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#99

HBO-1

SCHEMATIC REPRESENTATION OF THUNDERSTORM RAINFALL[1/]

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INTRODUCTION

Hydrologic research is being conducted by the Southwest Watershed Research Center of the Agricultural Research Service on the 58-square-mile Walnut Gulch watershed in southeastern Arizona (Fig. 1). Rainfall and runoff data have been collected on the watershed since 1953, with the precipitation network now totaling about 95 weighing-type recording rain gages (Fig. 2). Runoff results almost entirely from summer thunderstorm rainfall. Therefore, mathematical descriptions, or models, of thunderstorm rainfall are important to researchers and others involved in hydrologic investigations in the Southwest.

Arnold Court (1961) reviewed depth-area rainfall formulas proposed by half a dozen investigators. He compared all the methods that he reviewed by plotting a 2-inch maximum depth for each method (Fig. 3). Of particular interest to persons in the Southwest were his comments on a depth-area model suggested by Woolhiser and Schwalen (1959), and the Woolhiser-Schwalen paper itself. The Woolhiser-Schwalen model was the "slimmest" of the bell-shaped figures, which indicated the dominance of the purely convective thunderstorms in the region. Court concluded that "any realistic representation of the variation of rainfall amount with distance from the storm center should

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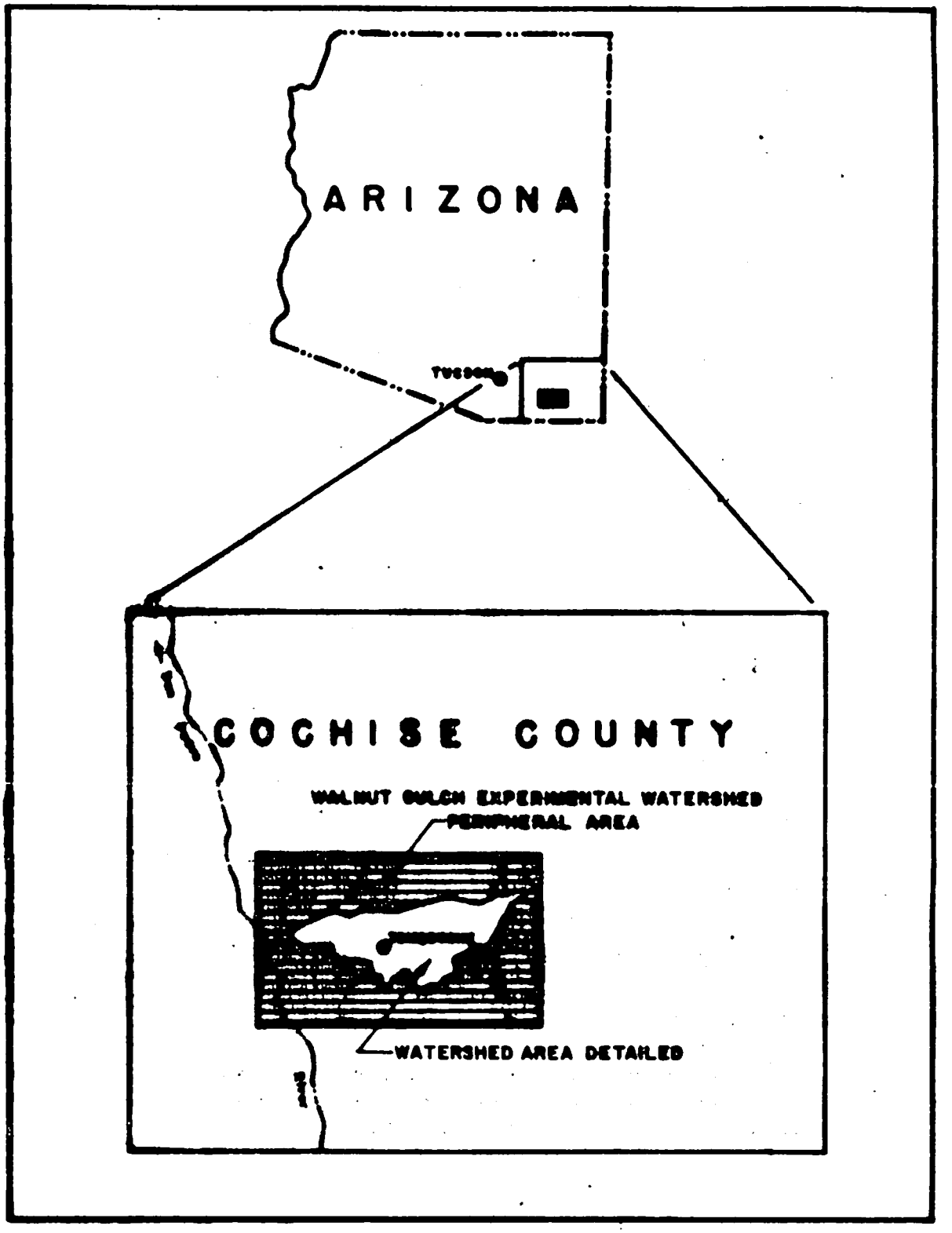
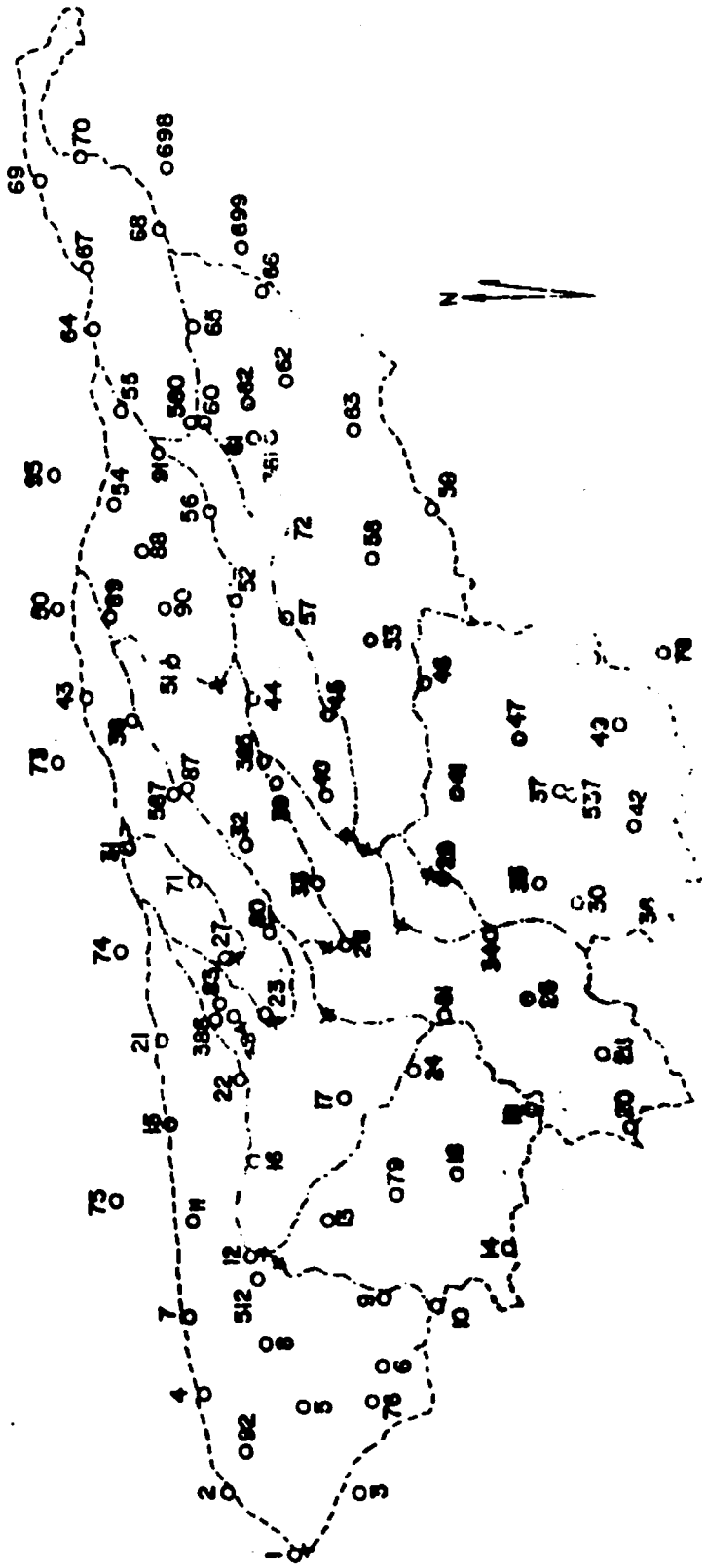

ARIZONA
TUCSON
COCHISE COUNTY
WALNUT GULCH EXPERIMENTAL WATERSHED
PERIPHERAL AREA
WATERSHED AREA DETAILED

FIGURE 1



WALNUT GULCH WATERSHED

NETWORK 1969

FIGURE 2

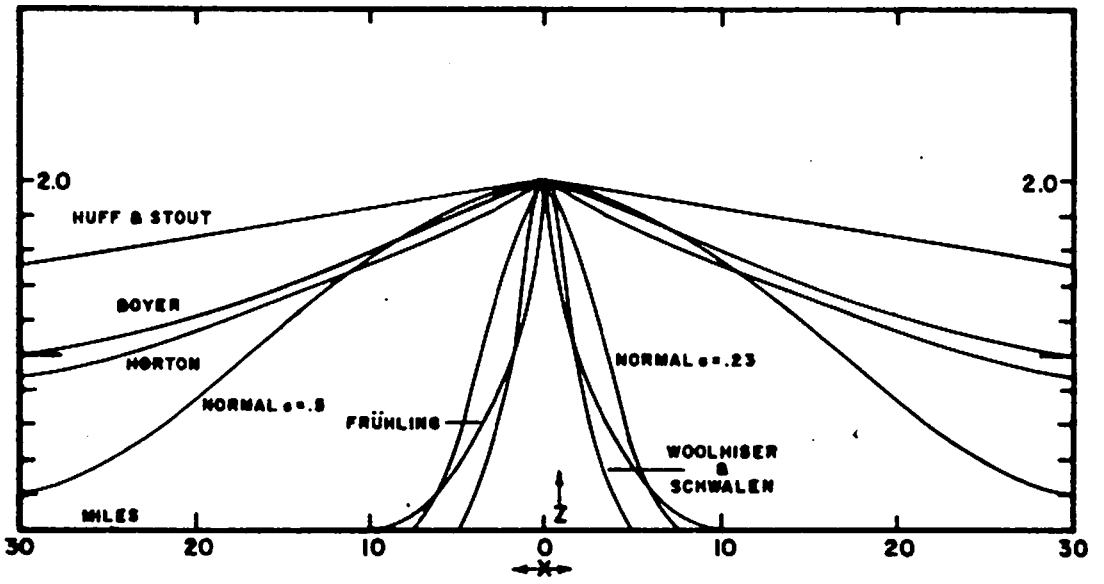


FIGURE 3. VARIATION OF ISOHYETAL VALUE Z (INCHES) WITH DISTANCE X (MILES) FROM STORM CENTER, ASSUMING CENTRAL PRECIPITATION TO BE M=2 INCHES, ACCORDING TO VARIOUS FORMULAS.

be smooth at the center." In other words, he felt that a dome-shaped figure was essential. Three of the models included in this review, including that by Woolhiser and Schwalen, and those based on a Gaussian distribution, met this condition.

Court also felt that "at the other extreme, an asymptotic approach to zero rainfall with increasing distance seems desirable." The Gaussian models met this condition, but the Woolhiser-Schwalen model did not.

Woolhiser and Schwalen based their model on data from the 18-square-mile Atterbury watershed near Tucson, Arizona. Although there are apparently significant climatological and topographical differences between the Walnut Gulch and Tucson areas, considerable similarity would be expected in the areal extents and magnitudes of thunderstorm rainfall at both locations. The 58-square-mile watershed should provide a better basis for either verifying or establishing a rainfall model because of the greater areal coverage of the rain gage network.

WALNUT GULCH RAINFALL

Storms on Walnut Gulch were analyzed for the period 1961 through 1968. Good isohyetal rainfall maps were available for this period. There were about 50 storms in which over 1" of rainfall was recorded at at least one storm center on the watershed.

From the 50 storms, about 45 storm centers were defined sufficiently to include in the analysis. None of the storms with centers of more than 1.2" could be completely defined to as low as the 0.6" isohyet. In other words, all storms with a maximum point rainfall of 1.2" or more were spread out over the watershed boundary and outside the rain gage network, and the isohyets could not be "closed." Rainfall below 0.6" was so poorly defined that no effort was made to include lower isohyets in the analysis.

In general, the storms on Walnut Gulch had one steep edge as represented by relatively closely spaced isohyets and one gently sloped edge as represented by relatively widely spaced isohyets. The

steep or tightly spaced isohyets are referred to in this paper as the "short axis" of the storm; the widely spaced isohyets are referred to as the "long axis." Although the long and short axis of the rainfall were not generally at right angles, the storms appeared to be more elliptical than any other simple shape.

In a significant number of storms, at least one edge of the storm was defined down to zero rainfall. Court's second premise was that an asymptotic approach to zero rainfall was necessary for a reasonable rainfall model. It appears that thunderstorm rainfall is definitely limited in areal extent and that the Woolhiser-Schwalen model, which does go to zero, is satisfactory, at least in this respect.

The distances from the storm center to each succeeding, and decreasing, isohyet were measured along the long and short axis. These values for the four largest storms during the period were plotted to give a schematic representation of thunderstorm rainfall (Fig. 4). By far the greatest rainfall both in maximum recorded depth and volume was recorded on the afternoon of September 10, 1967. Three and one-half inches of rain were recorded at the storm center. Maximum recorded point rainfalls for the next three largest storms were 2.65", 2.62", and 2.53". The September 10, 1967 storm was compared to averages of individual storms in the ranges from 2.21" to 2.40", 2.01" to 2.20", and 1.81" to 2.00" (Fig. 5), and to averages of individual storms in the ranges from 1.41" to 1.60", 1.21" to 1.40", and 1.01" to 1.20" (Fig. 6).

Several observations were made from these figures. In Figure 4 the September 10, 1967 storm does not cover significantly more area at the 0.6" isohyet than do the next three largest storms. The isohyets, particularly on the short axis, are extremely closely spaced for the largest storm. Above the 1.0" isohyets, the 1967 storm covered more area than any of the next three largest events because of the greater extent of the long axis of the storm. In Figures 5 and 6, the areal extent at each increasing depth was clearly greater for the 1967 storm. At the 0.6" isohyet, the larger storm was more extensive than the median-sized and smaller storms, again primarily because of the greater extent of the long axis.

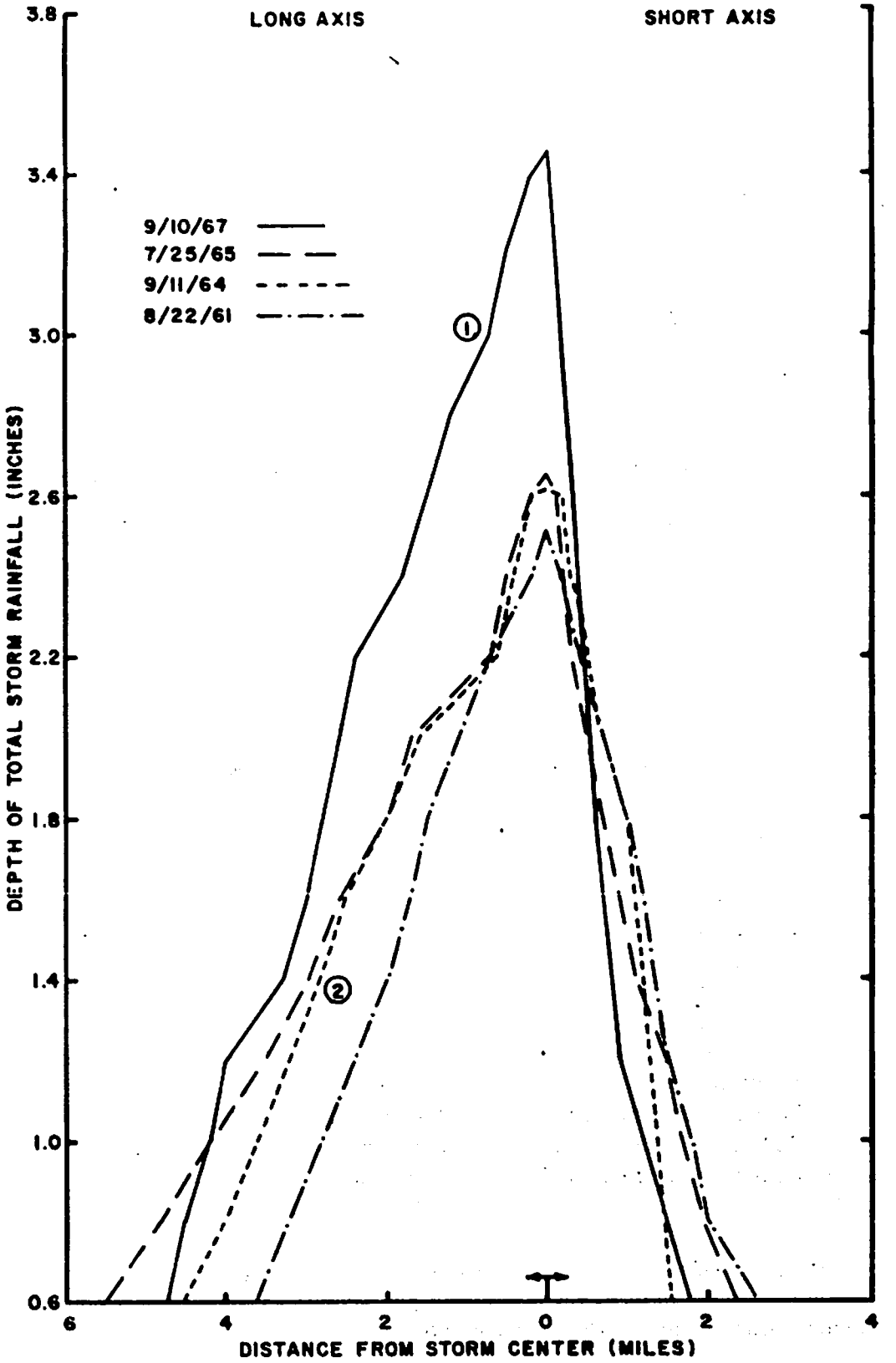


FIGURE 4. SCHEMATIC REPRESENTATION OF EXTREME STORMS BASED ON DISTANCE FROM STORM CENTER TO GIVEN ISOHYETS FOR 4 LARGEST EVENTS ON WALNUT GULCH, 1961—1968

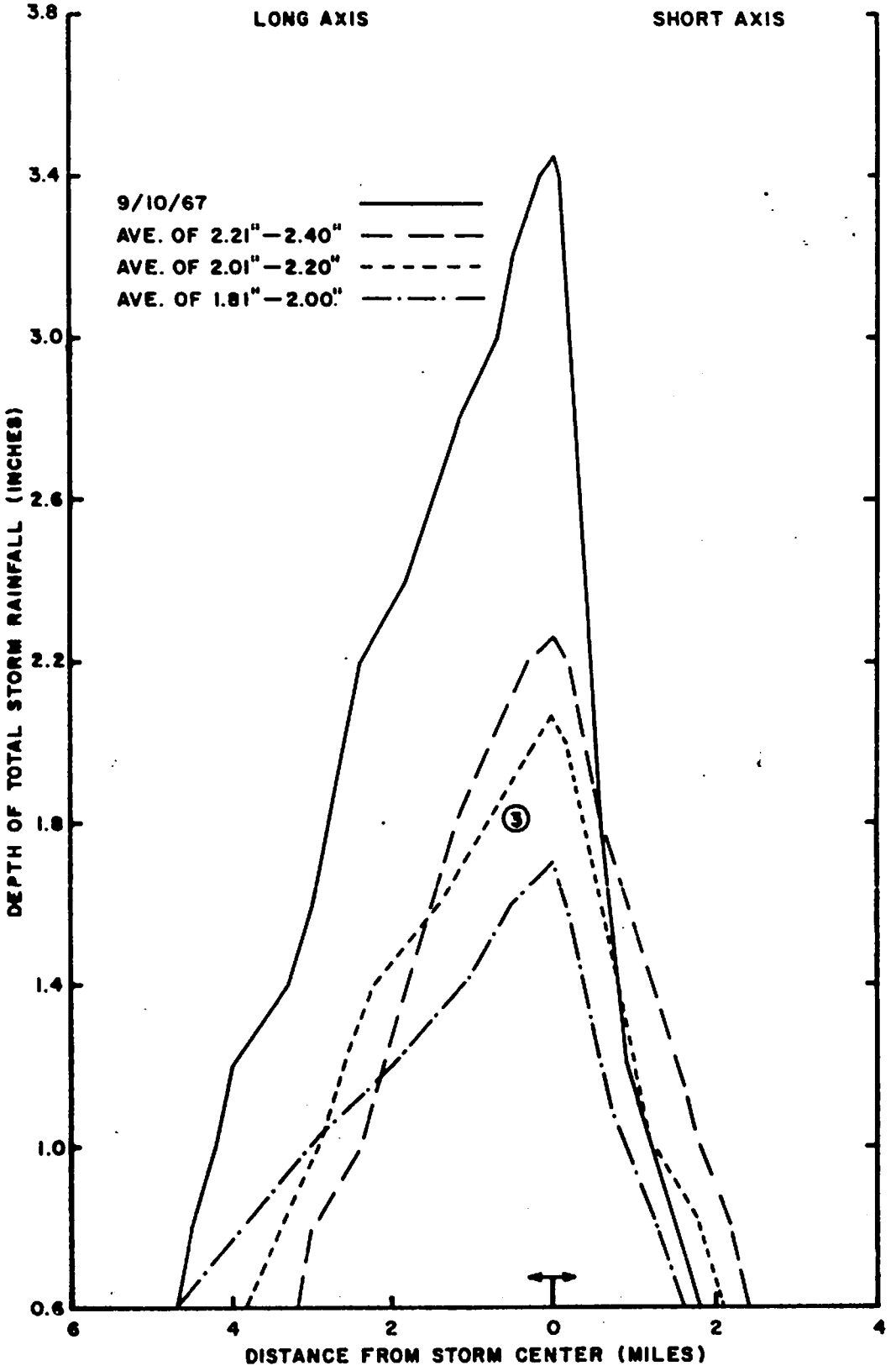


FIGURE 5. SCHEMATIC REPRESENTATION OF THE MAXIMUM STORM EVENT AND 3 AVERAGED EVENTS BASED ON DISTANCE FROM STORM CENTER TO GIVEN ISOHYETS FOR WALNUT GULCH, 1961-1968.

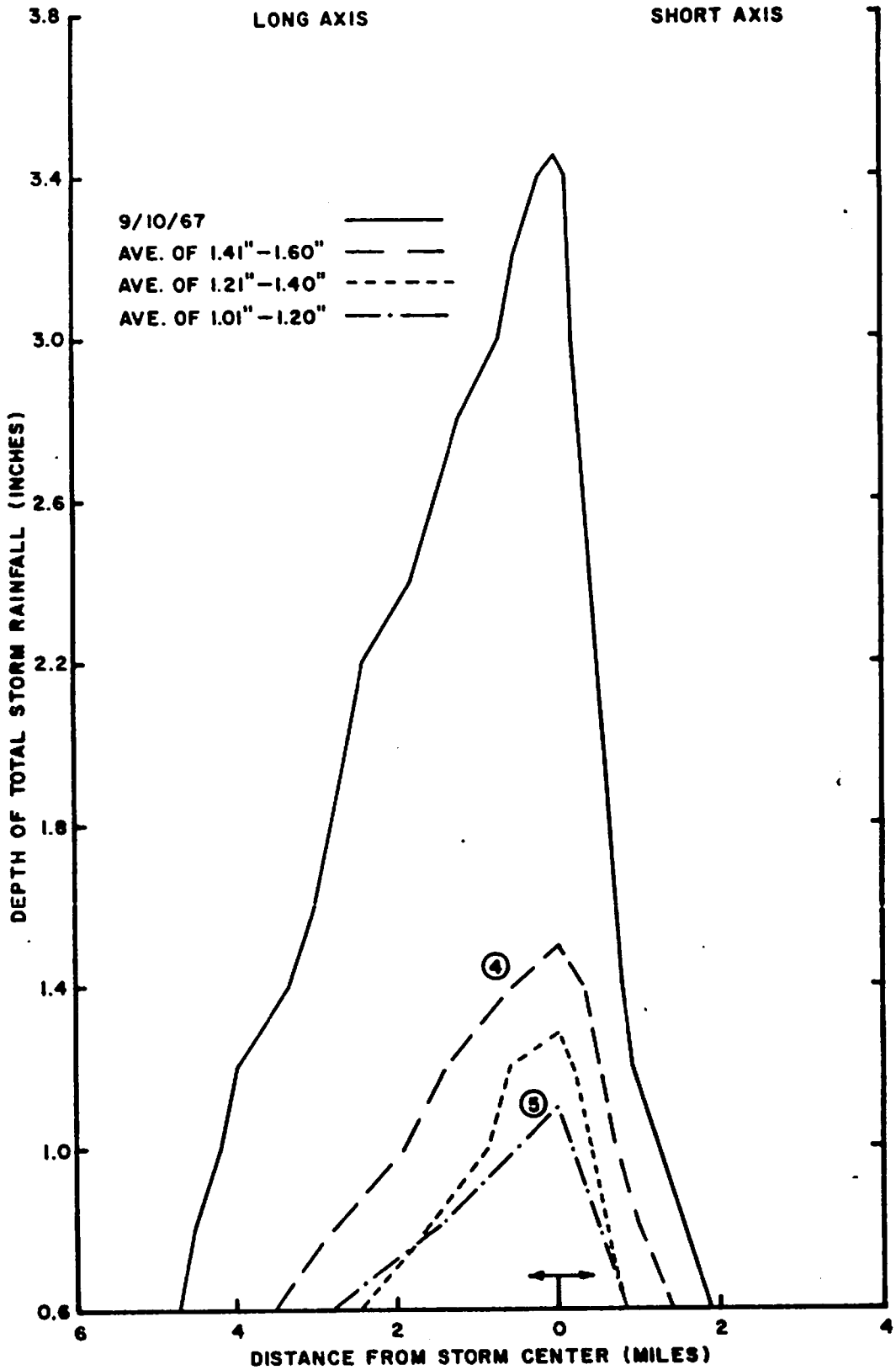


FIGURE 6. SCHEMATIC REPRESENTATION OF THE MAXIMUM STORM EVENT AND 3 AVERAGED EVENTS BASED ON DISTANCE FROM STORM CENTER TO GIVEN ISOHYETS FOR WALNUT GULCH, 1961-1968

Composite storms were developed from the schematic representations in Figures 4, 5, and 6. These composite storms were developed for maximum center rain depths of 3.5", 2.6", 2.0", 1.5", and 1.2" (Fig. 7). The largest composite storm was based on the 1967 storm; the second largest was based on the next three largest events; the three smaller composite storms were based on 13 or 14 storms each in their respective ranges of center depths. The final composite representations for all but the largest storm probably could be approximately by triangles. The schematic composites developed here have "lost" the bell-shaped dome that was evident in plotting true cross sections of thunderstorms as represented by isohyetal maps. The "dome" should probably be added for a rainfall model as indicated by Court and Woolhiser and Schwalen. For most purposes, the figures could be extended linearly to zero for a complete model.

The Woolhiser-Schwalen model and the Walnut Gulch schematic composite were compared in Figure 8, using a 2" storm for the basis of comparison. Both figures were in a sense bell-shaped, but the "dome" on the Walnut Gulch composite was "lost" in the averaging. The Woolhiser-Schwalen model implied a circular pattern of isohyets which appeared to be about the average between the long and short axis for the Walnut Gulch figure.

The volume of rainfall for the model and composite would be about the same if the composite were assumed to be an elliptical model. This indicated that both the Woolhiser-Schwalen model and the Walnut Gulch composite were in the right order of magnitude in representing thunderstorm rainfall.

Woolhiser and Schwalen based their model on a plot of "area enclosed by isohyet vs. depth at storm center minus depth of isohyet " (Fig. 9). A similar approach was attempted using Walnut Gulch storms. In Figure 10 the three largest events were compared using the distance along the long and short axis vs. the incremental depth, which was similar to the system used by Woolhiser and Schwalen except that distances replaced areal extent. In Figure 11 the composite storms were compared by using the axial distances vs. the incremental depth.

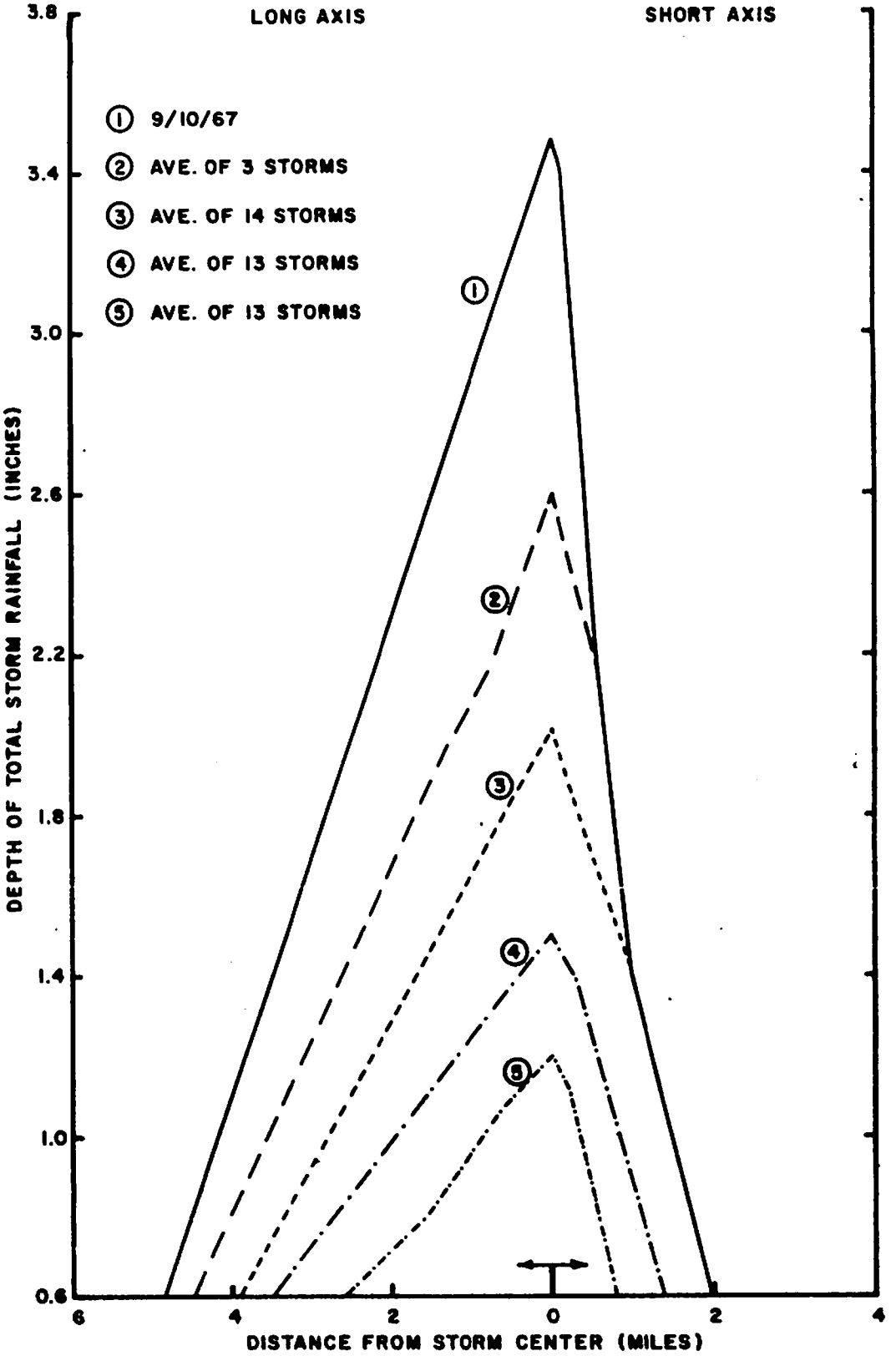


FIGURE 7. COMPOSITE STORMS BASED ON DISTANCE FROM STORM CENTER TO GIVEN ISOHYETS FOR WALNUT GULCH, 1961–1968.

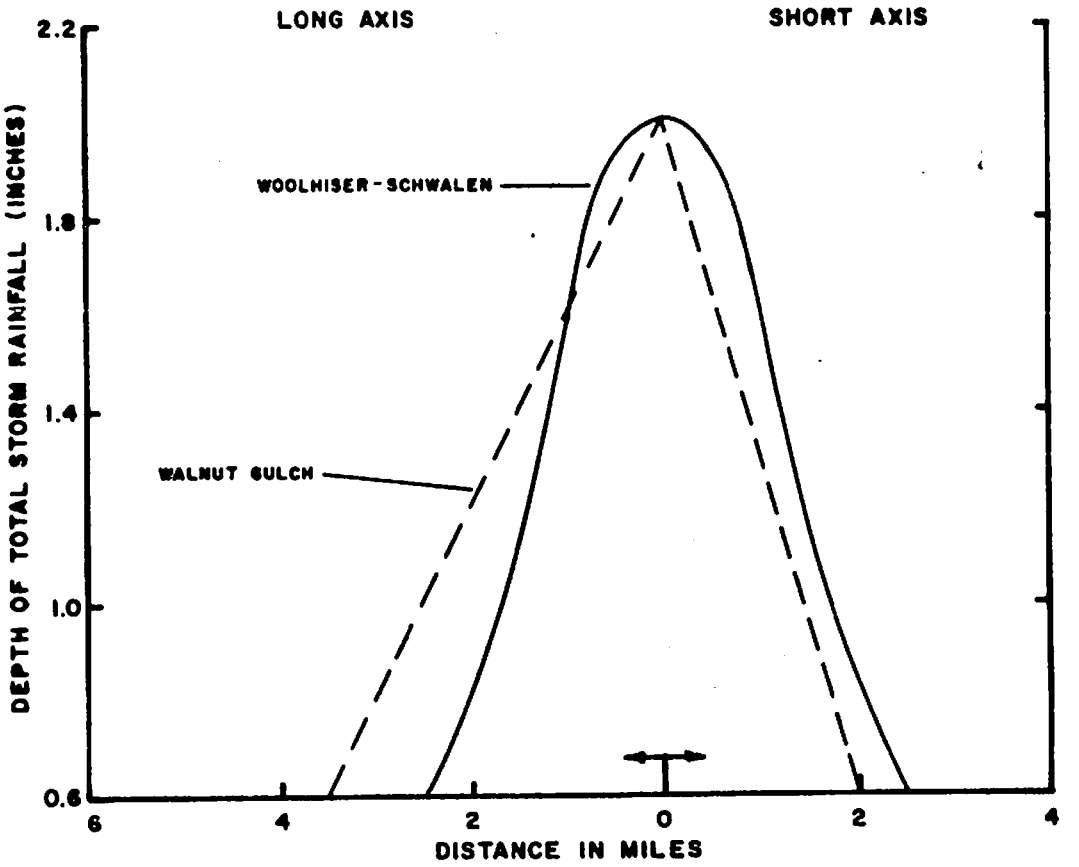


FIGURE 8. COMPARISON OF COMPOSITE SCHEMATIC WALNUT GULCH 2-INCH RAIN WITH WOOLHISER-SCHWALEN 2-INCH RAIN.

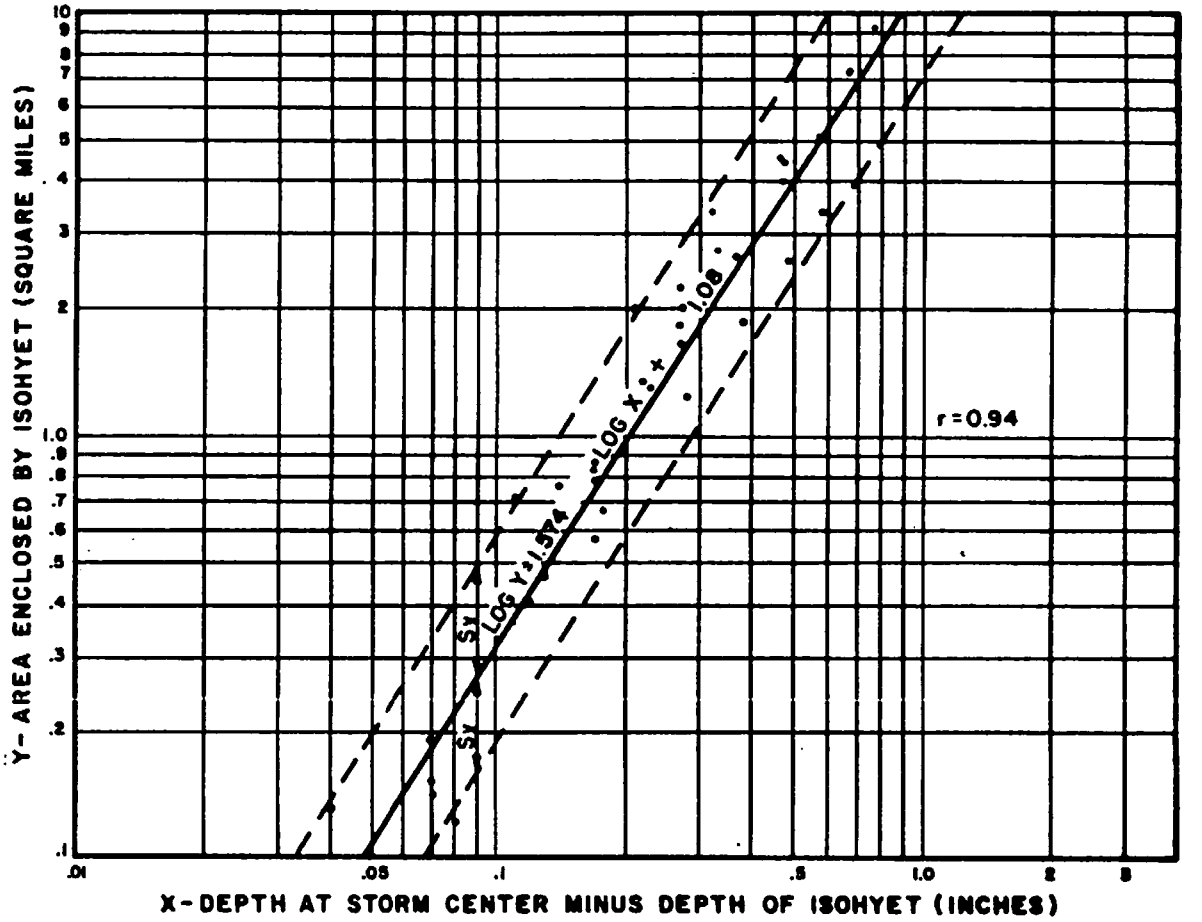


FIGURE 9. STORM CENTER AREA — DEPTH RELATIONS.

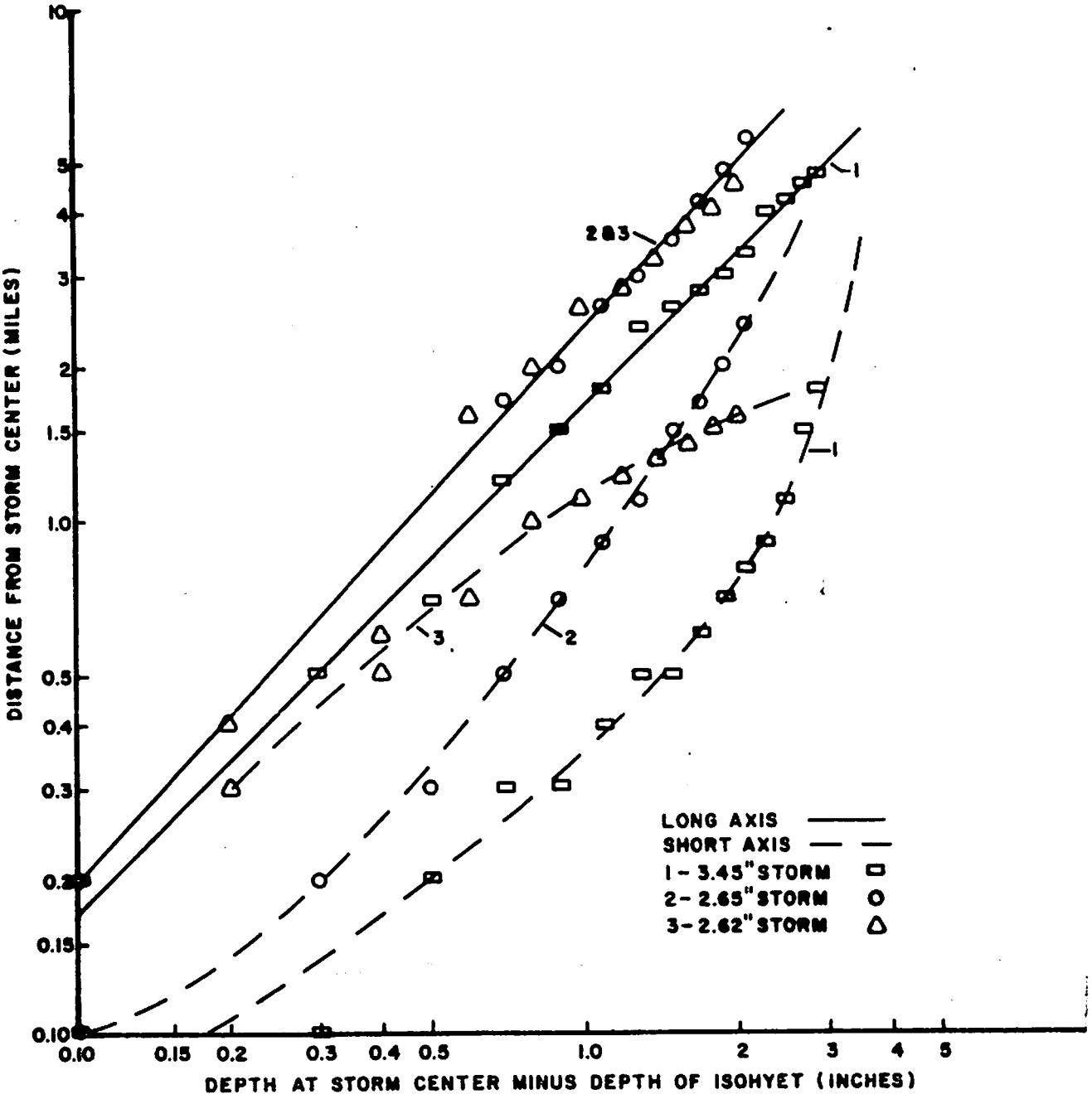


FIGURE 10. DISTANCE FROM STORM CENTER VERSUS INCREMENTAL DEPTH OF RAINFALL, FOR THE THREE LARGEST STORMS ON WALNUT GULCH, 1961-1968.

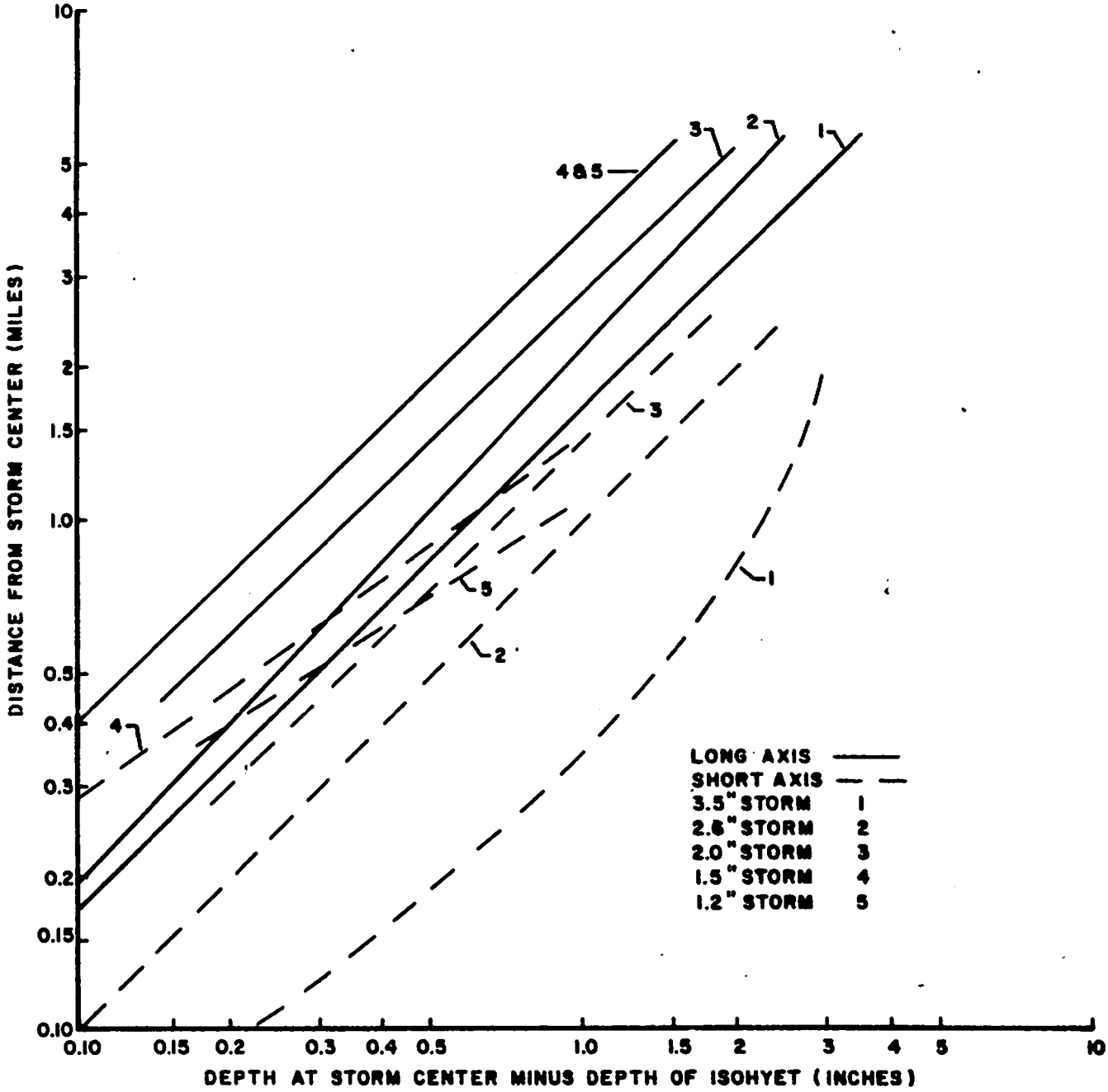


FIGURE 11. DISTANCE FROM STORM CENTER VERSUS INCREMENTAL DEPTH OF RAINFALL, FOR THE COMPOSITE STORMS ON WALNUT GULCH, 1961–1968.

It is apparent that the Walnut Gulch storms do not, for every depth, fit into the same pattern as the Woolhiser-Schwalen storms. Woolhiser and Schwalen came up with one formula, $\log y = 1.574 \log x + 1.08$. For the Walnut Gulch storms, there would be a series of parallel formulas for the long axis, depending on the maximum depth of the storm center. The plots for the short axis of the 3 largest storms were clearly curved. Curvilinear lines on log-log paper are difficult to explain. When the composite storms were plotted, the lines on the short axis, except for the September 10, 1967 storm, tended to plot as straight lines as well as for the long axis.

The equation for the long axis for line 1 on Figure 10 was $\log y = \log x + 0.22$, or $y = 1.65\ x$. Lines 2 and 3 could be represented by a similarly-sloped log-log equation. Possibly a family of log-log equations based on maximum storm depth could be developed, but further investigation is needed to determine the use and validity of such equations.

CONCLUSIONS

To this date the Woolhiser-Schwalen model and the Walnut Gulch schematic composites appear to be reasonable developments in thunderstorm rainfall analysis. Further analysis in this vein may answer some of the many questions concerning thunderstorm rainfall. They include the following: (1) In general, can thunderstorms be considered elliptical?, circular?; (2) If not, for specific studies, such as rainfall-runoff correlation, can thunderstorms be considered elliptical?, circular?; (3) If the thunderstorms cannot be considered elliptical or circular, can they be described in some other way?; and (4) Should thunderstorms be broken into shorter increments, say 10-minute periods, to develop rainfall models?

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Woolhiser, D. A., and H. C. Schwalen. Area-depth-frequency relations for thunderstorm rainfall in southern Arizona. Tech Paper 527, Agr. Engr. Dept., Arizona Agr. Expt. Sta., University of Arizona, 1959.

Court, Arnold. Area-depth rainfall formulas, Jour. Geophys. Res. Vol. 66, No. 6, 1961.