HYDROLOGY OF A SOUTH-CENTRAL MISSOURI CEDAR GLADE

Joseph A. Gates, Carl D. Settergren,
Gray S. Henderson and J. John Krstansky[1/]

Abstract.--The first 11 months of the calibration period for three catchments on a cedar glade showed that after 34 runoff events runoff prediction equations have correlation coefficients of 0.993 or better. Fourteen events yielded volumes greater than 1 m^3, ranging in size from 0.8 m^3 to 230 m^3, accounting for 99.7 percent of the runoff losses for the period.

Even though soils are shallow (<60 cm) and slopes steep (25%) storm hydrographs show that interflow is a major contributor to total storm runoff. Unlike those from most semi-pervious areas, storm hydrographs have steep ascending limbs, sharp peaks, and long tapering descending limbs. Runoff responses were calculated to be between 0.21 and 0.27.

A water balance shows precipitation inputs were 89 cm, runoff losses 12 cm; ET and deep seepage were estimated at 42 cm and 36 cm, respectively.

Keywords: cedar glades; paired watersheds; hydrology; water balance

INTRODUCTION

Over 65,000 ha of the Mark Twain National Forest in south central Missouri are classified as cedar glades and are used extensively for recreation and grazing. As a result of modern fire prevention programs and improved suppression techniques, encroachment of red cedar over the glades has accelerated. To maintain the openness of the glades for recreational and grazing purposes the Forest Service periodically clears the red cedar and other woody species and prescribe burns to stimulate forage production. Recently concern has been voiced that these practices may have some serious long-term consequences. The most immediate concern is with erosion and soil productivity losses, as well as the probable increased sediment and nutrient inputs to local streamflow. These practices also have the potential for creating source areas for overland flow, posing a serious flood hazard for the receiving streams at lower elevations.

This study was initiated in 1981 to determine the effects of these practices on glade hydrology and water quality using the paired watershed ap-

[1/] Research Assistant, Forest Hydrology; Professor of Forest Hydrology; Associate Professor of Forestry; and Research Specialist, Forest Hydrology, University of Missouri-Columbia.

proach. This paper will report on baseline hydrology only. No extensive research has been done previously on the hydrology of these unique geologic landforms.

THE CEDAR GLADES

The majority of the cedar glades occur in the south central Missouri Ozarks. They are mostly confined to the Jefferson City and Cotter dolostone formations of the Ordovician system on Gasconade series (fine, mixed, mesic, Lithic Hapludoll) soils less than 60 cm to bedrock. These soils form in limestone or dolostone residuum on steep slopes (2-50%). Slopes are convex with frequent horizontal dolostone ledge outcrops. The surface of the glades is covered with chert and incompletely weathered bedrock. The glades can be identified by their dome and stairstep appearance.

Vegetation is sparse, consisting of red cedar and associated hardwoods over a mixture of native prairie grasses and forbs. Even though the region has sufficient precipitation to support a mixed mesic hardwood forest, factors which are not completely understood at present, create conditions more favorable to the tall grasses and forbs. Woody plants generally occupy the deeper soils, and appear as bands following the contour just below major ledges. The glade-topped ridges have a distinct open savannah appearance.

Observers on the glades during heavy storms say that surface runoff occurs as sheet flow, cascading over the continuous lengths of the dolostone ledges. Even though overland flow occurs, the frequent ledges have a natural terracing effect and with the shallow soils channelization is minor. Also, tufts of grass and surface rocks help to break up channelized flow and create a diffuse flow pattern. Major flow paths can barely be traced downslope, and tend to wander across the catchment. Hydrologic boundaries may form nearly straight lines parallel to the slope direction and perpendicular to the ledges. Relief across the drainages is expressed in a few centimeters difference in elevation, and the ledges themselves are nearly level.

THE STUDY SITES

The catchments selected for the study are located 32 km southwest of Ava, Missouri on slopes averaging 25% on the south aspect of the same east-west ridgeline, and have not had fire or grazing for more than 10 years. Soils which average 25 cm in depth are deepest just below a dolostone ledge and gradually thin out downslope to bare rock just above the next ledge. Major dolostone ledges are generally massive, 30-60 cm thick, and spaced 30-50 m apart along the slope. Minor ledges may occasionally occur between major ledges, but barely break the soil surface. The surface layers between ledges are severely fractured in all planes. Local annual normal precipitation and temperature are 104 cm and 13.6°C, respectively.

The three catchments have been determined to be 0.30, 0.38 and 0.55 ha. Each has been equipped with a 60 cm H-flume, a Coshocton splitter and an ISCO discrete sampler for water quality sampling, and a Belfort FW-1 stage recorder. A recording raingauge is installed midslope and equidistant between two of the catchments. Runoff and precipitation samples have been

analyzed for pH, conductivity, turbidity, suspended solids, total Kjeldahl-N, NH_4, NO_3, P, Ca, Mg, K, Na, and SO_4.

RESULTS AND DISCUSSION

Analysis of Hydrologic Characteristics

At first glance it would seem that the steep slopes, shallow soils, and sparse vegetation might combine to create conditions very favorable for overland flow. The storm hydrographs might be expected to look similar to those generated from other impermeable areas with rapidly descending limbs, possibly elongated slightly to reflect the minor storage capabilities of the shallow soils. This is not the case on these cedar glades as is evident in a representative hydrograph for a short, high intensity storm (Fig. 1).

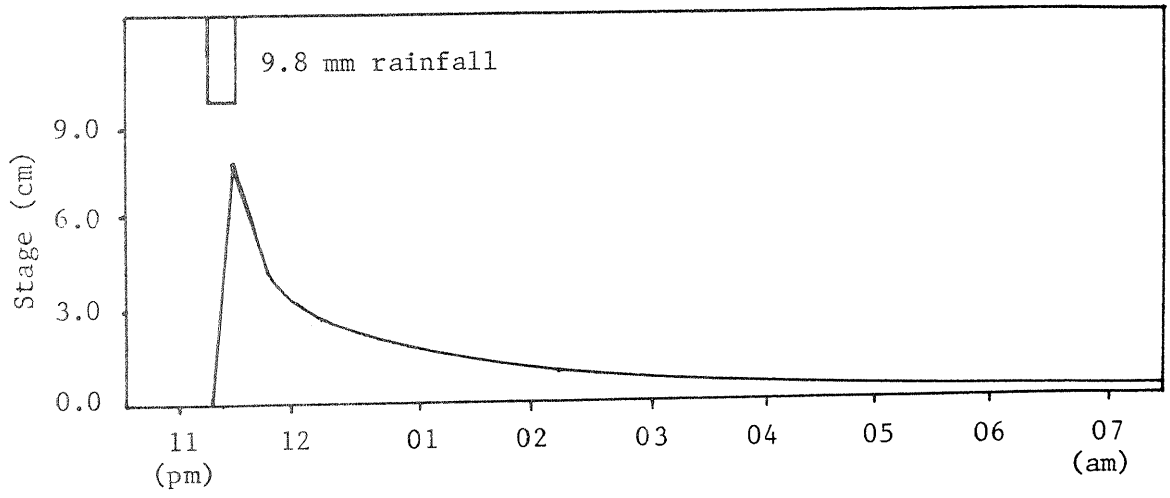

Fig. 1. Storm hydrograph from a 0.55 ha cedar glade catchment following a 15 minute, 9.8 mm storm starting at 11:40 p.m. on March 15, 1982.

The very steep ascending limb of the hydrograph is indicative of rapid overland flow contributions. However, the descending limb after 12 midnight is long and gradual, providing evidence of a large contributing interflow component. The "interflow" rate and volume is more than was first expected from detention storage.

Three possible explanations are offered for this phenomenon. First, the ledges, rock pavement, and grass tufts increase surface storage and lengthen flow paths sufficiently to increase the drainage time of the glades. Second, the soils offer considerable detention storage which flows as much horizontally as vertically downslope. Finally, deep percolation flows through the vertical fracture lines of the interlayers and is later rediverted to the surface via the horizontal ledges.

None of the three hypotheses can be offered as a sole explanation for the hydrograph form. The steep descending segment immediately following the peak shows surface runoff is a major contributor to storm runoff. The slightly shallower slope of this segment, as compared to the ascending limb, can be attributed to the rapid release from surface detention storage after rainfall stops. This initial steep recession does not last long. A slower decline takes over suggesting that interflow has become the major source of stormflow. This is further supported in the analysis of the ISCO discrete water samples. Calcium and magnesium concentrations are the lowest at or near the storm runoff peaks (11 to 20 mg/L and 4 to 11 mg/L, respectively) suggesting that overland flow is a major contributor to storm flow at this point on the hydrograph. Higher concentrations of calcium and magnesium (20 to 48 mg/L and 15 to 30 mg/L, respectively) are found further from the peak, thus indicating a longer contact time with a soluble calcium and magnesium source, a result of either interflow through soil or flow along fracture planes.

Although the Gasconade soils are high in clays (40%) they are still classified as excessively drained. Such a soil should be capable of producing the interflow rates indicated by the storm hydrographs. Also, the interlayers between ledges are highly fractured near the surface. This splitting, through weathering, of the massive beds into thinner beds and finally into 10-15 cm angular chips is characteristic of the Cotter formation (Rapp 1956) and results in the appearance of a brick wall of dolostone rocks mortared with soil. The soil is not compacted and roots are often seen in the fractures. Such a structure allows for water movement in any direction beneath the soil. However, the more massive dolostone ledges appear less fractured and can act as semi-permeable layers forcing percolating water back to the surface. Seepage, easily observed across the ledges after heavy storms, seems to support this interpretation. Generally, measureable flow terminates on the glades 24-36 hours after rainfall terminates, but the ledges may drip water for 2-3 days longer. The soil immediately above the seeping ledge is saturated, but only a few meters upslope the soils are firm and drained.

As shown, the catchments respond quickly to precipitation inputs and drain rapidly, but average runoff only accounts for 12 cm of the 89 cm of precipitation on the catchments (Table 1). The remaining 77 cm is a combination of evapotranspiration (ET) and deep seepage losses. A water budget analysis estimates ET and deep seepage losses for the period to be 42 cm and 36 cm, respectively.

ET losses were estimated using the Thornthwaite and Mather (1955) method and deep seepage was calculated as the residual of precipitation minus runoff estimated ET. Deep seepage thus includes deep percolation, lateral movement of water out of the catchment, and any changes in total soil storage.

To determine how these catchments compare to other areas the runoff response for the catchments was calculated using the method described by Hewlett and Hibbert (1965). The runoff response is the quotient of quickflow runoff (RO) and precipitation (P) minus ET losses (EQ. 1).

$$Ry = \frac{RO}{P - ET} \qquad (1)$$

Table 1. Hydrologic balance of three cedar glades near Ava, Missouri.

	CATCHMENT 1	2	3	4
Size (ha)	0.30	0.38	0.55	
	cm			
Precipitation (P)	89.3	89.3	89.3	89.3
Runoff (RO)	11.5 (12.9)[1/]	12.8 (14.3)	10.2 (11.4)	11.5 (12.9)
Evapotranspiration (ET)	41.7 (46.7)	41.7 (46.7)	41.7 (46.7)	41.7 (46.7)
Seepage (S)	36.1 (40.4)	34.8 (39.0)	37.4 (41.9)	36.1 (40.4)
	unitless			
Runoff response (RY)[2/]	0.24	0.27	0.21	0.24

[1/] ( ) % of total precipitation.

[2/] $RY = \frac{RO}{P - ET}$

As no baseflow exists on the glades quickflow and measured runoff are synonymous. The three catchments were found to have runoff responses of 0.21, 0.24 and 0.27 (Table 1). These values are lower than was expected for conditions present on the glades, but it compares well with values of 0.28 to 0.55 for other shallow soilwatersheds (Hewlett and Hibbert 1965).

Regression Analysis

From the period March 1981 to February 1982, 54 precipitation events were recorded, 34 of which resulted in measurable runoff. Only 14 of the runoff events yielded more than 1 m^3 of runoff on any catchment. Nearly all (99.7%) of the total runoff during the period is accounted for by these 14 events. The calibration regression analysis of the catchments was performed using runoff events ranging in volume from 0.8 m^3 to 230 m^3. Linear regression analysis showed excellent prediction correlation among the catchments for the comparison of catchments # 1 to # 2, # 1 to # 3, and # 2 to # 3, respectively. The prediction equations are:

$$Y_2 = 1.419\ X_1 + 0.48\ m^3 \qquad r = 0.997 \qquad (2)$$
$$Y_3 = 1.936\ X_1 - 6.50\ m^3 \qquad r = 0.993 \qquad (3)$$
$$Y_3 = 1.360\ X_2 - 7.81\ m^3 \qquad r - 0.994 \qquad (4)$$

where: Y = the predicted runoff volume in m^3
X = the actual runoff volume in m^3
Subscript denotes catchment.

The high correlation coefficients show how similar the catchments are in terms of watershed characteristics and hydrologic responses. Such high correlations coefficients are desirable if the significance of the subsequent treatment effects are to be identified or quantified.

SUMMARY

After the first 11 months of the calibration period the hydrologic response characteristics of the catchments have been identified and shown simi-

lar for all three catchments. Water balances for the three catchments are nearly identical. Regression analysis of total runoff/storm data has yielded excellent runoff prediction models for the catchments. However, before treatments are initiated the remaining goal of the calibration period is to verify the prediction models over the next season and make any needed adjustments.

LITERATURE CITED

Hewlett, John D. and Alden R. Hibbert. 1965. Factors affecting the response of small watersheds to precipitation in humid areas. In International Symposium on Forest Hydrology. Pergamon Press, Inc., New York. pp. 275-290.

Rapp, David W. 1956. A comparison of the type sections of the Jefferson City, Cotter, and Powell formations. Unpublished M.A. thesis, University of Missouri-Columbia.

Thornthwaite, C. W. and J. R. Mather. 1955. The water balance. Publications in Climatology, Drexel Institute of Technology 8:1-104.

This project funded through a grant provided by the U.S. Forest Service.