Hydrologic Research on Coastal Plain Watersheds of the Southeastern United States

J. M. SHERIDAN and W. C. MILLS

ABSTRACT

The Southeast Watershed Research Laboratory (SEWRL), of the Agricultural Research Service, U.S. Department of Agriculture, is conducting hydrologic research studies on watersheds in the Coastal Plain of the southeastern United States. The Coastal Plain is a region where extensive hydrologic data bases have generally not been available because of difficulties associated with the accurate measurement of streamflow in the low-gradient channel systems of the broad, heavily vegetated floodplains. The SEWRL has a 129-square mile drainage area, the Little River Watershed (LRW), which is divided into seven subwatersheds that are instrumented to obtain hydrologic data (rainfall, streamflow, and alluvial groundwater) for use in analyzing and evaluating Coastal Plain hydrologic processes. A description of the experimental study areas and the associated hydrologic instrumentation is presented. Basic hydrologic information is presented, as well as flood design information including instantaneous peak flow and maximum mean daily flow relationships developed from the LRW hydrologic data. Ratios of instantaneous peak flows to maximum mean daily flows for selected return intervals for watersheds of 1 to over 100 square miles are also presented. Additionally, an evaluation of the application of the Cypress Creek procedure (commonly used for agricultural drainage design) on two LRW subwatersheds is presented.

The Southeast Watershed Research Laboratory (SEWRL) of the Agricultural Research Service, U.S. Department of Agriculture (USDA-ARS) in Tifton, Georgia, is conducting hydrologic research studies on watersheds in the Coastal Plain of the southeastern United States. The SEWRL has instrumented as its primary study area a 129-square mile watershed, the Little River Watershed (LRW). This watershed is considered to be generally representative of the Southern Coastal Plain Land Resource Area (1). The Southern Coastal Plain is a rather extensive, agriculturally important region. It is also a region where accurate hydrologic data bases have generally not been available because of the difficulties associated with the measurement of streamflow in the low-gradient channel systems of the broad, heavily vegetated floodplains that are characteristic of the region.

The LRW was instrumented to provide data for analyzing and evaluating Coastal Plain hydrologic processes and for the development and testing of conceptually based prediction methodologies for use on ungauged watersheds in low-relief physiographic regions. In addition to the original hydrologic objectives, these facilities are also providing a valuable data base for the SEWRL and other ARS scientists and their cooperators for erosion and water quality modeling.

This paper presents an overview of the LRW experimental study areas, and the associated hydrologic instrumentation, as well as some basic hydrologic data and flood flow analyses from these watersheds.

STUDY AREA DESCRIPTION

Location and Topography

Little River originates 6 miles west of Ashburn, Georgia, and flows in a southerly direction, to its confluence with the Withlacoochie River, then to the Suwanee River, eventually emptying into the Gulf of Mexico. The instrumented portion of the LRW includes Little River and its tributaries from its headwaters downstream to approximately 4 miles west of Tifton, Georgia--a drainage area of about 129 square miles. The LRW is located in Tift, Turner, and Worth Counties, Georgia, and is divided into seven subwatersheds ranging from approximately 1 to 45 square miles. Figure 1 shows the location of the experimental study area within the Southern Coastal Plain Land Resource Area.

Topographically, LRW is an area of floodplains, river terraces, and gently sloping uplands. Woodruff (2) described the area as "one of low relief; a gently undulating surface of broad interfluves and shallow valleys." Valley bottoms are nearly level, and valley side slopes are generally less than 5 percent, although some range from 5 to 15 percent. Floodplains range in width from 200 ft to 0.5 mile (3). Surface elevations within the watershed range from about 260 to 470 ft above mean sea level.

Geology, Soils, and Vegetation

The Coastal Plain province of the United States extends from New England in the Northeast, south along the Atlantic Coast, and then west into Texas (4). LRW lies within the Tifton Upland subprovince of the southeastern Coastal Plain. The Tifton Upland is defined by the outcrop area of the Miocene series, Hawthorne Formation, which is the surface formation in most of the Tifton Upland. The Hawthorne Formation is overlain by loose, unconsolidated Quaternary and Recent sediments that form shallow phreatic aquifers. The Hawthorne Formation is an aquiclude of low vertical transmissibility that should yield very little surface water to deep aquifers (5). A shallow water table exists throughout the watershed at

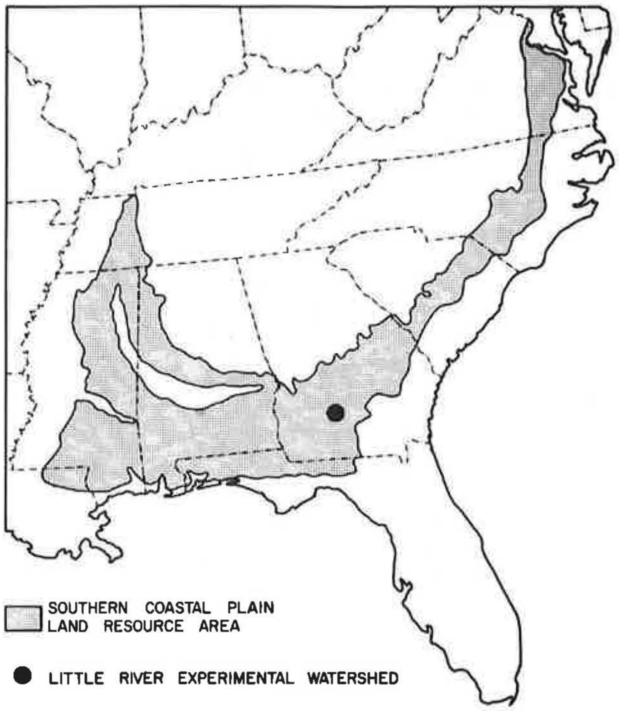

FIGURE 1 Location of LRW within the Southern Coastal Plain Land Resource Area.

depths of 0 to 19 ft. Depths to the water table along drainage divides range from 9 to 19 ft, and generally decrease toward the major stream (5).

Soils of this region have been formed from materials of the Miocene and possibly the Pliestocene age. The upland soils developed in place whereas most materials on stream terraces and bottoms of creeks and rivers were derived from alluvium washed from the upland Coastal Plain soils (3).

Soils of the watershed are predominantly sandy and light-colored with high infiltration rates (6). At depths of 3 to 20 ft, a relatively impermeable material described as plinthite greatly restricts downward movement of soil water, resulting in perched water tables. Internal drainage of most upland soils is good, but that of the swamp-alluvial soils is poor to very poor, with water standing on the surface during portions of the year (7).

The native upland vegetation of the LRW (longleaf, pine/perennial wiregrass) has been almost totally replaced by row crops, pastures, pine plantations, roads, and residential and commercial properties (8). A transitional area of hardwood pine generally occurs between the dry uplands and the wet bottomlands. A dense undercover is characteristic of this community, which is generally found on the Alapaha soil series (9). The bottomland or riparian areas of the LRW are classified as Blackwater swamp systems (10). Swamp hardwood communities occur along stream edges--the canopy is closed, and the undergrowth is thick. This community is characteristic of the alluvial soil series (9).

General Hydrology

Precipitation in the Tifton Upland occurs almost exclusively as rainfall. During the winter and early spring months, events are characterized by widespread frontal storm activity. During the late spring and summer months, convective thunderstorm activity often produces short duration rainfall events with high intensities--frequently of a localized nature. Intensities during these events may exceed the generally high infiltration capacities of Coastal Plain soils for short time intervals.

Precipitation data from the Coastal Plain Experiment Station (CPES) for 1923-1983 show a mean annual rainfall of 47.41 in. with a standard deviation of 8.73 in. Observed extremes of annual rainfall were 23.25 in. (1954) and 70.90 in. (1928). Average monthly precipitation amounts are well distributed throughout the year except for the fall, with average monthly totals exceeding 3.5 in. except for October. Although monthly averages are well distributed, actual monthly rainfall totals show wide variation. Significant rainfall-deficient periods may occur during all seasons of the year (11).

The occurrence of the Hawthorne Formation (an aquiclude) and the high infiltration characteristics of the upland soils of the region result in conditions that are conducive to subsurface movement of significant quantities of infiltrated precipitation from upland areas and valley flanks to the stream systems. Instrumented upland areas have shown that approximately 80 percent of the flow moving from those areas is subsurface (12,13). This is confirmed by estimates of base flow or delayed subsurface flow from LRW watersheds that ranged from 58 to 82 percent (14,15). This prolonged subsurface flow from the uplands results in high water tables or standing water in the low-lying, poorly drained areas of these watersheds for up to 3 weeks after streamflow ceases (16). This further results in a saturated or high water table zone that is believed to conform to the source area theory of runoff that has evolved in the work of numerous researchers.

During prolonged periods of low or deficient rainfall, streamflow typically ceases on the smaller streams and rivers, generally during the late summer and fall months. During this time, water in the poorly drained areas is depleted by evapotranspiration and these areas, which usually function as high runoff-producing zones during storm events, may become zones of high water storage capacity for incident rainfall, as well as for surface and subsurface runoff from valley flanks and adjacent uplands.

HYDROLOGIC INSTRUMENTATION

The original hydrologic monitoring network on LRW included precipitation measurement at approximately 55 sites, 8 streamflow measuring sites, and alluvial groundwater measurements at 3 channel cross sections. Some of these measurement sites, however, have been discontinued in recent years. Figure 2 shows the LRW study areas and the location of hydrologic instrumentation for the measurement of rainfall, streamflow, and alluvial groundwater on these watersheds. Construction and/or installation of instrumentation on LRW began in 1967 and was completed in 1972.

Rainfall Measurement

Rainfall on the LRW is measured by digital rain gauges that record cumulative rainfall totals to the nearest 0.1 in. Each gauge consists of a collector for catching and storing rainfall, a device for weighing the water, and a recording mechanism that punches a binary decimal code on paper tape at 5-min intervals. The rain-gauge network provides denser spacing of gauges on the smaller subwatersheds at the upper end of the main basin, and more sparse spacing at the lower end of the basin. This spacing was designed to provide more accurate measurement of rainfall on the smaller drainage areas where localized storms could cause extreme variability in storm runoff.

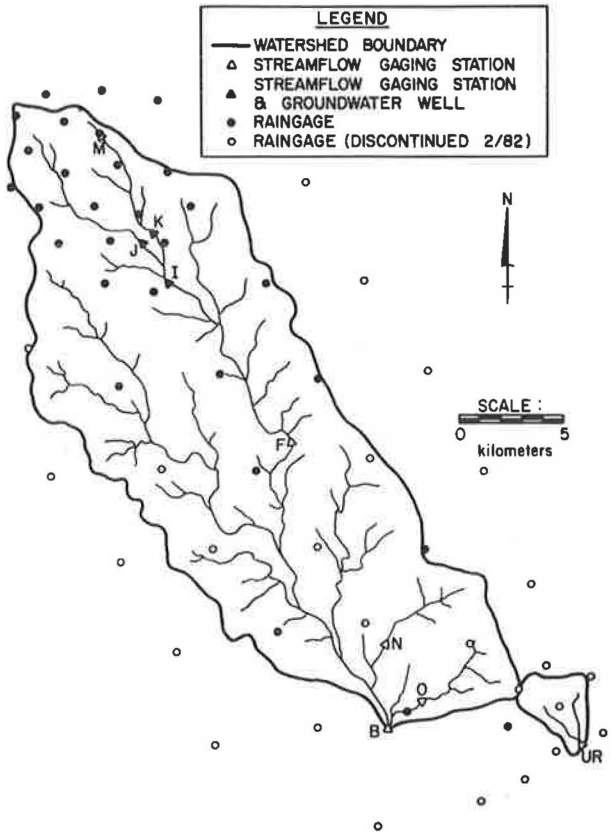

FIGURE 2 Location of hydrologic instrumentation on LRW.

Streamflow Measurement

The low-gradient drainage systems of the Coastal Plain region of the southeastern United States present a particular challenge in the measurement of stream discharge. This region is typified by broad floodplains with very poorly defined stream channels. Channel-bed slopes are generally less than 0.1 percent, and channels are distinguishable only at extremely low flow rates. The floodplains are heavily vegetated, and at moderate-to-high flow rates, discharge is spread over the entire floodplain--a width of several hundred feet. Therefore, the only practical location to confine flows for measurement is at highway bridges or culverts, which are built into raised roadbeds that transect the floodplain. Any control device that is used must be capable of withstanding some degree of submergence during substantial periods of operation while maintaining acceptable levels of gauging accuracy.

A flow measurement device referred to as a Virginia V-notch weir (17) was selected. The measurement control is a horizontal weir with a V-notch center section. This weir, although not a true broad-crested weir, does not exhibit the sensitivity to submergence of sharp-crested weirs. It also provides accuracy of measurement at low flows that is typical of the V-notch configuration, and is relatively maintenance free in operation.

Flow measurement sites selected are shown in Figure 2. These sites include five structures (M, K, I, F, and B) located in series on one of the main stems of the experimental study area. Watersheds defined by these sites in series range in area from 1.0 to 129.05 square miles. In addition, Stations J and K, and O and N provide parallel pairs of subwatershed study areas that range from 6.05 to 8.54 square miles.

Flow measurement control structures were designed to contain all flow within the V-notch portion of the weir approximately 90 to 95 percent of the time, which represents approximately 65 to 70 percent of the total flow volume (18). The structures were also designed to accurately measure the estimated 25-yr peak flow rate without exceeding the physical limitations of the control.

Each structure consists of a sheet steel piling cutoff and support wall capped by a reinforced concrete weir cap, a combination stilling-well and recorder shelter, an energy-dispersing apron, and a footbridge for use in making high-flow measurements.

Digital stage-recording devices provide continuous data on water stage elevations, both upstream and downstream. These digital recorders punch water stage evaluation in 0.01-ft increments at 5-min intervals. In addition to the two digital recorders originally installed at each site, an analog recorder was later installed to provide a backup record for the digital data.

For additional details on structural design and actual construction methods, the reader is referred to discussions by Yates (18-20), Yates and Sheridan (21,pp.345-352), and Mills et al. (22).

Alluvial Groundwater Measurement

Monitoring of alluvial groundwater was accomplished through the use of observation wells drilled into the floodplain alluvial material at three locations near streamflow measurement sites I, J, and K. Weekly manual observations were initiated on these wells in 1967, and digital stage recorders were subsequently installed in 1969 to provide continuous recording of alluvial groundwater stage.

Rates of movement of groundwater through the valley alluviums were determined with Darcy's equation for flow through porous media, using the estimated saturated alluvial cross-sectional area, estimated valley contact slope, and aquifer hydraulic conductivities obtained by conducting alluvial-well pumping tests. Results of these analyses indicate that despite the highly permeable alluvial floodplain material, and the typically large cross-sectional alluvial areas, virtually all runoff moving from these watersheds was monitored by measurement of surface runoff in the channel systems and that less than 0.01 percent of the total water budget was estimated to be allocated to alluvial subsurface water movement (23).

HYDROLOGIC DATA SUMMARY

Annual Rainfall

For the LRW period of record (1968-1983), the mean annual rainfall measured at the CPES at Tifton was 47.88 in. (standard deviation was 4.93 in.), with extreme recorded amounts of 38.38 in. and 55.30 in. For this period, the recorded average annual rainfall at the CPES was slightly greater than the long-term CPES mean. Annual amounts for 1968-1983 exhibited less variability than the long-term record, as indicated by the standard deviation, which is approximately one-half of the standard deviation of the long-term record.

Watershed weighted-average annual rainfall totals for the entire LRW, computed using the reciprocal distance squared technique (24) for the 1968-1983 period averaged 49.48 in., or more than 1.5 in. greater than the mean annual rainfall measured at the CPES. Individual subwatershed weighted-average annual totals were generally 2 to 4 in. greater than the CPES annual totals. Only 3 of 16 yr showed subwatershed totals less than the CPES annual rainfall total, whereas for 12 of the 16 yr, weighted subwatershed totals exceeded the CPES annual totals. For 1979, the upper LRW subareas averaged 8 to 10 in. more rainfall than the CPES total.

Annual Water Yield

Preliminary analyses of streamflow data from Watershed M (the 1-square mile drainage area) indicated that all runoff from that watershed may not be passing through the flow measurement device, and that some flow may instead by bypassing through an undetermined route. Cursory examination of the flow data indicated that although stormflow volumes from Watershed M were similar to those from other watersheds, the base flow volumes were significantly lower. For this reason, Watershed M water yield data were not included in these analyses. Peak flow or storm event data for Watershed M were, however, included in the flood event analyses because surface runoff boundaries are determinable.

Annual water yields for 1968-1983 on LRW subareas ranged from 1 in.[2] to nearly 30 in.[2] of runoff. This range of variability is evident in a period in which annual rainfall variability is less than typical. Annual yields by watersheds are shown in Table 1. Because available record periods are not the same for all watersheds, a common record period (1972-1981) was selected to minimize the effects of year-to-year variation in rainfall totals. Both the water yield and the percent water yield are given. Percent water yields were computed because differences in rainfall totals between upper and lower watersheds were observed. For comparison, the precipitation and water yield data from Watershed Z, an 0.85-acre, instrumented, upland cropped area located on the CPES, was included in Table 1. The water yield for Watershed Z includes both surface and subsurface measured flows.

TABLE 1 Average Annual Water Yield, Percent Water Yield, and Mean Annual Flow Rates by Watersheds for Common Record Period (1972-1981)

Watershed	Area (square miles)	Average Annual Water Yield (in.)	Water Yield (%)	Mean Annual Flow Rate[a] (ft^3/sec)	Mean Annual Flow (ft^3/sec/mile)
I	19.38	15.95[a]	31.8[a]	22.75	1.17
J	8.54	15.50[a]	30.7[a]	9.74	1.14
K	6.43	15.19[a]	30.3[a]	7.19	1.12
N	6.05	14.28[a]	29.0[a]	6.36	1.05
F	44.34	14.00[a]	28.3[a]	45.69	1.03
O	6.15	13.67[a]	28.0[a]	6.19	1.01
Z	0.0013	13.68[a]	28.8[a]	0.0013	1.03
B	129.05	12.93[a]	26.1[a]	122.82	0.95

[a]Means with the same letter are not significantly different at the 5 percent level for Duncan's Multiple Range Test.

The mean annual water yields were also converted to mean annual flow rates for the respective watersheds. Water yields and mean annual flow rates per square mile appear to be relatively independent of area, although the flows from Watershed B are somewhat lower than those of all subwatersheds.

FLOOD DESIGN INFORMATION

Instantaneous Peak Flows

Design of highway and agricultural drainage structures requires reliable estimates of peak flow rates from ungauged areas for selected return periods. To evaluate peak flow data and develop information suited to making design estimates for Coastal Plain watersheds, a frequency analysis was performed on annual (water year) peak flow rates for each watershed using the total available record. The log-Pearson Type III probability distribution was fitted to the LRW annual peak flows using procedures that were recommended by the U.S. Water Resources Council (25), and that were contained in computer programs developed by the Soil Conservation Service (SCS), U.S. Department of Agriculture (personal communication with Roger Cronshey).

The U.S. Geological Survey (USGS), in cooperation with the Georgia Department of Transportation, in a study on flood flows on small (<20 square miles), rural streams in Georgia, has published regression equations for estimating peak flows developed from 10 yr of extensive flow measurements on small watersheds in Georgia (26). Multiple regression analyses were performed by Golden and Price on a regional basis to evaluate 10 climatological and basin parameters.

Their analyses indicated that drainage basin size was the most significant predictor and that other parameters did not significantly decrease the standard error. For the Coastal Plain region of Georgia, two subregions were identified by this regressional analysis as having a geographic bias. These two regions were the Sand Hills of Georgia (a narrow belt across the state that separates the Coastal Plain from the Piedmont, which is characterized by soils with extremely high infiltration rates) and the Ochlocknee basin, an area of high flood runoff located in southeast Georgia near the Georgia-Florida boundary. Elimination of these areas left in 105 stations that were used by USGS in the development of regression equations for peak flows in the Coastal Plain region.

The USGS regression equations are shown in Table 2 along with regression equations developed from frequency analyses on the LRW data. For all return intervals, the regressions developed from the LRW data have somewhat lower coefficients than the USGS regressions. For the shorter return intervals, the LRW regression exponents are higher than the USGS values, whereas the exponent is the same at the 10-yr recurrence interval. For the longer return periods (25 and 50 yr), exponents for the LRW regressions are slightly lower than the USGS regression exponents.

TABLE 2 Summary of Regression Equations for Instantaneous Peak Flows

Recurrence Interval (yr)	LRW	USGS Region 3 *(25, 26)*
2	$86\ A^{0.69},\ r^2 = 0.98$	$99\ DA^{0.58}$
5	$145\ A^{0.63},\ r^2 = 0.97$	$167\ DA^{0.59}$
10	$190\ A^{0.59},\ r^2 = 0.96$	$216\ DA^{0.59}$
25	$252\ A^{0.56},\ r^2 = 0.95$	$280\ DA^{0.59}$
50	$302\ A^{0.53},\ r^2 = 0.94$	$332\ DA^{0.60}$

Note: DA = the drainage area of the watershed; LRW includes 8 coastal plain watersheds and USGS Region 3 includes 105 coastal plain watersheds.

The estimated peak flow rate for the 25-yr event (the design return interval for the LRW structures) is plotted for each subwatershed in Figure 3. The USGS regression for the 25-yr return period for Region 3 (the Coastal Plain) is also plotted for comparison. There is generally good correspondence between the fitted 25-yr peak flow rates for the LRW and the USGS regressions, although the LRW values are somewhat lower than those estimated with the

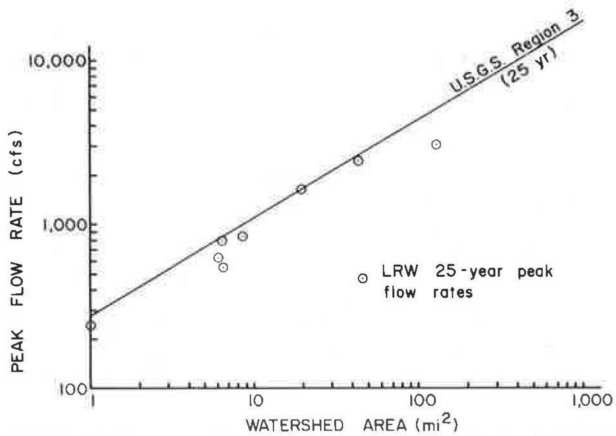

FIGURE 3 LRW 25-yr instantaneous peak flows (as determined by frequency analyses) and peak flows predicted by USGS regression for 25-yr return period.

USGS regression. The 25-yr peak flow rate for Watershed B, the total Little River drainage basin, is particularly low. An evaluation of spatial rainfall distribution for major events on Little River has shown that for most of these events, the largest amount of rain occurred on the upper portion of the watershed (22). This lack of total coverage of the basin by major events is a possible cause of reduced peak flows at the lower end of the watershed.

Another factor that could account for some deviation between the LRW and the USGS regressions for Region 3 is that Little River represents a single Coastal Plain drainage basin. The USGS regressions were developed from data collected from a number of Coastal Plain basins.

Also, the original work by Golden and Price (26) cautioned that use of developed regressions should be limited to watersheds of less than 20 square miles in area. However, a more recent report by Price (27) contained regressions that were applicable for watersheds with drainage areas of 0.1 to 1,000 square miles, the regression parameters that were recommended for Region 3 were unchanged from those reported earlier (26).

Maximum Mean Daily Flows

Regression analyses were performed to relate drainage area to observed maximum mean daily flow rate for subwatersheds on the LRW. Maximum mean daily flows were determined for selected return intervals by fitting of the log-Pearson Type III distribution to annual (water year) maximum mean daily peaks. Although the maximum mean daily flow rate is not identical to the maximum 24-hr flow rate used by the SCS in design of drainage systems for agricultural areas, it approaches the 24-hr maximum for larger watersheds and should provide useful information for agricultural drainage design. Regressions developed for predicting maximum mean daily flows by return frequency are shown in Table 3.

Fitted regression exponents for the Coastal Plain watersheds are very close to 5/6, or 0.833, the exponent of the Cypress Creek formula, which is used by the SCS and others in design of agricultural drainage systems. The Cypress Creek formula was apparently originated by McCrory et al. (28) in Arkansas. Subsequent work by Stephens and Mills (29) in the Florida Flatwoods has confirmed that this is also a reasonable exponent for use in runoff design estimates for flatwoods areas. Regression coeffi-

TABLE 3 Summary of Regression Equations for Mean Maximum Daily Flows

Recurrence Interval (yr)	Regression for LRW Fitted Max. (MDQ)	Coefficient of Determination (r^2)
2	$30\ DA^{0.89}$	0.99
5	$45\ DA^{0.86}$	0.98
10	$54\ DA^{0.84}$	0.98
25	$66\ DA^{0.83}$	0.97
50	$75\ DA^{0.82}$	0.97

Note: DA = the drainage area of the watershed; MDQ = mean daily discharge.

cients shown in Table 3 are within the range of C values reported for the Florida watersheds of 20 to 130 for storm events with estimated return frequencies of from 2 to 50 yr.

Stephens and Mills (29) also developed a relationship for estimating C values for Florida Flatwoods watersheds based on excess precipitation. Computed C values for storm runoff data from Watersheds K and O are plotted for comparison with the Florida regression for determining C values in Figure 4. LRW C values were computed by dividing the maximum mean daily discharge (MMDQ) by the drainage area (DA) raised to the 5/6 power. Thus, $C = MMDQ/DA^{5/6}$. The C value was then plotted versus the excess rainfall (i.e., the measured storm runoff).

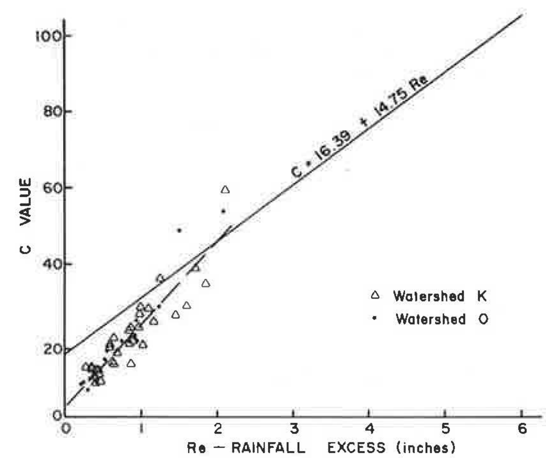

FIGURE 4 Comparison of C-values computed for LRW with C-value relationship developed for Florida Flatwoods.

As can be seen in Figure 4, the LRW C values for low excess rainfall volumes appear to be lower than those estimated by the Taylor Creek regression. However, at about 2 in. of excess rainfall, the relationships are approximately the same. Because storm event excess rainfall was about 2 in. or less for the LRW data, a regression is not presented for design use because excess amounts greater than 2 in. would require considerable extrapolation beyond the range of observed values.

Application of Cypress Creek Procedure on the LRW

Simple regression relationships are a good means of estimating design flow rates based on the single variable drainage area. However, in practice, some watersheds show differences in peak flood flows that are not explained by differences in drainage area alone. An example of this is the case of Watersheds K and O on Little River, the smaller of which, Watershed O (6.15 square miles), shows substantially larger peaks than the larger Watershed K (6.43 square miles).

The agricultural drainage design procedure that incorporates the Cypress Creek formula allows for the estimation of differences in runoff volume, and, consequently, peak 24-hr flows that are caused by differences in soil characteristics and land use. To evaluate the use of this procedure in making design discharge estimates for Coastal Plain watersheds, a sample computation was made on Watersheds K and O.

The design procedure for agricultural drainage systems (30) starts with the selection of the return frequency of the storm event and the estimation of rainfall amount (31). The SCS runoff curve number procedure (32) is then used to estimate the volume of storm runoff, or excess rainfall. The excess rainfall (Re) is then used to determine the C value based on the relationship

$$C = 16.39 + 14.75\ Re$$

that was developed by Stephens and Mills (29). This C value can then be used in the Cypress Creek formula, $Q = CM^{5/6}$ where M is the drainage area in square miles, to compute the maximum 24-hr runoff. As previously indicated, relationships developed on the Little River data indicate that the 5/6 exponent is a reasonable value for use on the Coastal Plain watersheds.

For Watersheds K and O, design 24-hr rainfall amounts (31) of 4.0, 5.3, 6.3, 7.3, and 8.0 in. were determined for 2-, 5-, 10-, 25-, and 50-yr return intervals, respectively. These totals were then multiplied by a 0.97 factor for depth-area reduction. Excess rainfall, or storm runoff amounts, was then computed using the SCS runoff curve number procedure (32).

Effective runoff curve numbers for these two watersheds were computed based on the percent area of each of the watersheds in selected soil types (i.e., B and D hydrologic soil groups), and the percent area in selected land use categories (lowland forest, agricultural cropland, and upland forest). One departure from conventional procedure was made. For the alluvial floodplains only, the average antecedent condition was assumed to be a wet, or AMC III, condition. It is believed that this assumption is justified because, as discussed in the general hydrology section of this paper, the delayed subsurface flow from upland areas in these watersheds results in saturated or high water table areas within the floodplain for major portions of the year. Use of this assumption on these two watersheds, where floodplain/alluvial soils account for 22 and 28 percent of the total watershed areas, resulted in increases in the effective average runoff-producing condition curve number of 2.5 and 4.0. Runoff curve numbers were computed for high, average, and low runoff-producing antecedent conditions, and excess rainfall (storm runoff) was determined graphically (32).

Results of this computation for the two watersheds (shown in Table 4) indicate that the use of the average runoff-producing condition for determining excess rainfall and then determining C value based on this excess rainfall estimate using the regression developed for the Florida Flatwoods by Stephens and Mills (29) may lead to significantly underpredicted maximum mean daily design discharge rates for Coastal Plain watersheds. This is true particularly for the shorter return interval storms, which are the primary application of the Cypress Creek formula in agricultural drainage design. This underestimation occurred even with the use of the wet condition as the average antecedent condition for the floodplains. Use of the high runoff-producing antecedent condition overpredicted the maximum mean daily flow rate.

This observed tendency is believed to be caused by the use of design return period rainfall to predict runoff for a comparable return period. Rainfall for any specified return interval may fall on a watershed of high runoff-producing or wet antecedent condition, or it may fall on a watershed of average or of low run-off producing conditions. As can be seen in Table 4, for these Coastal Plain watersheds, the estimated runoff volume from a 50-yr rainfall

TABLE 4 Comparison of Estimated MMDQ for High, Average, and Low Runoff-Producing Conditions with MMDQ Obtained from Frequency Analyses on Two Little River Subwatersheds

Watershed K	Return Period (years)				
	2	5	10	25	50
24-hr RF (in.)	4.00	5.30	6.30	7.30	8.00
x 0.97 (in.)	3.88	5.14	6.11	7.00	7.76
High-Runoff-Producing Conditions (CN-71)					
RO (in.)	1.32	2.22	3.00	3.75	4.35
C-value	36.0	49.0	60.5	71.5	80.5
MMDQ	169.6	230.9	285.1	336.9	379.3
Average-Runoff-Producing Conditions (CN-53)					
RO (in.)	0.40	0.95	1.45	1.98	2.40
C-value	22.5	30.5	38.0	45.5	51.5
MMDQ	106.0	143.7	179.1	214.4	242.7
Low-Runoff-Producing Conditions (CN-47)					
RO (in.)	0.25	0.58	1.00	1.45	1.88
C-value	20.0	25.0	31.0	38.0	44.0
MMDQ	94.2	117.8	146.1	179.1	207.3
MMDQ (frequency analysis)	159	207	234	264	284

Watershed O	Return Period (years)				
	2	5	10	25	50
24-hr RF (in.)	4.00	5.30	6.30	7.30	8.00
x 0.97 (in.)	3.88	5.14	6.11	7.00	7.76
High-Runoff-Producing Conditions (CN-78)					
RO (in.)	1.80	2.81	3.70	4.58	5.20
C-value	43.0	58.0	71.0	83.5	93.0
MMDQ	195.2	263.4	322.4	379.2	422.3
Average-Runoff-Producing Conditions (CN-59)					
RO (in.)	0.65	1.30	1.90	2.52	3.02
C-value	26.0	35.5	44.0	53.5	61.0
MMDQ	118.1	161.2	199.8	242.9	277.0
Low-Runoff-Producing Conditions (CN-51)					
RO (in.)	0.35	0.80	1.28	1.78	2.20
C-value	21.5	28.0	35.0	42.0	48.5
MMDQ	97.6	127.1	158.9	190.7	220.2
MMDQ (frequency analysis)	145	197	232	277	310

Note: RF = rainfall; RO = runoff.

event with low runoff-producing antecedent conditions will be exceeded by the runoff volume from a 5-yr storm event on a watershed with high runoff-producing conditions.

Ratio of Instantaneous Peak Discharge to Maximum Mean Daily Flow

Ratios of instantaneous peak discharge to maximum mean daily discharge were computed for the respective return periods for each of the subwatersheds. A regression of this ratio on the log transform of drainage area gave good results, with r^2 ranging from 0.91 to 0.99 for the 2- to 50-yr return frequencies. These fitted regressions permit the generation of a family of curves (see Figure 5) that may be used for converting estimated maximum mean daily flow rate to peak instantaneous discharge for any size drainage area from approximately 1 to over 100 square miles, and for any of the specified return intervals.

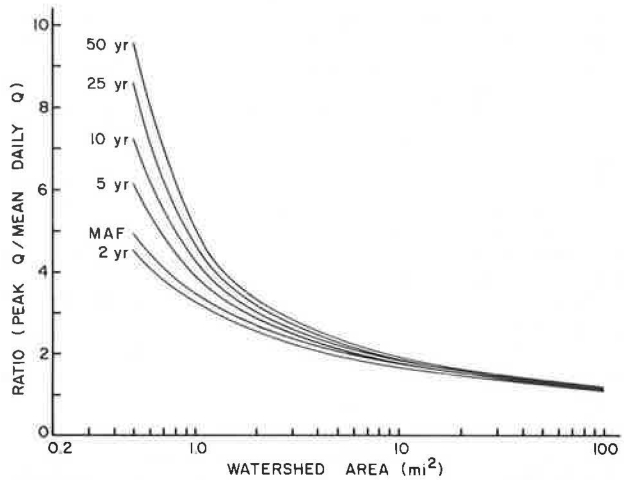

FIGURE 5 Curves for estimating ratios of instantaneous peak flow to maximum mean daily discharge based on watershed area for selected return periods.

The derived ratios for the Coastal Plain (LRW) data were compared with ratios (Q_i/Q_{24}) developed by Stephens and Mills (29) for the Florida Flatwoods watersheds. The average ratios for the Flatwoods watersheds ranged from 1.54 for a 10-square mile watershed down to 1.14 for a 100-square mile watershed. Ratios for the Caostal Plan watersheds ranged from about 1.80 for a 10-square mile watershed down to about 1.15 for a 100-square-mile watershed for the mean annual flood, MAF (2.33-yr return period).

The family of curves developed on the LRW data gives considerable additional capability by providing ratios for making estimates of instantaneous peak flows from Coastal Plain watersheds based on maximum mean daily flow rates for a range of return periods. These curves also extend to drainage areas of under 10 square miles, which provide conversion values down to 1 square mile.

CONCLUSIONS

The following conclusions may be observed:

1. Observed annual water yields on LRW Coastal Plain watersheds ranged from 1 to nearly 30 in.^{2}, which averaged about 13 in^2 for the total watershed (129.05 square miles) for the record period 1972-1983. Relative yields averaged from 26 to 32 percent of annual rainfall.

2. Peak instantaneous flow rates from the LRW subwatersheds generally fit the available regional USGS regressions, although the peak flow from the total 129.05-square mile drainage area was particularly lower than the predicted value using the USGS regression.

3. Maximum mean daily flows regressed on drainage area generally conformed to the 5/6 exponent in the Cypress Creek formula that has been widely used for agricultural drainage system design.

4. Computed C values for the LRW appear to be lower for low excess rainfall amounts than those estimated by using the available regression developed on Florida Flatwoods watersheds. Sufficient data are not available to develop a relationship between excess rainfall and C value for the LRW data.

5. Use of an average runoff-producing antecedent watershed condition underpredicted observed maximum mean daily flow rates for two subwatersheds of LRW, particularly for the shorter (2-5 yr) return intervals predicted by using the Cypress Creek formula and the regression of the excess rainfall and C value developed for Flatwoods watersheds in Florida. Use of the high runoff-producing condition overestimated observed maximum mean daily flow rates.

REFERENCES

1. Land Resource Regions and Major Land Resource Areas of the United States. Agriculture Handbook 296. Soil Conservation Service, U.S. Department of Agriculture, 1981, 156 pp.
2. J.F. Woodruff. Some Geomorphic Aspects of the Upper Little River Watershed, Tift, Turner, and Worth Counties, Georgia. In Progress Report of Hydrology Study of Upper Little River Watershed. Univ. of Georgia; U.S. Department of Agriculture, Tifton, 1968.
3. E.R. Jensen, L.E. Aull, J.L. Shepard, C.B. Thomas, R.L. Carter, E.S. Haygood, and R.G. Middleton. Soil Survey of Tift County, Georgia, No. 3. Soil Conservation Service, U.S. Department of Agriculture, 1959, 28 pp.
4. N.M. Fenneman. Physiography of the Eastern United States. McGraw-Hill Book Company, Inc., New York, 1970, 689 pp.
5. R.E. Carver. Reconnaissance Geology of the Little River Watershed, Tift, Turner, and Worth Counties, Georgia. In Progress Report of Hydrology Study of Upper Little River Watershed, University of Georgia; U.S. Department of Agriculture, Tifton, 1967.
6. W.J. Rawls, P. Yates, and L.E. Asmussen. Calibration of Selected Infiltration Equations for the Georgia Coastal Plain. Report ARS-S-113. Agricultural Research Service, U.S. Department of Agriculture, 1976, 110 pp.
7. J.W. Calhoun. Soil Survey of Tift County, Georgia. Soil Conservation Service, U.S. Department of Agriculture, 1983, 102 pp.
8. R.R. Lowrance, J.K. Sharpe, and J.M. Sheridan. Long Term Sediment Deposition in the Riparian Zone of an Agricultural Watershed. Tech. Rept. ERC 03-84, U.S. Department of Interior Project A-109-GA. U.S. Department of Interior, 1984.
9. J.C. Ritchie, C.A. Ritchie, and G. Plummer. Final Report of Hydrology Study of Upper Little River Watershed. University of Georgia; U.S. Department of Agriculture, Tifton, 1969.
10. C.H. Wharton. The Natural Environments of Georgia. Georgia Department of Natural Resources, Atlanta, 1978, 278 pp.

11. J.M. Sheridan, W.G. Knisel, T.K. Woody, and L.E. Asmussen. Seasonal Variation in Rainfall and Rainfall-Deficient Periods in the Southern Coastal Plan and Flatwoods Regions of Georgia. Bull. 243. College of Agriculture Research, University of Georgia, Athens, 1979, 73 pp.
12. W.M. Snyder and L.E. Asmussen. Subsurface Hydrograph Analysis by Convolution. Journal of Irrigation and Drainage Division, ASCE, Vol. 98, No. IR3, 1972, pp. 405-418.
13. R.K. Hubbard and J.M. Sheridan. Water and Nitrate Losses from a Small Upland Coastal Plain Watershed. Journal of Environmental Quality, Dec. 1983, pp. 291-295.
14. W.G. Knisel and J.M. Sheridan. Procedure for Characterizing Hydrologic Processes in the Coastal Plain of the Southeastern United States. In Proc., International Symposium on Hydrology of Large Flatland Areas, Buenos Aires, Argentina, 1983.
15. A. Shirmohammadi, W.G. Knisel, and J.M. Sheridan. An Approximate Method for Partitioning Daily Streamflow Data. Journal of Hydrology, Vol. 74, No. 3/4, 1984, pp. 335-354.
16. J.C. Ritchie, C.A. Ritchie, and G.L. Plummer. Plant Ecology Studies on the Little River Watershed: Monthly Soil Moisture Variations. In Progress Report of Hydrology Study of Upper Little River Watershed. University of Georgia; U.S. Department of Agriculture, Tifton, 1968.
17. W.O. Ree and W.R. Gwinn. The Virginia V-Notch Weir. Report ARS-41-10. Agricultural Research Service, U.S. Department of Agriculture, 1959, 7 pp.
18. P. Yates. Design, Construction, and Operation of Streamflow-Measuring Facilities in the Little River Watershed, Georgia. Report ARS-S-148. Agricultural Research Science, U.S. Department of Agricultural, 1976, 15 pp.
19. P. Yates. V-Notch Weir for Submerged Flow Measurement. Agricultural Engineering, Vol. 51, No. 3, 1970, pp. 132-133.
20. P. Yates. Research Program and Facilities of the Southeast Watershed Research Program. Lab Note SEWRL 047801. Southeast Watershed Research Laboratory, Tifton, Ga., 1978, 52 pp.
21. P. Yates and J.M. Sheridan. Flow Measurement of Low-Gradient Streams in Sandy Soils. In Proc., International Symposium on Hydrometry, Koblenz, Germany, Vol. 1, United Nations Education, Scientific and Cultural Organization--World Meteorological Organization--International Association of Hydrological Sciences, 1973.
22. W.C. Mills, J.M. Sheridan, and V.A. Ferreira. Hydrologic Measurements on Southern Coastal Plain Experimental Watersheds. Paper 84-2006. Presented at Summer Meeting of the American Society of Associated Executives, Knoxville, Tenn., June 24-27, 1984.
23. J.M. Sheridan, P. Yates, and L.E. Asmussen. Hydrology, Nutrient, and Sediment Movement from Southeastern Coastal Plain Watersheds. In Proc., International Symposium on Nutrient Cycling in Agricultural Ecosystems. Special Publication 23. College of Agriculture, Univ. of Georgia, Athens, 1983.
24. T.C. Wei and J.L. McGuiness. Reciprocal Distance Squared Method: A Computer Technique for Estimating Areal Precipitation. Report ARS-NC-8. Agricultural Research Service, U.S. Department of Agriculture, 1973.
25. Guidelines for Determining Flood Flow Frequency. Bulletin 17B. U.S. Water Resources Council, 1981.
26. H.G. Golden and M. Price. Flood Frequency Analysis for Small Natural Streams in Georgia. Report 76-0511. U.S. Geological Survey, 1976, 91 pp.
27. M. Price. Floods in Georgia, Magnitude and Frequency. Water-Resource Investigations 78. U.S. Geological Survey, 1979, 137 pp.
28. S.H. McCrory, D.G. Baxter, D.L. Yarnell, L.A. Jones, and W.J. Schlick. Report Upon the Cypress Creek Drainage District, Desha and Chicot Counties, Arkansas. Bull. 198. Office of Experiment Stations, U.S. Department of Agriculture, 1915.
29. J.C. Stephens and W.C. Mills. Using the Cypress Creek Formula to Estimate Runoff Rates in the Southern Coastal Plain and Adjacent Flatwoods Land Resource Areas. Report ARS-41-95. Agricultural Research Service, U.S. Department of Agriculture, 1965, 17 pp.
30. Drainage of Agricultural Land: A Practical Handbook for the Planning, Design, Construction, and Maintenance of Agricultural Drainage Systems. Soil Conservation Service, U.S. Department of Agriculture, 1973, 430 pp.
31. Rainfall Frequency Atlas of the United States. Technical Paper 40. U.S. Department of Commerce, 1961, 115 pp.
32. SCS National Engineering Handbook, Section 4: Hydrology. Soil Conservation Service, U.S. Department of Agriculture, 1972, 548 pp.