep Fork Creek at Eastern Avenue	Bluff Creek
SWMM	No. of subcatchments	5	6	3
	Effective impervious cover, percent	45	25	25
	Impervious Manning's "n"	0.03	0.03	0.013
	Pervious Manning's "n"	0.4	0.25	0.05
	Ratio actual subcatchment width to WWIDTH	.95	1.3	1.0
	Actual channel through upper subcatchments modeled	No	Yes	Yes
	Channel Manning's "n"	0.03	0.03	0.03
	Max. infiltration rate, in/hr (mm/hr)	3 (76)	1 (25)	5 (127)
	Min. infiltration rate, in/hr (mm/hr)	0.15 (3.8)	0.10 (2.5)	0.55 (14)
	Decay rate of infiltration, l/sec	0.00115	0.00115	0.00115
MINICAT	No. of subcatchments	10	12	6
	Subcatchment Manning's "n"	0.3	0.5	0.4
	Effective impervious cover, percent	45	45	45
	Average divisor of overland length	2	3	2
	Channel Manning's "n"	0.015	0.05	0.03
	Initial loss rate, in/hr (mm/hr)	4 (102)	1 (25)	5 (127)
	Steady loss rate, in/hr (mm/hr)	0.35 (8.9)	0.07 (1.8)	0.6 (15)
	Decay rate of infiltration, l/min	0.07	0.07	0.07

third the volume is on the rising side and two-thirds the volume runs off after the peak. However, the unit hydrograph for Bluff Creek has more of its volume after the peak, probably due to attenuation by the ponds upstream and a backwater condition late in the floods from down stream from the flood gage site.

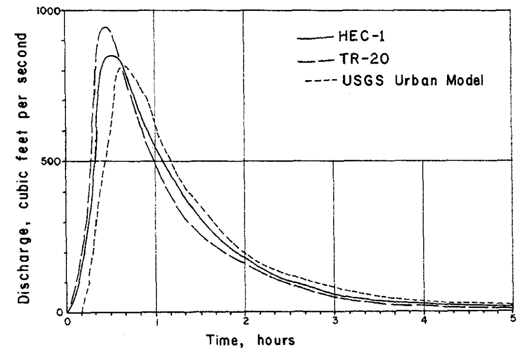

FIGURE 3. Unit hydrographs for Bluff Creek at Northwest Highway

The infiltration rates being reported here are typical of those reported for other urban areas in other calibration studies.

The fact that antecedent rainfall and evaporation were found to have no influence on the calibration can be attributed to a combination of three causes. The first is random uncertainty in the discharge measurements, which is estimated by the USGS to be about five percent. The second cause is much larger, due to random errors in the rainfall hyetograph input to the calibration. The rainfall records were collected at the flood gage sites at one end of the basins, and probably do not represent basin-wide averages. Also the storms probably moved across the basins with time, and that was not taken into account in the calibration due to lack of information. Random errors in the input rainfall lead to errors in the runoff volumes which lead to errors in the peak discharges. By using the procedure of the SCS (8, Fig. 4.6) it is estimated that the probable error in the input rainfall data for Deep Fork Creek at Portland Avenue and Bluff Creek is ±5-15%, and for Deep Fork Creek at Eastern Avenue ±20-50%. It may be that antecedent soil moisture is an influence on runoff, but it was masked in this study by uncertainties and errors in input data. A third cause may be that some lawn watering during dry periods may keep soil moisture up artificially, as though there had been recent rains before the storms used in a study. Most of the native soil in the study area is clay loam with a moderate to slow infiltration rate whether saturated or not, and compacting it during urban construction has probably slowed down infiltration into the soil, whether saturated or not.

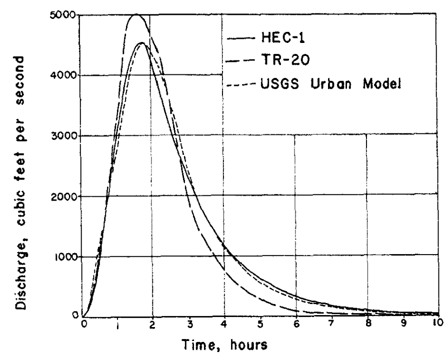

FIGURE 2. Unit hydrographs for Deep Fork Creek at Eastern Avenue

The different unit hydrographs have different values for time of concentration and lag for the same basins because they use different mathematics for computing the hydrographs. For example, both HEC-1 and the USGS Urban Model use Clark's concept of the unit hydrograph, but HEC-1 attenuates the translated time-area histogram by a convex equation, while the USGS does it with an exponential equation.

There have been many studies to relate drainage basin characteristics to hydrologic performance, and how the data from this study fit some of the commonly available regression reports is presented next. The USGS has already compared the data of the three basins used in this study to its regional regression study by Thomas (1, pp. 43-49). The SCS (16) has a procedure for urban hydrology, and when the basin characteristics data in Table 1 were treated by that procedure, the result was a hydrograph lag seventy percent longer than that obtained and reported in Table 2 for Deep Fork Creek at Portland Avenue, and forty percent longer than that calibrated for Bluff Creek. The Deep Fork at Eastern Avenue basin was too large for use with this procedure. The method presented in a recent American Society of Civil Engineers publication (17) gave almost exactly the same lags for Deep Fork Creek at Portland Avenue and Bluff Creek as those found in this study. The Deep Fork Creek at Eastern Avenue basin again exceeds the limits of the procedure. Anderson's (18) graphs gave a lag time for Deep Fork Creek at Portland Avenue that was very nearly that obtained in this study, about twenty percent shorter than the lag found for this study on Bluff Creek, and about ten percent shorter than the one for Deep Fork Creek at Eastern Avenue. The ratio of actual subcatchment widths to conceptual subcatchment widths being reported here falls within the ranges found in other calibrations of SWMM by Sharon (19), MacLaren (20) and Diniz (21). The ratio of actual impervious cover to effective impervious cover being reported here for the SWMM and USGS Model calibrations falls within the range reported by others, as in Alley (22), but effective impervious cover for the MINICAT calibration seems rather high. An attempt at lowering the effective impervious cover resulted in using higher rainfall loss rates without improving the calibration reliability. A more complete listing of literature on other researchers' calibrations is found in K. Williams (13).

Some of the results presented here have already been used by others in flood control and drainage engineering. The City Engineering Departments of Tulsa and of Stillwater, Oklahoma both have charts for Snyder's Unit Hydrograph Parameters obtained from Mr. Dale Reynolds, Tulsa District, COE, that incorporated the HEC-1 results of this study (23, 24). The COE also used the HEC-1 loss rate functions found in this study for the Bluff Creek Basin for some dam safety evaluations in the same area. The Thomas report (1) already enjoys wide acceptance by some state and federal agencies and consultants for application for flood plain management and engineering projects.

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