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Model Complexity Required to Maintain Hydrologic Response

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An increasing number of practitioners are using distributed hydrologic models employing kinematic routing. Watersheds are typically represented by a set of overland flow plane and channel elements, yet no guidelines exist for determining how complex the model representation must be. A small semiarid watershed was divided into plane and channel segments using a large scale topographic map. A kinematic rainfall-runoff model was used to obtain runoff hydrographs for the watershed representation for three rainfall events. Methodology was developed to aggregate model elements into a smaller number of equivalent elements. Model performance at various levels of aggregation was measured. Model aggregation for the study basin was readily accomplished for small floods.

INTRODUCTION: The use of physically based distributed models has increased significantly because of the realization of the limitations of simpler models and the accessibility to greater computer power. Physically based models are input data intensive. The quantity of input data and computational time is directly proportional to the number of elements used to represent the watershed. Guidelines for the proper number of elements, or analogously, the degree of averaging over homogeneous or heterogeneous areas that is permissible, are sorely lacking. The objective of the work discussed herein is to develop an objective, repeatable procedure to select the proper degree of geometric model complexity that maintains basin hydrologic response. It is likely that criteria developed will be a function of basin scale, climate and modeling objectives, but the findings presented were developed from study of a single small semiarid watershed.

RAINFALL-RUNOFF MODEL: The event model (KINEROS) has evolved from the work of Rovey, Woolhiser and Smith (1977). In this model both overland and channel flow are approximated using one dimensional kinematic wave equations. Infiltration is described by the Smith-Parlange (1978) model. This infiltration model is interactive with rainfall rate and can handle cases when rain ceases or drops to a rate less than the infiltration capacity. In this case infiltration can continue from the rain or any remaining water flowing over the surface. One of the major conclusions of Freeze (1980) was that the spatial variability of saturated hydraulic conductivity (Ks) should be incorporated into physically based rainfall runoff models. This has been accomplished in a straight forward manner within KINEROS. The procedure, discussed in Woolhiser and Goodrich (1988), employs within element (planes only) variability of Ks using an assumed lognormal distribution of Ks specified by an input mean and coefficient of variation (CV).

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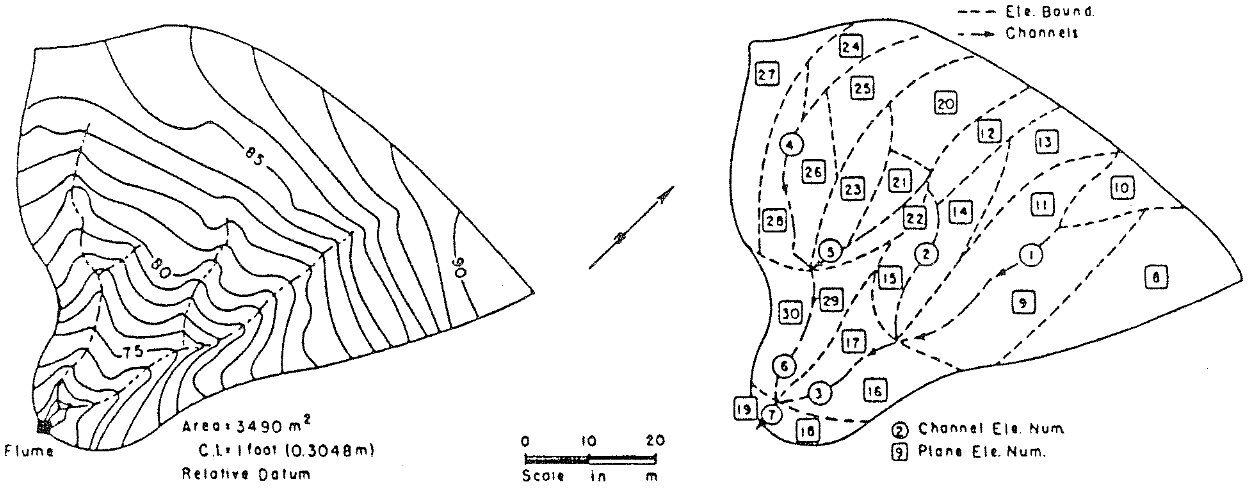
Geometric input parameters (lengths, slopes, widths) of plane elements are derived from topographic maps via a repeatable procedure developed for this study. Channel characteristics can be derived from maps or field surveys. Infiltration parameters can be estimated from ring infiltrometer measurements or, as was the case for this study, from textural classification of soil samples (Rawls et. al. 1982).

STUDY BASIN: The watershed investigated (Lucky Hills 106) is located within the Walnut Gulch experimental watershed operated by USDA-ARS near Tombstone, AZ. It is 3490 m^2(0.86 acres) in size and is situated in a semiarid climate with sparse creosote bush, whitethorn, and tar bush vegetation cover. Soils vary from a silt loam to loam in textual classification with a large percentage of rock. A recording raingage roughly 180 m from the watershed centroid provided input data that was assumed to be spatially uniform. Watershed maps with 1 ft (0.3048 m) contours and the basin subdivision into overland flow and channel segments are shown in Figure 1.



Topographic Map Runoff Model Elements

Figure 1 - Lucky Hills 106

APPROACH: The goal of this study was to investigate the effects of geometric model simplification. Therefore, <u>none</u> of the initial model parameters values as estimated from field data were altered to minimize differences between computed and observed runoff. Observed runoff is, however, reported for comparative purposes. Small, medium, and large events (based on return period) were selected for the study. Event statistics are summarized in Table 1.

Event	Date	Dur. (min.)	Tot. Depth (mm)	Peak Int. (mm/hr)	Wtd. Mean Int. (mm/hr)	Return Per.* (years)	Relat. Size
1	8/10/71	64	27.4	133.4	25.7	~ 2.8	large
2	8/31/66	133	16.5	50.8	7.0	< 1.0	small
3	8/23/82	96	30.7	68.6	19.2	~ 2.0	medium

Table 1 - Rainfall Event Statistics
* Osborn and Renard (1988)

The question of geometric model simplification is closely linked to basin map scale. For example, if Figure 1 were created from a 7 1/2 minute USGS topographic map, there are no channels shown in the basin. On an intermediate scale map the first order channels depicted in Figure 1 might not be detected. In such a case, all of the overland flow elements contributing to a first order channel and the first order channel itself (as shown in Figure 1) would be perceived as a single overland flow element. For example planes 8, 9, 10, and 11, as well as channel 1 in Figure 1, would be viewed as a single plane on a smaller scale map. The distinction between the two systems is due to the modelers perceived reality of the watershed as interpreted through the base map.

The single plane is obviously a simpler system than the one deduced from a larger scale map. A central issue is the hydrologic equivalence of the simple and complex systems. From another perspective one might ask how the elements of the complex system might be lumped into a single element and yet maintain system hydrologic response? With this in mind, a methodology was developed to aggregate not only first order systems into single overland flow elements, but also to lump cascades of overland elements and adjacent overland flow elements.

Preservation of a characteristic time of the system to be replaced was the major criterion used in formulating the aggregation methodology. This time is computed by utilizing the integrated storage of an impervious system under steady state flow conditions obtained from a constant rainfall intensity. Once a characteristic time is defined for the system the roughness value (Manning's "n") is altered so that the single equivalent overland flow plane has the same storage under the original steady state conditions. The other geometric and infiltration parameters of the single equivalent plane are obtained from repeatable geometric relationships. For example, when replacing a first order channel system by a single plane, the overland flow length of the single plane is equal to the area of the system divided by the length of channel being replaced. The width of the plane then becomes equal to the length of channel, so area is preserved. Equivalent slope and soil parameters are computed using an area weighted average. Space limitations do not permit a full explanation of the procedure. For further details the reader is referred to Wu et. al. (1978).

With these repeatable and objective rules, aggregation of channel and overland flow elements can continue. At each level a simpler system is obtained. At the ultimate level of aggregation the entire watershed is replaced by a single equivalent overland flow plane. Indeed, a watershed of this size is only a portion of a single flow plane for the model representation of much larger basins containing

Lucky Hills 106. The successive levels of aggregation of the Lucky Hills 106 watershed are schematically diagrammed in Figure 2.

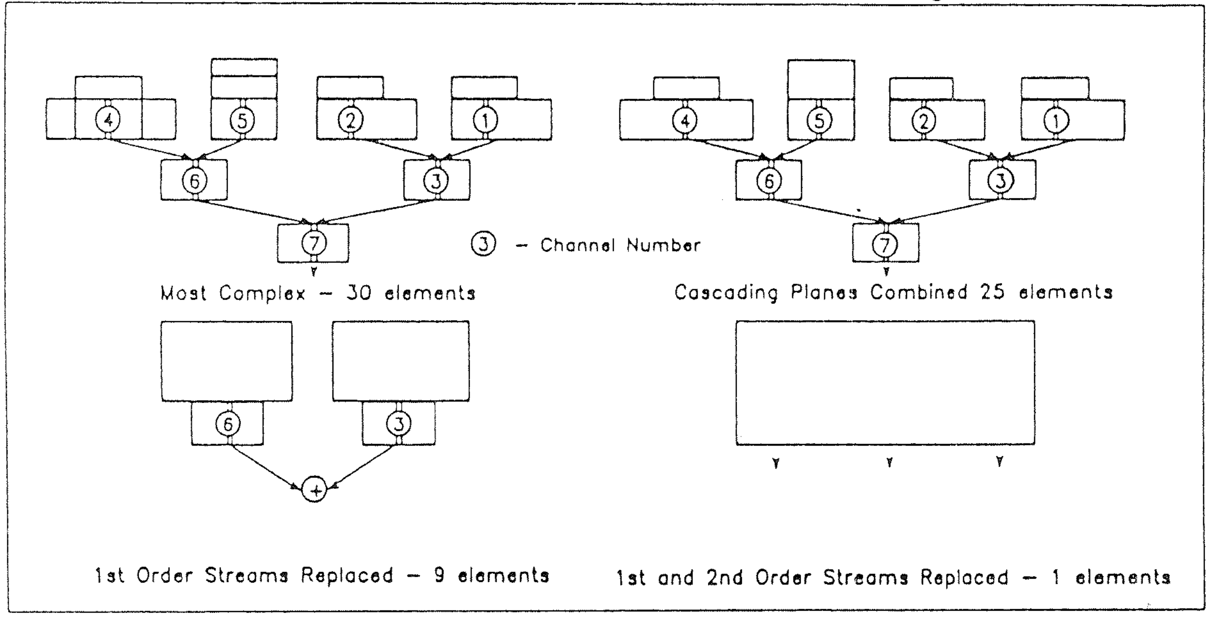


Figure 2 - Levels of Model Aggregation

Each rainfall event was applied to all aggregatation levels of the model representation of the basin. Output from each level of aggregation was compared to the most complex representation (30 elements). This was done for the case of uniform Ks within an element and for spatially varying Ks with CV = 0.8. For each run the computational CPU time of VAX 11/750 was also recorded. The results are summarized in Table 2 and the hydrographs at various levels of aggregation for event 2 and CV=0.8 are shown in Figure 3. The most complex hydrograph for the case of CV=0.0 is also plotted. In reviewing Table 2, note that no model parameters were adjusted to attempt to fit observed runoff.

DISCUSSION AND CONCLUSIONS: For the relatively large storm (event 1), Table 2 illustrates that very little model simulation accuracy is lost through the full range of aggregation from 30 to 1 element. This storm is large enough to overwhelm the variability of infiltration and geometric parameters represented in the 30 element system. The storm controls the runoff dynamics to a much greater degree than the basin, thus allowing extensive model aggregation. Although this event was considered large for this study, as Table 1 shows, it is still quite small from an annual frequency viewpoint (~2.8 year return period). For flood design work, this implies that extensive geometric model simplification can be made without sacrificing model accuracy. If a great deal of geometric model simplification can be accomplished for flood events it may also imply that extensive simplification in model type (nonlinear to linear) can also be made. The success of unit hydrographs methods for flood design attests to this observation.

For the small and medium sized storms (events 2 and 3) the nonlinearities attributed to thresholds of infiltration are much more evident. For these events the basin, not the rainfall, has greater

Event	CV	Num. Ele.	Q peak (mm/hr)	% Diff.	Tot.Vol. (mm)	% Diff.	Observed Qp	Observed Vol.	CPU Time (min:sec)
1	0.0	30	90.4		10.13		106.9	17.2	1:22.4
		25	91.2	-0.88	10.11	0.20			1:18.4
		9	92.2	-1.99	10.07	0.59			0:31.3
		1	92.7	-2.54	9.93	1.97			0:12.2
1	0.8	30	90.4		11.01				8:24.8
		25	90.7	-0.33	11.00	0.09			7:08.2
		9	91.7	-1.44	10.97	0.36			2:25.6
		1	91.9	-1.66	10.90	1.00			0:58.6
2	0.0	30	12.6		1.03		16.1	2.34	1:20.9
		25	12.5	0.79	1.02	0.97			1:15.1
		9	11.6	7.94	0.99	3.88			0:27.9
		1	10.3	18.30	0.96	6.80			0:12.3
2	0.8	30	16.5		1.86				9:13.9
		25	15.8	4.24	1.73	6.99			7:45.2
		9	15.6	5.45	1.70	8.60			2:31.2
		1	15.3	7.27	1.63	12.4			0:52.5
3	0.0	30	15.3		3.58		20.8	9.47	2:21.6
		25	15.3	0.0	3.42	4.47			2:12.8
		9	14.9	2.61	3.38	5.59			0:48.2
		1	14.2	7.19	3.22	10.1			0:17.2
3	0.8	30	18.0		5.24				13:56.2
		25	17.9	0.55	5.12	2.29			11:52.4
		9	17.8	1.11	5.07	3.24			3:51.7
		1	17.7	1.67	4.94	5.73			1:28.2

Table 2 - Summary of Aggregation Results

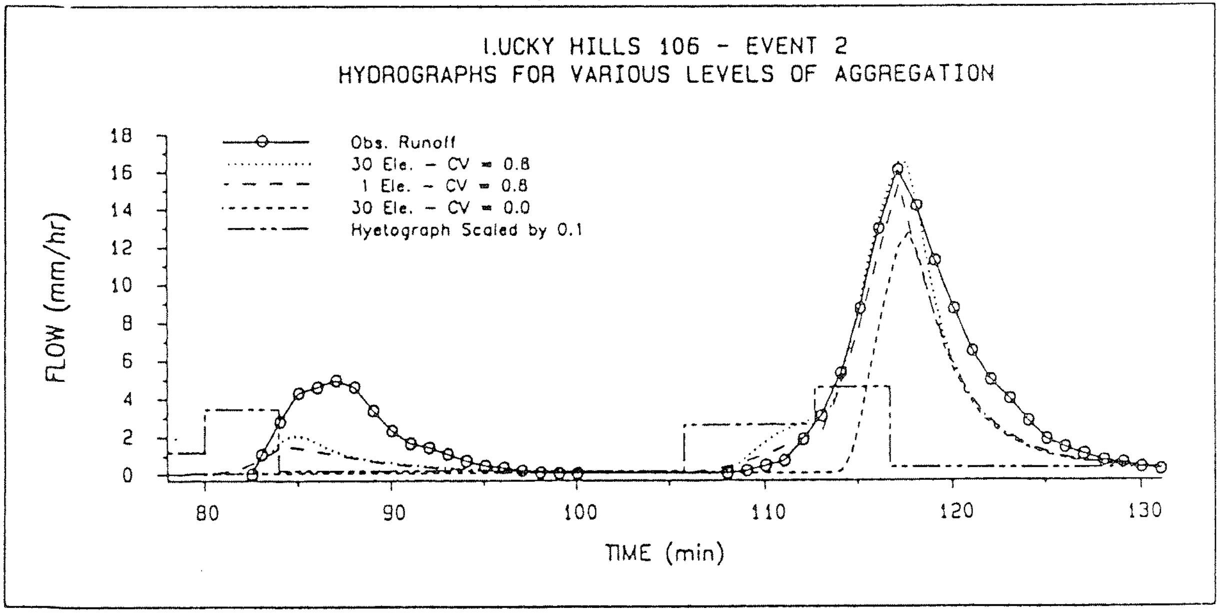


Figure 3 - Event 2 Hydrographs

control over runoff response. In these cases model simplification can not be accomplished to the same degree as for the large storm at a specified level of accuracy (say 5% total volume error). Thus water yield studies would require greater model complexity.

For events 1 and 3, incorporation of within element spatial variability of Ks (CV=0.8) improves the aggregation results over the CV=0.0 (uniform) case. Event 2 does not show this trend but closer examination of the hydrographs in Figure 3 shows that the runoff from the CV=0.8 case is much more like the observed runoff. In the CV=0.0 case no runoff occurs from the first peak at any level of aggregation and no error in total volume is introduced in this region. This accounts for the different trend in the aggregation results of event 2 as compared to events 1 and 3 in Table 2 for the CV=0.0 and CV=0.8 cases. The incorporation of small scale spatial variability of Ks compensates for the variability lost by the averaging that occurs in the aggregation process.

Although the basin studied was very small it provided a starting point to assess model complexity requirements. Efforts are under way to assess the impact of geometric model simplification in a series of watersheds of increasing area. At increasing spatial scales the effects of channel losses and spatial rainfall variability will have a greater impact on runoff response and aggregation. These results will be forthcoming in a journal presentation. It should be noted that although this study indicated that a great deal of model simplification may be realized in certain situations for hydrologic response it is unlikely that similar simplification could be made when modeling sediment or chemical transport.

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