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well be a problem and it is for this reason that for some installations we have provided for ease of removal of relatively short and light individual screen sections.

With respect to the sensitivity of velocity distribution to design parameters we paid particular attention to the spacing and percentage of area of the inner sleeve perforations. In general, the greater the open space the poorer the velocity distribution. It is necessary to create a head loss through the inner sleeve in order to distribute the flow over the entire sleeve area. Open area was varied to obtain the desired distribution with minimum head loss. There are many possible variations of spacing of the inner perforations and we are presently preparing for model tests to study this for a new project with intake criteria somewhat different from the original project discussed in our paper.

Quazi suggested the adjustment of the distance between the intake and the protective dolphins to reduce scouring and sedimentation problems. It is interesting to note in this connection that the dolphins, which were tested singly and in multiples at several locations, were not very effective in keeping debris from floating over or impinging on the intake. If they were enlarged to be more effective, the undesirable effect on the river bottom was greater. If they were moved upstream to reduce this effect on the intake, they were ineffective as barriers. We carried the tests only far enough to solve our particular problem.

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STOCHASTICS CONSIDERATIONS IN THUNDERSTORM MODELING[a]

Discussion by Herbert B. Osborn[2] and Kenneth G. Renard,[3] Members, ASCE

The author has attacked an important area of runoff prediction—thunderstorm rainfall. Thunderstorms produce the maximum flood peaks on small watersheds and significant runoff on larger areas throughout the country. In the Southwest, thunderstorms produce almost all arid-land runoff. In discussing the physics of thunderstorms, Corotis correctly stated that thunderstorms occur from convective heating and along unstable frontal systems, as well as along squall lines. He stated the user must specify whether he wants to simulate an air-mass or bank-type thunderstorm, without stating what the difference will be in his STORM program.

Storm Occurrance.—In western Texas and eastern New Mexico, major thunderstorm events are usually associated with frontal activity, whereas, in western New Mexico and southern Arizona, most major thunderstorms are air mass

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[a] July, 1976, by Ross B. Corotis (Proc. Paper 12231).

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(42). Both maximum depths and area extent are significantly greater (or occurrence of exceptional events much more common) in eastern New Mexico than in western New Mexico and southern Arizona (43, 38). Furthermore, the flow of moist air into the Southwest from the Gulf of Mexico and California is vital to the occurrence of thunderstorm rainfall and, therefore, there is daily persistence in the thunderstorm activity, or lack of activity, when the flow of moist air is cut off (26). There is also a very pronounced diurnal effect for air-mass thunderstorms (most occur in the afternoon or evening) (41). Neither phenomenons were provided for in the author's model.

Storm Initialization.—This section gives a good description of the life of a thunderstorm. The necessary simplifications in the model for the most part are reasonable, except for air-mass thunderstorm rainfall. Several investigators have found good correlation between maximum 30-min thunderstorm rainfall and runoff for small (100 sq miles and less) watersheds (44,42), and several investigators reported good correlation between maximum 15-min rainfall and runoff for very small (less than 1 sq mile) watersheds (39,35). The author stated that shorter durations are necessary for small watershed runoff design or air-mass thunderstorm rainfall, or both. Possibly, the author could assume shorter duration for individual cells, which the first writer found worked well in developing a similar stochastic model for air-mass thunderstorm rainfall (41).

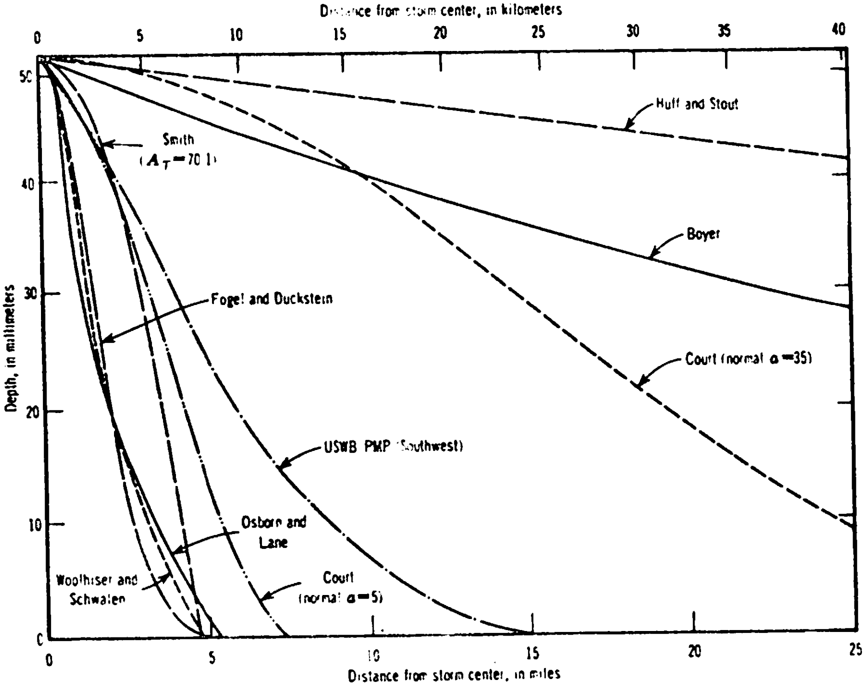

FIG. 9.—Depth-Area Relationships for Various Models, Each Assumed Symmetric around Center Depths

Many authors have presented analytic expressions for the depth-area relationship of thunderstorms (45). These curves vary appreciably because of differing atmospheric conditions and because of differing mathematical expressions (Fig. 9). Those for air-mass thunderstorms (prevalent in the Southwest) are generally much-more limited in areal extent than those in the Midwest (Fig. 9). The author's depth-area-curves (Figs. 7 and 8) would plot similar to the three flatter Midwestern curves. Although the six air-mass thunderstorm curves seem somewhat similar when plotted for a 2-in. (51-mm) storm, there are obvious differences in rainf volumes that increase with depth. For example, the first writer and Lane showed that the relationships between center depth and area is non-linear, w more rapid decay of the depth-area curves with greater depths.

Storm Development.—The senior writer found for Southwestern thunderstorm that despite wind direction, the location of the "second" storm cell in air-ma thunderstorms usually occurred randomly with respect to direction from th "first" cell, and that subsequent cells tended to develop in the same direction as the second cell. Prevailing wind direction was important in the dissipating nonrunoff-producing portion of the thunderstorm (41). Ludlam (37) pointed out that "When a storm has become intense and persistent, it is difficult to know how to measure the wind and other properties in its environment." Also, a 6-hr storm may not be realistic for air-mass thunderstorms in the Southwest. Runoff-producing rainfall occurrences, simulated for air-mass thunderstorms, correlated to real data when storms were assumed to dissipate completely within 2 hr. Then significant rainfall later the same day was predicted as a separate event (41).

Examples of Applications.—The author's choice of a 144-sq mile grid for simulation for storm area is acceptable. However, rather than using "storm centers" for the Atterbury data, he might have used "cell centers." There is no certainty that any of the 79 centers were the real storm maximum, particularly on a long narrow drainage, like Atterbury.

Storm Magnitude.—Again, there are real differences in storm depths, depending upon the type of thunderstorm. Otherwise, this section seems good.

Results.—Translation of Tucson data to Phoenix is acceptable, since air-mass thunderstorms are the principal source of runoff-producing rainfall at both locations. However, the writers question why the author used Phoenix data, since there are daily rainfall records available from 1957-1971 for the Tucson NWS recording raingage at the Tucson International Airport. Also, daily rainfall occurrence is based on one point, which underestimates the actual days o measurable rain within a 144-sq mile area. Some rains will be recorded o such an area in the Southwest without being recorded on a central gage.

Large-Scale Thunderstorms.—The example of a thunderstorm covering a ver large area reaffirms the writer's opinion that the author's model is best adapte to Midwestern large-scale thunderstorms and not to the much-smaller Southwestern air-mass thunderstorms. Also, the author does not explain how his model fits line thunderstorms. In the Southwest, fast-moving line thunderstorms do not normally produce exceptional runoff from small watersheds. However, when the storms stop "moving" or "cast off" a cell that remains relatively stationary, then runoff can be exceptional. How does the author's model handle such situations?

Conclusions.—The model presented by the author seems more appropriate for large-scale major thunderstorm occurrences in the Midwest. His model does not satisfy several basic attributes of air-mass thunderstorm rainfall in the

Southwest. The areal extent of air-mass thunderstorm rainfall is less than that of frontal-convective events; the relationship between depth and areal extent is nonlinear; storms are shorter in duration, usually lasting less than 30 min and almost always less than 1 hr; there is daily persistence in rainfall and pronounced diurnal effects of rainfall occurrence.

The writers feel that a "universal" thunderstorm rainfall model may be impractical. For example, in many parts of the West, there are strong orographic influences on thunderstorm rainfall. Several regional models, based primarily on climatic and topographic features, may be the solution.

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