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EFFECTS OF INTERANNUAL VARIATION OF PRECIPITATION ON STREAM DISCHARGE FROM RHODE RIVER SUBWATERSHEDS[1]

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ABSTRACT: The purpose of this study was to determine the relationships between precipitation at the seasonal and annual scale and water discharge per surface area for seven contiguous first- and second-order tributaries of the Rhode River, a small tidal tributary to Chesapeake Bay, Maryland, USA. The goal was to quantify the effects of a wide range of precipitation, representative of interannual variations in weather in this region. The discharges measured included both overland storm flows and groundwater, since the aquifers were perched on a clay aquiclude. Precipitation varied from 824 to 1684 mm/yr and area-weighted Rhode River watershed discharge varied from 130 to 669 mm/yr with an average of 332 mm/yr or 29.1 percent of average precipitation. Average annual discharges from three first-order watersheds were significantly lower per surface area and varied from 16.0 to 21.9 percent of precipitation. Winter season precipitation varied from 125 to 541 mm. Area-weighted Rhode River winter discharge varied from 26.3 to 230 mm with an average of 115 mm or 43.9 percent of average precipitation. Spring season precipitation varied from 124 to 510 mm and watershed discharge varied from 40.0 to 321 mm with an average of 138 mm or 46.9 percent of average precipitation. In the summer and fall seasons, watershed discharge averaged 40.6 and 40.9 mm or 13.5 and 14.3 percent of average precipitation, respectively. Except in winter, the proportion of precipitation discharged in the streams increased rapidly with increasing volume of precipitation. Stream order showed a higher correlation with volume of discharge than vegetative cover on the watershed.
(KEY TERMS: surface water hydrology; precipitation; land use; long-term; forest; cropland; coastal plain.)

INTRODUCTION

A number of long-term studies have measured water discharge of small watersheds in the eastern United States as a part of much broader biogeochemical research programs. These include studies of Little River, Georgia (Lowrance *et al.*, 1983); Coweeta, North Carolina (Swift *et al.*, 1988); Walker Branch, Tennessee (Luxmoore and Huff 1989); Mahantango Creek, Pennsylvania (Schnabel *et al.*, 1993); Fernow, West Virginia (Adams *et al.*, 1994); Coshoctin, Ohio (Owens *et al.*, 1994); and Hubbard Brook, New Hampshire (Likens and Bormann 1995). Many of these studies were initiated by the U.S. Forest Service in the 1930s and the study sites are completely forested mountain areas. Three (Mahantango Creek, Little River, and Coshoctin), were initiated by the U.S. Department of Agriculture and include farm lands. This study was of the Rhode River, Maryland, on the inner mid-Atlantic Coastal Plain. The most analogous other long-term study was that at the Little River, Georgia, site, also on the inner Atlantic Coastal Plain, but at a lower latitude. These two sites were also similar in that the landuse of both included agriculture.

A number of issues which relate to the hydrology of small, headwaters first- and second-order watersheds can only be adequately addressed with summaries of rather long-term data. This study of a mid-Atlantic inner Coastal Plain agroecosystem sought to determine (a) the mean annual and seasonal water discharges per surface area for tributaries of different hydrological order, (b) the variations in stream discharge related to the wide interannual variations in seasonal and annual precipitation characteristic of this region, and (c) the effects of watershed vegetation in modifying stream discharges. The results of this study will be of value in predicting some of the impacts on the Chesapeake Bay region of global climate change. If the regional climate becomes drier, discharges from Chesapeake Bay tributaries in the inner Coastal Plain should decline much as these study watersheds did during dry years.

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The interpretation of water quality research will also be improved by a better understanding of how the volume of stream discharge is related to the volume of precipitation at the seasonal and annual temporal scale.

This paper analyzes stream discharge data beginning in the fall of 1971 and completed in the fall of 1996. Mean seasonal and annual water discharges per surface area calculated from these data are compared with mean seasonal and annual precipitation data measured on site and with long-term precipitation data measured near the Rhode River watershed by other parties. Many of the results are presented as either (a) Rhode River watershed discharges in which an area-weighted mean is calculated for all of the studied subwatersheds, (b) the mean of the four second-order subwatersheds, and (c) the mean of the three first-order subwatersheds.

METHODS

Site Description

The watersheds studied are small, contiguous, first- and second-order subwatersheds of the Rhode River (Table 1), a small tidal tributary to the Chesapeake Bay in Maryland, and are within the inner Atlantic Coastal Plain. Table 1 gives the stream order, area, and landuse composition of the watersheds. The watershed has sedimentary soils from the Pleistocene Talbot formation at low elevations on the eastern part of the watershed, Eocene Nanjemoy formation soils at low elevations further west, Miocene Calvert formation soils at intermediate elevations and Pleistocene Sunderland formation soils at the highest elevations. All of the soils are fine sandy loams and the mineralogy of the soils is fairly uniform, with a high level of montmorillonite and quartz, intermediate levels of illite and kaolinite, and low levels of gibbsite, chlorite, potassium feldspar, and plagioclase (Correll *et al.*, 1984). Bedrock is about 1,000 meters below the surface. The Marlboro Clay layer forms an effective aquiclude slightly above sea level throughout the watershed (Chirlin and Schaffner, 1977). Each subwatershed has a perched aquifer so that overland storm flows, interflow, and groundwater discharges all move to the stream channel draining each subwatershed. The slopes of the watersheds average between five and nine percent. The study watersheds ranged in size from 6.1 to 253 ha and differed in land use and order (Table 1). One small first-order watershed (#110) was completely forested, another (#109) was primarily row-cropped. One (#111) was primarily grazing land until the spring of 1989 when it was planted with pine seedlings (Correll *et al.*, 1995). The other somewhat larger second-order watersheds had mixed land use. For more detailed descriptions of the site see Correll (1981) and Correll and Dixon (1980).

Sampling Procedures

Watershed discharges were measured with sharp-crested V-notch weirs, whose foundations were in contact with the Marlboro Clay aquiclude (Correll, 1977). All weirs were 120° notches, except for watershed 111, which was 150°. Each weir had an instrument building and a stilling well. Depths were measured to the nearest 0.3 mm with floats and counterweights and were recorded every 5 minutes for watersheds 101, 109, 110, and 111 and every 15 minutes for the other watersheds. Prior to the summer of 1974, discharges

TABLE 1. Areas (ha) and Land Use Composition (percent) of Rhode River Subwatersheds in 1976 (Correll, 1977). The Rhode River watershed is located at 38°51'N, 76°32'W.

Watershed	Stream Order	Area	Forest	Row	Pasture and Hay Fields	Residential	Old Fields
101	2	226	38	10	27	6	19
102	2	192	47	18	22	6	7
103	2	253	63	2	16	5	14
108	2	150	39	24	20	3	14
109	1	16.3	36	64	0	0	0
110	1	6.3	100	0	0	0	0
111	1	6.1	27	0	73*	0	0

*Until 1989, when it was planted with pine seedlings.

from watershed 101 were measured with a 90° V-notch weir and recorded on a strip chart (Pluhowski, 1981).

Rainfall volume data were obtained from the weather station at the research center, located on subwatershed 101 approximately at the center of the watershed study area (Higman and Correll, 1982; and subsequent data). All of the watershed drainage under study was within four km of the weather station. Rainfall volumes were measured with standard manual rainfall gauges, and also with a Belfort weighing gauge.

Data Preparation

Weir discharges and rain volumes were summed for seasons, which were winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). Discharge years began with December. Comparisons are made with a 160-year record for precipitation (Higman and Correll, 1982). Higman and Correll (1982) summarized data collected from 1967 to 1977 at the Smithsonian Environmental Research Center; from 1857 to 1967 at the U.S. Naval Academy in Annapolis, Maryland; and from 1817 to 1856 at the U.S. Army Fort Severn, just north of Annapolis, Maryland. Gaps in the Annapolis data (1846-1856 and 1877-1893) were filled with data from Fort Severn. All three sites are on the upper western shore of Chesapeake Bay and at the times of data collection were fairly small towns. Thus any "heat island" effects were minimized. Annapolis and Fort Severn are approximately 12 and 15 km north of the research center, respectively.

The study was conducted from the fall of 1971 through the fall of 1996. The three first-order watersheds were not equipped until the mid-1970s, and thus there were less years of data for these watersheds. Several significant gaps in individual watershed data records resulted from storm damage to the weirs. Data from any individual weir were only included in the analysis when the weir was operational for a complete season or year. From 5 to 10 percent of the discharge data for any given weir were missing due to short-term equipment failures. When no significant precipitation occurred during the data gap, these data were estimated by interpolation of data from the same weir. When storm events occurred during the data gap, these data were estimated by correlation with discharge data from adjacent watersheds of the same stream order.

The watersheds in this study constitute a classic case of paired watersheds. The watersheds are contiguous small basins with similar slopes, soils and weather. Discharge measurements were taken at the same times by the same methods. Therefore, we used the paired T-test to examine the data for significant differences in watershed discharges.

RESULTS

Annual Data

All individual watersheds discharged higher proportions of precipitation during years of higher rainfall, but this relationship had considerable variation. In Table 2, precipitation at the Rhode River site during this 25-year study (1972-1996) is summarized seasonally and annually as mean, standard deviation about the mean, and range for each time period. These values are then compared to analogous values for the 160-year regional record. Annual precipitation at the study site varied from 824 to 1684 mm. The average annual precipitation on the site was 1139 mm, and was not significantly different from the 160-year average of 1080 mm/yr ($P < 0.05$). In Table 3, stream discharges from each subwatershed and the area-weighted mean are summarized seasonally and annually as the mean and range of the means. The number of complete seasons and years of data for each watershed are also given. The data for the area-weighted mean discharge per unit area each year (Figure 1A) and the means of discharges from the first- and second-order subwatersheds per unit area each year (Figure 1B) are plotted versus the precipitation for that year. Linear regression fits and statistical summary data are included in Figure 1. The area-weighted mean watershed discharge varied from 130 to 669 mm/yr (Figure 1A) with an average of 332 mm/yr (Table 3) or 29.1 percent of average precipitation. Average discharges from individual watersheds 101, 102, 103, and 108, which are all second-order streams, varied from 24.7 to 29.6 percent of precipitation, while average discharges from individual watersheds 109, 110, and 111, which are first-order streams, varied from 16.0 to 21.9 percent of precipitation (Tables 2 and 3). The rate of increase of second-order stream discharge with precipitation (slope) was 2.1 times greater than for first-order streams (Figure 1B).

Paired T-tests indicated that of the second-order stream discharges, only those of watershed 103 were significantly different from those of watersheds 101 and 102. All of the first-order stream discharges were significantly lower than all of the second-order streams. Among the first-order streams all were significantly different from each other except 109 and 111.

TABLE 2. Comparison of Precipitation During This 25-Year Study with Long-Term Weather Precipitation for the Rhode River Region.

	Winter	Spring	Summer	Fall	Annual
	Precipitation (mm/period)				
Mean ± 1SD[1]	246 ± 71.9	280 ± 85.3	314 ± 115	245 ± 89.3	1080 ± 218
Range[1]	82.3-434	101-539	108-645	57.4-578	537-1690
Mean ± 1SD[2]	261 ± 10	295 ± 96.6	301 ± 79.8	281 ± 93.6	1139 ± 210
Range[2]	125-541	124-510	114-511	114-473	824-1684

[1]From Higman and Correll 1982 (160 years of precipitation).
[2]From this study of 25 years (1972-1996).

TABLE 3. Summary of Watershed Discharge Data (mm/time period). N equals number of complete seasons or complete years measured.

	A. Annual			B. Winter			C. Spring			D. Summer			E. Fall		
Watershed	Mean	Range	N	Mean	Range	N	Mean	Range	N	Mean	Range	N	Mean	Range	N
101	337	139-705	25	120	23.4-230	25	144	39.6-353	25	13.5	2.7-167	25	40.0	0.1-210	26
102	290	126-603	20	107	24.2-222	22	136	35.6-292	23	13.8	0.8-149	23	42.3	0.2-223	23
103	274	121-494	20	97.4	25.7-190	22	133	45.4-323	23	37.6	1.9-154	23	33.6	0.1-221	23
108	282	130-473	20	98.4	34.3-233	22	131	36.9-309	22	42.5	0.7-187	21	29.6	0.1-164	21
109	240	113-419	19	90.2	17.4-235	20	110	27.4-278	20	35.5	0.0-154	19	19.1	0.1-73.0	20
110	182	33.3-321	19	48.2	1.4-81.8	19	100	16.8-227	19	22.0	0.0-119	20	16.0	0.0-146	21
111	196	77.0-321	16	75.3	18.5-230	17	81.9	23.0-197	17	25.6	3.9-106	18	17.9	2.4-62.4	18
Area-Wtd. Mean	332	130-669	25	115	26.3-230	25	138	40.0-321	25	40.6	1.6-162	25	40.9	0.8-218	26

Seasonal Data

Winter seasons averaged somewhat wetter than the longer-term records and some winters had more precipitation than occurred in the 160 year record period (Table 2). In Figure 2, individual seasonal discharges for the means of the first- and second-order streams are plotted versus precipitation along with regression lines and statistical summary information. The winter season area-weighted mean watershed discharge varied from 26.3 to 230 mm/winter with an average of 115 mm/winter or 43.9 percent of average winter precipitation (Table 3). Area-weighted mean winter discharges varied from 38.4 to 48.8 percent of precipitation and the proportion of precipitation discharged was not highly correlated with volume of precipitation. Average winter discharges from the four second-order streams varied from 37.7 to 45.9 percent of precipitation, while discharges from the three first-order streams varied from 18.5 to 34.6 percent of precipitation (Figure 2). The year of highest winter precipitation for which individual watershed discharge data are complete was 1978 (precip. = 437 mm). In 1978 the discharges of the four second-order streams ranged from 43.5 percent of precipitation for watershed 102 to 53.3 percent for watershed 108, while the three first-order stream discharges ranged from 14.6 percent of precipitation for watershed 110 to 44.1 percent for watershed 111 to 53.8 percent for watershed 109.

Paired T-tests indicated that of the four second-order stream winter discharges, only watershed 103 was significantly different from watersheds 101 and 102. Of the three first-order stream winter discharges, watersheds 110 and 111 were significantly lower than all of the four second-order watersheds,

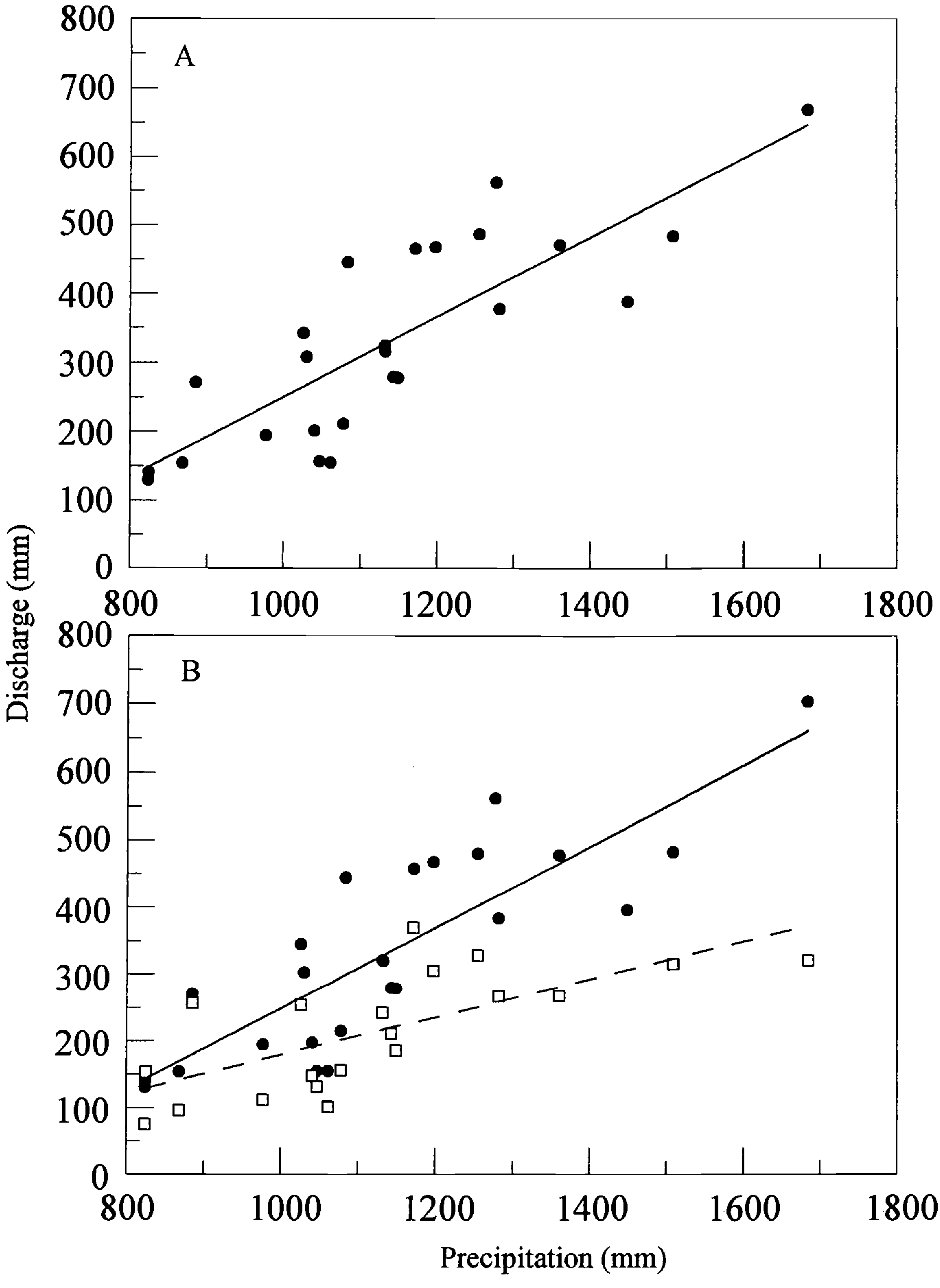

Figure 1. Variations in Annual Watershed Discharge with Volume of Precipitation.
Panel A. Area-weighted mean Rhode River watershed. Discharge = 0.580X -328; R^2 = 0.68; P < 0.000001.
Panel B. Means of three first-order (open squares and dashed line) and four second-order Rhode River subwatersheds (solid circles and solid line). First-order stream discharge = 0.283X - 104; R^2 = 0.48; P < 0.000001. Second-order stream discharge = 0.602X - 352; R^2 = 0.70; P <0.000001.

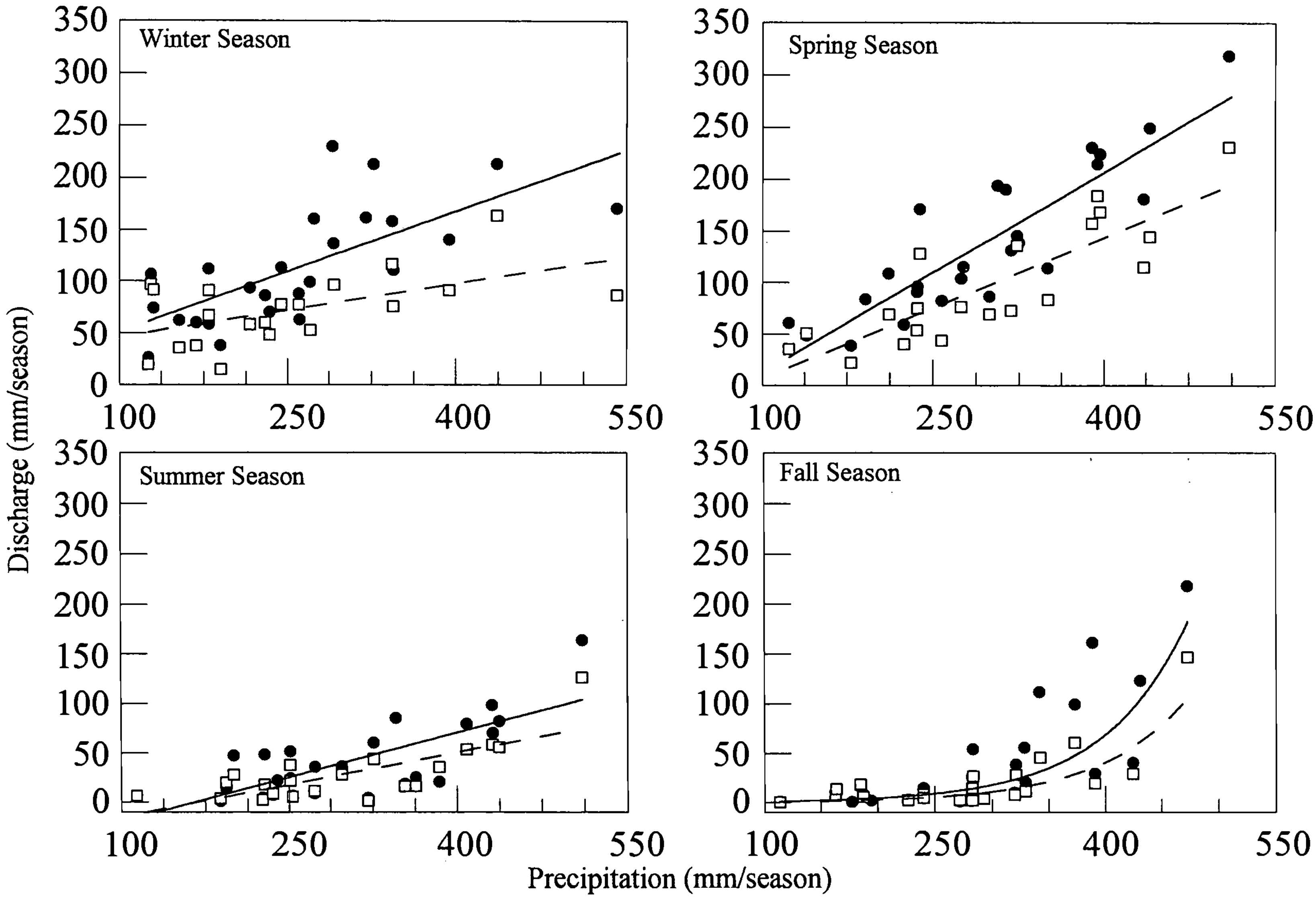

Figure 2. Variations in Seasonal Discharges of Means of Three First-Order (open squares and dashed lines) and Four Second-Order (solid circles and solid lines) Rhode River Subwatersheds with Volume of Precipitation. Winter season first-order stream discharge = 0.172X + 1.72; R^2 = 0.30; P < 0.01. Winter season second-order stream discharge = 0.391X + 12.2; R^2 = 0.50; P < 0.0001. Spring season first-order stream discharge = 0.458X - 38.9; R^2 = 0.71; P < 0.00001. Spring season second-order stream discharge = 0.649X - 52.0; R^2 = 0.77; P < 0.0000001. Summer season first-order stream discharge = 0.218X - 36.3; R^2 = 0.57; P < 0.0001. Summer season second-order stream discharge = 0.301X - 49.4; R^2 = 0.55; P < 0.0001. Fall season first-order stream discharge = $0.221e^{0.0130X}$; R^2 = 0.46; P < 0.0001. Fall season second-order stream discharge = $0.326e^{0.0134X}$; R^2 = 0.60; P < 0.00002.

but watershed 109 discharges were only significantly lower than watersheds 101 and 102. Among the first-order streams, watershed 110 winter discharges were significantly lower than those of watersheds 109 and 111, but 109 and 111 were not significantly different from each other. Mean winter discharge of first-order streams increased only 44 percent as much with volume of precipitation as the mean of second-order streams (ratio of slopes in Figure 2).

Spring seasons averaged somewhat wetter than the average of the 160-year record (Table 2). The area-weighted mean spring watershed discharge varied from 40.0 to 321 mm/spring (Table 3) with an average of 138 mm/spring or 46.9 percent of precipitation (Tables 2 and 3) and the proportion of precipitation discharged increased rapidly with higher precipitation. Area-weighted mean spring discharges varied from 22.4 to 63.0 percent of precipitation and the proportion of precipitation discharge increased with volume of precipitation. Average spring discharges from the four second-order streams varied from 22.1 to 62.6 percent of precipitation, while average discharges from the three first-order streams varied from 12.5 to 46.9 percent of precipitation (Figure 2). Individual watersheds generally discharged higher proportions of spring precipitation during years of higher rainfall. The year of highest spring precipitation for which individual watershed discharge data were complete was 1983 (precip. = 510 mm). In 1983 spring discharges ranged from 57.2 percent of precipitation for watershed 102 to 69.2 percent for watershed 101, while the three first-order stream discharges ranged from 38.7 percent of precipitation for watershed 111 to 54.5 percent for watershed 109.

Paired T-tests indicated that, among the second-order stream spring discharges none were significantly different. All three of the first-order stream spring discharges were significantly lower than those of all of the second-order streams. Among the first-order streams only the discharges of watersheds 109 and 111 were significantly different. Mean spring discharge of first-order streams increased only 71 percent as much with volume of precipitation as the mean of second-order streams (Figure 2).

Summer seasons averaged slightly drier than the average of the 160 year record (Table 2). The area-weighted mean watershed summer discharge varied from 1.6 to 162 mm/summer (Table 3), with an average of 40.6 mm/summer or 13.5 percent of precipitation (Tables 2 and 3). Area-weighted mean summer discharges varied from 0.9 to 31.8 percent of precipitation and the proportion of precipitation discharged increased rapidly with increasing precipitation. Average summer discharges from the four second-order streams varied from 0.8 to 32.2 percent of precipitation, while discharges from the three first-order streams varied from 2.0 to 24.7 percent of precipitation (Figure 2).

Paired T-tests indicated that none of the four second-order stream summer discharges were significantly different. Of the three first-order streams, watershed 110 summer discharges were significantly lower than those of all second-order streams, but watershed 111 discharges were only significantly lower than those of watershed 108; and watershed 109 discharges were not significantly lower than those of any of the four second-order watersheds. Among the three first-order streams, summer discharges were only significantly different for watersheds 109 and 110. Mean summer discharge of first-order streams increased only 72 percent as much with volume of precipitation as the mean of second-order streams (Figure 2).

Fall seasons averaged wetter than the average for the 160-year record (Table 2). The area-weighted mean watershed fall discharge varied from 0.8 to 218 mm/fall (Figure 2) with an average of 40.9 mm/fall or 14.3 percent of precipitation (Table 3). Area-weighted mean fall discharges varied from 0.5 to 46.1 percent of precipitation and the proportion of precipitation which was discharged increased rapidly with increasing volume of precipitation. Average fall discharges from the four second-order streams varied from 0.7 to 46.1 percent of precipitation, while mean discharges from the three first-order streams varied from 0.02 to 30.9 percent of precipitation (Figure 2). An exponential regression fit the data better than a linear regression (higher R^2, Figure 2).

Paired T-tests indicated that none of the four second-order stream fall discharges were significantly different. Of the three first-order streams, watershed 110 fall discharges were significantly lower than those of all second-order streams. Discharges of watershed 109 were only significantly lower than those of watershed 101 and watershed 111 discharges were not significantly different from those of any of the second-order streams. Among the three first-order stream fall discharges only those of watersheds 109 and 110 were significantly different. Regression of watershed 111 discharges versus precipitation had a very low correlation. Linear regression coefficients of determination for the other watersheds ranged from 0.42 for watershed 108 to 0.53 for watershed 101. Mean fall discharge of first-order streams increased only 53 percent as much with volume of precipitation as the mean of second-order streams (Figure 2).

By considering the sum of winter and spring discharges one can see differences among watersheds that are not as related to vegetation or the kinetics of groundwater discharge. There is relatively little transpiration because the vegetation is almost all deciduous or herbaceous. Also, by combining winter and spring the effects of snow carry over from winter into spring were minimized. For example, completely forested watershed 110 had unusually low discharges (14.6 percent of precipitation) in the winter of 1978 due to accumulation of snow pack, but very high discharges in the spring of 1978 (57.8 percent of precipitation). Finally, during unusually wet nongrowing periods changes in soil moisture storage and aquifer storage should be less important. The wettest winter plus spring, for which discharge data for individual watersheds was complete was 1978 (precip. = 830 mm vs 160-year average of 526 mm). Watershed discharge data for this time period were examined for differences among watersheds. For the combined period in 1978, discharges from the seven watersheds varied from 291 mm/ha (watershed 110) to 477 mm/ha (watershed 108). Discharges from the four second-order watersheds varied from 49.2 percent of precipitation for watershed 103 to 57.4 percent for watershed 108, while the three first-order watersheds varied from 35.1 percent for watershed 110 to 41.1 percent for watershed 111 to 49.8 percent for watershed 109.

DISCUSSION

The Rhode River watershed has dendritic channel morphology and an aquiclude at an elevation that facilitates the accurate measurement of total discharges from each of a series of subwatersheds. Because its rainfall has high interannual seasonal and annual variability, it is an excellent site to test for effects of variations in weather on hydrology. The 25 years examined had widely differing rainfall as reflected in the ranges and standard deviations of the means (Table 2), but the 25-year annual average rainfall was not significantly different from the long-term mean. One year winter precipitation exceeded the maximum in the long-term record. However, on average the weather during this study was slightly wetter, especially in the fall than the long-term average. The Rhode River is also a good site for looking at differences in weather effects on water discharges from various land uses or vegetative covers.

It is not clear why the smaller first-order watersheds had lower mean discharge per surface area than the larger second-order watersheds (Figure 2). The differences between first- and second-order watersheds were more evident than differences among either individual first-order or individual second-order watersheds. While some differences were probably due to vegetation and its effects on evapotranspiration, the larger second-order watersheds had more forest than the first-order watersheds 109 and 111 (Table 1) and thus would be expected to have had higher transpiration rates. Even in 1978 when non-growing season precipitation was unusually high, discharges from the smaller watersheds were lower than from the larger second-order watersheds. Another possibility is that the second-order streams have larger, well developed floodplains and thus had larger partial contributing areas (Hibbert and Troendle, 1988). This possibility is supported by a comparison of the average seasonal discharges from the means of the first- and second-order streams. First-order stream discharge was closer to that of the second-order streams in the summer, but was quite a bit lower in the winter and spring, the seasons of highest discharge (Figure 2, Table 3). Much of the summer discharge is due to high intensity thunder storms, which primarily generate overland flows (e.g., Correll *et al.,* 1987). Since conditions are usually very dry at those times, the partial contributing area would have less influence. Completely forested watershed 110 had significantly lower annual discharges than all other watersheds. Its discharges in the spring were not significantly lower than the other two first-order watersheds. This seems the most evident case where vegetative cover could have had a significant effect on discharge.

If we use precipitation minus discharge as a measure of evapotranspiration (ET), the average annual ET for the area-weighted mean of Rhode River watershed (807 mm/yr) was near the average for other eastern United States watersheds with long-term records (Table 4). Since the Rhode River watershed is at a low elevation and a mid-latitude, its ET seems reasonable compared to the other watersheds. Evapotranspiration rates are much more similar among these watersheds than are discharges (Table 4), but for Rhode River ET does vary with the volume of precipitation, ranging from 612 mm in 1980 to 1059 mm in 1975. These ET values are similar to pan evaporation, which for April through October averaged 950 mm over a six year period from 1973-1978 (Higman and Correll 1982).

At the seasonal level, area-weighted mean discharges were the highest proportion of precipitation in the spring (46.9 percent) and the lowest in the summer (13.5 percent). In the wettest spring, area-weighted spring discharges were 63 percent of precipitation, while in the driest summer discharges were only 0.9 percent of precipitation, and in the driest fall discharges were only 0.5 percent of precipitation. Thus, there was a lot of variation from the mean annual Rhode River discharge of 29.1 percent of precipitation.

TABLE 4. Comparison of Average Precipitation, Watershed Discharge, and Evapotranspiration for Rhode River Watershed and Other Small Watershed Sites (WS = watershed).

	Rhode River Maryland Area-Wtd Mean[1]	Fernow West Virginia WS 4[2]	Little River Georgia Sum WS N,O,J,K[3]	Walker Branch Tennessee Sum E & W forks[4]	Coweeta North Carolina[5] WS 2	Coweeta North Carolina[5] WS 36[5]	Hubbard Brook New Hampshire[6]
Precipitation (mm/yr)	1,139	1,458	1,258	1,368	1,772	2,222	1,295
WS Discharge (mm/yr)	332	640	379	713	854	1675	801
Ratio Discharge to Precipitation	0.29	0.44	0.30	0.52	0.48	0.75	0.62
Evapotranspiration (mm/yr)	807	818	879	655	918	547	494

[1]Area-weighted mean, 25 years
[2]Adams et al. (1994), 40 years
[3]Lowrance et al. (1985), 11 years
[4]Luxmoore and Huff (1989), 15 years
[5]Swift et al. (1988), 37 & 39 years
[6]Likens Bormann (1995), 19 years

CONCLUSIONS

Seasonal and annual precipitation were good predictors of watershed discharge in these Coastal Plain watersheds. Four second-order watersheds had similar annual discharges per surface area, despite significant differences in vegetative cover, while three small first-order watersheds discharged significantly lower volumes per surface area. Discharges from a completely forested first-order watershed were the lowest, perhaps due to higher ET. Except in the winter, the proportion of precipitation discharged by all watersheds increased rapidly with increases in precipitation. Thus, when unusually high precipitation occurred, watershed discharge increased disproportionately. For the spring season, in the wettest spring, the area-weighted watershed discharged 63 percent of precipitation, which was 233 percent of the discharge in a spring with average precipitation, while in the driest spring discharge was only 22.4 percent of precipitation, which was only 29 percent of the discharge in a spring of average precipitation. It is important for water resource managers not to overlook the impacts of this large interannual range in seasonal and annual water discharge from watersheds like the Rhode River. Much of the variation in nutrient discharges into receiving waters is due to differences in the volume of water discharged from the watershed. In this study the Rhode River had a five-fold range in annual discharge and the range of seasonal discharges varied from eight-fold in the spring to 272-fold in the fall. It would be helpful to water resource managers to have comparable watershed discharge data from other physiographic regions.

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