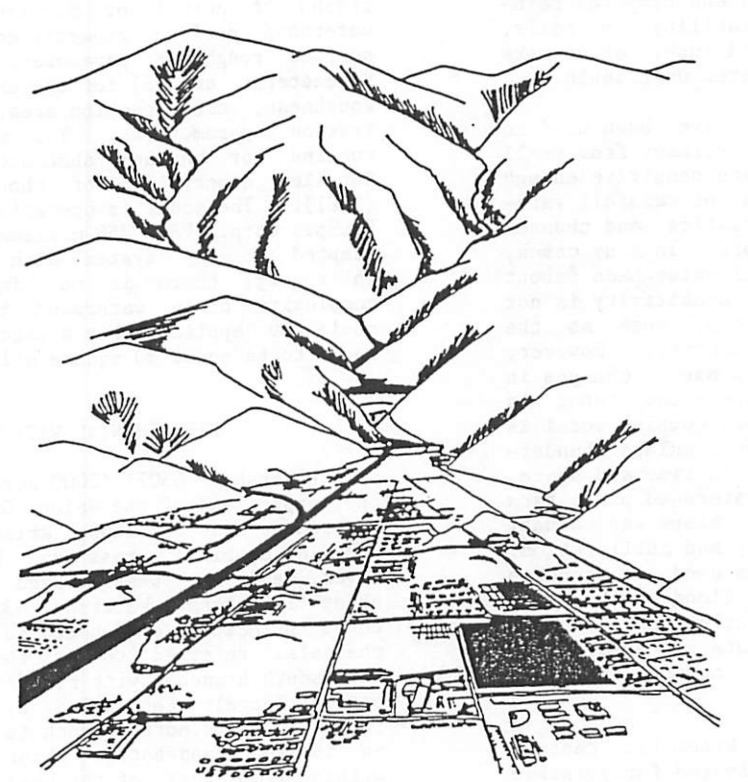
#553

Proceedings of a Western State High Risk Flood Areas Symposium

Improving the Effectiveness of Floodplain Management in Arid and Semi-Arid Regions



Association of State Floodplain Managers, Inc.

March 24-26, 1986

Las Vegas, Nevada

Simulation of Flood Peaks and Volumes by Kinematic Modeling: An Aid to Floodplain Management

Herbert B. Osborn
and
Carl L. Unkrich
USDA, Agricultural Research Service. Western Region

INTRODUCTION

In much of the western United States, and particularly in the Southwest, small watershed runoff is dominated by infrequent short-duration, high intensity thunderstorm rainfall. Thunderstorm runoff is of interest to hydrologists, engineers, and others involved in water supply, design of culverts and bridges, sediment transport and deposition, and floodplain management. Spatial and temporal rainfall variability, and variability in soils, cover, topography, and land use, often make runoff peak and volume estimates unreliable.

Many different models have been used to estimate runoff peaks and volumes from small watersheds, but few models are sensitive enough to separate the influences of rainfall variability, watershed characteristics, and channel routing in estimating runoff. In many cases, particularly for very small watersheds (about 100 acres or less), such sensitivity is not needed, and simple equations, such as the Rational Method, may be satisfactory. However, to delineate hydrologic response to changes in an urbanizing watershed when the input is thunderstorm rainfall, a more complex model is required. Such a model must simulate thunderstorm rainfall input, both in time and space, as well as the important watershed parameters such as infiltration, cover, slope and channel parameters such as geometry and infiltration. When a distributed model is used, an accurate procedure for routing the flood peaks from watershed elements to the outlet must be used. The model also must simulate the abstracting ephemeral stream channel common to the Southwest.

In this paper, a kinematic cascade rainfall-runoff model is evaluated for possible use in floodplain management of urbanizing southwest rangeland watersheds. The model is adapted for breakpoint rainfall input, and infiltration parameters can be spatially varied. Watershed geometry is modeled as a series of rectangular planes and trapezoidal channels. The kinematic approximation is used for unsteady flow calculations on planes and channels, and the Smith-Parlange model (Smith, 1981) is used for infiltration. The hydrologic effects of anticipated changes in land use are illustrated with simulations of four actual rainfall-runoff events on a well-instrumented 2000-acre experimental rangeland watershed.

RAINFALL-RUNOFF MODEL

The kinematic cascade model, KINEROS (Kibler and Woolhiser, 1970; Rovey et al., 1977; Lane and Woolhiser, 1977; Smith, 1981), used in this study, is versatile and sensitive to both rainfall and watershed characteristics (Osborn, 1984). It is a well-tested nonlinear, deterministic, distributed parameter model (Rovey et al., 1977). Inputs are: (1) hyetographs of actual or simulated rainfall, (2) watershed surface geometry and topography, (3) surface roughness parameters, (4) infiltration parameters, and (5) for the channels, hydraulic roughness, cross-section area, slope and infiltration parameters. The model includes a routine for channel abstraction. For a more detailed description of the model, see Smith (1981). The model is operational on a *Digital Equip. Corp. VAX 750 minicomputer, and can be adapted to any system with similar capacity. In theory, there is no limit to the size or complexity of a watershed to which KINEROS could be applied, but a practical upper limit seems to be about 30 square miles

EXPERIMENTAL WATERSHED

Watershed 63011 (2000 acres) is located on the upper end of the Walnut Gulch experimental watershed near Tombstone, Arizona (Fig. 1). It has a combined grass and brush vegetation cover, and has been grazed continuously for about 100 years. Watershed 63011 is drained by three principle sand-bottomed ephemeral stream channels, referred to as the north, central, and south branches, with runoff from the central branch largely controlled by two stockponds (Fig. 1). The north branch is characterized by an incised sand-bottom channel extending to within 1200 feet of the head of the drainage. The south branch is dominated by an incised channel in the lower half of the drainage. The channels are normally dry; there is no base flow. An active headcut is cutting into a broad swale as it moves up the south branch. There are no buildings or paved roads on 63011.

---

* Mention of a trade name in no way constitutes endorsement of the product by the U.S. Government.

There are 10 weighing-type recording raingages on, or immediately adjacent to, the 2000-acre subwatershed (Fig. 1). Runoff from the watershed was measured at a flume (Smith et al., 1982) at the watershed exit, and 19 runoff events were selected to validate the model.

MODEL VALIDATION AND CALIBRATION

For KINEROS, watershed 63011 was divided into 28 planes and 11 channels (the plane and channel numbers correspond to the order of processing within the program - Fig. 2). A representative plane is shown to indicate the level of simplification required (Fig. 3). Surface geometries were determined separately for each plane and channel reach. There was no significant overflow from the ponds on the central branch for the events selected, so the planes and channel reaches above the ponds were not included in this analysis.

Parameters describing infiltration,surface roughness, and channel losses were adjusted based on hydrograph simulations and actual runoff hydrographs. Because of the relative homogeneity of watershed 63011, the same infiltration and roughness characteristics were used for all planes. Different values can be used for each plane but values cannot be varied within a plane. The soil classification for 63011 fell between loamy sand and sandy loam, with 40% rock content. Based on Rawls et al. (1982), average saturated conducivities for loamy sand and sandy loam (with 40% rock content) were 0.72 and 0.31 in/hr. The calibrated infiltration rate of 0.53 in/hr fell nicely within this range. Also, a sorptivity parameter value of 3.0 inches fell within the range of 2.4 to 4.3 inches for loamy sand and sandy loam suggested by Rawls et al. (1982). Once the characteristic watershed parameters, including channel infiltration, were determined, antecedent soil moisture was varied for individual events, to match actual and simulated peaks for 19 events (Table 1). The differences between actual and simulated volumes can be considered as a measure of the accuracy of the model.

ANALYSIS

Four of the more recent runoff events on 63011, with reliable rainfall and runoff records, were used to illustrate the use of KINEROS for simulating peaks and volumes from an urbanizing watershed (Fig. 4-7). We then assumed that a changing land use (high density residential development) had reduced the final infiltration rate for the watershed (not including the channels) to 0.10 in/hr, with all other variables remaining unchanged.

With reduced infiltration, runoff peaks were two to four times as great (Table 2). In effect, the expected frequencies for storm peaks were changed significantly, which is particularly important in floodplain management. For example, the simulated peak of 874 cfs for the natural watershed, for 04 Aug 80, has about a 5-yr recurrence interval for 63011. The simulated peak of 1733 cfs, based on reduced infiltration and no channel losses,

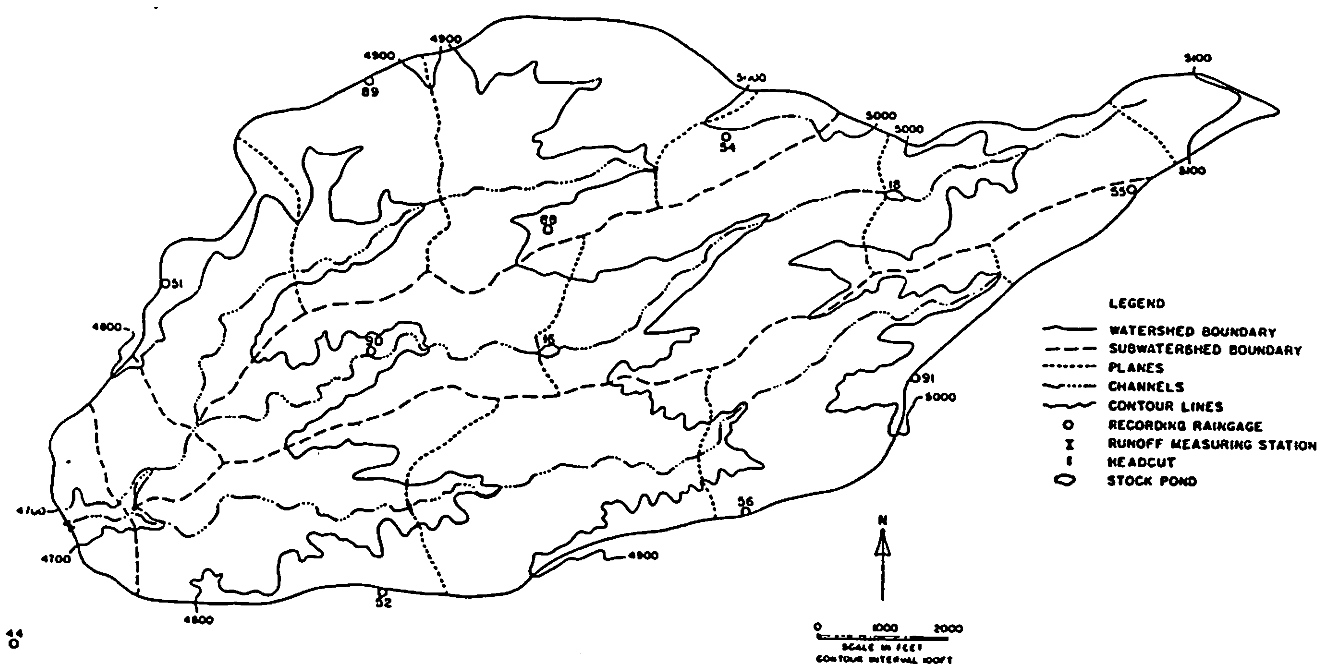


Figure 1. Walnut Gulch experimental watershed 63011.

has about a 25-yr recurrence interval. In other words, the expected frequency of the larger peak, 25 years, is now that of the smaller peak, 5 years.

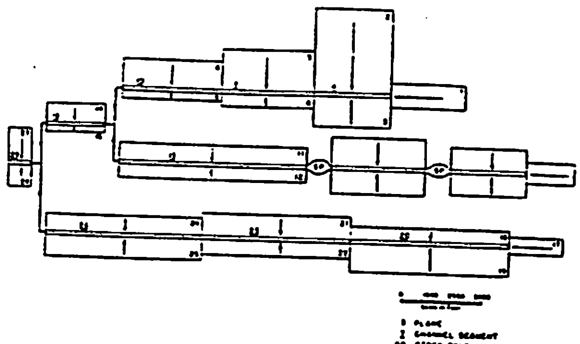


Figure 2. Schematic of watershed 63011 for KINEROS.

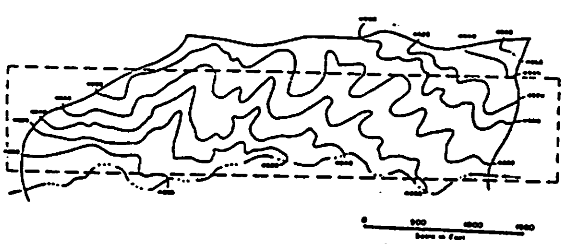


Figure 3. Example of required simplification of a watershed segment to a rectangular plane with the same area.

With reduced infiltration, storm runoff volumes also increased significantly, as expected. Simulated volumes compared fairly well with actual storm volumes when KINEROS was calibrated (Table 1), but if only runoff volumes are needed in a particular study, simpler models, such as the SCS method, are equally reliable.

Table 1. Storm rainfall (P) and actual and final simulated peaks (Q_p) and volumes (Q) for calibrating KINEROS for watershed 63011, Walnut Gulch, AZ

Date	P	ACTUAL		SIMULATED	
		Q_p	Q	Q_p	Q
	(in)	(cfs)	(in)	(cfs)	(in)
06Aug66	.80	319	.141	318	.134
07Jul67	.60	123	.046	120	.046
10Sep67	2.05	1706	.775	1710	.737
05Aug68	1.10	876	.168	880	.089
12Aug71	.61	348	.127	345	.089
18Aug71	1.09	434	.129	434	.157
12Jul73	.90	372	.077	373	.093
16Jul73	.74	232	.063	236	.080
12Aug75	.74	780	.154	787	.269
13Sep75	.88	698	.286	697	.230
27Jul76	1.06	519	.180	523	.195
30Jun77	.63	202	.110	201	.090
16Aug77	.67	107	.043	107	.055
01Sep77	1.38	992	.437	996	.442
04Aug80	1.24	874	.284	874	.307
15Jul81	.77	340	.106	334	.136
10Aug81	.47	97	.034	97	.028
27Aug82	1.73	3400	1.180	3394	1.166
11Sep82	.92	655	.373	658	.348

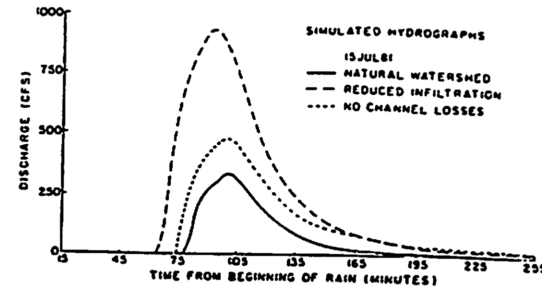


Figure 4. Simulated hydrographs for three land uses for watershed 63011.

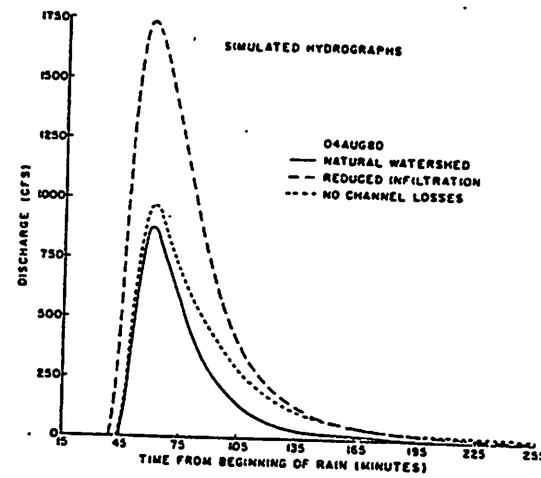


Figure 5. Simulated hydrographs for three land uses for watershed 63011.

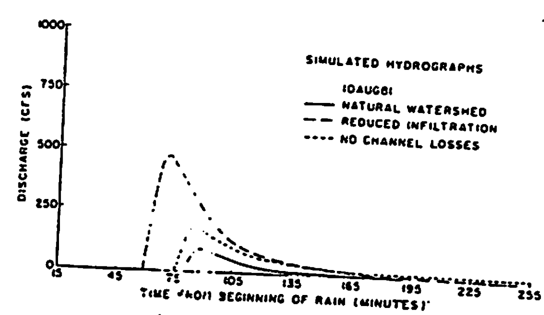


Figure 6. Simulated hydrographs for three land uses for watershed 63011.

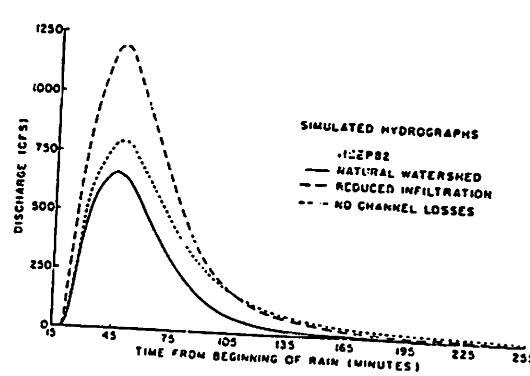


Figure 7. Simulated hydrographs for three land uses for watershed 63011.

We also looked at the effect of lining the channels while leaving the remainder of the watershed untouched. The resulting change was less extreme than when we reduced watershed infiltration, and in most situations, the increased volume would not be significant. However, if the floodplain manager is concerned about potential groundwater recharge (as is the case in cities such as Tucson, Arizona), then changes in volume could be significant. Total estimated channel abstractions from unlined channels for the four events ranged from 7.4 to 23.3 ac-ft. Even though only a fraction of the channel abstraction may reach the groundwater table, such simulations would provide a guide to potential losses in groundwater recharge when channels are lined.

Finally, when we simulated runoff peaks and volumes assuming a final infiltration rate of 0.10 in/hr, along with impervious channels (Table 2), volumes were increased by about 50 to 100 percent.

Table 2. Simulated peaks and volumes for selected events on Walnut Gulch Watershed 63011

Storms	SIMULATED PEAKS (cfs)				SIMULATED VOLUMES (AC-FT)			
	Natural watershed	No. channel losses	Reduced infiltration	Reduced infil. and no. channel losses	Natural watershed	No. channel losses	Reduced infiltration	Reduced infil. and no. channel losses
04Aug80	874	961	1733	1793	42.7	65.4	109.4	120.3
15Jul81	335	477	939	1005	18.9	37.5	66.8	77.1
10Aug81	97	172	470	513	3.9	11.3	23.4	31.1
11Sep82	658	796	1194	1265	44.1	67.4	87.4	98.8

DISCUSSION

With the rapid advances in computer technology, more sophisticated mathematical models are available for evaluating hydrologic changes with changing land uses for southwest rangelands. One such model, a kinematic cascade model, KINEROS, appears to be particularly well-suited for analyzing rangeland watersheds undergoing change when flood peaks or total hydrographs are needed. The model works well for volume comparisons, but simpler models are acceptable if only volume comparisons are needed.

In this analysis, we assumed two simple situations of changing land use to illustrate the potential value of a kinematic cascade rainfall-runoff model for floodplain management. However, the model is much more flexible than this. One could look at the effect of development on different parts of the watershed, including topographic changes such as terracing. The number of possible configurations and combinations of land use is limited only by the size of the planes.

KINEROS includes several options which we did not illustrate. For example, a subroutine for sediment transport, which may be helpful in determining potential sedimentation problems for retention reservoirs and of the potential for "clear water" scour below nonerodible areas within a watershed, is included. Also, retention and detention structures can be included in the model.

SUMMARY

A kinematic cascade rainfall-runoff model (KINEROS) has been adapted as a tool for rangeland research in the Southwest. During the period of adaptation (3 years), while the model was being improved for research uses, advances in computer technology have suggested the potential for other practical uses, such as floodplain management. The model can be used to simulate hydrographs for real or design storms, and the effects of changes on the hydrology of the watershed can be estimated through "before" and "after" hydrograph simulations.

REFERENCES

Kibler, D.H. and D.A. Woolhiser. 1970. The kinematic cascade as a hydrologic model. Colo. State Univ. Hydrology Paper 39.

Lane, L.J. and D.A. Woolhiser. 1977. Simplifications of watershed geometry affecting simulation of surface runoff. J. Hydrology 35: 173-190.

Osborn, H.B. 1984. Storm cell properties influencing runoff from small watersheds. Transportation Research Board, NRC, TRR 922: 24-32.

Rawls, W.J., D.L. Brakensiek, and K.E. Saxton. 1982. Estimation of soil water properties. Trans. ASAE 25 (SW1982): 1316-1320, 1328.

Rovey, E.W., D.A. Woolhiser, and R.E. Smith. 1977. A distributed kinematic model of upland watersheds. Colo. State Univ. Hydrology Paper 93.

Smith, R.E. 1981. A kinematic model for surface mine sediment yield. Trans. ASAE 24(6): 1508 1519.

Smith, R.E., D.L. Chery, K.G. Renard, and W.R. Gwinn. 1982. Supercritical flow flumes for measuring sediment-laden flow. USDA-ARS Tech. Bul. 1655, 70 p.