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Dimensionless S-Graphs for Urban Watersheds

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S-Graph Method

In developing generalized unit hydrographs for regional design, the analysis often takes one of two paths. First, measured rainfall and runoff data are analyzed to develop *T*-hour unit hydrographs from which a generalized instantaneous unit hydrograph (IUH) can be computed using the S-graph approach. Second, where measured rainfall and runoff data are not available, time-area analysis can be made for watersheds. The derivative of a time-area curve is a synthetic instantaneous unit hydrograph, which could be compared with the IUH developed from rainfall/runoff data analysis. Unit hydrographs for any duration *T* can also be computed from the S-graph computed with the IUH obtained from the time-area analysis.

The S-graph method is widely used in developing unit hydrographs for any duration. An S-graph is the hydrograph that results from an infinite series of runoff increments of 1 area-in. for a duration of *T* hrs. For a given S-graph, the unit hydrograph for any other duration can be computed, including the IUH.

Analysis of Urban Data

The data base used for this study included seven watersheds in Los Angeles, with areas ranging from 7.70 sq mi (19.9 sq km) to 37.30 sq mi (96.6 sq km). Characteristics for each of the watersheds are given in Table 1. Topographic and land cover maps were also available for each of the seven watersheds.

The analysis involved computing dimensionless S-graphs using both the time-area approach and the analysis of measured rainfall hyetographs and runoff hydrographs for storms on each watershed. The two approaches can then be compared and the accuracy assessed.

Regionalized Urban S-Graph.—Measured rainfall hyetographs and runoff hydrographs were analyzed by the Corps of Engineers using HEC-1. The average S-graph is then developed by taking the mean of the ordinates of the several calibrated S-graphs of storms of significance from the flood control studies. For each of the seven watersheds, the most severe 3 to 6 storms which produced floods of record during the last seven years were considered. In this way, the average watershed S-graphs

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TABLE 1.—Watershed Characteristics

Gage name (1)	Length (ft) (2)	Length to centroid (ft) (3)	Drop in elevation (ft) (4)	Area pervious (%) (5)	Area (acres) (6)	Time lag (hrs) (7)
Arcadia	31,000	16,000	920	57	4,925	0.41
Alhambra	45,500	22,000	710	57	8,750	0.61
Eaton	43,000	18,000	740	60	7,050	0.54
Rubio	50,000	27,000	1,190	60	7,810	0.63
Compton 1	50,000	20,000	135	47	9,650	0.85
Compton 2	67,000	35,000	175	47	15,780	1.18
Domingue 7	60,000	26,000	90	40	23,875	1.50

Note: 1 ft = 0.3048 m.

represent the current level of urban development in the watersheds, with the percentages of imperviousness on the seven watersheds ranging from 40 to 60%. From the results, S-graphs were derived for each of seven watersheds. For example, Fig. 1 shows the S-graph obtained from three storm events on the Alhambra Wash watershed and the resulting average S-graph. The seven watershed S-graphs were then used to develop a regionalized S-graph for urban watersheds. This regionalized S-graph obtained from the analysis of measured rainfall/runoff data can be used for comparison with the synthetic S-graph obtained from time-area analyses.

Dimensionless Time-Area Curves.—Time-area diagrams were developed for each watershed. In all cases initial subarea travel time values were based on the Kirpich formula, and subsequent travel time routing estimates were based on normal depth flow velocities. The initial sub-

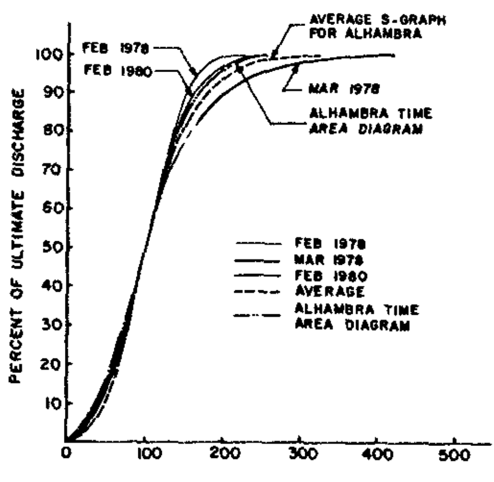

FIG. 1.—Comparison of Time-Area Diagram and Storm Event S-Graphs for Alhambra Wash

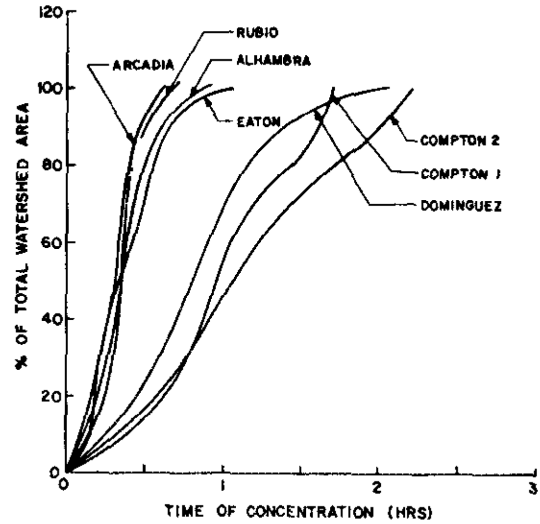

FIG. 2.—Time-Area Diagrams for Seven Urban Watersheds

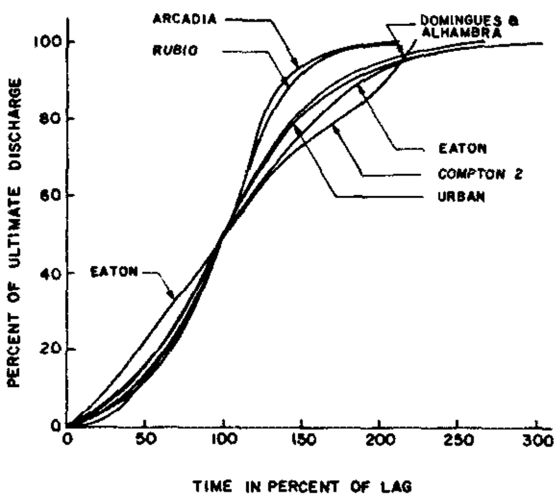

FIG. 3.—Comparison of Dimensionless S-Graph and Time-Area Diagrams

area was defined to be less than 10 acres (4 ha) with a travel length of less than 1,000 ft (305 m). Travel times in pipelines were assumed based on a flow velocity equivalent to open channel flow, where the pipeline size is estimated assuming an 82% pipe capacity flowrate. The separation of flows in streets and pipes are neglected in these studies, assuming that the flow characteristics are dominated by an adequately-sized storm drain system. Open channel flow velocities are estimated based on normal depth flow in a full channel.

The resulting time-area diagrams are shown in Fig. 2. From the figure, it is evident that the resulting time-area diagrams show strong similarities to the shape of the regionalized urban S-graph. The time-area diagrams were normalized by setting the point of 50% of the ultimate discharge of the time-area diagram to occur at a time equal to the watershed lag, where the ultimate discharge is the total storm event discharge. Watershed lag is defined as the time from the beginning of effective rainfall to the time that the summation hydrograph reaches 50% of the ultimate discharge. The normalized time-area diagrams can be compared to the urban S-graph (see Fig. 3). From Fig. 3 the urban S-graph that was developed from the storm event data as an average of the mean S-graph for each watershed indicates a good average plot of the watershed time-area diagrams.

Accuracy Assessment.—There are two components of accuracy that need to be assessed: (1) The variation of the storm event S-curves about the average time-area diagram for a watershed; and (2) the variation of the average watershed time-area diagram about the regionalized urban S-graph. Both components of error contribute to the error in using a regionalized unit hydrograph for hydrologic design.

The results for Alhambra Wash shown in Fig. 1 are typical of the seven watersheds. Fig. 1 can be used to assess the error in the variation of the storm event S-curves about the mean watershed time-area diagram. On the rising limb the maximum error, which is defined as the maximum absolute difference between the two curves expressed as a percentage of the discharge, for any one storm was 2.5% and the average maximum error for the three storms was about 1%. On the recession limb, which should be far less critical to the accuracy of most designs, the maximum error for any one storm event was 7%, with an average maximum error for the three storm events of 4%.

Fig. 3 can be used to assess the error in using the regionalized urban S-graph in place of the S-graph for the particular watershed. On the rising limb only the S-graph of Eaton Wash showed very noticeable variation (8% from the regionalized S-graph, with the next largest maximum error being about 4% and the average maximum error being about 2.5%). The maximum errors were much larger on the recession limb, with the average maximum error for the seven watersheds being about 7.5%. The largest maximum error was 15% for Arcadia Wash.

Conclusions

While peak discharge formulas were a primary hydrologic design tool in the past, unit hydrograph design storm methods are being used more frequently. The accuracy of designs based on such methods depends on the representativeness of the underlying unit hydrograph. When measured hyetographs and hydrographs are not available, the results of this study suggest that accurate estimates of the shape of unit hydrographs for specific watersheds can be obtained from time-area analyses. For the watersheds included in the analyses, Fig. 3 shows that there is little variation in the normalized S-graphs for the individual watersheds about the regionalized urban S-graph, which was derived from the measured hyetograph and hydrograph data. The normalized S-graph for Eaton Wash is the only watershed that shows some variation in the rising limb. The dimensionalized time-area curves for Acadia, Rubio, and Compton Creek 2 show some deviation from the regionalized S-graph but only in the tail of the S-graph. However in each case, the accuracy of the dimensionless S-graph is well within the bounds that should be expected, and the variation is probably no more than the variation in the S-graphs from the individual storm events about the watershed average, as shown for Alhambra Wash in Fig. 1.

In summary, it appears that dimensionless S-graphs obtained from time-area analyses are very accurate representations of S-graphs obtained from measured data and can be used to improve the accuracy of designs based on the unit hydrograph design storm approach.