CONVENTIONAL URBANIZATION AND ITS EFFECT ON STORM RUNOFF

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CONTENTS

Abstract

This study explores the real hydrologic effect on runoff events of various magnitudes caused when rural basins covered with row crops are converted to residential, apartments, or commercial developments.

The Illinois Urban Drainage Area Simulators, ILLUDAS, is a storm runoff model published in 1974 to model flows from an urban basin resulting from rainfall imposed on the basin. In this report a description is given of modifications developed for ILLUDAS which allow it to be used for rural basins of the midwest.

For two rural basins near Treynor, Iowa, the modified ILLUDAS model was verified. For 14 storms the flood runoff volumes and flood peaks were simulated adequately. Results are given in tables and graphs. For four storms on a rural basin near Monticello, Illinois, the verification results are inadequate and are given.

For a 288-acre tributary basin to the Fox River in Illinois an observed flood frequency curve for 15 years is available. The basin is 70 percent row crops and 30 percent pasture. Using rainfall frequency to produce two-year to 100-year design storms, and the ILLUDAS model to produce flood peaks, the simulated peaks adequately compared with the observed peaks.

Rural basins in Illinois are usually planted in row crops, being corn or soybeans. As development takes place the important ILLUDAS parameters in percent of the basin are:

	Directly-Connected Paved Area	Supplemental Paved Area	Grass
Residential	16	7	77
Apartments	49	11	40
Commercial	64	11	25

These developments were hypothesized to take place on the 288-acre basin and the runoff and flood peaks were simulated. Results are

described and provide much insight and understanding of how this urbanization affects runoff.

Observed frequency curves for the urban Boneyard Creek and the rural Kaskaskia Ditch in central Illinois are presented. The change in shape of the frequency curves from rural to urban is similar to the hypothetical change shown on the Pox River Tributary. Alternatives are shown to exist to the usual increase in peak flows from urban areas. Natural detention areas can counteract this increase.

INTRODUCTION

Background

In a randomly selected group of people there would be general agreement that urbanization of a watershed increases runoff and flood peaks. This agreement stems from two related assumptions; first, that urbanization means paved streets and roof tops and second, that these surfaces produce greater amounts of runoff than the cornfields or grassed areas that they replaced. These are certainly valid assumptions, and in many cases the accepted idea that urbanization increases flood peaks has been reinforced by observations of increased runoff from new shopping centers or parking lots. To the individual who lived on a small stream before and after a large shopping center developed in the watershed, the effects of that development on runoff are indeed obvious.

Despite the validity of the assumptions mentioned above and the indisputable observed increases in runoff from parking lots, the generally-held views of the effects of urbanization on runoff need to be carefully examined. The word urbanization carries with it extensive implications relating to specific land use patterns and policies. To say that urbanization increases runoff is to imply a specific type of urban development. If it can be shown that some types of urbanization can occur without increases in runoff, then it is not valid to say that urbanization increases runoff. In this study the word <u>urbanization</u> will not be used again without the adjective <u>conventional</u> preceding it.

It was mentioned above that observed increases in runoff from parking lots and shopping centers has reinforced the commonly held beliefs. In fact the events that are being observed are the more frequent storms. Increased runoff from storms that occur several times a year or perhaps as infrequently as once in five years are observed. Because the general public does not tend to think in terms of return periods or probability of runoff, it is assumed that all flood peaks are similarly increased. Many home-owners who have experienced flood damage in an urban area have not lived in the basin long enough to have experienced a similar rainfall event when the basin was rural in nature. It is entirely possible that similar flood elevations could have occurred when the basin was rural. It is not unusual for developers to build and sell homes in natural flood plains. Such areas will ultimately suffer flood inundation whether there is upstream urbanization or not.

Although hydrologists tend to agree that the effects of conventional urbanization decrease as the probability of occurrence decreases, there is considerable disagreement as to the degree of effect on rare events. It would seem then that before the general public can be made to understand flooding and the implications of urbanization, it is up to hydrologists and engineers to clarify terminology and to isolate the real culprits in flooding and urban flood damage.

Scope

Two questions will be examined in this study, the effect of man's decisions and policies in land development on runoff and the effects of conventional urbanization on rare runoff events.

An existing model "ILLUDAS," the Illinois Urban Drainage Area Simulator, Terstriep and Stall (197*0, will be used to answer the above questions. Special modifications were made in the model to adapt it for rare events and agricultural land use. These modifications and verifications will be discussed.

It is hoped that the results of this study will produce better understanding of urbanization and its effect on storm runoff. An attempt has been made to present the results of this study in such a way that they may be used to further the understanding among laymen. Hopefully planners will also be able to use the results to make better land use and development decisions.

ILLUDAS MODIFICATIONS

Model Selection

In 1976 a large number of models are available and could be used for a study of this nature. Because it is a continuous simulation rather than an event simulation model, Hydrocomp Simulation Programming (HSP), Hydrocomp (1969), might be a good choice for this project. The amount of data required and the significant expense involved in obtaining HSP, however, rule it out for this analysis.

. The EPA Storm Management Model (SWMM), Metcalf and Eddy (1971), is capable of performing the operations necessary for this study. SWMM has many other capabilities that are not needed in this study, however, and make the model more difficult to use. Some studies, Hudson (1975) and Marsalek (1974), have shown that although SWMM requires considerably more data and computer time than ILLUDAS, it does not produce significantly better runoff prediction.

McPherson (1975) describes some 16 models including those mentioned above which could conceivably be used in this study. The choice then comes down to what the author is most familiar with that will fulfill the needs of this study. ILLUDAS, Terstriep and Stall (19740, was chosen for these reasons even though some modifications were necessary before it could perform the required tasks. The author's familiarity with the model is of considerable benefit since all of the limitations of the model are well known. This is often not the case when an unfamiliar model is adopted and used.

ILLUDAS, The Illinois Urban Drainage Area Simulation, uses an observed or specified temporal rainfall pattern uniformly distributed over the basin as the primary input. The basin is divided into sub-basins, one for each design point in the basin. Paved-area and grassed area hydrographs are produced from each sub-basin by applying the rainfall pattern to the appropriate contributing areas. These hydrographs are combined and routed downstream from one design point to the next until the outlet is reached. Pipe sizes are determined or existing pipes evaluated at each design point. Detention storage can be included as part of the analysis in any sub-basin. Although portions of the ILLUDAS procedure will be referred to from time to time in this report, no detailed description of the method will be given.

LAND USE

ILLUDAS has been tested extensively on urban basins. Since urban basins usually consist of impervious (paved) surfaces and pervious (earth) surfaces with grass cover, ILLUDAS contains only functions to handle these two types of surfaces. In order to examine the effects of urbanization on runoff, it was necessary to add the capability of dealing with additional land uses to ILLUDAS.

Initially an attempt was made to incorporate a curve number approach such as that used by the U. S. Soil Conservation Service, SCS (1969). This approach would allow any combination of land uses to be weighted and an appropriate curve number to be selected. The curve number is in effect a runoff ratio for an entire storm event, however, and infiltration curve parameters such as the initial and final rates of infiltration could not be developed from the curve numbers alone. It was desirable to develop an infiltration curve for each land use since this procedure was developed and used for grassed areas in ILLUDAS. It seemed advantageous to develop the additional land use capabilities of ILLUDAS as nearly parallel to the existing and proven methods used for grass as possible.

After an examination of the many basic land uses and variations within each land use, it was decided to limit the additional land uses to just one--row crop. Available infiltrometer data did not justify the use of crop conditions, crop types, or seasons. Forested watersheds were not considered because of the small portion of Illinois basins changing from forest cover to urban use. In Illinois, the predominant development pattern is from row crop or pasture to urban use.

Of overriding importance in this study was to develop and test an agricultural land use infiltration function that was parallel to and compatible with the bluegrass function used in ILLUDAS. To accomplish these ends the same source of data used to develop the blue grass infiltration functions was used to develop the row crop infiltration functions. These data developed by Holtan and Musgrave (1947) consist of actual infiltration rates observed on bluegrass turf and cornfields at Elmhurst, Illinois. These observations were made on hydrologic group B, C, and D soils. The Hydrologic Soil Group classification was used in the original development of ILLUDAS and is described by the U. S. Soil Conservation Service as follows:

A-Low runoff potential, high infiltration rates (consist of sand and gravel)

B-Moderate infiltration rates and moderately well drained

C-Slow infiltration rates (may have a layer that impedes downward movement of water)

D-High runoff potential, very slow infiltration rates, (consists of clays with a permanent high water table and a high swelling potential)

In figure 1 is plotted the observed infiltration curves at Elmhurst for a Hydrologic group B soil with bluegrass cover and with corn. For comparison purposes, the Hydrologic group B "bluegrass" curve used in the original version of ILLUDAS and the Hydrologic group B "row-crop" curve to be used in this study are plotted on the same figure. Comparisons of the C and D soil group curves are similar. The ILLUDAS bluegrass curve is somewhat below the observed bluegrass curve because of considerable variability in observed infiltration curves for different group B soils and a desire of the authors to be conservative in their estimates of bluegrass infiltration. Since no data were available for an A row-crop soil, a curve similar to and in conformance with the A bluegrass and the B. row-crop curves was adopted. Figure 2 shows the row crop infiltration curves adopted for use in the modified ILLUDAS program, and figure 3 shows the bluegrass curves presently used in ILLUDAS.

These curves are represented in the ILLUDAS program by the Hortan equation and given by Chow (1964) as:

$$f = f_c + (f_o - f_c)e^{-kt} \tag{1}$$

where

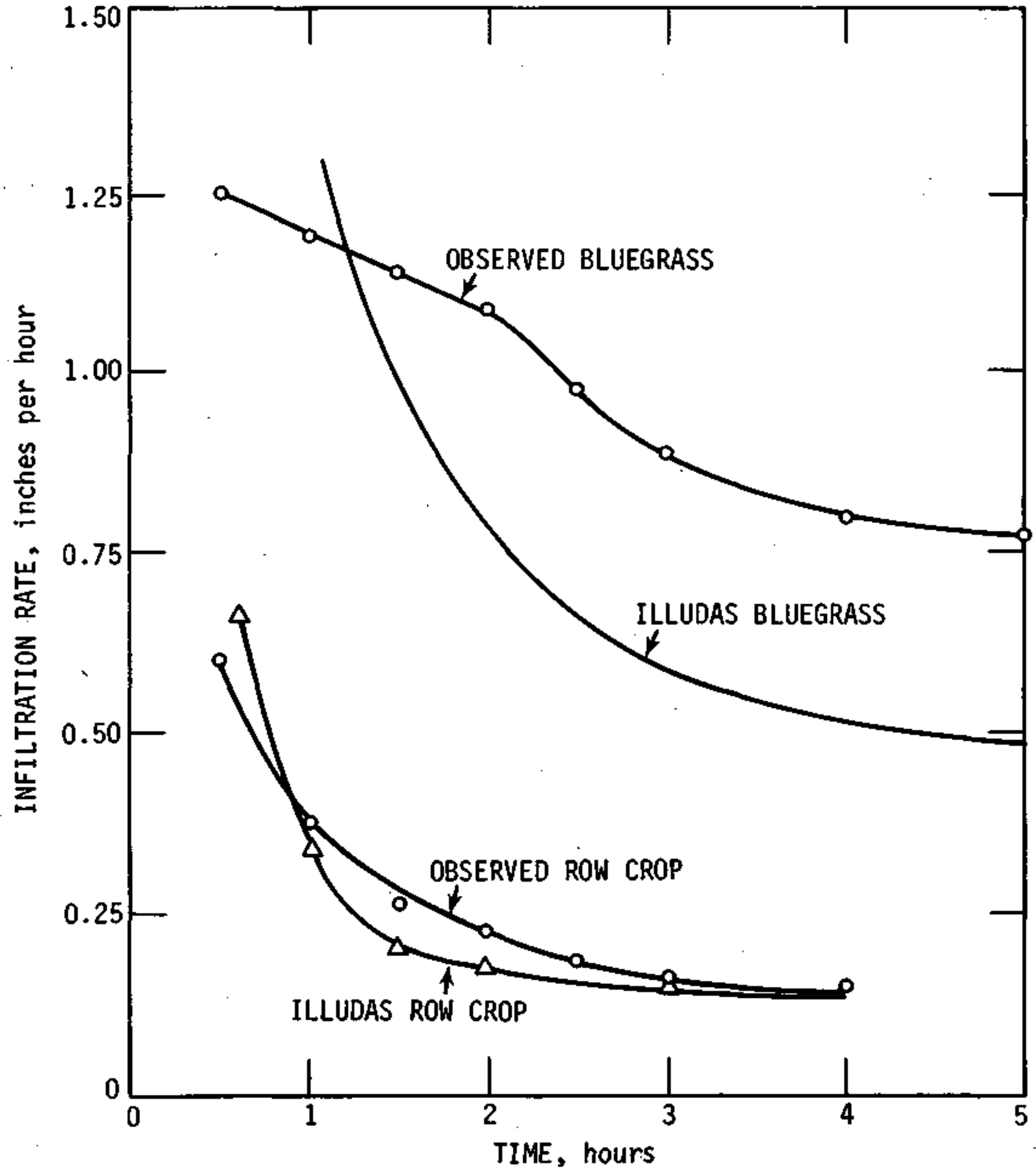


Figure 1. Observed and "ILLUDAS" Infiltration curves for a Hydrologic Group B Soil

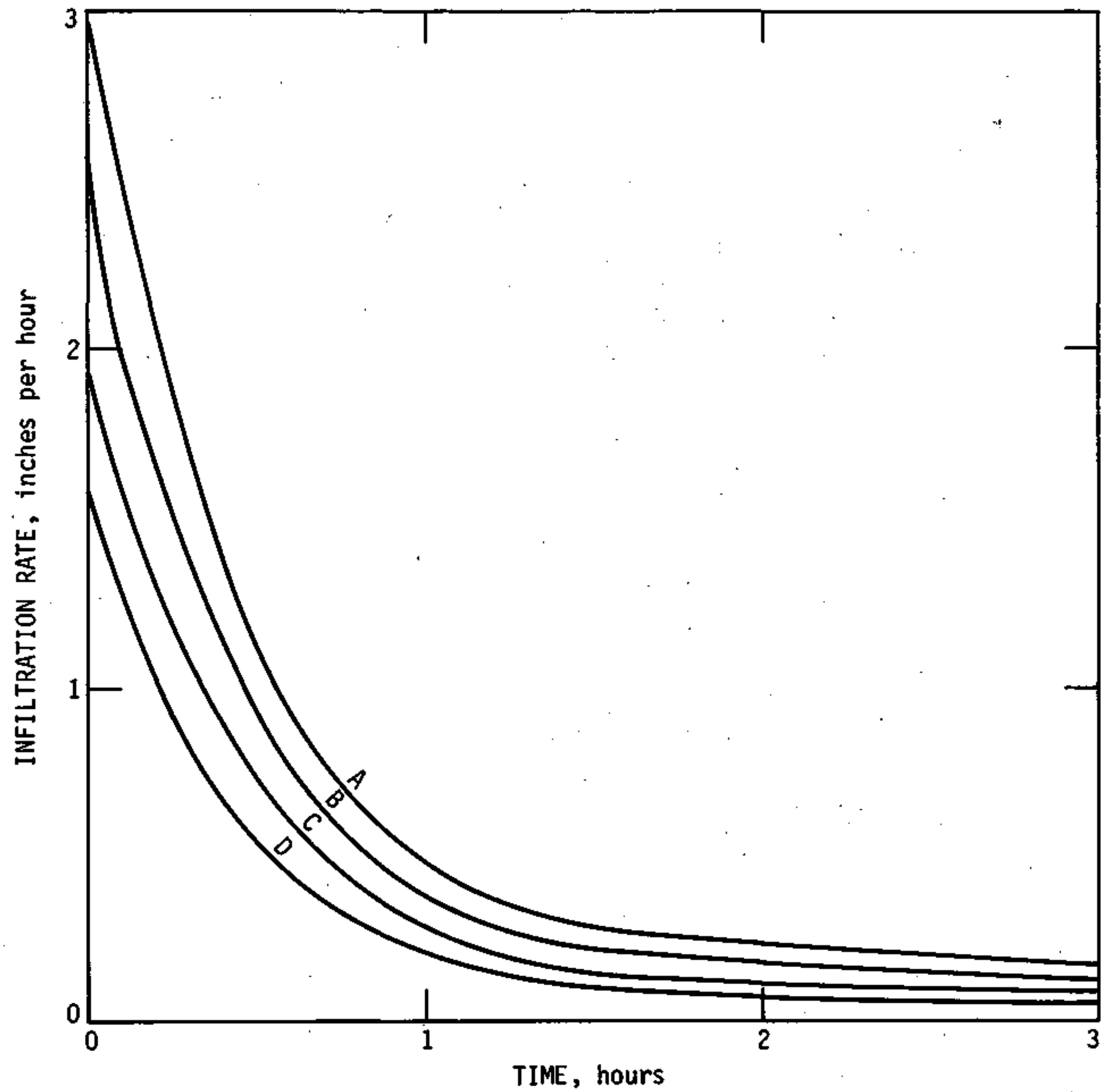


Figure 2. Infiltration curves used in ILLUDAS for soils with Row Crop cover.

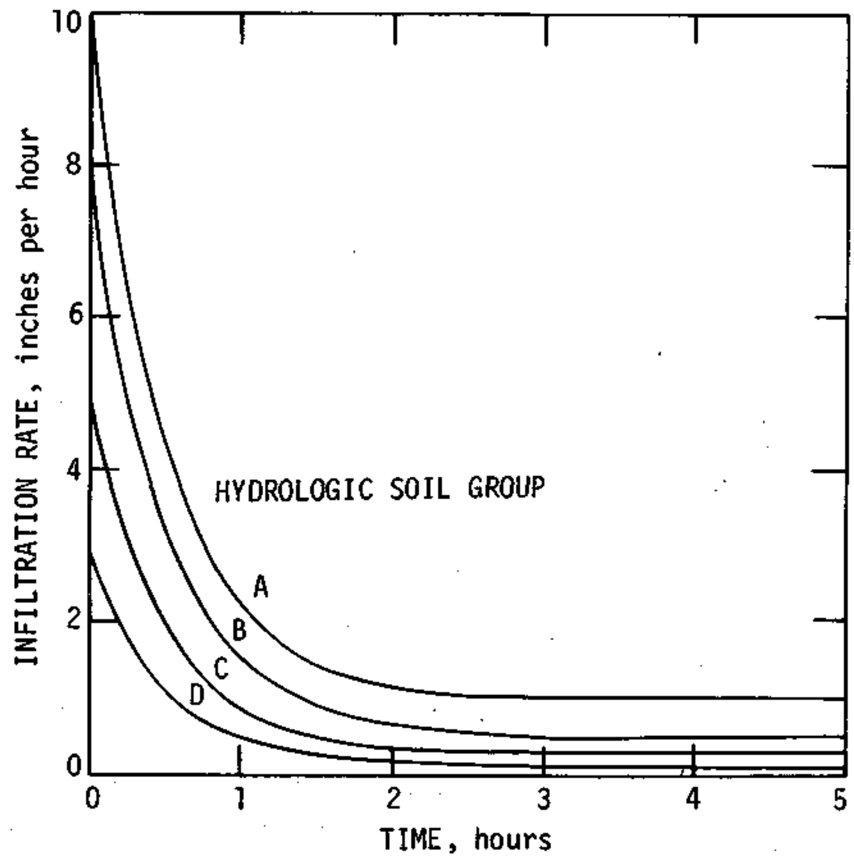


Figure 3. Infiltration curves used in ILLUDAS for soils with grass cover.

f = infiltration rate at time t, inches per hour
f_o = initial infiltration rate, inches per hour
f_c = final constant infiltration rate, inches per hour
e = base of natural logs
k = a shape factor
t = time from start of rainfall, hours

The values used in this equation to develop the curves in figures 2 and 3 are presented in table 1. These parameters are weighted linearly with the amounts of grassed and row-crop area in each sub-basin to generate a composite infiltration curve for that sub-basin.

The starting point on the appropriate infiltration curve for a particular event depends on the infiltration accumulated in the soil mantle prior to the beginning of the event. Infiltration accumulated, or conversely available storage in the soil, depends on weather and growing conditions prior to the event. The variability of this soil parameter presents a complex question the answer to which will not be attempted here. For the purposes of this study, soil conditions at the beginning of any event will be described by four antecedent moisture conditions (AMC). These four conditions are related to the total rainfall for five days preceding the event as shown below.

ILLUDAS NUMBER	DESCRIPTION	TOTAL INCHES OF RAINFALL DURING FIVE DAYS PRECEDING THE STORM
1	Bone dry	0
2	Rather dry	0 to 0.5
3	Rather wet	0.5 to 1.0
4	Saturated	over 1.0

These same four conditions were used in the original development of ILLUDAS.

The next step in determining the starting point on the infiltration curve for a particular event is to determine the amount of infiltration accumulated in the soil for each AMC. Table 2 presents the values used in ILLUDAS for both bluegrass and row-crop cover. Having these values, the starting point can be determined

Table 1. Factors Used in the Hortan Equation for Calculating Infiltration Curves for Bluegrass and Row Crop Land Uses.

Item	Value			
BLUEGRASS				
Hydrologic Soil Group	A	B	C	D
Final Constant Infiltration Rate f_c (inches per hour)	1.0	0.50	0.25	0.10
Initial Infiltration Rate f_o (inches per hour)	10	8	5	3
Shape Factor, K	2	2	2	2
ROW CROP				
Final Constant Infiltration Rate f_c (inches per hour)	0.20	0.15	0.10	0.05
Initial Infiltration Rate f_o (inches per hour)	3.0	2.5	2.0	1.5
Shape Factor, K	2.5	2.5	2.5	2.5

Table 2. Values of Infiltration Accumulated in the Soil Mantle for Various AMC, Soil, and Cover Combinations.

HYDROLOGIC SOIL GROUP		A	B	C	D
BLUEGRASS					
Infiltration Accumulated at the Start of Rainfall (inches)					
Bone Dry	AMC=1	0.0	0.0	0.0	0.0
Rather Dry	AMC=2	2.0	1.5	1.0	0.7
Rather Wet	AMC=3	4.0	3.0	2.0	1.5
Saturated	AMC=4	6.0	4.0	3.0	2.0
ROW-CROP					
Infiltration Accumulated at the Start of Rainfall (inches)					
Bone Dry	AMC=1	0.0	0.0	0.0	0.0
Rather Dry	AMC=2	0.5	0.4	0.3	0.23
Rather Wet	AMC=3	1.0	0.8	0.7	0.46
Saturated	AMC=4	1.5	1.2	1.0	0.69

by integrating under the infiltration curve until the specified accumulated moisture is attained.

Floodplain Representation

As originally conceived, the drainage system in ILLUDAS could be represented by one of three sections: circular, rectangular, and trapezoidal. This did not impose any serious restrictions in the use of ILLUDAS since rare events that would include overbank flow in open channels or street flow in areas with underground drainage were not normally encountered.

Because this study will include events of 100 year return period, it is necessary to represent flood plains or secondary flowpaths in the model. More than one roughness coefficient will be required to represent these higher flows.

The following description of the storm sewer-street flow combination indicates that the pipe system would be under pressure. In this application the pipe flow has not been increased above the full flow capacity of the pipe. This is a reasonable assumption for two reasons. First, inlets to the pipe system are often undersized and subject to considerable head loss and prevent true pressure flow from occurring. Second, when one portion of a pipe drainage system is surcharged, other portions of the system are also likely to be surcharged. As a result the effective head on a given reach is usually very small. Third, the increases in flow from surcharge heads are many times insignificant as indicated by figure 6.

The geometric simulation of a pipe-street system is shown in figure 4. The direction conventions are used according to a downstream view of the cross-section in all figures.

WL, WR, and W are the base widths of the left overbank, right overbank, and street and BSL and BSR are the left and right bank slopes. CH is the curb height while DI is the depth to invert from the street surface. S_S is the street slope, and N_S and N_B are the Manning's roughness coefficient N for the street and bank sections, respectively. The geometric and hydraulic characteristics of the storm sewer remain unchanged from ILLUDAS' present form.

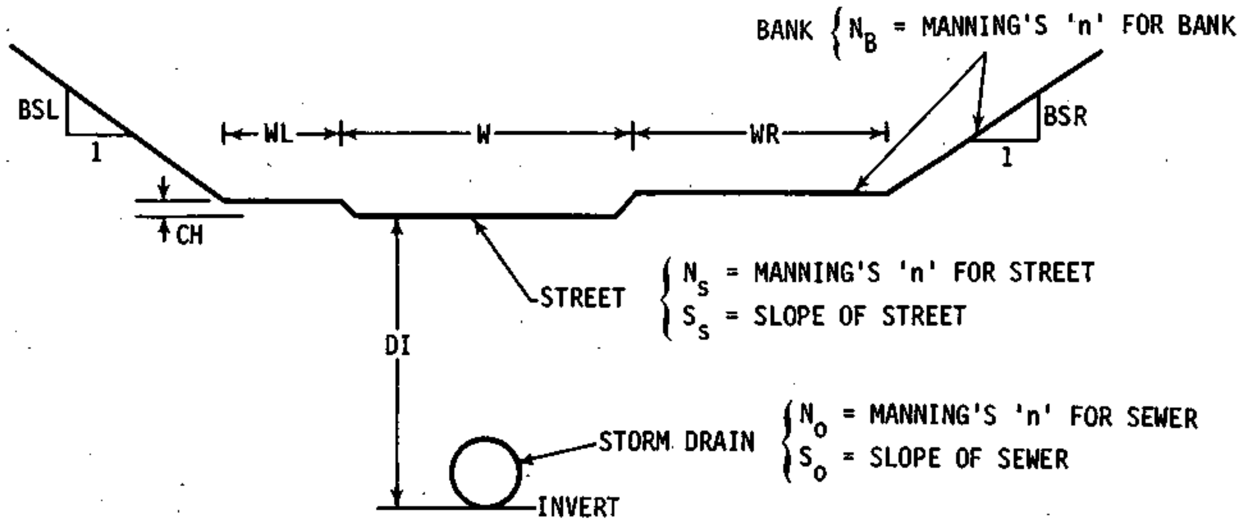


Figure 4. Geometric relationships for a Pipe-Street-Floodplain flow combination.

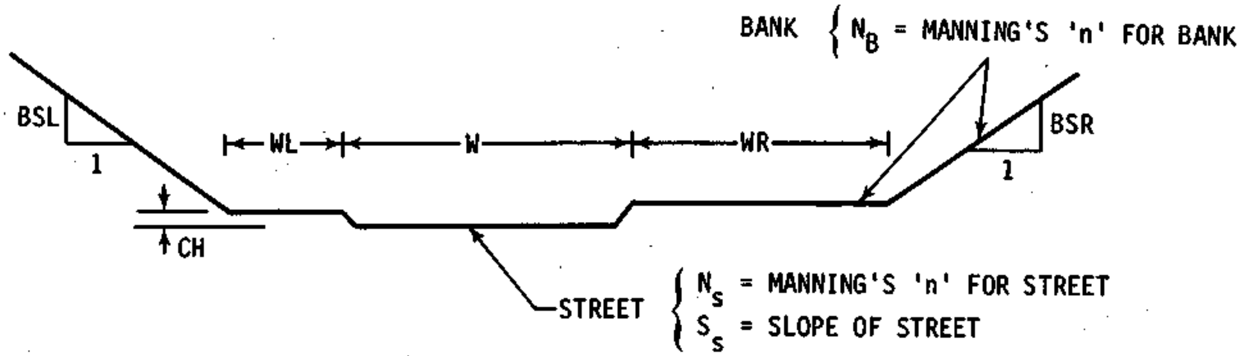


Figure 5. Geometric relationships for a Street-Floodplain flow combination.

Because surcharging is considered to increase the storm drain flow minimally, DI is not needed for the stage-discharge relationships developed for routing flows through the reach. As with the stage discharge relationship, DI has little influence on increases in storage. Small amounts of storage may be held in man-holes and inlets but not enough for the accuracies expected from the routing routines.

Geometric representation of an open-channel and its floodplain are illustrated in figure 5. The similarity of the open-channel and floodplain and the street and bank geometries is evident. The overbank flow N in both cases is a composite Manning's N computed from the formula

$$N_C = \frac{(P_S N_S{}^{1.5} + P_B N_B{}^{1.5})^{2/3}}{(P_S + P_B)^{2/3}} \tag{2}$$

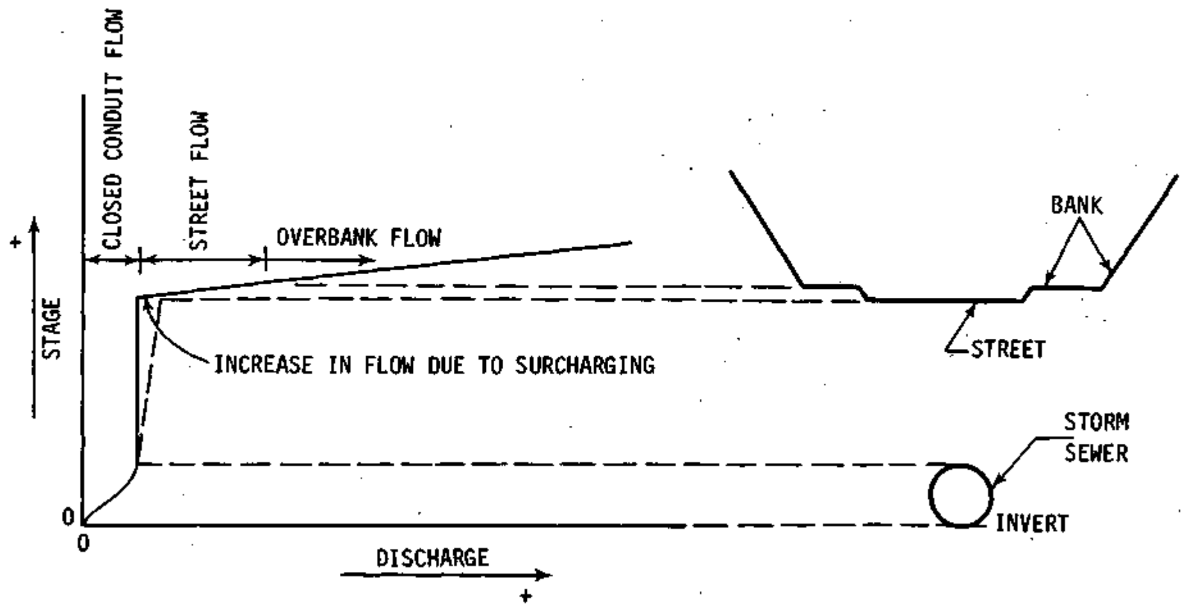
where P_S and N_S are the wetted perimeter and Manning's N for the street or channel, respectively. Likewise, P_B and N_B are the wetted perimeter and Manning's N for the bank section, respectively. N_C is the composite Manning's N for the section, as developed by Horton and given by Chow (1959) assuming that each part of the area has the same mean velocity as the whole section.

The storage routing technique used in ILLUDAS requires a relationship between stage, discharge, and storage. A typical stage-discharge relationship for a pipe-street system is shown in figure 6A. Figure 6B shows the storage-discharge relationship for the same section. These same relationships are shown in figures 7A and 7B for an open channel configuration.

VERIFICATION

The results of ILLUDAS applications on three rural basins with basically row-crop land use are presented in this section. The urban modeling capabilities of ILLUDAS have been well tested and no additional verification will be attempted here.

For each of the three rural basins there is a brief description of the basin, soil type, instrumentation, and distinguishing features.



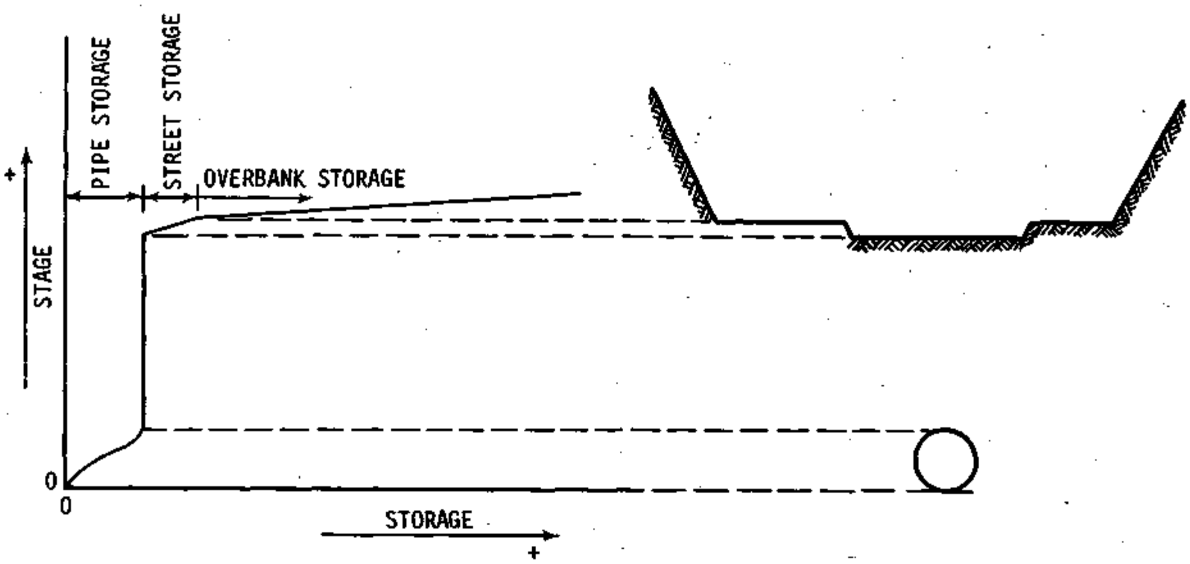


Figure 6. Stage-discharge and stage-storage relationships for a pipe-street flow combination.

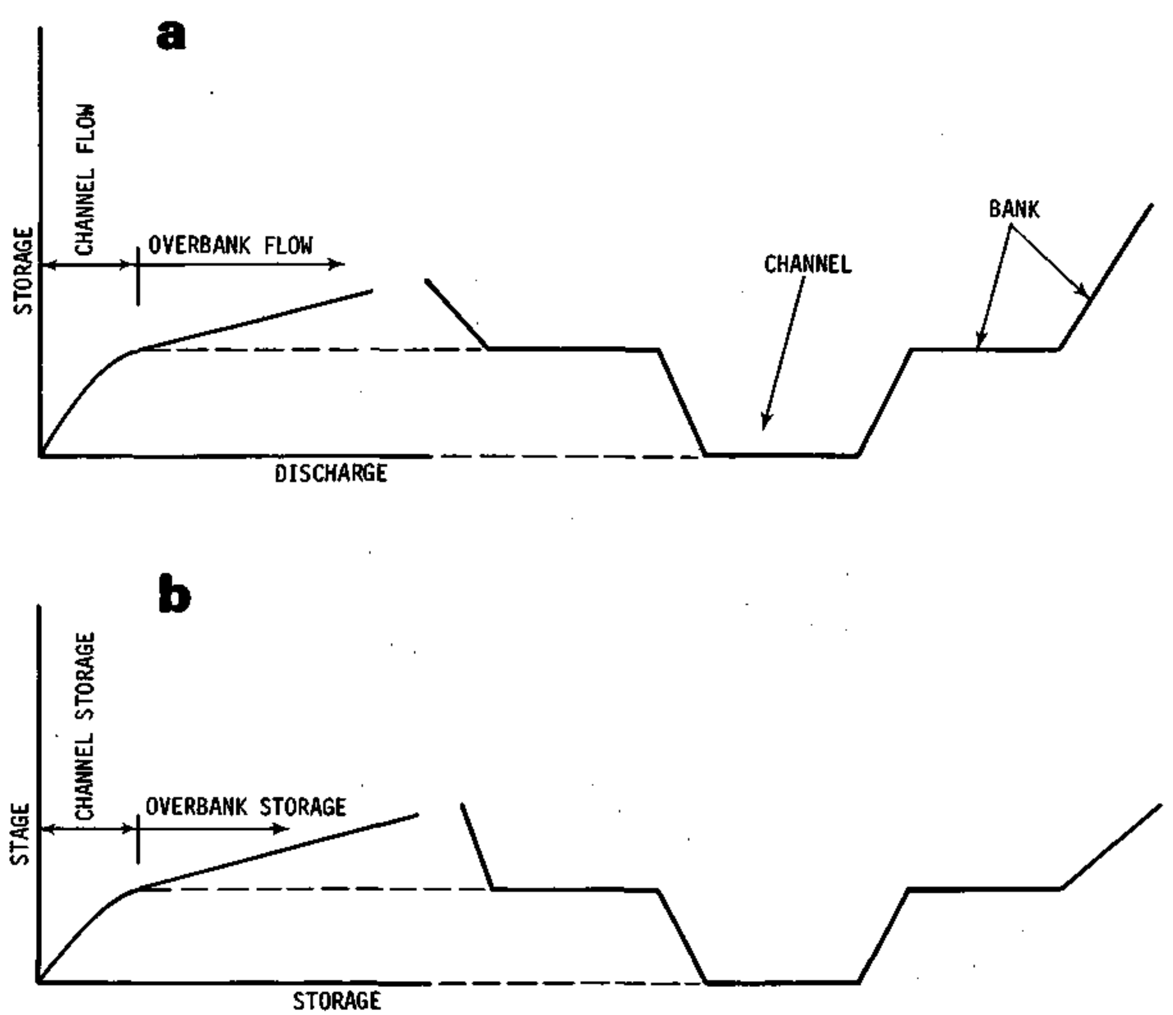


Figure 7. Stage-discharge and stage-storage relationships for a channel-floodplain flow combination.

Following the description there is a topographic map showing the stream gage and rain gage locations. Also presented is a plot of the observed rainfall pattern and runoff hydrograph along with the hydrograph calculated by ILLUDAS for one event. The observed peaks and runoff volumes are then shown plotted against the respective computed values. Finally a summary table containing the storm data used and results by storm is presented.

Basin Description - Treynor Watersheds

The Treynor watersheds are two of five small research watersheds located in Pottawattamie County, approximately five miles southwest of Treynor, Iowa. The Agricultural Research Service began research in these basins in 1964 with the objective of studying effects of conservation and farming practices on hydrology, gully erosion, and sheet erosion. Ongoing research includes a nutrient washoff study begun in 1969.

The topography of the area is quite hilly, with mean slopes near 8%. The soil is characterized as a deep mantle of loess overlying glacial till, which overlies bedrock. The principal soil types of the basins are of Marshall, Monona, Napier, and Ida groupings, all of which are included in hydrologic soil group B. During base flow periods there is continuous discharge into the gullies in all the watersheds. In both Watersheds 1 and 2, grasses grow on the gully bottom.

TREYNOR NO. 1: Flow from this basin (figure 8) discharges into Silver Creek, then to West Nisnabotna River, and eventually to the Missouri River. The basin area is 74.5 acres with a mean slope of 8.0%. Vegetative cover in this watershed has been contoured corn occupying 95%. of the area; the remaining area consists of grassed waterways and gully. The length of the principal waterway is 3500 feet, and the length of the gully at the time of interest was about 420 feet.

Flow out of the watershed is determined at a broad-crested (3:1) stainless steel weir equipped with two FW-1 water level recorders. Weighted averages for rain on the basin are calculated from records of three recording raingages within or near the basin boundary.

Treynor No. 1 - Results

Figure 9 shows the excellent fit that ILLUDAS was able to obtain on this basin and storm. As with all storms on this basin the predicted time to peak was quite close to the observed. Figures 10A and 10B indicate that the peaks and runoff volumes were acceptable.

Table 3 summarizes the verification of ILLUDAS on Treynor No. 1. The range of errors in the runoff volumes and peak flows were acceptable, and mean values for the observed and computed runoff ratios were very close. ILLUDAS overestimated the runoff volume in some cases but overall was able to do an acceptable job on this basin. ILLUDAS modeling of the time to peak for this basin was excellent.

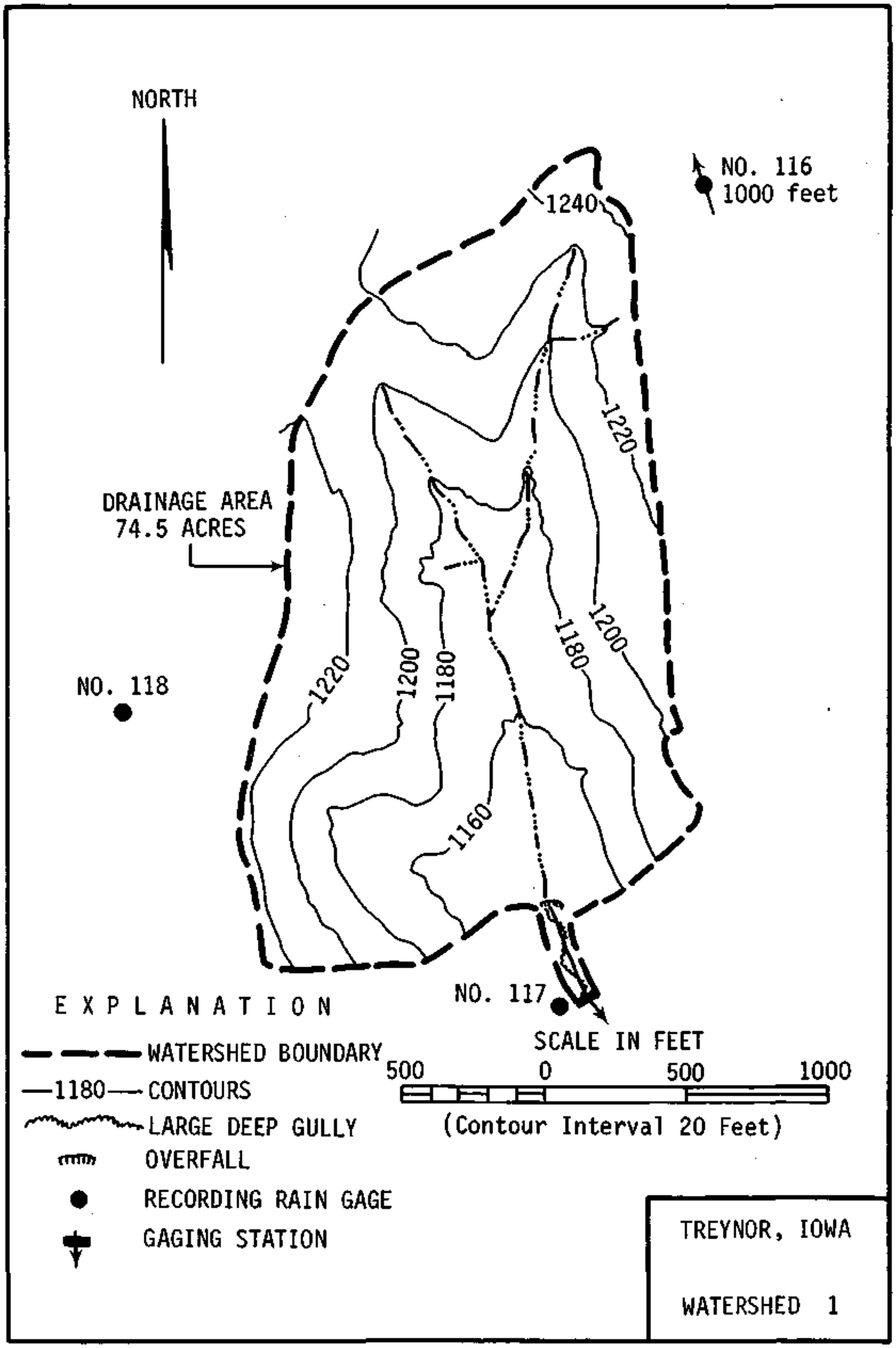


Figure 8. Topographic Map, Treynor No. 1 Watershed

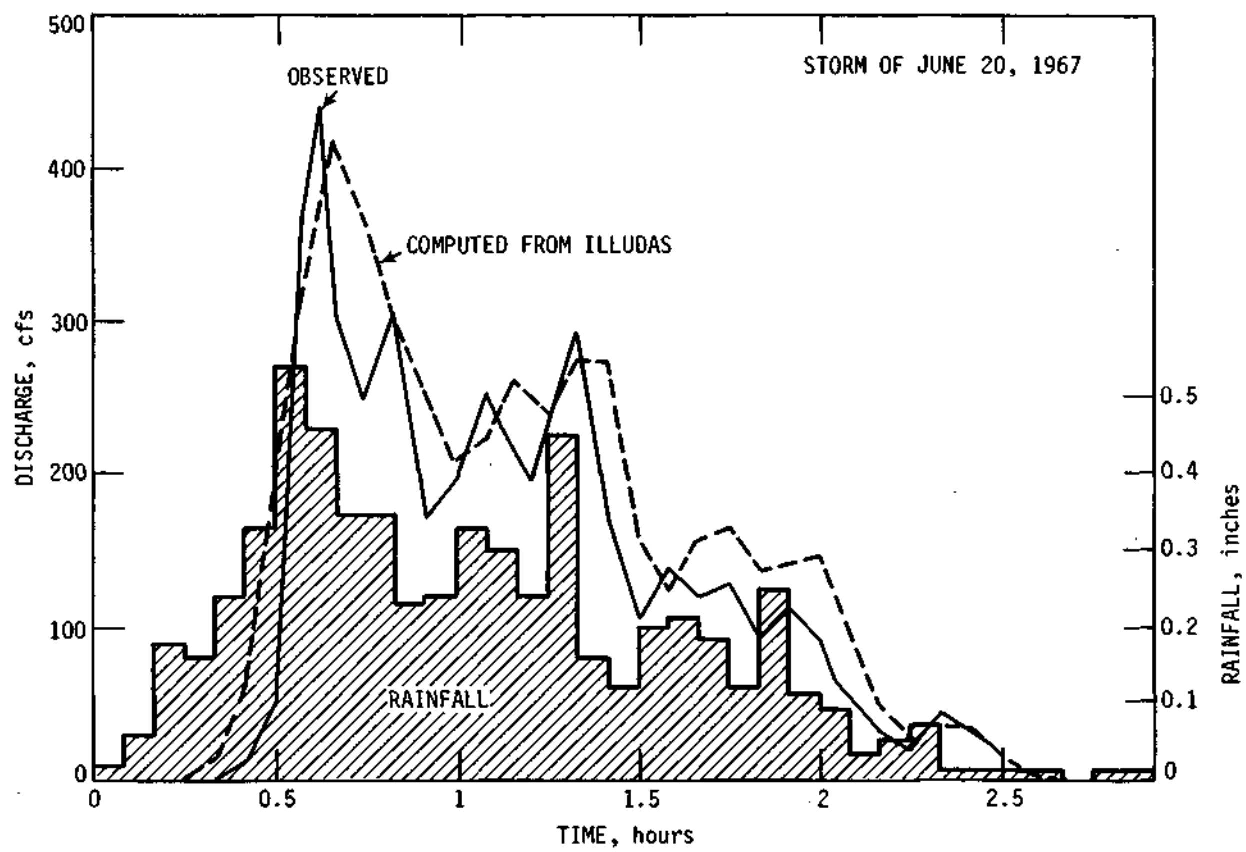


Figure 9. Observed and computed hydrographs for Treynor No. 1 watershed.

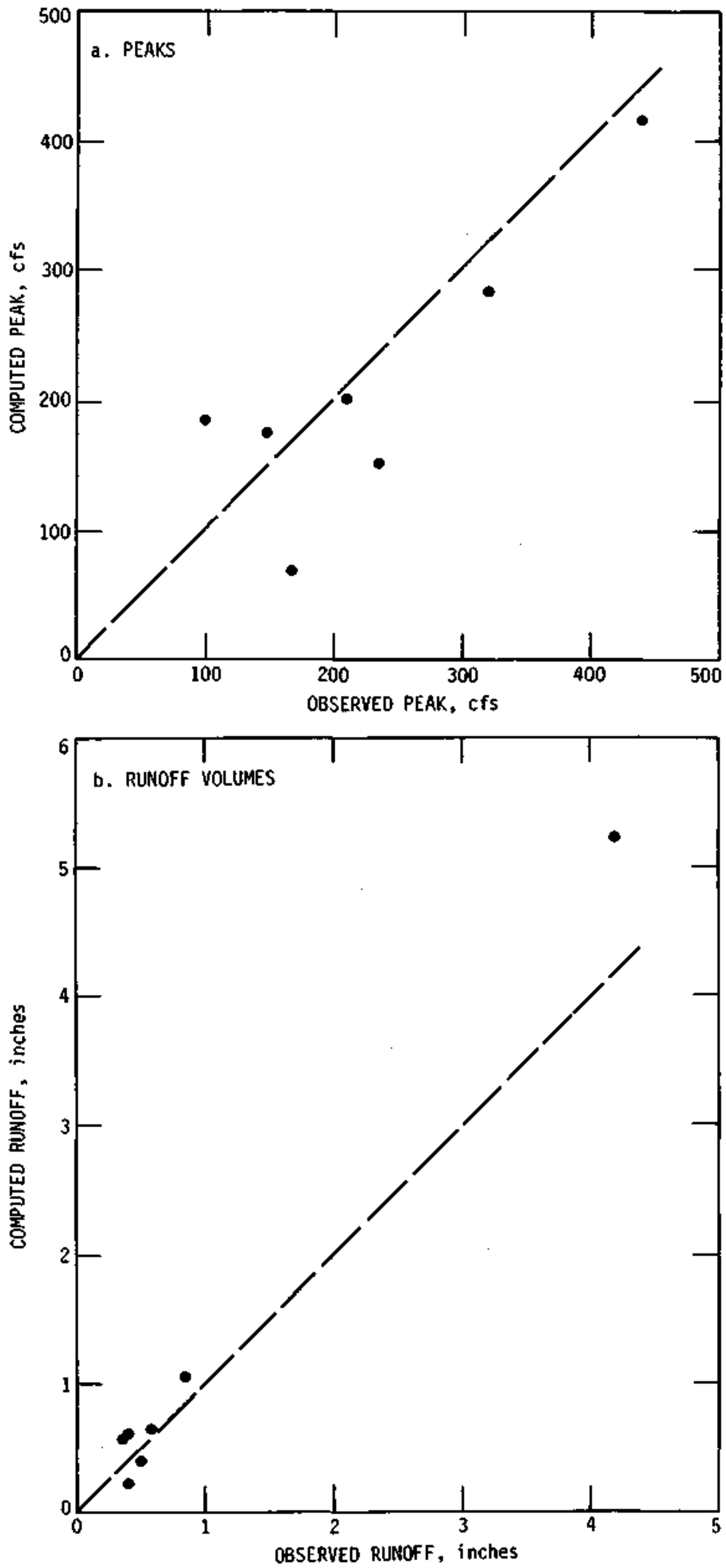


Figure 10. Observed vs. computed peaks and runoff volumes for Treynor No. 1.

Table 3. Storm Data and Results for Treynor No. 1 Basin

				Observed				Computed				% Error	
Date	AMC	Rain (ins)	Dur (min)	Runoff (in)	Runoff Ratio	Peak Flow (cfs)	Time to Peak (min)	Runoff (in)	Runoff Ratio	Peak Flow (cfs)	Time to Peak (min)	Runoff	Peak Flow
6/22/64	3	1.12	55	0.57	0.51	212	45	0.66	0.59	201	45	16	-5
9/22/64	2	1.55	110	0.40	0.26	98	76	0.61	0.39	185	75	52	89
5/21 & 5/22/65	4	0.67	115	0.39	0.58	168	60	0.22	0.33	68	60	-44	-59
6/29/65	4	1.40	95	0.86	0.62	313	39	0.96	0.68	285	45	11	-9
6/26/66	4	0.92	60	0.36	0.40	146	17	0.58	0.63	175	15	58	20
6/14/67	4	0.77	95	0.49	0.64	235	28	0.41	0.53	152	25	-16	-35
6/20/67	3	6.09	175	4.22	0.69	439	37	5.22	0.86	414	40	24	-6
	Mean Values				0.53				0.57			32	32

TREYNOR NO. 2: Plow from the basin (figure 11) discharges into Keg Creek, and from there to the Missouri River. Basin area is 82.8 acres with a mean slope of 7.6%. Contoured corn occupies 95% of this area with the remaining area in grasses, waterways, and gully. The length of the principal waterway is 3,000, and of the gully, 780 feet.

Discharge from the watershed is determined at a broad-crested triangular (2:1) stainless steel weir equipped with two FW-1 water level recorders. Weighted averages from rain on the basin are calculated from records of three recording raingages within or near the basin boundary.

Treynor No. 2 - Results

Figure 12 is an illustration of an observed and computed outfall hydrograph. Again, ILLUDAS was able to predict the time to peak very well. Figures 13A and 13B indicate the observed and computed peak discharges and runoff volumes obtained from the modeling of Treynor No. 2. The computed peak discharges and runoff volumes were, as a whole, high compared to the observed values.

Table 4 summarizes the verification of ILLUDAS on Treynor No. #2. Notice the higher absolute errors in the runoff volume and peak discharges when compared to the results from Treynor No. 1. Average observed and computed runoff ratios were acceptable but their difference was greater than the difference obtained from the modeling of Treynor No. 1.

ILLUDAS again overestimated the runoff volume in some cases but overall was able to do an acceptable job in modeling the outfall hydrographs from this basin. Again the simulation was able to predict the time to peak quite well.

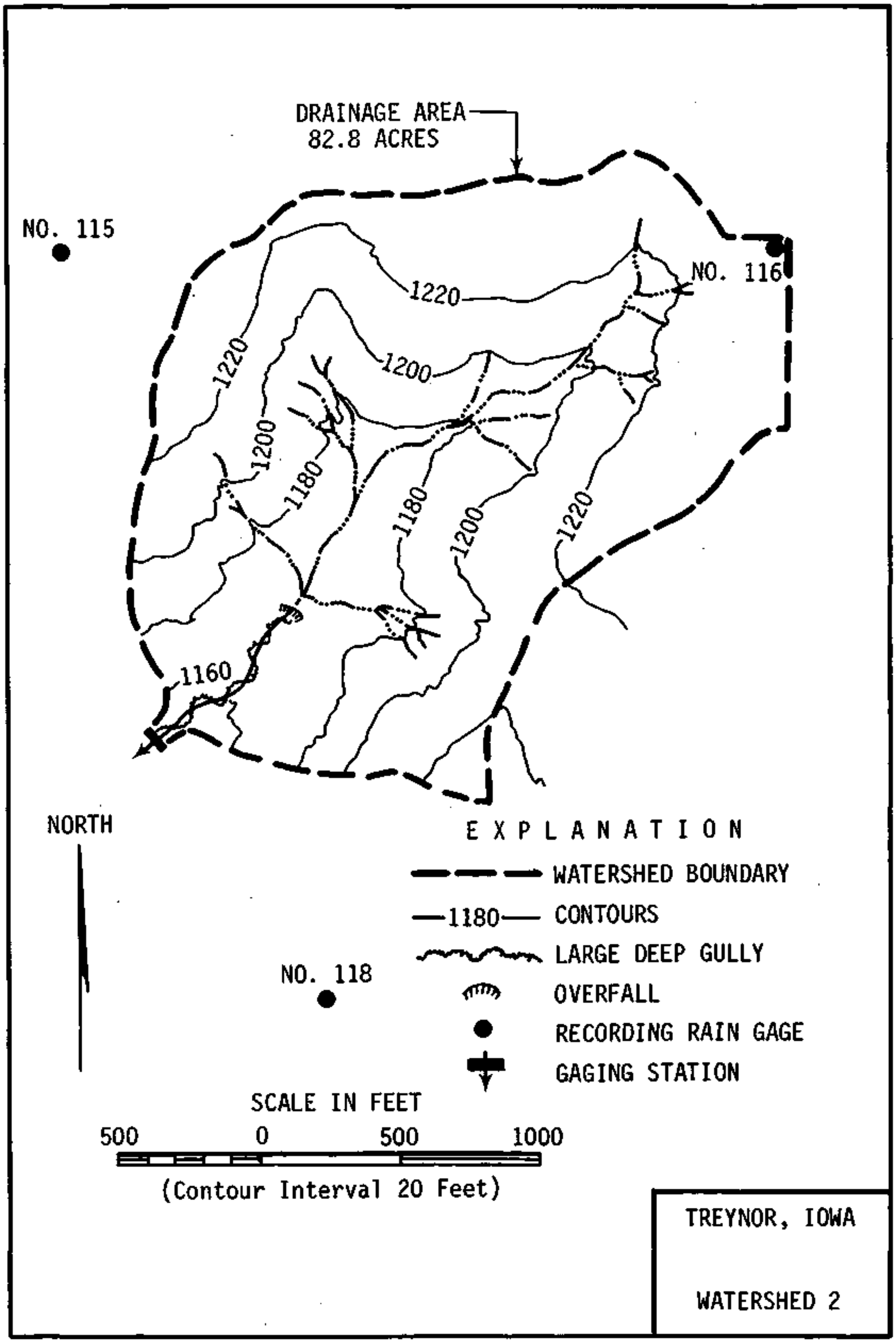


Figure 11. Topographic map for Treynor No. 2 Watershed.

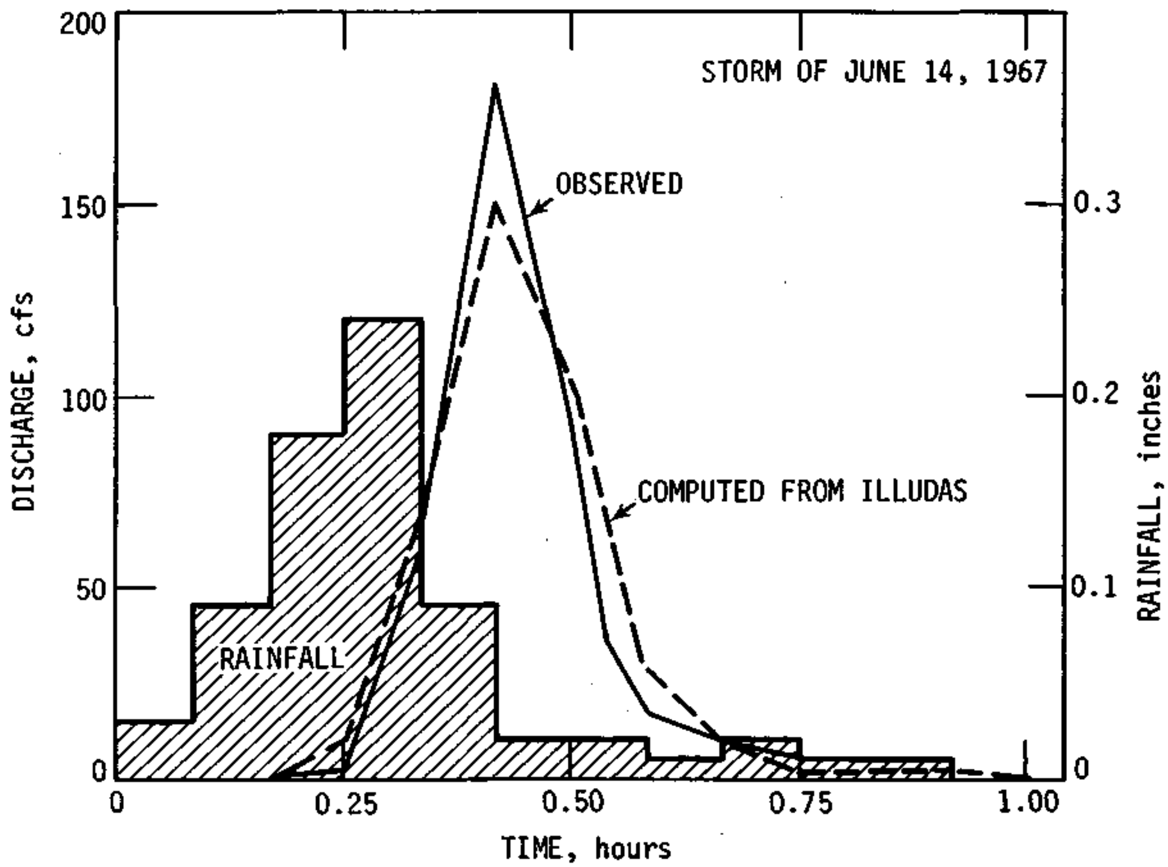


Figure 12. Observed and computed hydrographs for Treynor No. 2 watershed.

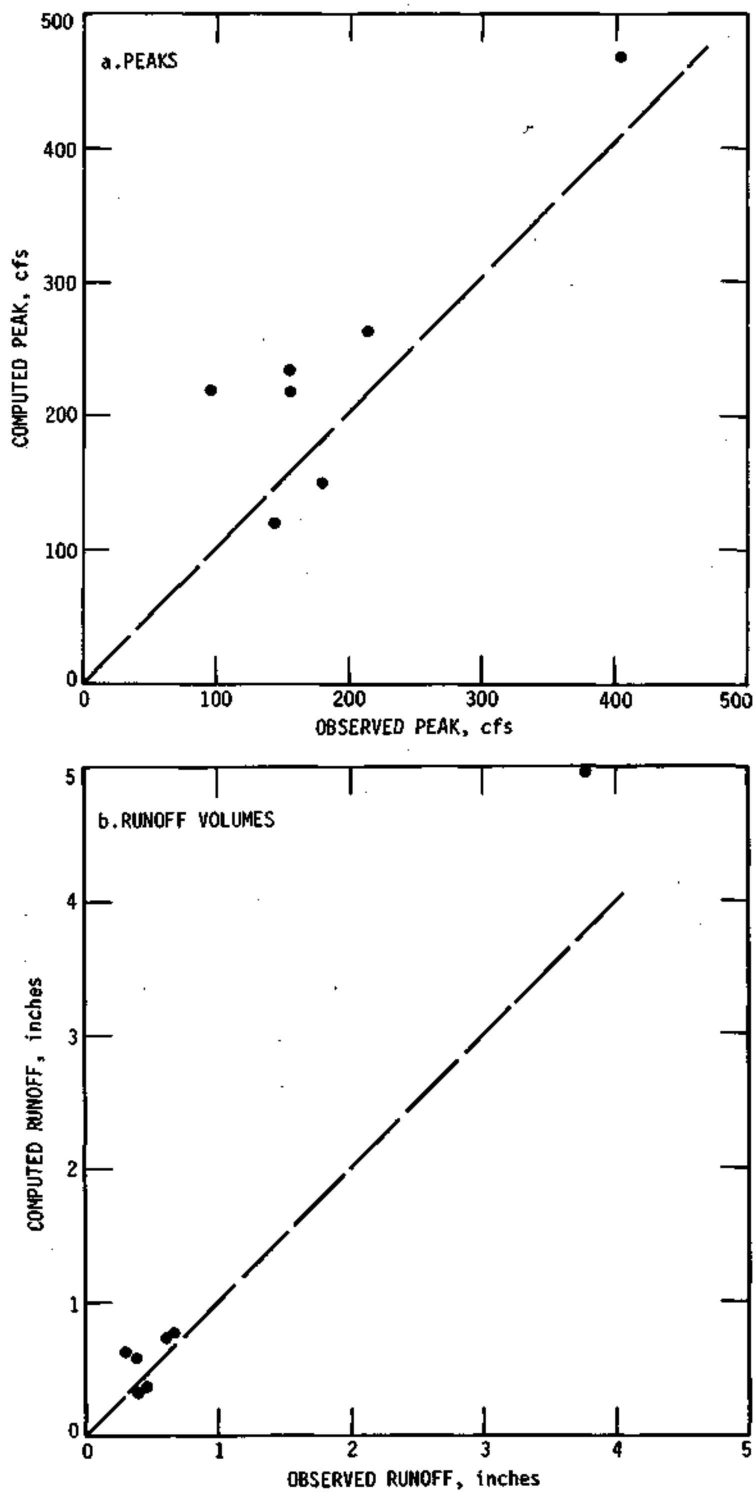


Figure 13. Observed vs. computed peaks and runoff volumes for Treynor No. 2.

Table 4. Storm Data and Results for Treynor #2 Basin

				Observed				Computed				% Error	
Date	AMC	Rain (ins)	Dur (Min)	Runoff (in)	Runoff Ratio	Peak Flow (cfs)	Time to Peak (min)	Runoff (in)	Runoff Ratio	Peak Flow (cfs)	Time to Peak (min)	Runoff	Peak Flow
6/22/64	3	1.17	40	0.58	0.50	216	37	0.72	0.61	265	35	23	23
9/22/64	2	1.57	105	0.33	0.21	98	68	0.62	0.40	221	65	89	126
5/22/65	4	0.73	85	0.38	0.52	144	23	0.32	0.44	119	25	-15	-17
6/29/65	4	1.25	105	0.64	0.51	157	35	0.76	0.61	217	35	19	38
6/26/66	4	0.93	70	0.40	0.43	154	25	0.58	0.63	234	20	46	52
6/14/67	4	0.78	105	0.44	0.56	182	25	0.37	0.48	150	25	-15	-18
6/20/67	3	5.82	165	3.78	0.65	407	38	4.97	0.85	468	40	31	15
	Mean Values				0.48				0.57			34	41

Basin Description - Montlcello

Watershed IA (figure 14) is one of three small research watershe located in Piatt County, Illinois approximately three miles southwest of Monticello, Illinois. The Agricultural Research Service began research on these basins in 1949 to examine small watershed hydrology. The topography of the area is flat with mean slopes near 1%. The soil is characterized as a glacial till over 200 feet thick. The principal soil types of the basin are a brown silt loam to a black clay loam on drab clay both of which are in hydrologic soil group B.

Flow from Watershed IA discharges into a small lake and then the Sangamon River into the Illinois River. Vegetative cover from 19.2% to 57.7% row crop occurred for the events examined. The length of the principal waterway is 1500 feet and the basin occupies approximately 82 acres.

Plow from the watershed is determined at a broad-crested (5:1) concrete V-notch weir equipped with one FW-1 level recorder. Area weighted averages for rain on the basin are computed from records of three recording raingages, two within the basin and one near it.

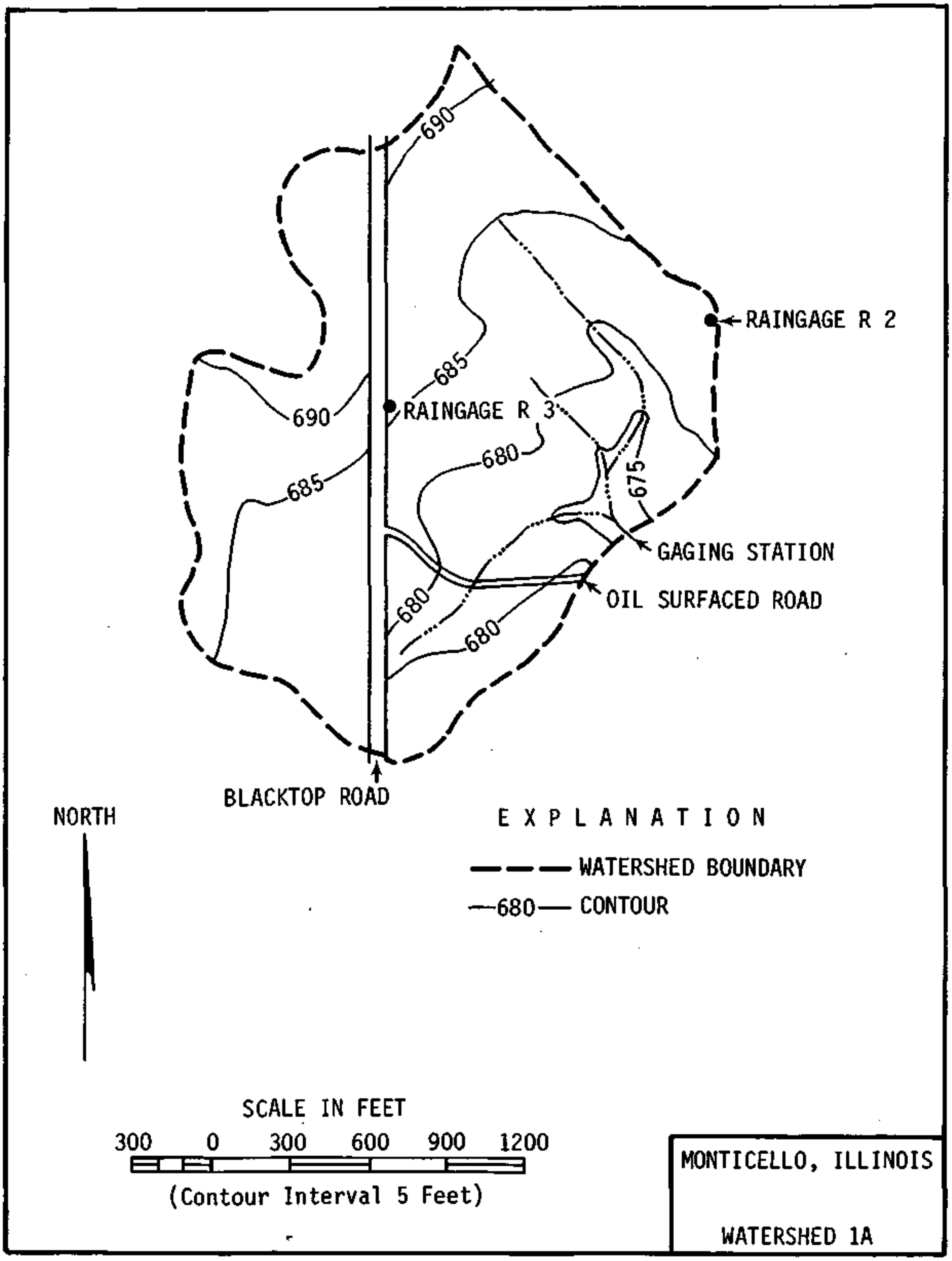


Figure 14. Topographic map for Monticello 1-A watershed.

Montlcello - 1A Results

Figure 15 is a plot of a runoff event simulation by ILLUDAS. Notice the long drawn out nature of the computed hydrograph. While the peak and time to peak were predicted satisfactorily, it can be seen that the runoff volume is excessive. This was observed in all the events modeled on this watershed. The model seems unable to retain and detain the flow getting to the outfall for this basin. Figures 16A and l6B further illustrates this point. Consistently the computed peaks and runoff volumes were higher than the observed values.

Table 5 summarizes the results from the modeling of Monticello IA basin by ILLUDAS. As with the Treynor watersheds, ILLUDAS over estimated most parameters. It wasn't able to predict time to peak as well as it did with the Treynor basins. ILLUDAS did an unacceptable job on this basin, indicating the potential variability of results to be expected from rural basins.

The data on this basin could have been affected by surface runoff by passing the gage through an existing field tile. During the authors recent visit to the site a sink hole was observed in the grass waterway above the gage. A 12-inch field tile was exposed and broken which could have accepted a considerable volume of surface runoff. Such runoff would have bypassed the gage.

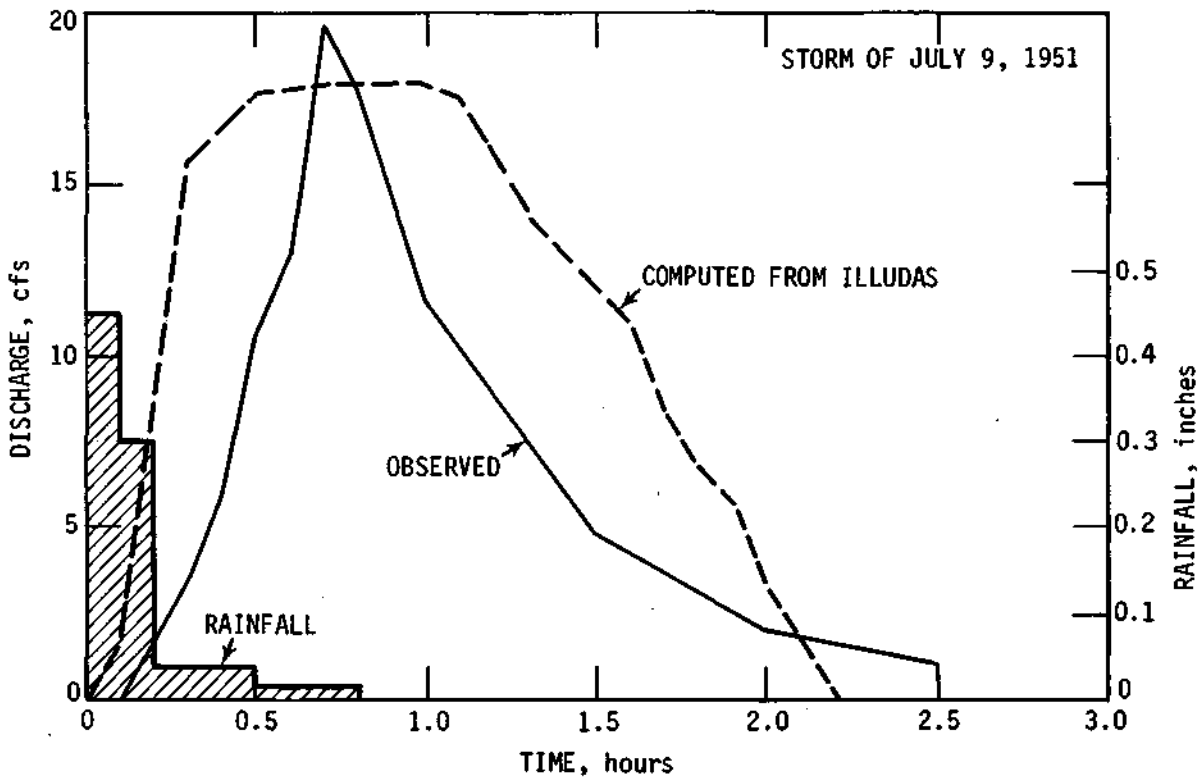


Figure 15. Observed and computed hydrographs on Monticello 1-A watershed.

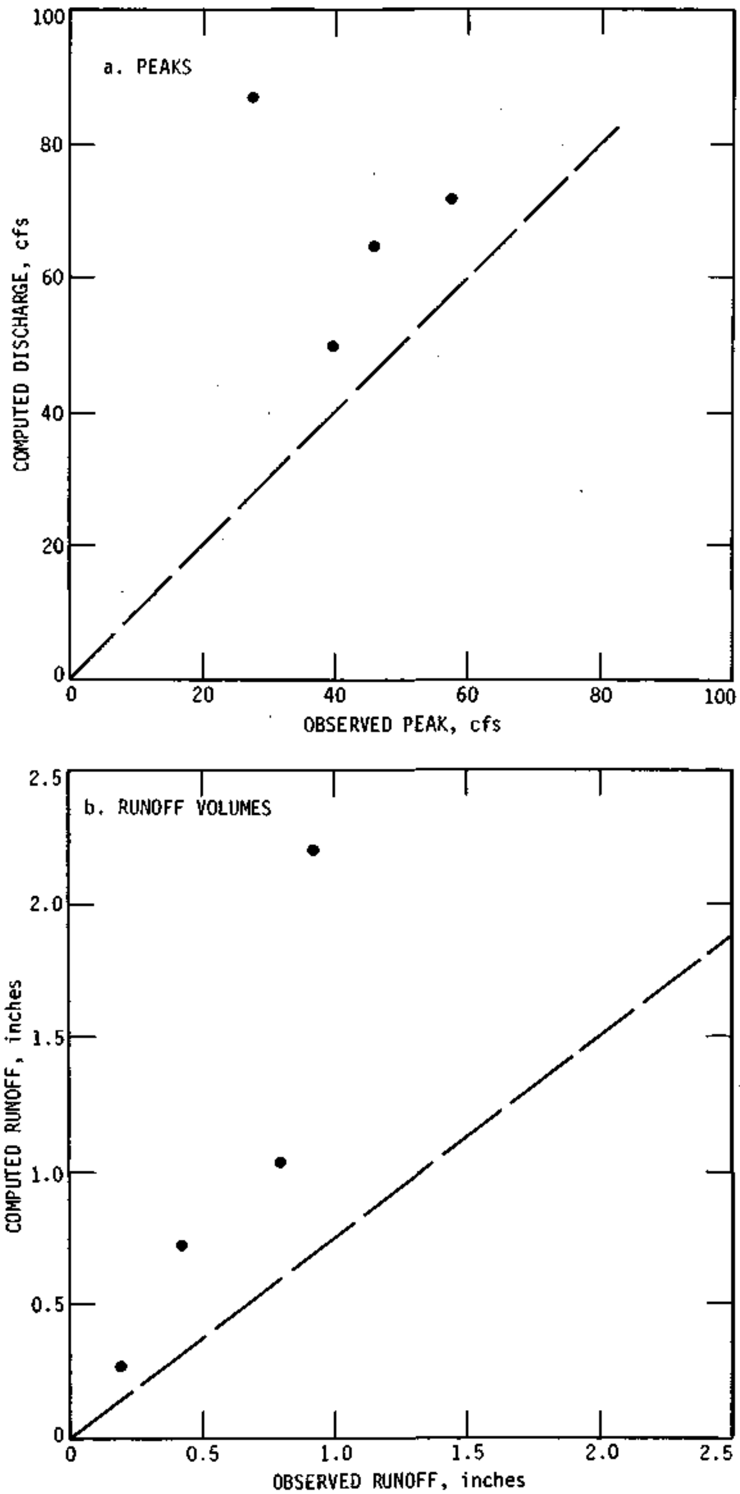


Figure 16. Observed vs. computed peaks and runoff volumes for Monticello 1-A

Table 5. Storm Data and Results for Monticello A-l Basin

				Observed				Computed				% Error	
Date	AMC	Rain (ins)	Dur (min)	Runoff (in)	Runoff Ratio	Peak Flow (cfs)	Time to Peak (min)	Runoff (in)	Runoff Ratio	Peak Flow (cfs)	Time to Peak (min)	Runoff	Peak Flow
10/21/49	4	0.90	40	0.20	0.22	20	40	0.26	0.29	18	50	31	-8
6/27/51	4	1.83	160	0.56	0.31	41	46	0.72	0.39	51	65	67	24
7/9/51	4	2.23	80	0.80	0.36	58	54	1.03	0.46	72	60	29	24
10/6/55	4	4.58	235	0.92	0.20	28	183	2.19	0.48	87	85	138	211
	Mean Values				0.27				0.41			66.3	66.8

Verification Summary

Better results between computed and observed parameters could have been achieved if more detailed inspection of land uses and cultivation practices within each basin were possible. Computed results from ILLUDAS used 100% cropland as input in all basins to weight linearly the infiltration functions by area. Closer inspection probably would have yielded some grassed area within the basin. This would have tended to decrease runoff ratios and make them agree more closely with the observed runoff ratios.

Large amounts of natural detention, retention, and leaf interception on an agricultural watershed make it difficult to simulate observed outfall hydrographs accurately. Variability in the observed runoff ratios would tend to indicate this. For example, large amounts of leaf interception by crops can occur depending on the crop, stage of crop growth, and the crop variety and planting population. Likewise, various tillage practices can effectively change both the runoff ratio and entry times. A moldboard plowed field could develop large amounts of detention and retention storage. Similarly, the particular tillage practices of the farmer can have a great deal of influence on retention, detention, and entry time. Cultivation parallel to the contours causes higher detention and retention and slower entry times would be expected when compared to no cultivation. Conversely, cultivation perpendicular or at somewhat of an angle to the contours would tend to channelize the flow causing relatively quicker entry times and smaller amounts of detention.

Although cultivating at high angles to the contour is not common practice, where space limitations and non-erosive soils exist, farmers are able to cultivate at extremely large angles to the contours. Loess formations are in many cases extremely non-erosive and conducive to such tillage practices.

In summary, the hydrologic nature of an agricultural watershed is very dynamic in nature, changing from year to year with crop rotation, stage of crop growth, and tillage practices. Besides the dynamic cultural practices in farming, the changing nature of infiltration annually and even daily makes it a difficult parameter to model. Bare soil surfaces might initially allow large rates of infiltration to occur until the impact energy associated with rainfall breaks up the surface soil structure causing sizeable decreases in the infiltration rates of an agricultural soil. These are only a few examples of the problematic nature of agricultural watershed hydrology.

In conclusion, more basins should be run with ILLUDAS and its hew agricultural infiltration functions. Two watersheds yielded good results (Treynor No. 1 and Treynor No. 2) but one watershed resulted in unsatisfactory results (Monticello A-l). The flatness associated with the Monticello basin caused it to achieve larger detention and retention characteristics which were not modeled accurately by the agricultural functions in ILLUDAS. This points out the fact that ILLUDAS is capable of producing excellent results on row crop lands, but it should not be used without some calibration.

Effects of Conventional Urbanization on the Distribution of Peak Plows

Model Calibration

In order to investigate the effects of urbanization on the frequency distribution of peak runoff events, ILLUDAS was used to model a basin in Northeast Illinois. A small tributary to the Pox River in Kane County was chosen for the following reasons:

1. It is in a Northeast Illinois County that will be subject to urbanization in the near future.
2. It is now predominantly agricultural in nature.
3. Urbanization is imminent; 35 new homes now exist in the basin.
4. The slope of the basin is adequate to minimize natural detention.
5. A U.S.G.S. stream gage (Pox River Tributary No. 2 near Pox, Illinois) has been measuring peak flows since 1961.

The basin shown in figure 17 is about 288 acres in size and consists of about 30% pasture and wooded area and 70% row crop. In the model of the basin the pasture and wooded area was represented as grassed area. The average bed slope is 1.5% and lateral slopes range from 2% to 5%. Soils in the basin are all in hydrologic group B and include Dodge, Saybrook, Drummer, and Strawn.

For the purpose of modeling the basin the 10 sub-basins indicated by dashed lines in figure 17 were used. These ranged in size from 18 to 54 acres. Channel reach lengths varied from 600 to 1100 feet. As a test, twice as many sub-basins as shown in figure 17 were used to test the effect of reach length and sub-basin size on peak flows. Because the results were nearly identical, the larger sub-basin size was used to reduce data requirements. The basin was examined in the field and channel cross-sections were taken at several points.

No measured rainfall is available at the Fox Tributary site. For this reason, published Intensity-Duration-Frequency data (IDF) Illinois State Water Survey (1970) were used both for calibration of the model and for the tests that will be described later. Unless indicated to the contrary, all references to frequency or probability

FOX RIVER TRIBUTARY NUMBER 2
NEAR FOX, ILLINOIS

USGS No. 5551800

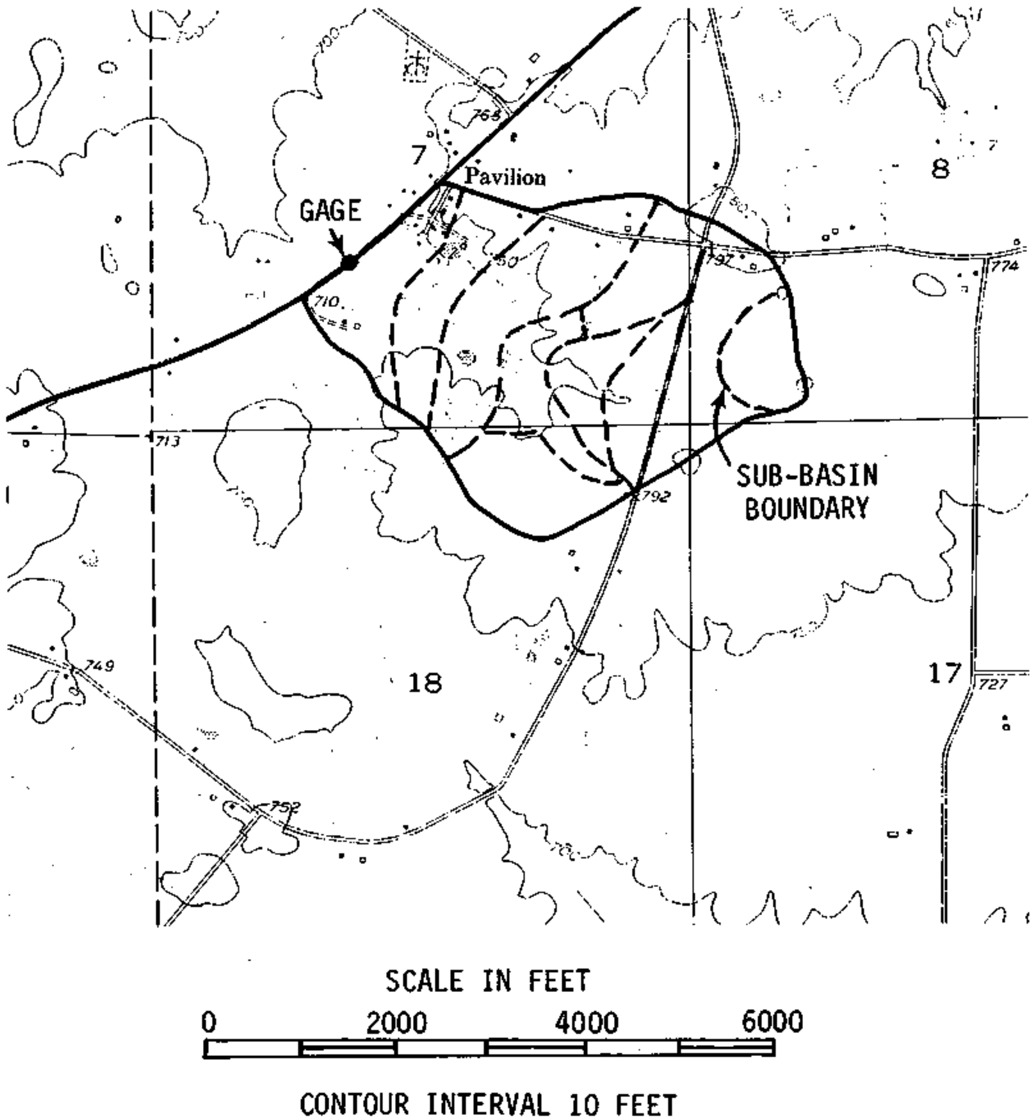


Figure 17. Topographic map for Pox River Tributary No. 2 watershed.

of occurrence will relate to rainfall frequency. This is a matter of considerable convenience for this study even though it does open the question of rainfall frequency versus runoff frequency.

To examine the general validity of using Intensity-Duration-Frequency data rather than real rainfall events, the critical duration of the basin was first determined. This was done by applying rainfall amounts of various frequency and duration to the model. The rainfall was distributed in time according to the "Huff" distribution built into ILLUDAS and shown in figure 18. For all return periods from 2 to 100 years, the 1 hour duration rainfall produced the highest peak runoff.

The long term rainfall record (1902-1974) for Chicago was then screened to select the one event each year containing the maximum 1 hour amount. This screening was facilitated by work previously done by the U.S. Geological Survey (USGS). The USGS has selected the 5 highest rainfall events for each year of the record.

The events containing the 15 highest hourly rainfalls were applied to the model. The resulting peaks were ranked and their return periods determined. They are shown plotted as points in figure 19. The two frequency curves were generated by ILLUDAS using the IDF data previously described. Antecedent moisture conditions of 2 and 3 were used for the lower and upper curves respectively. It was concluded from this comparison that IDF rainfall amounts could be used with the "Huff" distribution in place of actual rainfall events without a serious loss of reality.

ILLUDAS was "calibrated" to the rural condition of the basin by using the observed peaks and resulting frequency curve to select an antecedent mositure condition that would provide the best "fit". Figure 20 shows the observed peak flows on Fox Tributary No. 2 for the period 1961-1974 plotted against return period. Also shown in this figure is the frequency curve generated by plotting the peaks resulting from ILLUDAS simulation using the IDF rainfall amounts at the same return period as the rainfall. An antecedent moisture condition of 2 was used for this comparison and will be used throughout the remainder of the study.

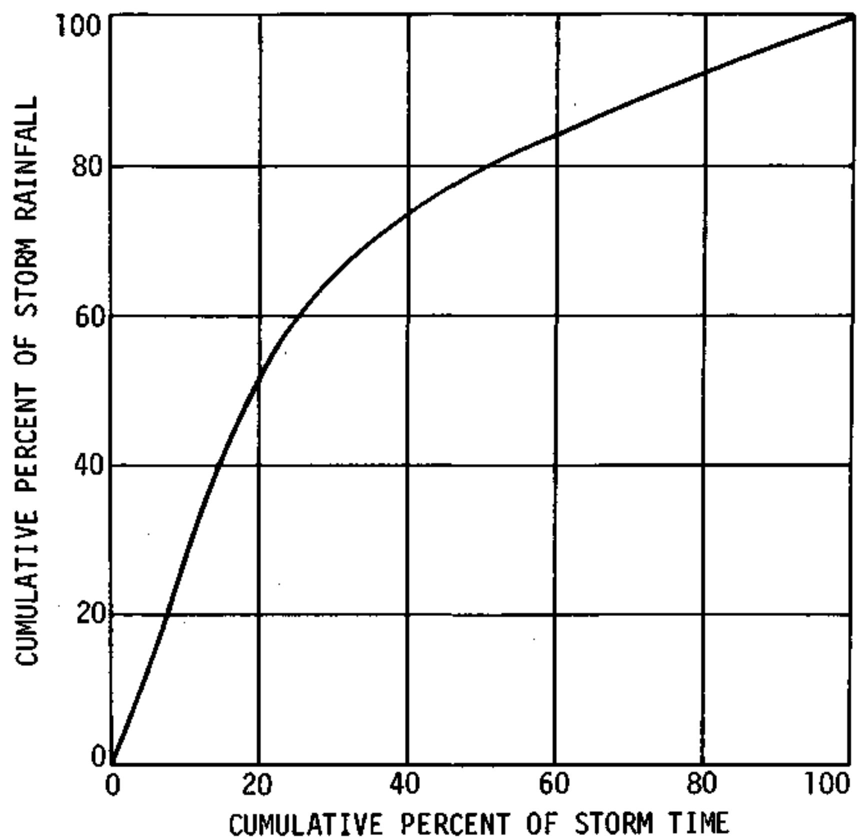


Figure 18. "Huff" rainfall distribution built into ILLUDAS.

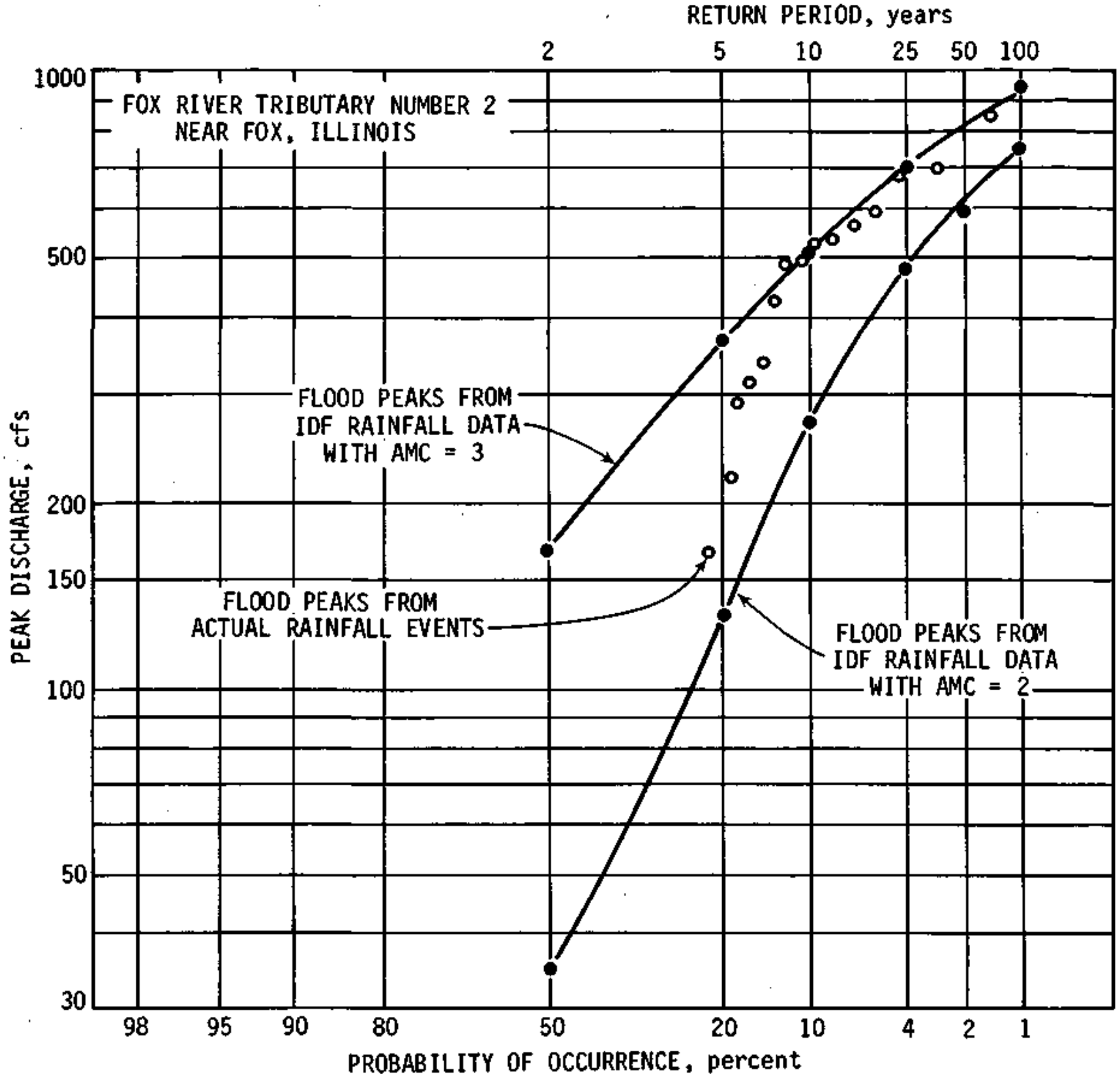


Figure 19. Frequency curves generated by ILLUDAS actual rainfall events and intensity-duration-frequency data.

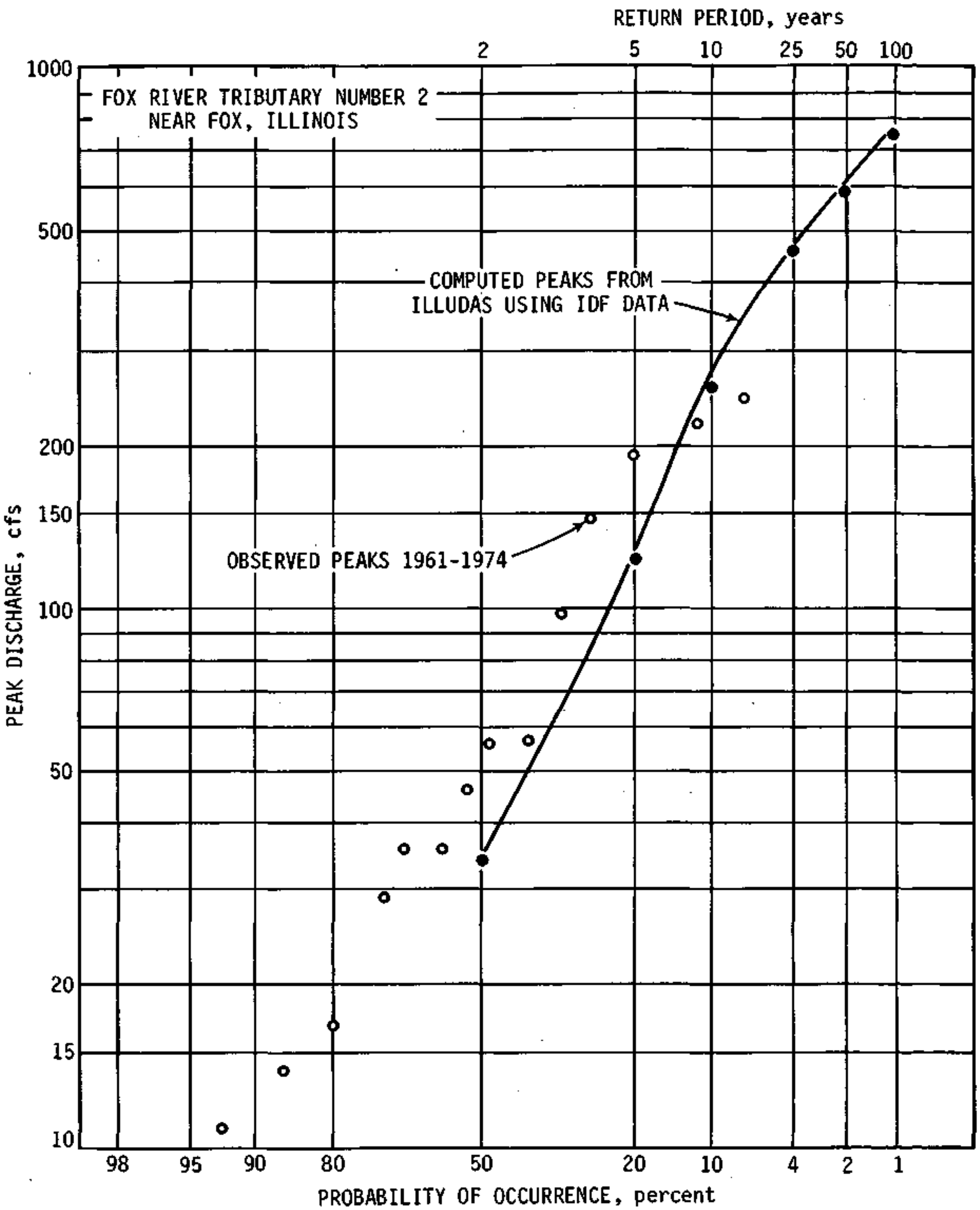


Figure 20. Observed and computed peaks.

Having calibrated ILLUDAS for use on this agricultural basin and establishing the type of rainfall input to be used, the effects of various urban developments were examined. The three different types of development described below were superimposed on the basin and the 2 thru 100 year rainfall events were applied. An effort was made to represent conventional urbanization in all three of these applications. The parameters used are typical of real developments and modeling of these parameters is well within the capability of ILLUDAS. In all three cases the type of development used will be applied uniformly over the entire basin; that is, there will not be a mix of residential and commercial or other uses. Although this may not occur in practice. it is a necessary assumption if the results are to be meaningful.

Residential

This is the least intense type of development to be applied to the basin and is representative of the kind of development actually occuring on the basin. This development is characterized by large single family residences on 100 x 200 foot lots. The computations below are based on the following factors and assumptions:

100' x 200' lots,
30' paved streets,
2400 ft^2 of roof per lot,
1000 ft^2 of driveway per lot,
300 ft^2 of sidewalk per lot,
2500 ft^2 of street per lot,
4000 ft^2 of street ROW per lot, and
10% open space.

To determine the number of lots per 100 acres, the lot area and street right-of-way area are combined for 24000 ft^2, the real land area per lot. The 100 acre total is then reduced by 10% for open area and divided by the 24,000 ft^2 per lot.

$$\frac{100 \times .9 \times 43560}{20000 + 4000} = 163.3 \text{ lots per 100 acres}$$

Contributing Areas per Lot in ft^2

Item	Directly Connected Paved Area	Supplemental Paved Area	Grassed Area
Roof	1200	1200	
Driveway	500	500	
Sidewalk		300	
Street	2500		
Grass			17800
Open Area	____	____	2667
Totals	4200	2000	20467
Total for 163.3 lots (100 Acres) in Acres and %	15.8	7.50	76.7

Apartments

This development is characterized by 2 and 3 story spartments and condominiums. Density is 20 dwelling units per acre with two off-street parking places per unit. The computations below are based on the following factors and assumptions:

2 & 3 Story Apartments and Condominiums,
20 dwelling units per acre, and
1000 ft^2 living area per unit,
500 ft^2 roof area per unit,
350 ft^2 parking area per unit,
150 ft^2 other paved area per unit,
14% gross street area.

Contributing Areas per Acre in ft^2

Item	Directly Connected Paved Area	Supplemental Paved Area	Grassed Area
Roof	5200	4800	
Street	6100		
Parking	7000		
Other Paved	3000		
Grass			17460
Total (ft^2)	21300	4800	17460
(%)	49	11	40

Commercial

This development may be thought of as a high intensity residential development of 20 to 30 dwelling units per acre plus a shopping center. It is similar to the apartment area just described with enough additional paved area to bring the total paved area to 75%. This is indeed a high intensity development and would probably never be reached by a modern development on a basin this large (288 acres).

Contributing Areas in percent

Directly Connected Paved Area	Supplemental Paved Area	Grassed Area
64%	11%	25%

Runoff Volume

As the basin goes from an agricultural state to residential, row crop lands are being replaced with paved area and grass. The paved area produces more runoff than row crops, however the grass produces less runoff than row crops. The net change in runoff thus depends on the relative amounts of paved area and grass. For the residential area specified above the results are demonstrated by the lower 2 frequency curves in figure 21. At the 2 year

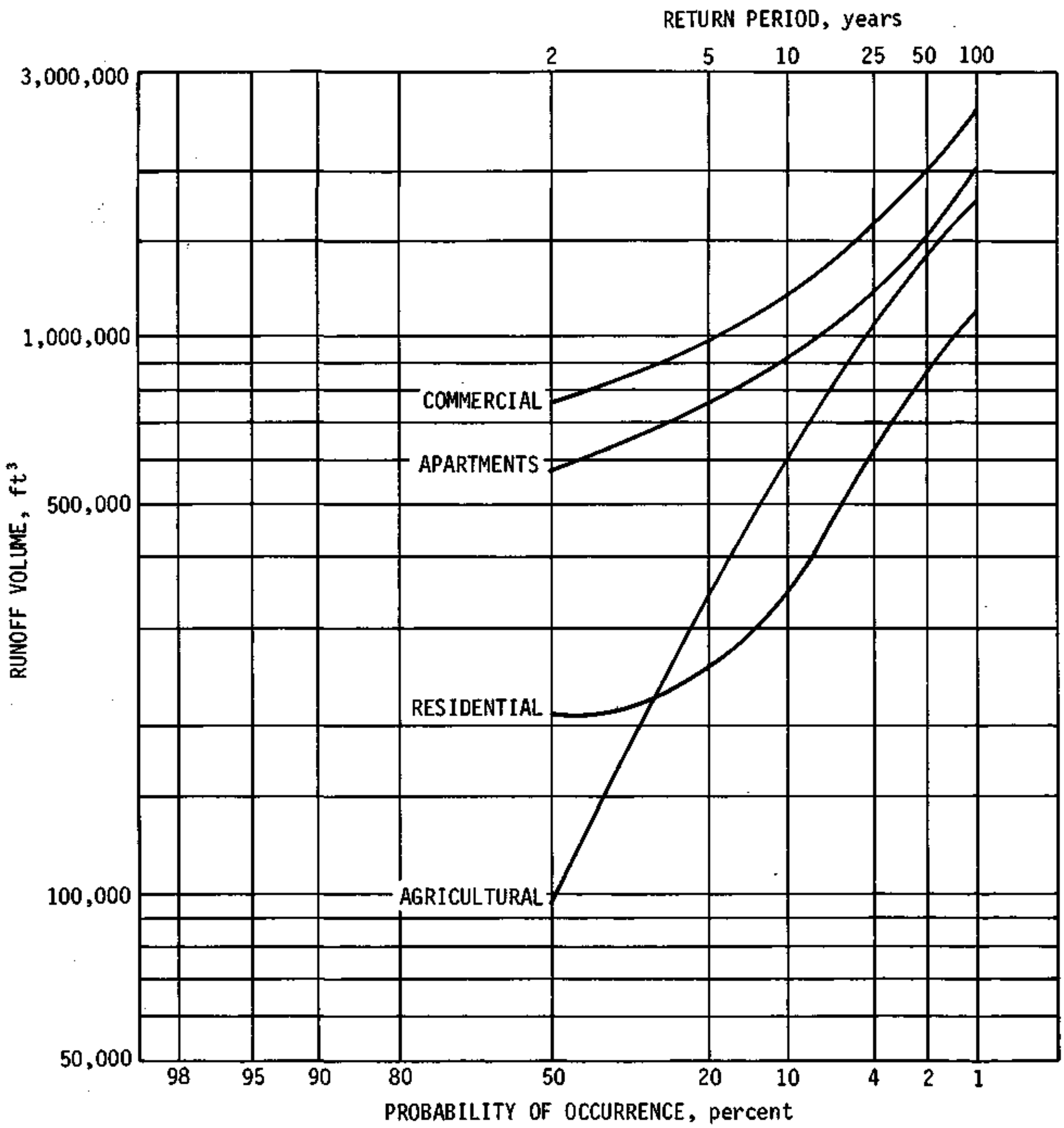


Figure 21. Runoff Volume-Frequency curves on Fox River Tributary No. 2.

level, runoff volume doubled. This happened because for a light rainfall (1.25 inches), 100% runoff from the small paved area greatly exceeds runoff from the large row crop area with a small runoff ratio.

As the rainfall increases, the runoff ratio from the row crop area increases, and the runoff from the relatively small amount of paved area is not so significant. At the same time high infiltration rates on the large amount of grassed area (76% of the basin) has more than compensated for the paved area runoff. This results in the 40% reduction in runoff volumes for the 10 to 100 year return period storms.

As the basin goes from residential to apartments grass is being replaced with paved area. The resulting increase in runoff is dramatic, threefold, at the two year level and nearly double at the 100 year level. Notice, however, that for the 100 year storm the apartment curve is only slightly higher than the agricultural curve.

As more grass is replaced with paved area the runoff volume increase proportionally. Prom apartments to commerical the total paved area increased by 20%. This is about equal to the average increase in runoff volume.

Peak Flows

The comparison of peak flows for various watershed conditions is more difficult than volumes because the hydraulic system is involved. The frequency curves in figure 22 represent peak flows generated by applying 2 to 100 year rainfalls to the four basin conditions described above. The hydraulic system for the agricultural case consist of the natural channel as actually measured in the field. For each of the other three basin conditions there is a dashed and a solid line between the 5 and 100 year return periods. The dashed and solid lines for each condition merge into one line in the 2 to 5 year range.

The dashed lines represent a hydraulic system consisting of a network of pipes large enough to carry the peak flows with no surcharge. These values are not realistic. The cost of pipes

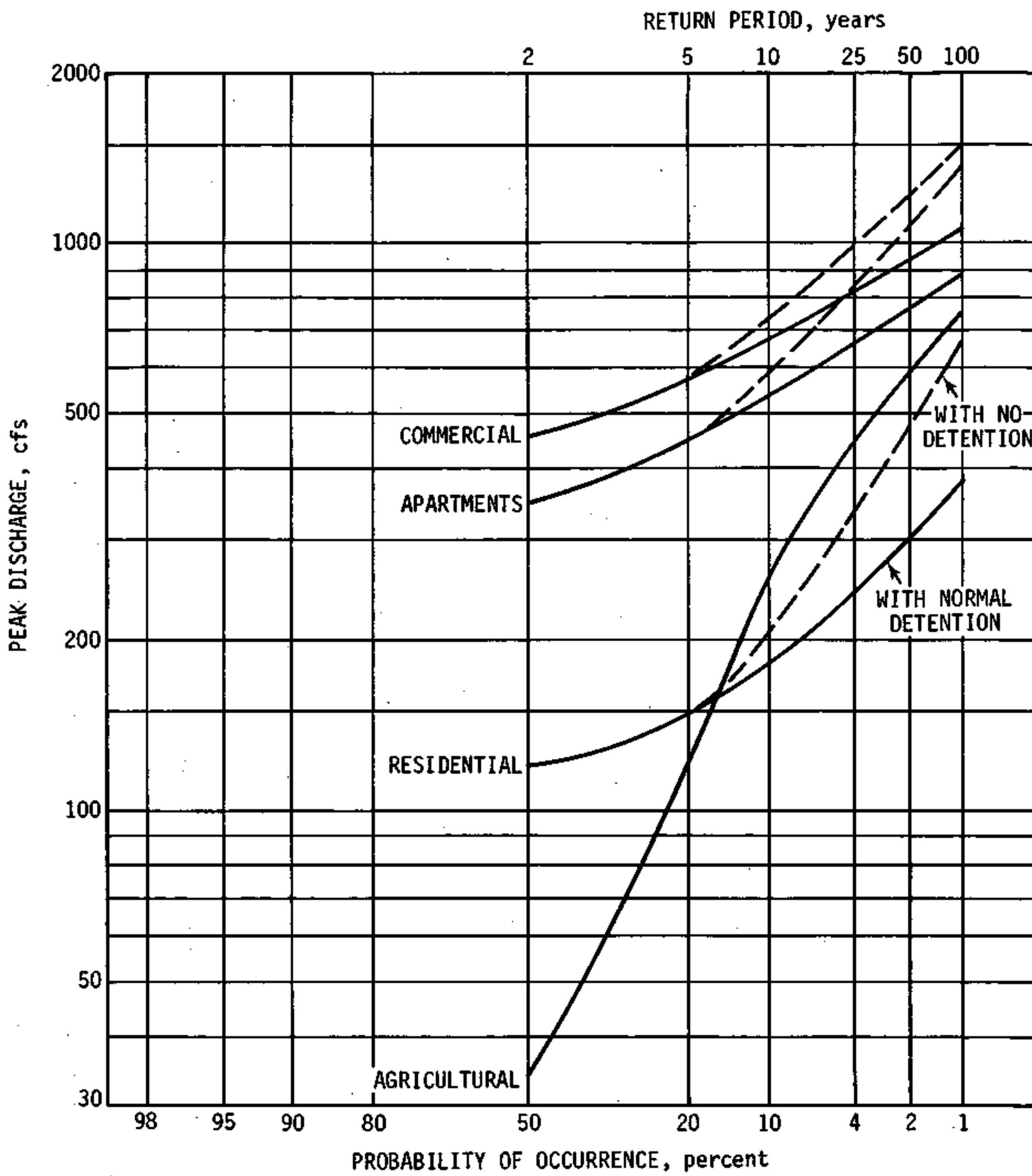


Figure 22. Peak-Frequency curves on Fox River Tributary No. 2 with Hydrologic Group B Soil.

sized to carry a 100 year event would be prohibitive. The values are presented here to indicate the potential peak possible with an extremely efficient drainage system.

As a first step in developing a realistic drainage system, pipe sizes were selected using the 5 year rainfall event. For rainfalls greater than this 5 year event the pipe system will be surcharged. Surcharging will increase the capacity of the drainage system and some runoff will leave the basin as street flow. When the system is surcharged, however, some peak rates of runoff will be detained on the basin until the hydraulic system can accept additional flow.

ILLUDAS can be used to determine the volume of surcharge in each sub-basin for each return period greater than the 5 year design. Because the portion of surcharge detained on the basin can vary widely depending on the geometry of the basin, a value of 50% was selected as representative. Thus when the 5 year design rainfall is exceeded and the system is surcharged, the capacity of the system is increased to accommodate 1/2 of the surcharge volume. The remaining 1/2 of the surcharge volume is detained on the sub-basin where it occurred until the pipe system can handle it. The solid lines for the residential, apartment, and commercial conditions of figure 22 were developed using this "50-50" assumption.

The volumes of storage detained on the basin using the above assumption are realistic. The following table which expresses the detention storage in average depth of water on the streets is presented for visualization of the above assumption.

Detention Storage Generated on Individual
Sub-basins (average depth on the street area in feet)

	Residential	Commercial
25 Year Storm		
Minimum depth on		
any sub-basin	.02	.06

	Residential	Commercial
Maximum depth on any sub-basin	.20	.16
100 Year Storm		
Minimum depth on any sub-basin	.14	.20
Maximum depth on any sub-basin	.53	.35

Referring again to the solid frequency curves in figure 22 the general pattern is similar to the runoff curves in figure 21. The residential development increases the 2 year agricultural peak by 2.5 times but decreases the 100 year agricultural peak by 50%. The apartment development increases the agricultural 2 year peak nearly 10 times but the 100 year peak by less than 20%. The commercial development increases the 2 year agricultural peak nearly 12 times and the 100 year peak by 40%.

The creation of detention storage during conventional urban development is very common. Most local ordinances prescribe 2 or 5 year design storms for residential drainage. In many cases inlets have smaller capacity than the drainage system and add to detention storage. Where no ordinances exist, developers spend a minimal amount of money on drainage and create many future drainage problems with undersized designs. Debris on inlets, sediment in pipes, and general lack of maintenance reduce the efficiency of the drainage system with age and contribute to detention storage.

Soil Type

Because the results just reported could easily be related only to a relatively pervious type soil, the same analysis was made using a hydrologic group D soil. All basin parameters except soil type remained the same. This approach brings up some rather obvious questions. The model is no longer calibrated against a real frequency curve and the channel shape and slope would no doubt be different for a real basin of the same size but with an impervious soil. Despite these weaknesses the comparison does offer some insight into the effect of soil type. Care should be excercised however, against making specific conclusions based on these results.

Figure 23 shows a family of frequency curves developed by arbitrarily changing the soil type on the Pox Tributary No. 2 basin and applying the same rainfall events used above. Again the resulting peak flows are plotted on the rainfall return period. The "Soil B" curve in figure 23 is the same as the agricultural curve in figure 22. The difference in peak flow between the "A" and "D" soils varies between 200 and 300 cfs for the entire range of return periods. The impact is of course much greater at the 2 year level because of the relatively small natural flow at this level. The net result of increasing the relative imperviousness of the soil is similar to adding impervious area by conventional urbanization. At the two year level the peak is increased by a factor of 12, but at the 100 year level by about 40%.

Having established the relationship between these soil types the Hydrologic Group "D" soil was selected for further analysis. The three types of conventional urbanization were superimposed on the basin and the 2 to. 100 year rainfall events were applied. The resulting frequency curves are shown in figure 24. Comparing these curves in figure 22 one can see that the same pattern has emerged. For the "D" soil however, the effects at the 2 to 5 year level are much less dramatic.

Other Basins

The flattening of the frequency curve by conventional urbanization, so apparent in figure 22, is not unusual. Frequency curves for two gaged basins in Champaign County are presented in figure 25. The lines shown are from a Log Pearson Type III analysis using station skew. These are plotted in cfs, because of the difference in size of the basins. The statistics for these basins are presented for comparison.

Boneyard Creek - Urban - 55% Impervious Area
Drainage Area 4.46 mi^2
Period of Record 1948 - 1975

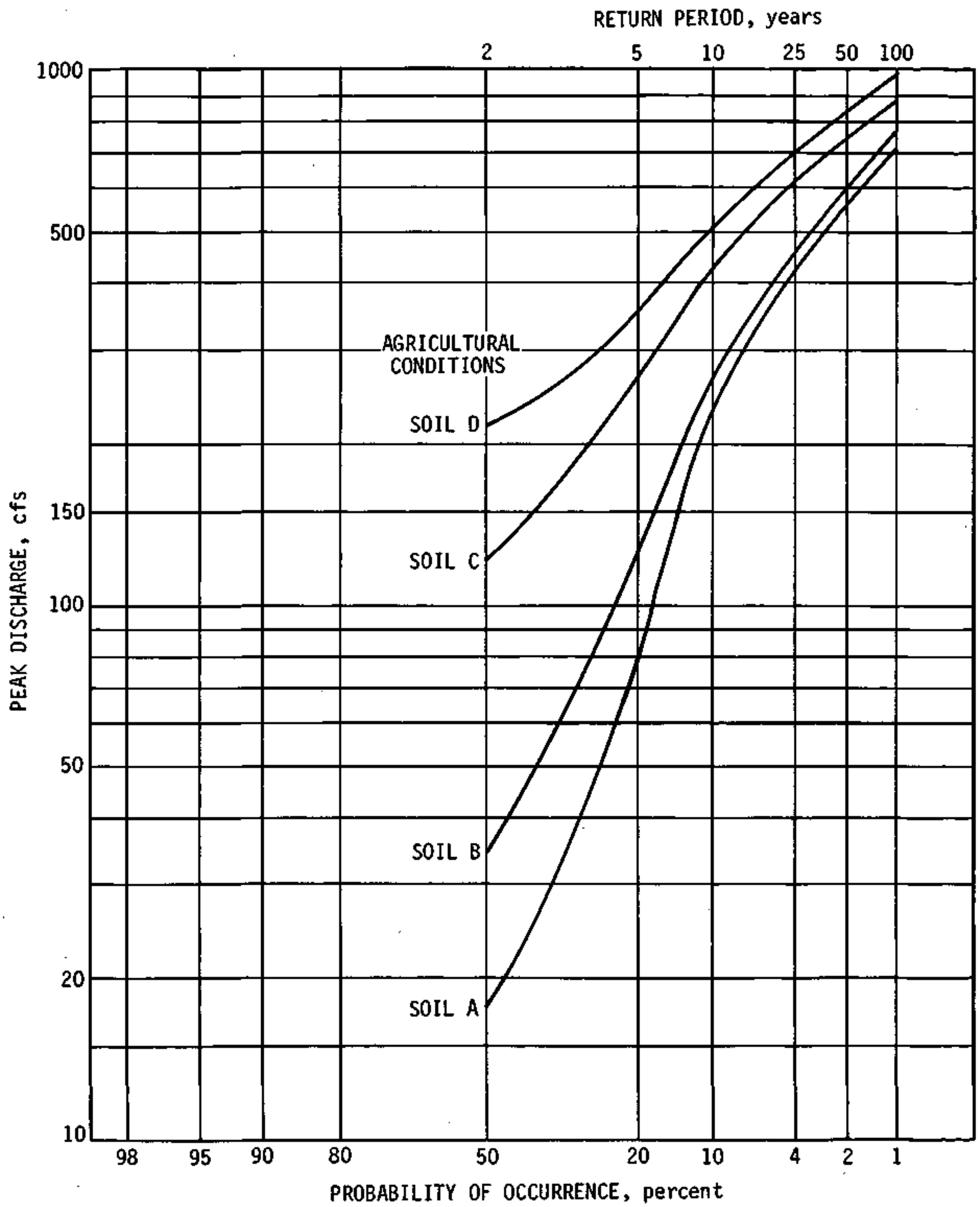


Figure 23. Peak-Frequency curves for Fox River Tributary No. 2 with various soil types.

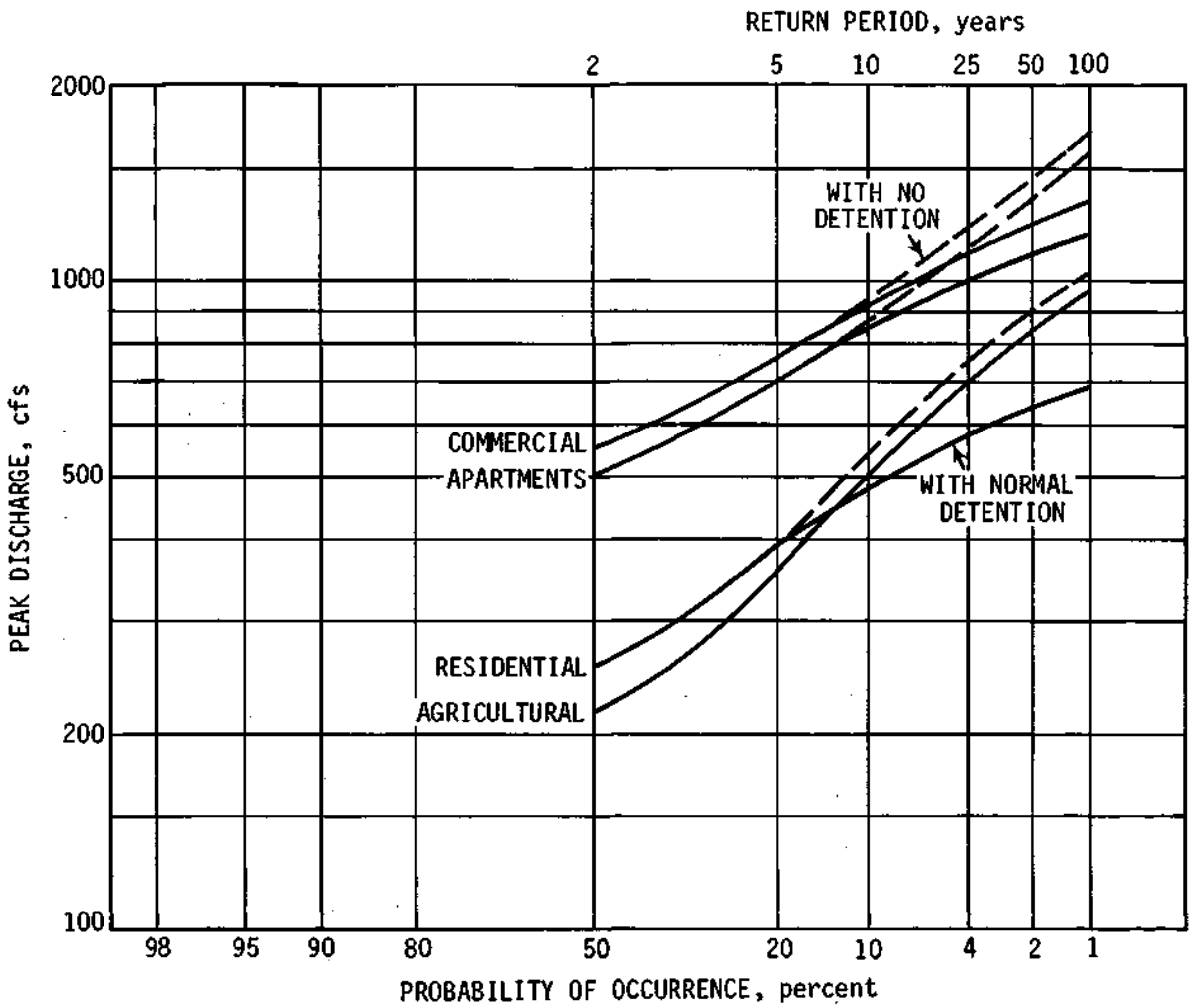


Figure 24. Peak-Frequency curves on Fox River Tributary No. 2 with Hydrologic Group D Soil.

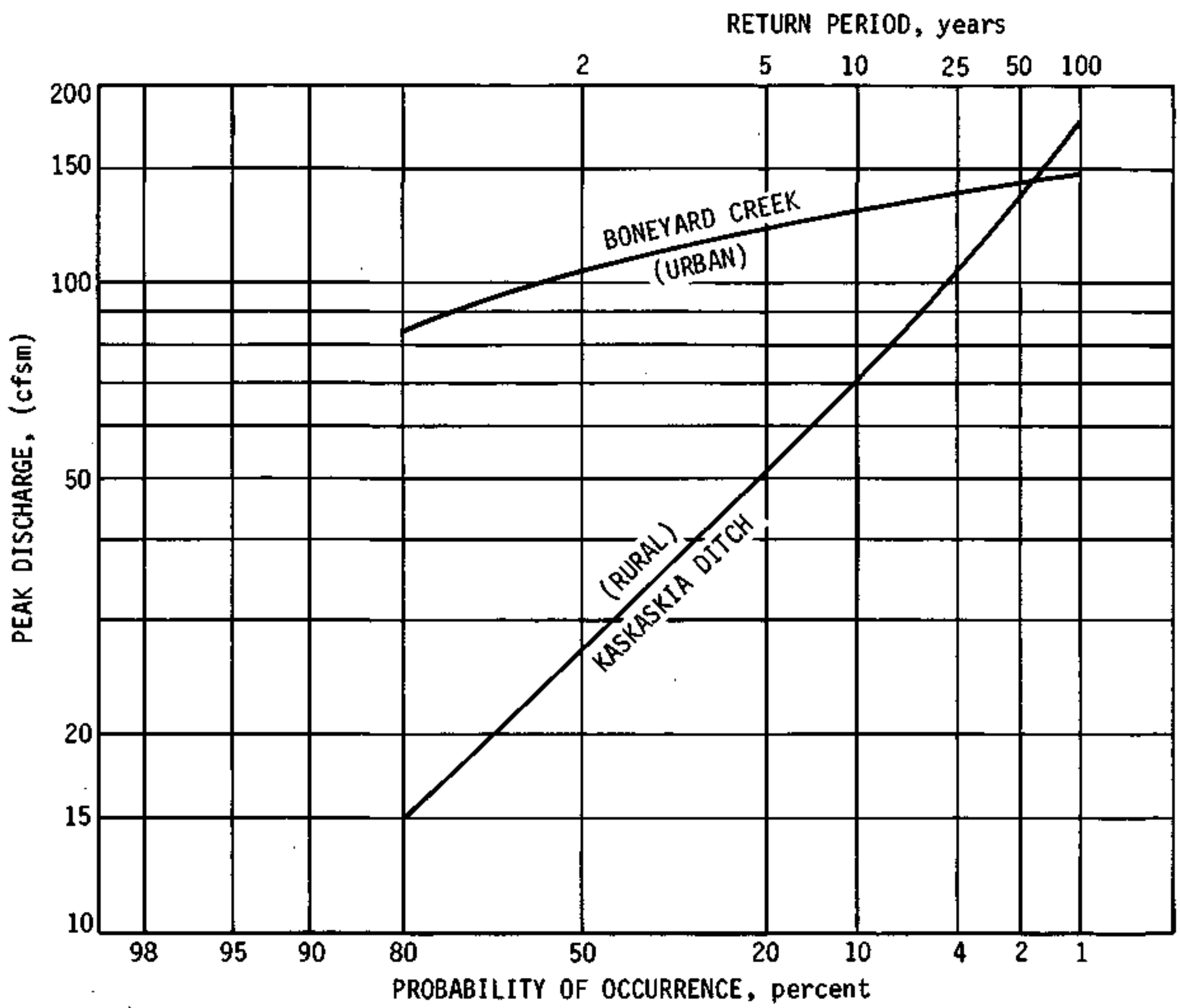


Figure 25. Observed Peak-Frequency curves on Boneyard Creek and Kaskaskia Ditch in Champaign Co. IL

Bed Slope 11 ft/ml
Station Skew - 0.698

Kaskaskla Ditch Rural
Drainage Area 12.4 ml^2
Period of Record 1948-1975
Bed Slope 15 ft/mi
Station Skew + 0.413

The basins are only about 10 miles apart, are both quite flat and are predominantly hydrologic group B soils. The only difference appears to be the conventional urbanization on Boneyard Creek. The creation of inadvertent detention storage during the development of the Boneyard Basin can be attested to by many residents. Large areas of the basin are subject to frequent short duration flooding. The conventional urbanization of the Boneyard Basin has had the same effect on the frequency curves in figure 25 as was demonstrated by ILLUDAS on the Pox River Tributary No. 2 Basin (figure 22).

Forest and Natural Detention

The results shown in this section are representative of real conventional urbanization of a well drained agricultural basin in Illinois. No attempt was made to determine similar effects on forested watersheds. Because the urbanization of forested watersheds in Illinois is relatively rare, this does not appear to be a major problem. The beneficial effect of returning agricultural lands back to forest in terms of runoff peak and volume reduction, however, are probably quite significant and deserve further attention.

One major exception to the results presented in this section is an agricultural or natural basin with significant natural detention. Many such basins exist in Northeast Illinois. These are usually quite flat and swampy and may contain year round marshy areas. The effect of removing these natural detention areas by drainage and development would be significantly increased flood peaks at all frequency levels. Although the subject will not be treated in this study, it is obviously very desirable to preserve such areas in future urban development for detention purposes.

Alternatives to Increasing Peak Plows

For some time it has been recognized that conventional urbanization increases peak rates of storm runoff for two reasons. The most obvious reason is the increase in paved area that tends to increase the volume of runoff. This larger volume of water is then concentrated more quickly by a more efficient hydraulic system which is the other reason for the increase. Until the advent of digital simulation models it was difficult to separate the effects of channel improvements for those of increased impervious area.

James (1965) called these principle variables the percent of the area urbanized and the percent of the channels improved. Using the Stanford Watershed Model he was able to show the relative effect of these variables. Using data developed by James and others, Leopold (1968) plotted percent of area sewered against percent of area impervious as in figure 26. The lines represent the ratio of the mean annual flood after urbanization to the mean annual flood before urbanization. The origin in figure 26 represents a natural or rural basin.

The distinction between a natural or rural basin is important, particularly if the rural basin happens to be in a grain producing area. Because our interest in this paper has been in the urbanization of agricultural basins typical to Illinois, figure 26 will be examined in that perspective. Assuming that the origin of figure 26 represents row-crop lands, both the ordinate and the abscissa may be extended in negative directions as in figure 27. Since the percent sewered area on the ordinate is inversely proportional to concentration time, the ordinate may be extended downward by using increasing concentration time as the scale.

Since the abscissa represents the replacement of row-crop lands with paved area in the positive direction, it seems reasonable to represent the replacement of row-crop lands with grass in the negative direction. A two dimensional space is thus defined with the agricultural basin as its center. The next step will be to define a simple hypothetical agricultural basin and use ILLUDAS to fill in all four of the quadrants in figure 27 with ratios of the altered flood peak to the agricultural peak.

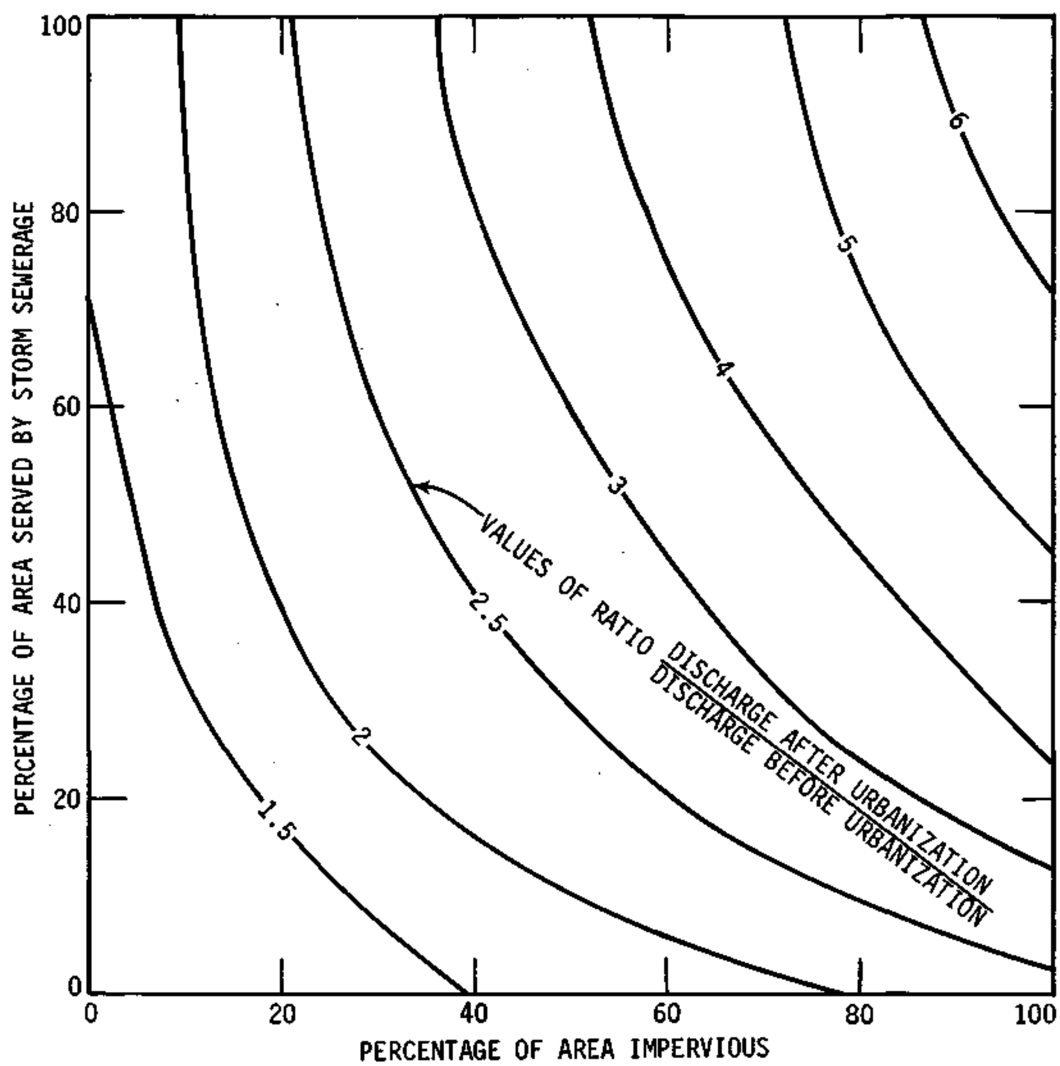


Figure 26. Ratio of modified to natural peal discharge rates for the mean annual flood-Leopold (1968)

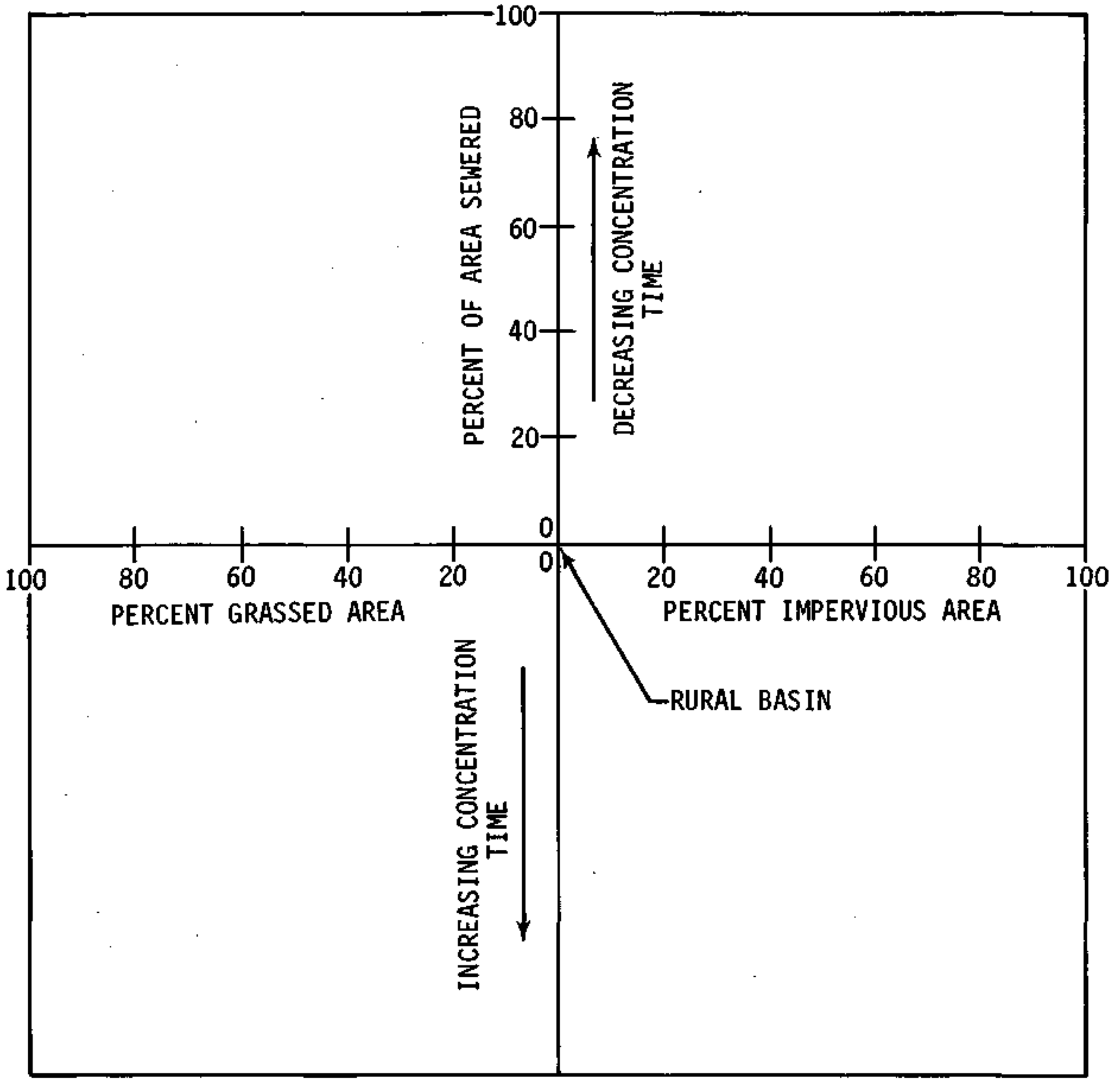


Figure 27. Scale extensions used to show all possible options in the development of a rural basin.

The basin to be modeled will consist of 20 acres and will be treated as one sub-basin so that routing will not be a factor. For the agricultural condition (the origin of figure 27) a time of concentration of 50 minutes will be used. This is based on an average overland flow velocity of 0.5 fps and a flow path of 1500 feet. It can be assumed that decreases in this time would be caused by the installation of storm drain systems and channels improvements associated with conventional urbanization. Increases in the time of concentration would be caused primarily by providing detention storage. The average residency or flow through time in the detention basin would add directly to the time of concentration. Later the volume of detention will be superimposed on the ordinate scale.

In order to establish actual basin conditions along the abscissa of figure 27, some rules must be established. There is no problem in the negative direction because row crop lands are simply being replaced with grass cover. In the positive direction, however, row crops are being replaced with both paved area and bluegrass. The proportions of paved area to bluegrass must therefore be established. Based on the authors experience with actual developments, it will be assumed that row crops will be replaced with 2 parts grass and 1 part paved area until all row crop is gone. At that point the basin will be two-thirds grass and one-third paved. As urbanization continues, grassed area will be replaced with paved area until the basin is all pav

Having described the meaning of the variables used on the scales of figure 27, ILLUDAS will be applied to the conceptual 20 acre basin. Peak rates of runoff were generated for the following watershed conditions:

1. 100% Grass
2. 50% Grass 50% Row Crop
3. 100% Row Crop (Rural)
4. 33% Paved 66% Grass (Residential)
5. 60% Paved 40% Grass (Apartments)
6. 75% Paved 25% Grass (Commercial)
7. 100% Paved

For each of these conditions, times of concentration of 10, 30, 50, 70, 90, 120, and 180 minutes were assigned. The peak flows were then expressed as a ratio to the rural condition and plotted on the scales described in figure 27. Figure 28 shows such a plot for the 2 year return period rainfall. The positions of the lines shown were determined by interpolation between the computed points.

The upper right quadrant of figure 28 is in general agreement with figure 26. Of importance is the complete picture provided by figure 28. Clearly illustrated are man's options in the development of an agricultural basin. In this example, as the agricultural basin goes to 50 percent paved, the peak would double if the time of concentration were cut in half. The peak could be kept the same if the time of concentration were increased from 50 to 70 minutes. The importance of grassed area in reducing peak runoff is apparent in this plot. The agricultural peak could be eut in half by replacing 40 percent of the row crop with bluegrass.

The effectiveness of detention storage in increasing time of concentration and decreasing peak flow is illustrated by the detention storage scale superimposed on the ordinate in figure 28. On this 20 acre basin, 0.1 inch of storage is equivalent to 71000 ft^3.

Figure 29 was developed exactly as figure 28 using a 100 year rainfall event. The slope of the lines is much flatter in figure 29 indicating less sensitivity of the land use factor at the 100 year level; that is, during heavy rainfall all land uses tend to produce about the same runoff.

The slight bump in the curves illustrates again that grassed area in sufficient amounts can more than compensate for paved area. The detention storage scale indicates that much larger volumes of storage are required at the 100 year level than at the 2 year level for equivalent reductions in peak flow.

To picture the effects of urbanization on peak flows in their simplest form it is convenient to think in terms of two basic variables. Time of concentration appears to be one convenient variable to use. Since land use, the abscissa in figures 26 and 28 is obviously related to runoff ratio, concentration time and runoff ratio might be good variables to consider. There

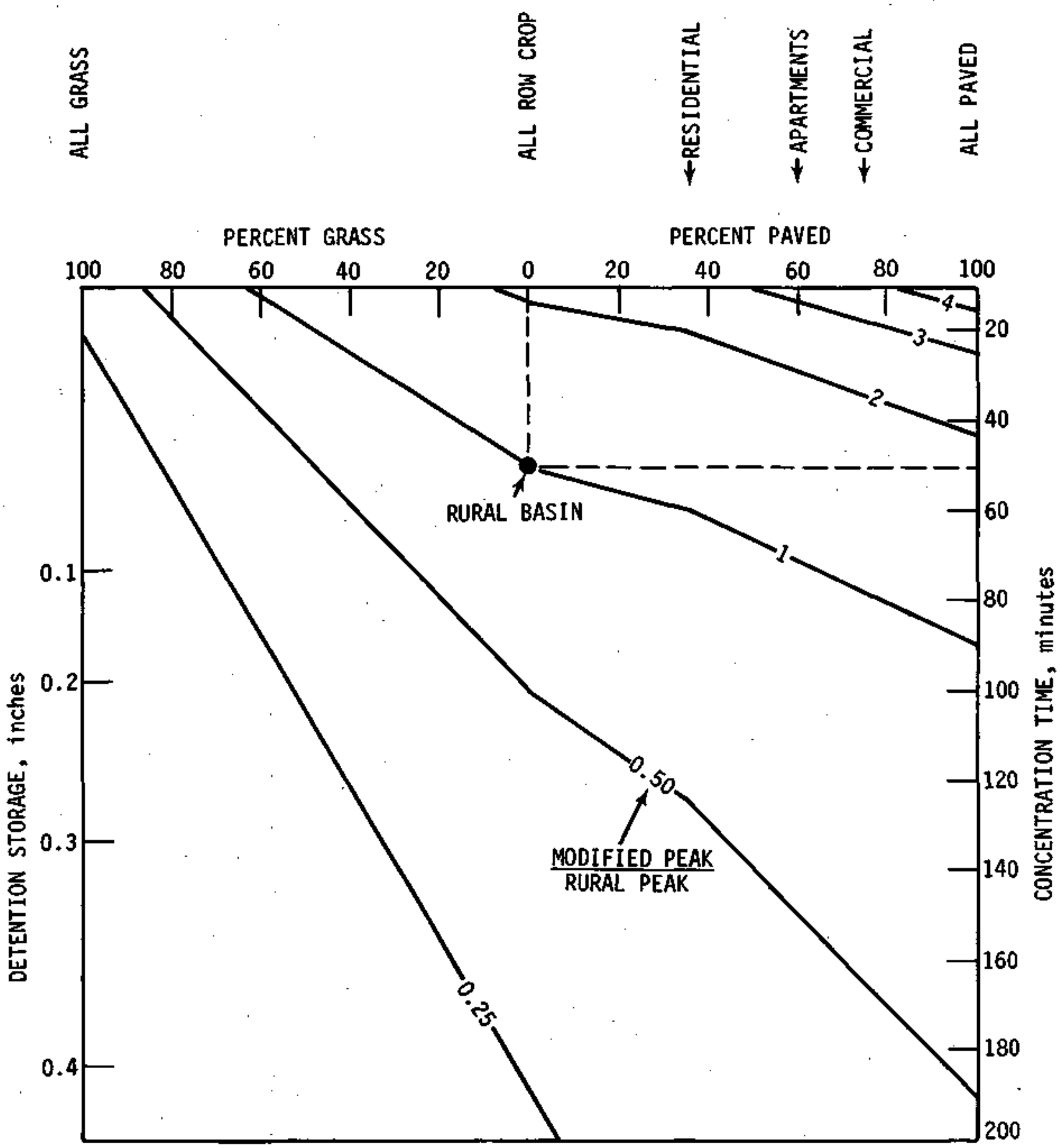


Figure 28. Ratio of modified to rural peak for 2 year rainfall events on a 20 acre hypothetical basin.

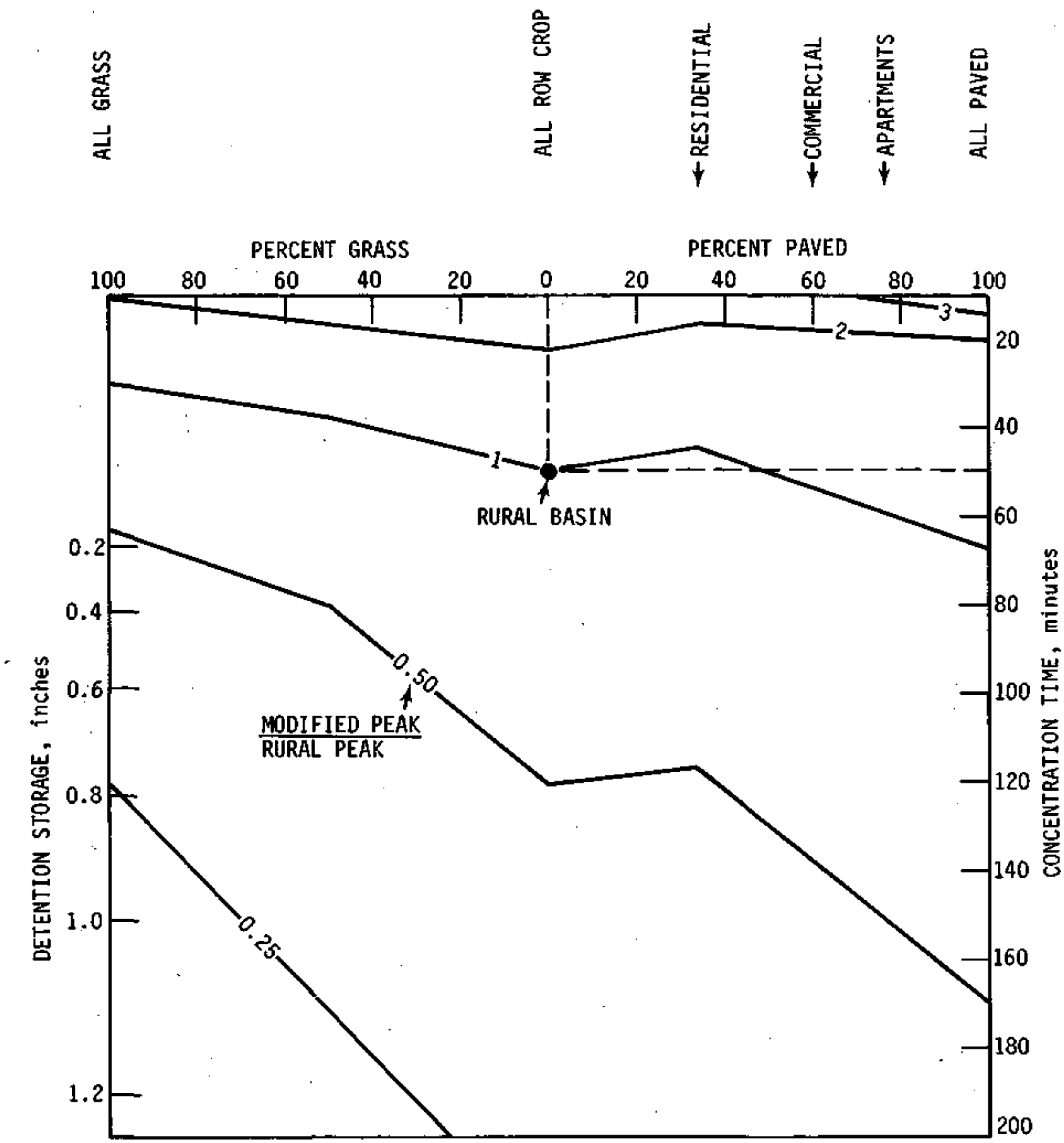


Figure 29. Ratio of modified to rural peak for 100 year rainfall events on a 20 acre hypothetical basin.

is of course a very complex interrelationship between runoff ratio and time of concentration.

The convenience of this simple rule is that almost any change in a watershed, whether natural or manmade can be intuitively related to one of these two simple variables. Thus if the goal is to reduce peak runoff, measures should be taken that will reduce the runoff ratio and increase the time of concentration. In a recent publication by the Soil Conservation Service, (SCS-1975) advantages and disadvantages of 17 runoff reducing and delaying measures are examined.

Conclusions

1. Not all types of conventional urbanization cause increases in the 100 year peak runoff. When row crop areas are replaced by low density residential developments the annual peaks will increase but the peaks of 10 to 100 year events may decrease.
2. Grassed area and its high infiltration rate can in sufficient amounts compensate for increased paved area as a basin develops.
3. Detention storage is a very effective means of reducing peak rates of runoff. Even when it is provided inadvertently during conventional development it can provide significant reduction in peak flows. Inadvertent detention in developed areas comes from underdesigned storm drains, underdesigned inlets, debris blocked inlets and storm drains, and development of flat lawns and recreational areas.
4. Detention storage should not be required in all new developments since some residential developments may actually decrease flood peaks.
5. The modified ILLUDAS program can be used to represent agricultural basins in Illinois, but it should not be used without calibration.
6. All of the variables involved in the effects of urbanization on peak rates of runoff can be related to two general variables; runoff ratio and time of concentration. Peaks may be reduced by decreasing runoff ratios or increasing time of concentration.

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