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HYDROLOGICAL MODEL PROJECT — AGRICULTURAL WATERSHED STUDIES

HYDROLOGICAL MODEL PROJECT

FINAL REPORT

PLUARG TASK C PHASE II

Agricultural Watershed Studies

Project 1.15

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Data for the project has been made available from several sources. Precipitation data has been provided by M. Sanderson of the University of Windsor for 1975 and 1976. Additional precipitation data was supplied by D. Coote of Agriculture Canada and by the Atmospheric Environment Service. Mr. D. Kimmet of the Water Survey of Canada office in Guelph has been helpful in supplying most of the streamflow data used for Canagagigue and East Canagagigue creeks. The Ontario Ministry of the Environment has provided flowrate data for Holiday Creek (AG-5).

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SUMMARY

A storm-event watershed model has been developed. The model has been named the GAWSER (Guelph Agricultural Watershed Storm-Event Runoff) model and a users manual has been produced for it. The model produces stream flowrate hydrographs from rainfall and/or snowmelt intensity inputs. Two components of storm runoff are computed by the model. These are surface (overland) runoff and subsurface storm runoff. Flow in drainage tiles is included in, and is likely a major part of, subsurface storm runoff.

An empirical infiltration equation developed by Holtan et al (1975) is used in the model to specify the variation of infiltration capacity with soil and cover type and with soil water content in the first few centimeters of soil depth. Seasonal variation in infiltration capacity is also allowed for. In the analysis of a storm event the infiltration capacity specification for a soil type is used to separate water at the soil surface into water available for surface runoff and water which enters the soil. Following this the overland runoff flowrates at the outlet of subwatersheds are calculated. The calculation is done by convoluting the point rates of surface runoff generation with the area-time^{-1} versus time curve for each soil type within the subwatershed. Subwatersheds of about 5Km^2 were used. Four soil types plus an impermeable area category (roads, ditches and streams) can be allowed for within each subwatershed. Calculations for flow between soil layers results in the calculated subsurface runoff flowrates for each subwatershed.

The routing and combining of subwatershed hydrographs to produce the total storm flowrate hydrograph at the downstream end of the watershed is done using a slight modification of HYMO procedures as developed by Williams and Hann Jr. (1973).

The GAWSER model has been applied to the Canagagigue (AG-4), East Canagagigue and Holiday Creek (AG-5) watersheds. The final project report includes information on the soil properties, channel configurations and routing reaches used in the analysis of storm hydrographs.

Storm events selected for analysis cover a variety of storm types. The storms analysed were principally rain-input events although some snowmelt input is included in a few. The reduced reliability of streamflow flowrates during events involving ice breakup, and the absence of snowpack data, led to a decision not to attempt any extensive analysis of flowrate-peak events caused principally by snowmelt. The period from which storms were selected for analysis covers the months from March through December of the years 1970 through 1976 for the two Canagagigue watersheds and of the years 1975 and 1976 for the Holiday Creek watershed.

The results show the variability of storm runoff generation due to seasons and soil types and rain intensity variations on all three watersheds. Most summer storms and many fall storms produce small storm

runoff due to a high soil-water deficit on all soil types. For some storms, even with daily rain totals above 50 mm, storm runoff is only generated from the stream surfaces and adjoining roads and ditches and is very small when expressed as a depth over the entire watershed area. Spring period storms and late fall and winter storms usually produce more storm runoff.

The proportion of overland runoff in total storm runoff also shows seasonal trends. For the large winter and spring runoff events surface runoff is often about half of the total storm runoff. For smaller runoff events in this period surface runoff is less than half of the total. In summer storms, surface runoff is commonly a larger proportion of total storm runoff and occasionally all storm runoff is surface runoff. The small total storm runoff amounts in summer storms must be kept in mind however.

The areal distribution of surface runoff which was obtained in the three watersheds studied reflects the assumptions made in the setting of soil water properties of the soils. The plausible structure governing the distribution of soil properties was that well-drained soils would be drier at the start of most storms and would have larger storage capacities than poorly drained soils. The correctness of the assumption on soil properties was judged by the overall fit obtained between observed and calculated storm hydrographs.

The results obtained for runoff amounts in the storms analysed illustrate a difference in response of well-drained and less well-drained soils.

Watershed & Soil Type	No Storms Analysed (No.of storms)	Overland Runoff Amounts > 3 mm (No.ofstorms)	> 10 mm (No.ofstorms)
Canagagigue (AG-4)			
Well-drained silt loam (67% of watershed)	30	8	3
Poorly-drained silt loam & muck (30% of watershed)	30	23	13
East Canagagigue			
Extremely well-drained sandy loam (23% of watershed)	29	4	2
Well-drained silt loam (60% of watershed)	29	10	2
Poorly-drained silt loam & muck (14% of watershed)	29	24	15
Holiday (AG-5)			
Well-drained silt loam (61% of watershed)	11	3	2
Poorly-drained silt loam & muck (36% of watershed)	11	8	4

The results from the model show the less well-drained silt-loam soils produced significant overland runoff about two and a half times more frequently than well-drained, silt-loam soils and about six times more frequently than sandy, well-drained soils. The soils lumped into the less well-drained category cover between 14 and 36 percent of the watersheds studied. This is an upper limit for the proportion of the area really active in overland flow generation. The poorly-drained soils are generally located in close proximity to stream channels.

The more frequent overland runoff generation on poorly-drained soils is directly related to the lower infiltration capacities which have been estimated for these soils as compared to better-drained soils. On the East Canagagigue watershed the end-of-storm infiltration capacity for sandy soils ranged from 4 mm hr^{-1} for large spring storms to 30 mm hr^{-1} at the end of moderate summer storms. For well-drained silt loam soils the range was 2 mm hr^{-1} to 25 mm hr^{-1} while for poorly-drained silt-loam soils the range was 1 mm hr^{-1} to 15 mm hr^{-1}. Canagagigue Creek and Holiday Creek values were similar to the latter two sets of values. The seasonal variation in infiltration capacity, with high summer values, is due to generally large soil-water deficits in the summer together with complete vegetative cover as contrasted with bare soils at planting time.

The more frequent generation of overland runoff on less well-drained soils does not mean they are the only source of overland flow. During prolonged, high-intensity summer storms, such as the August 13, 1976 storm on Holiday Creek, almost all the watershed area produces overland flow. It is also to be expected that during snowmelt period runoff extensive overland flow generation will occur, especially if surface soils are frozen or covered with an ice layer.

The distribution of percolation between subsurface storm runoff and input to deeper groundwater flow systems also varied seasonally. In mid summer about 40 percent of Canagagigue watershed area contributes to subsurface storm runoff while in the spring this proportion rises to 80 percent in large storms. The same trend occurs in the other two watersheds. The summertime proportion corresponds closely to the proportion of the Canagagigue watershed which was found to be systematically tiled as measured in a detailed farm-by-farm survey in 1976.

The results of this project indicate that remedial measures for control of overland-flow contributions to stream pollution must take into account areal and seasonal variation in the generation of overland storm runoff. Measures intended to apply in the growing season should be directed first to poorly-drained soil areas near streams as these areas produce overland runoff most frequently. It must also be noted that measures which relate only to the June through September period will be limited in direct effectiveness by the small probability of significant storm runoff reaching streams in this period.

Measures to control overland runoff from large summer storms, and from smaller snowmelt period events, would have to account for the likelihood of some widespread overland runoff generation in these events. Also the considerable volume of subsurface storm runoff, especially from spring and winter storms, must be allowed for in the accounting for nutrient and other pollution reduction.

This study has not examined in any depth the generation of overland runoff during the main snowmelt period. Events analysed which came from the end of the snowmelt period, and early winter thaw and rain events, show very low infiltration capacities even under conditions of unfrozen soil. In view of the large amount of total streamflow which occurs as a result of snowmelt-period events, we recommend continued study of overland flow generation and soil erosion processes in this critical period. Other areas which require further study are the development of better methods to delineate low infiltration capacity soils and examination of the effects of tile drainage on infiltration capacities of soils.

INTRODUCTION

This project resulted in the development of a hydrological model for storm runoff events for small (20 km^2) agricultural watersheds. The model attributes surface runoff amounts to specific land surfaces within the watershed. The model was developed for and applied to the watersheds of Canagagigue Creek (AG-4), Holiday Creek (AG-5) and East Canagagigue Creek. The name GAWSER (Guelph Agricultural Watershed Storm Event Runoff) was given to the model. A users manual has been published (Ghate and Whiteley, 1977).

The storm-by-storm areal distribution of surface runoff as determined from the model provides information about the frequency of runoff and the location of areas most subject to erosion. Combining this information with the results of related projects at the University of Guelph which deal with erosion amounts, the nutrient content of sediment and the fate of suspended sediment in the stream it is possible to specify which watershed areas are most productive of sediment and under what storm conditions sediment will be produced. The reasons for seasonal variation in the distribution of sediment production is revealed through analysis of storms from different seasons.

From this information the seriousness of surface runoff as a source of pollution can be assessed. Potential remedial measures can be evaluated to establish their appropriateness in relation to the source areas producing the largest and most frequent surface runoff amounts.

DATA COLLECTION

Geographic location

The hydrologic model, (GAWSER), developed under project 1.15 has been applied to three agricultural watersheds located in the Province of Ontario, Canada. The watersheds are Holiday Creek watershed (AG-5) near Embro and two branches of Canagagigue Creek near Floradale, Canagagigue (AG-4) and East Canagagigue watersheds. The watershed areas are 30.5, 18.6 and 23.5 km^2, respectively. Holiday Creek is a tributary of Thames River in Oxford County. Canagagigue Creek flows into the Grand River. Its watershed lies partly in Waterloo and partly in Wellington County.

The East Canagagigue watershed is similar to Canagagigue in topography and lies immediately east of it. The inclusion of this watershed in the project provides the opportunity to simulate the hydrographs for the same amount of rainfall and snowmelt data on adjacent watersheds with somewhat different soil-type distributions.

Watershed characteristics

Watershed boundaries were determined from the topographic maps of the watersheds and from observations made during field visits. Final location of the boundaries was reached as a concensus of observations by field visitors from this project and projects 7, 16, 17 and 19 of the Agricultural Watershed Studies.

Figures 1, 2 and 3 show the watershed maps of Canagagigue (AG-4), East Canagagigue and Holiday Creek (AG-5) watersheds. The downstream boundaries of watersheds are drawn through the location of the water level recorder at the downstream gauging station of each watershed. On Canagagigue (AG-4) and East Canagagigue Creeks the flowrate stations were operated by Water Survey of Canada. On Holiday Creek (AG-5) the Ontario Ministry of Environment collected flowrate data. Supplementary or intermediate flowrate gauging stations on Canagagigue (at cross-section 2) on East Canagagigue (cross-sections 13 and 15) and on Holiday Creek (cross-sections 4 and 14) are installed as part of projects 16, 17 and 19 of the Agricultural Watershed Studies.

Each watershed has been divided into a suitable number of subwatersheds as shown in Figures 1, 2 and 3. Subwatershed boundaries were chosen to pass through the locations of supplementary gauges. Areas of several subwatersheds along with the percentages of impervious areas have been tabulated in Table 1.

The watershed maps shown in Figures 1 to 3 show locations for several valley cross-sections of the streams. The sections were surveyed for their elevation and horizontal distance relationships. In addition, their hydraulic roughness was determined by a comparison of the section with sample values given by Chow (1959). Cross-section and hydraulic roughness data were essential to get rating curves (elevation-stage vs discharge relationships) for the sections.

CANAGAGIGUE CREEK (AG-4)

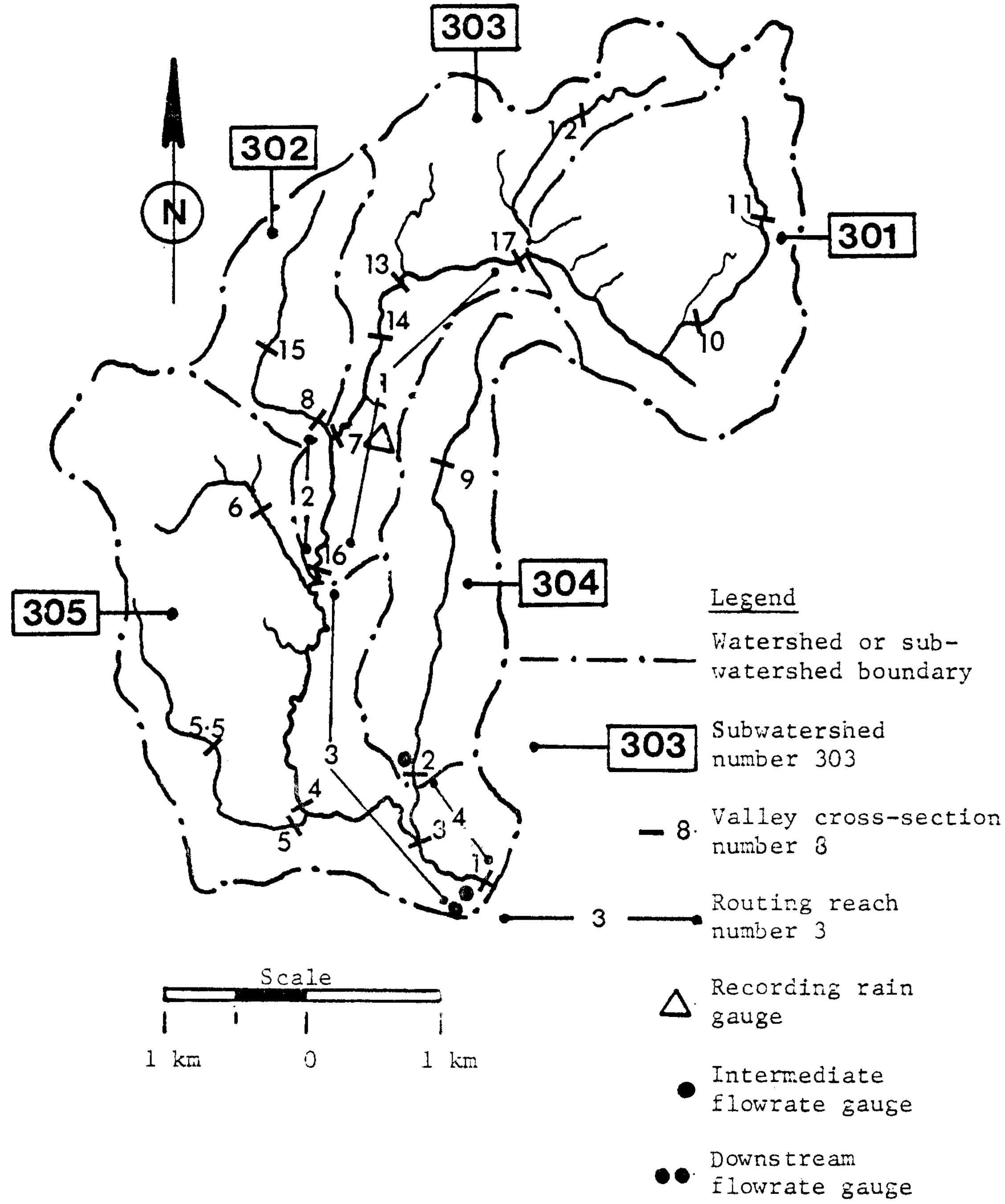

Fig. 1: Canagagigue (AG-4) Watershed
near Floradale, Ontario.

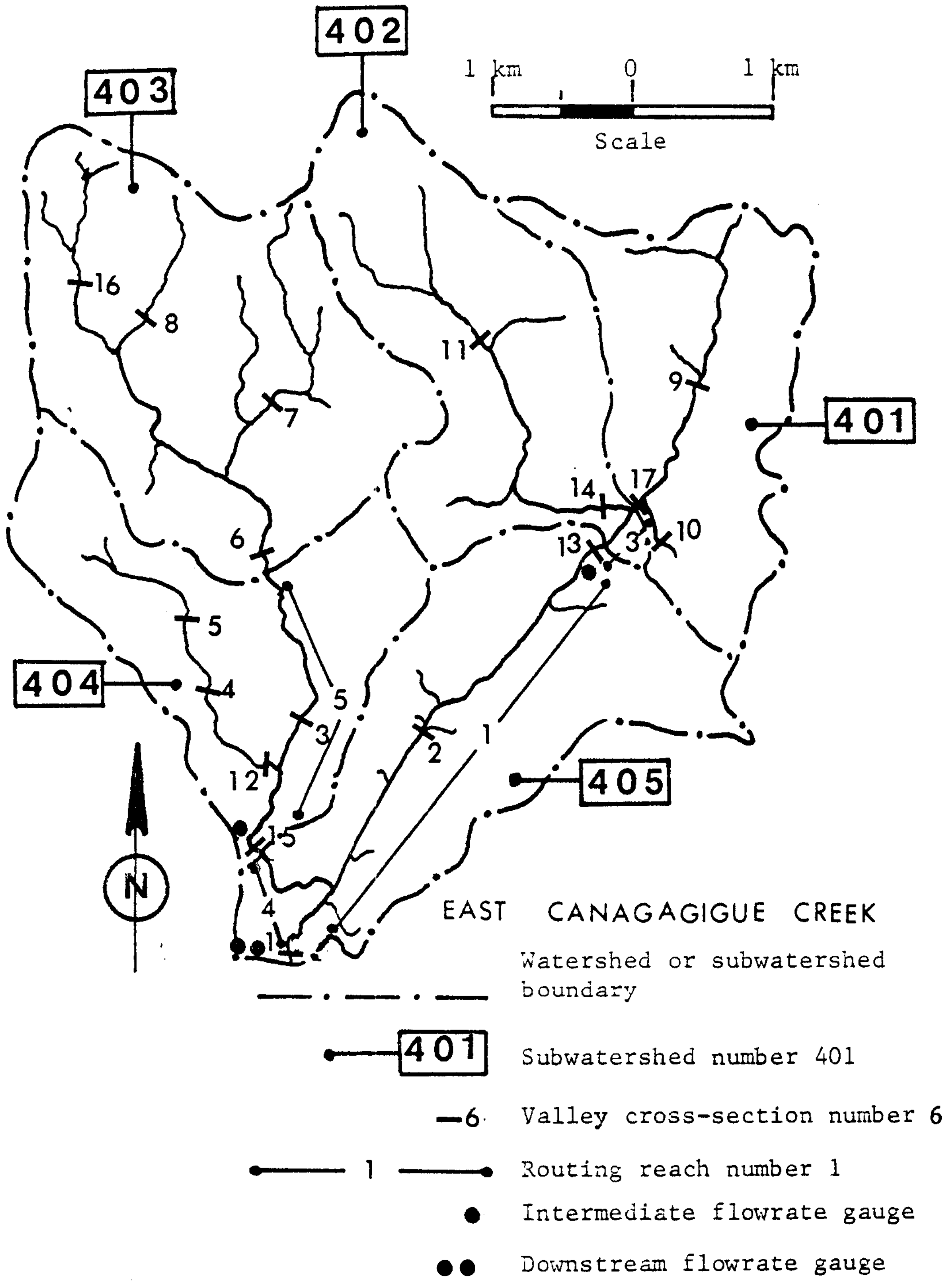

Fig. 2: East Canagagigue Watershed near Floradale, Ontario.

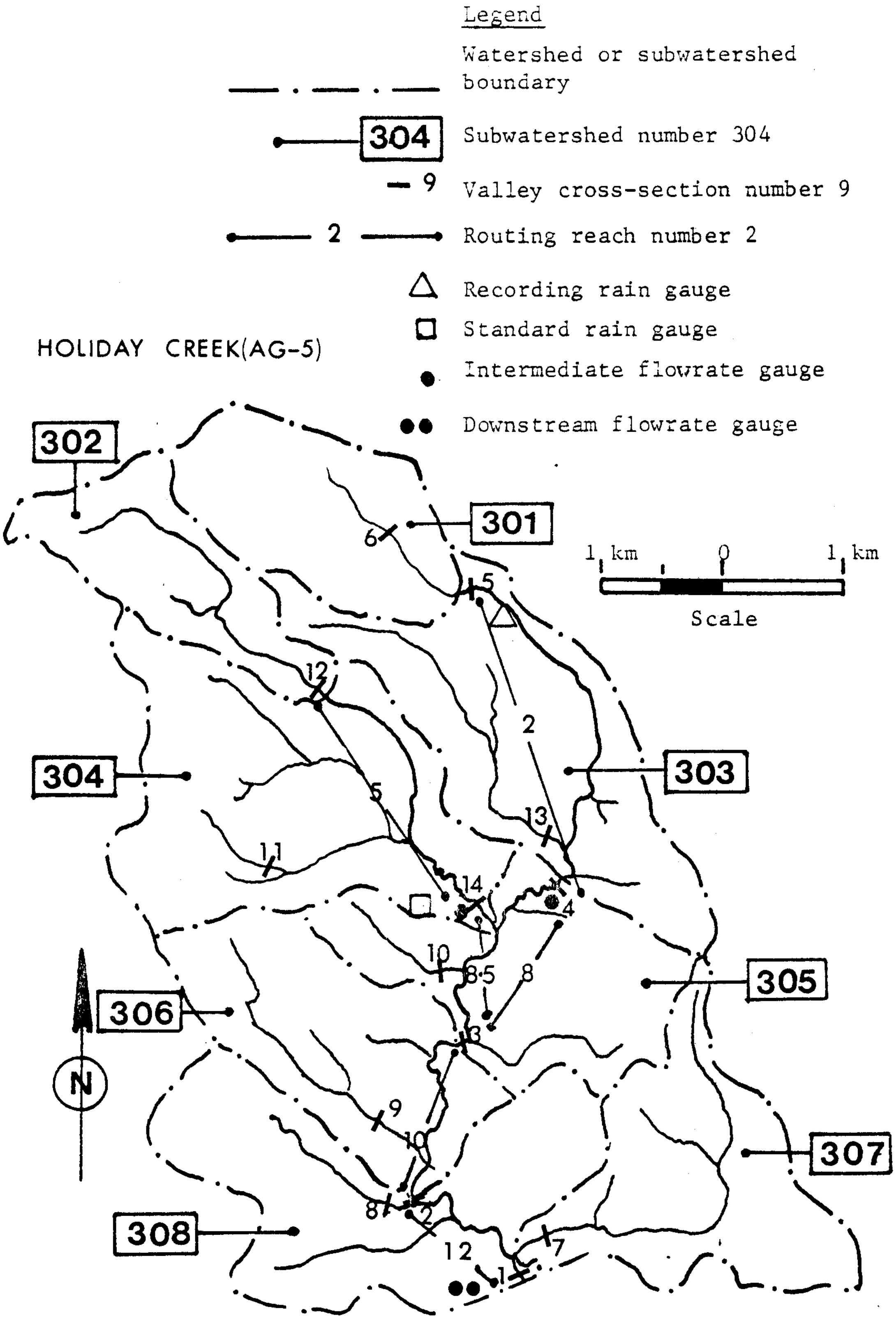

Fig. 3: Holiday Creek (AG-5) Watershed near Embro, Ontario.

The lengths of the streams and also of the roads, lanes etc., were estimated from 1:50,000 topographic maps of Canagagigue (AG-4) and East Canagagigue watersheds and from 1:25,000 topographic maps of the Holiday Creek (AG-5) watershed.

The field survey information does not include an established sea-level datum for a cross-section. The stream bed elevation for each section has been estimated from the contours on the topographic maps.

The maps shown in Figures 1 to 3 do not include the locations of roads, lanes and ditches. Their locations were noted from the topographic maps and also from the aerial photographs of the watersheds. These areas, and the areas occupied by streambeds, were assumed to be impervious since they would have almost no infiltration capacity. The impervious area was about 3% in Canagagigue (AG-4) and East Canagagigue watersheds and about 2.5% in Holiday Creek (AG-5) watershed as listed in Table 1.

The routing reaches shown on the maps are the reaches used for channel routing in the model. Their slope and length were measured from topographic maps. This data was used to calculate travel time and flow relationships for the reaches. Reach roughness was estimated as explained earlier and the flood plain roughness was taken as 0.07 for all reaches in all watersheds.

The rating curves for all valley cross-sections were determined using the HYMO program (1973). The curves for the downstream gauging stations (cross-section #1) were compared with latest rating curves available from Water Survey of Canada for both Canagagigue watersheds and from Ministry of Environment for Holiday Creek watershed (AG-5). Comparison of computed and recorded curves is given in Figures 4 to 6. The comparison of rating curves recorded and computed for intermediate gauging station was similarly done. The plots, however, are not presented in this report.

Soil types

The pervious areas of each watershed were divided into four soil types. Soil classification data are essential input to the hydrologic model. The detailed soil maps were provided by C. Acton and G. Patterson of Agriculture Canada. The soil types used in this model are shown in the soil maps of the watersheds in Figures 7 to 9.

Soil types of Canagagigue (AG-4) and Holiday Creek (AG-5) include well drained, imperfectly drained, poorly drained and very poorly drained soils. The East Canagagigue watershed has extremely well drained, well drained, imperfectly drained and very poorly drained soils. Extremely well drained and well drained soils are normally located in the upland region of the watersheds while the very poorly drained soils are usually found in the bottom land region near water courses. The distribution of soil types within the subwatersheds of each of the three watersheds studied is given in Table 2.

The above classification is very broad and is done from the point of view of hydrologic modeling data. The grouping of soils into the four types on each watershed required some lumping together of several different mapped soil types.

Table 1: Subwatershed Properties of Canagagigue (AG-4), East Canagagigue and Holiday Creek (AG-5) Watersheds

Canagagigue (AG-4)			East Canagagigue			Holiday Creek (AG-5)		
Sub-watershed number	Area, km^2	Percent of impervious area*	Sub-watershed number	Area, km^2	Percent of impervious area*	Sub-watershed number	Area, km^2	Percent of impervious area*
301	4.00	2.38	401	3.71	2.60	301	2.86	2.51
302	1.53	2.16	402	4.44	2.60	302	2.25	2.93
303	3.82	3.61	403	6.12	3.50	303	4.62	2.54
304	2.76	2.68	404	4.19	3.10	304	5.46	2.13
305	6.52	2.90	405	5.07	3.25	305	3.52	3.39
						306	3.56	3.34
						307	3.54	1.88
						308	4.72	1.55
Totals	18.63	2.84	Totals	23.53	3.06	Totals	30.53	2.45

* Includes areas of streams, roads, lanes and adjoining ditches.

Table 2: Distribution of soil types within each subwatershed for Canagagigue (Ag-4), East Canagagigue, and Holiday (Ag-5) Creeks.

WATERSHED SOIL TYPE
% of area

Canagagigue (Ag-4)

Subwatershed	Well Drained	Imperfectly Drained	Poorly Drained	Very Poorly Drained	Impervious
301	26.00	29.09	22.00	20.53	2.38
302	10.00	55.47	24.00	8.37	2.16
303	34.70	30.00	20.00	11.69	3.61
304	32.00	35.57	13.00	16.75	2.68
305	49.20	26.00	14.00	7.90	2.90
Total watershed	35.48	31.32	17.62	12.74	2.84

East Canagagigue

Subwatershed	Very Well Drained	Well Drained	Imperfectly Drained	Very Poorly Drained	Impervious
401	42.23	31.72	0.00	23.45	2.60
402	10.85	71.89	6.21	8.45	2.60
403	4.61	69.68	15.79	6.42	3.50
404	7.06	77.49	0.00	12.35	3.10
405	54.24	19.80	0.00	22.71	3.25
Total watershed	22.87	54.74	5.28	14.05	3.06

Holiday (Ag-5)

Subwatershed	Well Drained	Imperfectly Drained	Poorly Drained	Very Poorly Drained	Impervious
301	21.62	40.69	31.01	4.17	2.51
302	48.61	13.61	27.22	7.63	2.93
303	6.76	55.18	22.19	13.33	2.54
304	44.32	15.68	17.04	20.83	2.13
305	40.40	9.94	31.83	14.44	3.39
306	32.67	26.31	24.56	13.12	3.34
307	7.44	58.21	29.99	2.48	1.88
308	34.00	31.61	19.41	13.43	1.55
Watershed	29.14	31.82	24.33	12.26	2.45

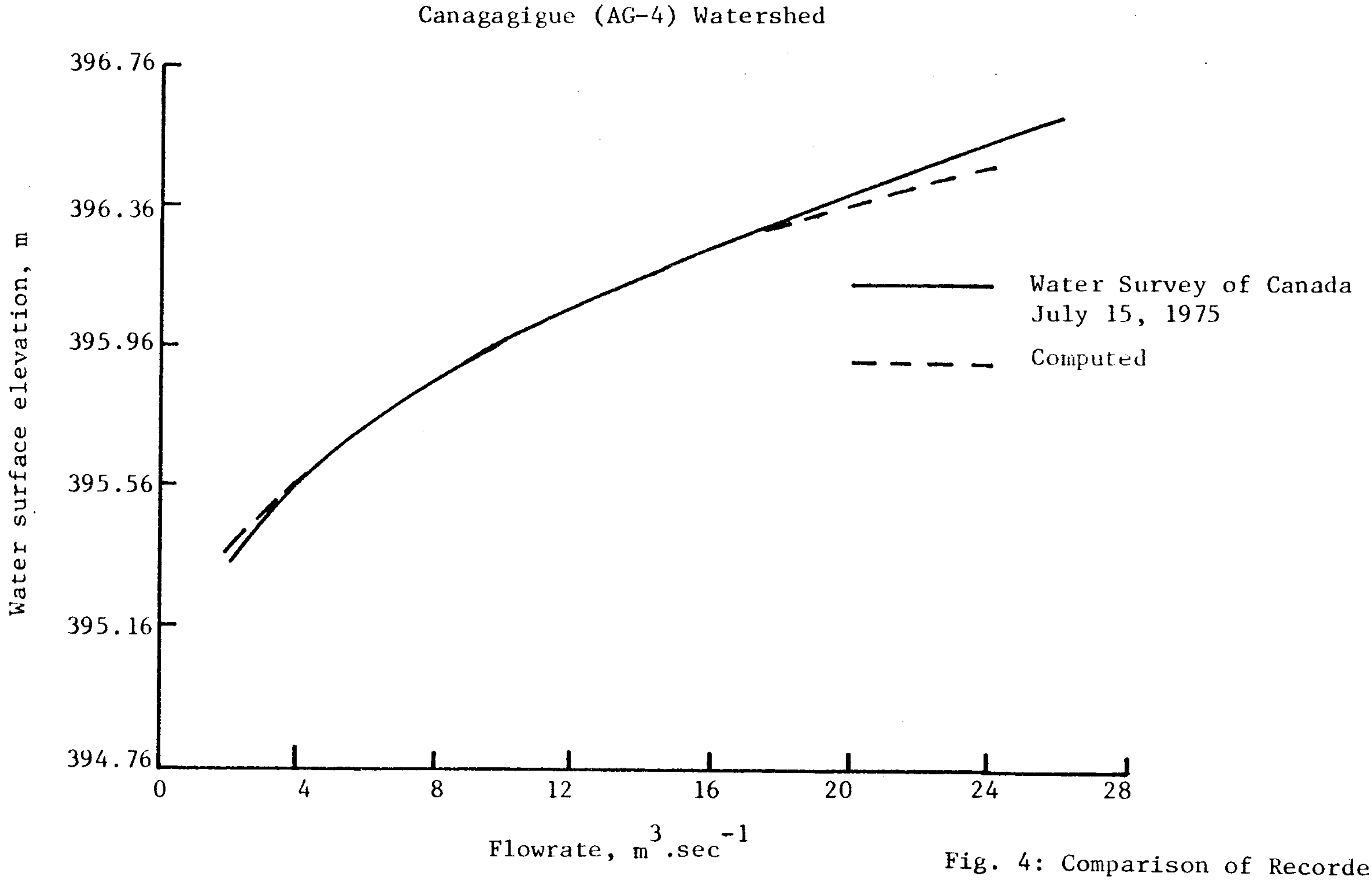

Fig. 4: Comparison of Recorded and Computed Rating Curves at the Downstream Gauging Station (at Cross-section 1) of Canagagigue (AG-4) Watershed.

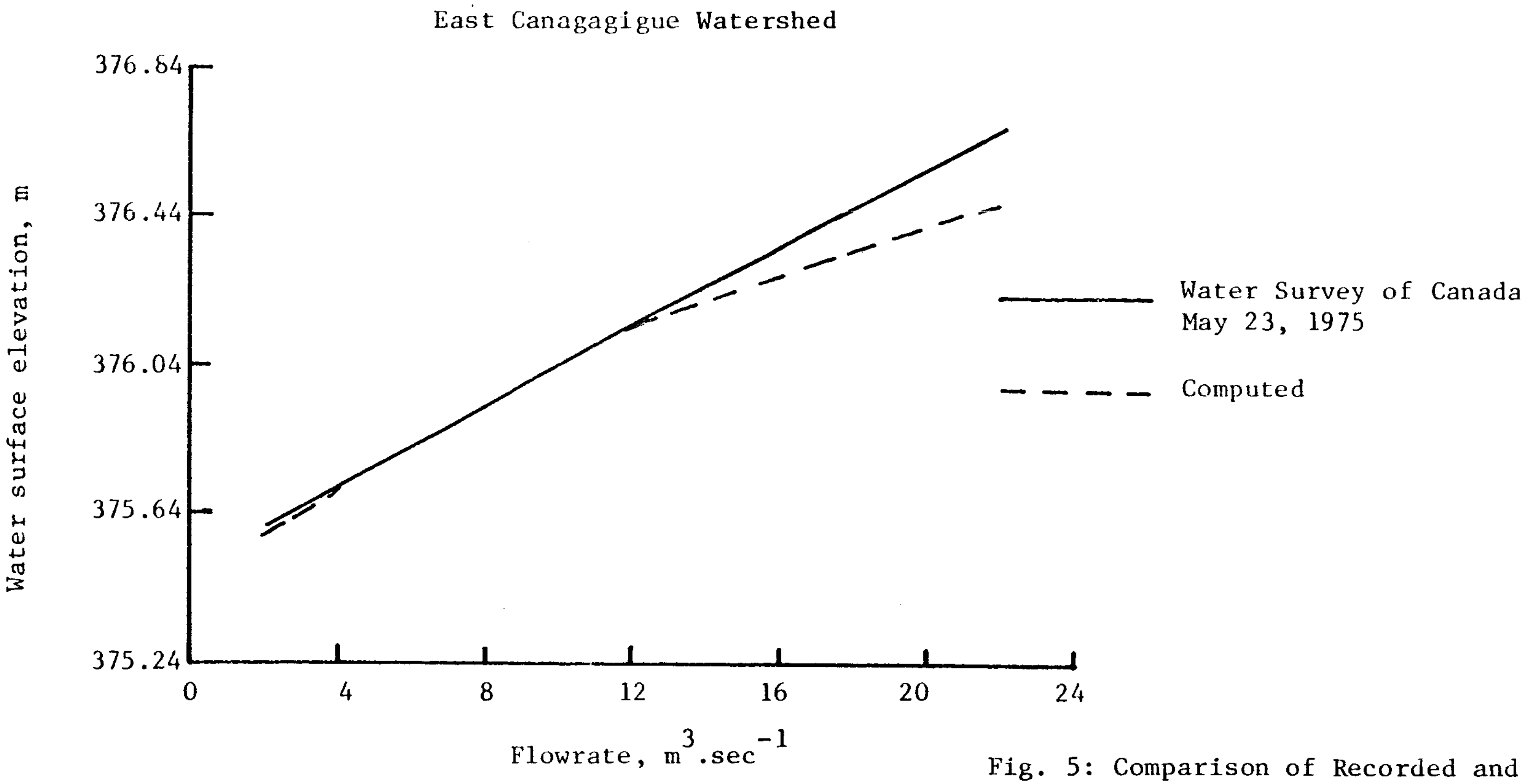

Fig. 5: Comparison of Recorded and Computed Rating Curves at the Downstream Gauging Station (at Cross-section 1) of East Canagagigue Watershed.

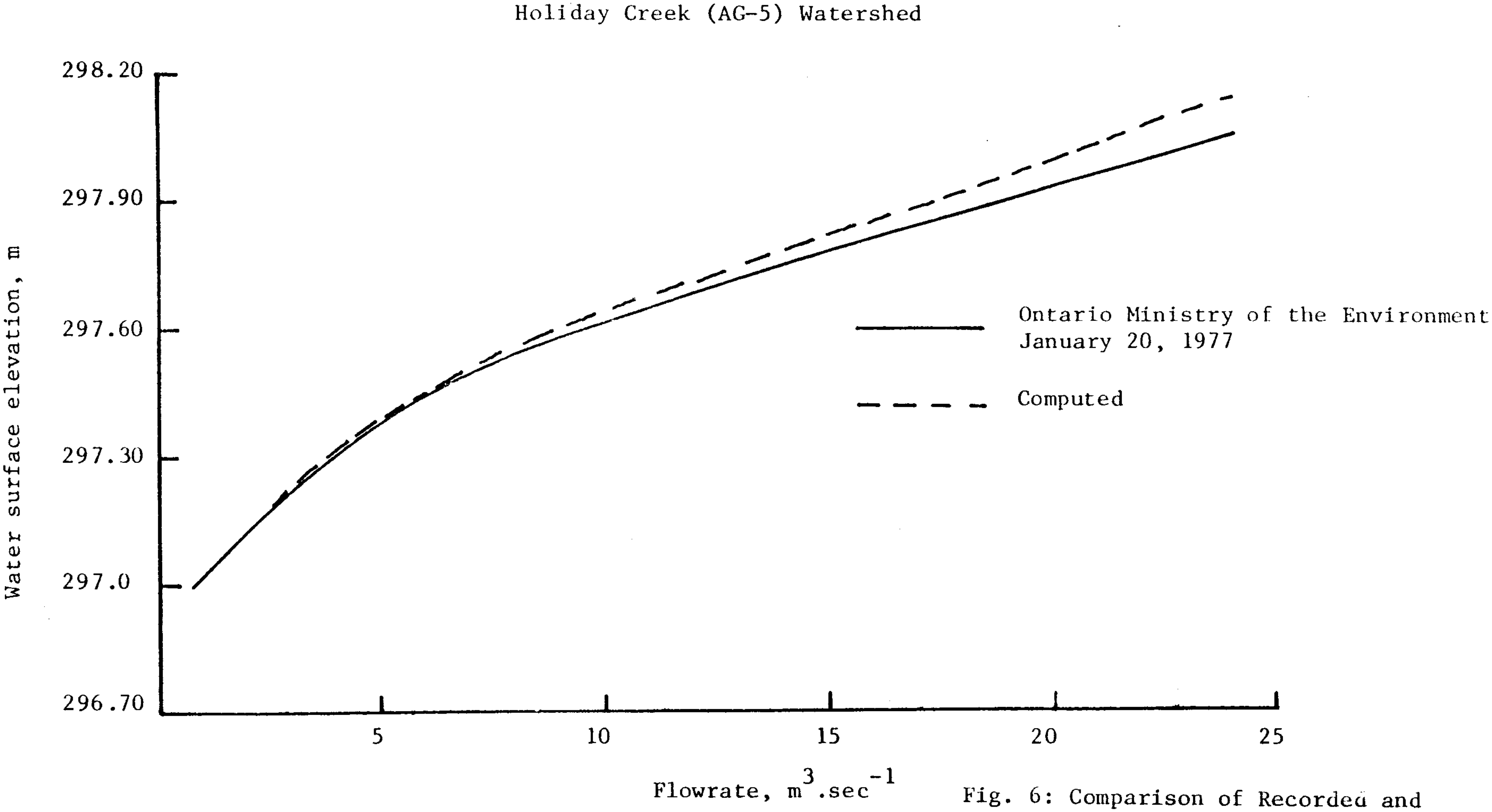

Fig. 6: Comparison of Recorded and Computed Rating Curves at the Downstream Gauging Station (at Cross-section 1) of Holiday Creek (AG-5) Watershed.

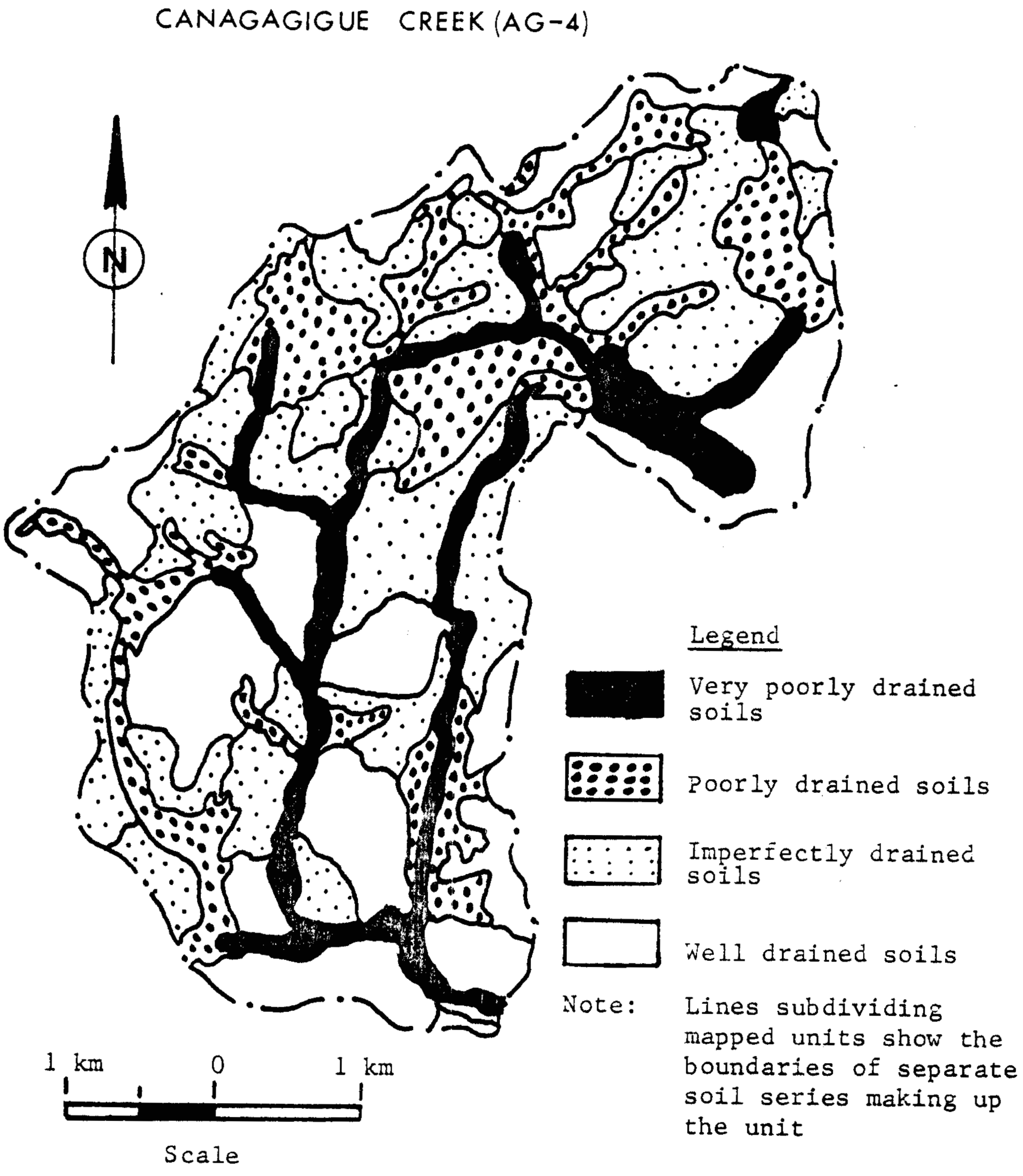

Fig. 7: Soil Map of Canagagigue (AG-4) Watershed.

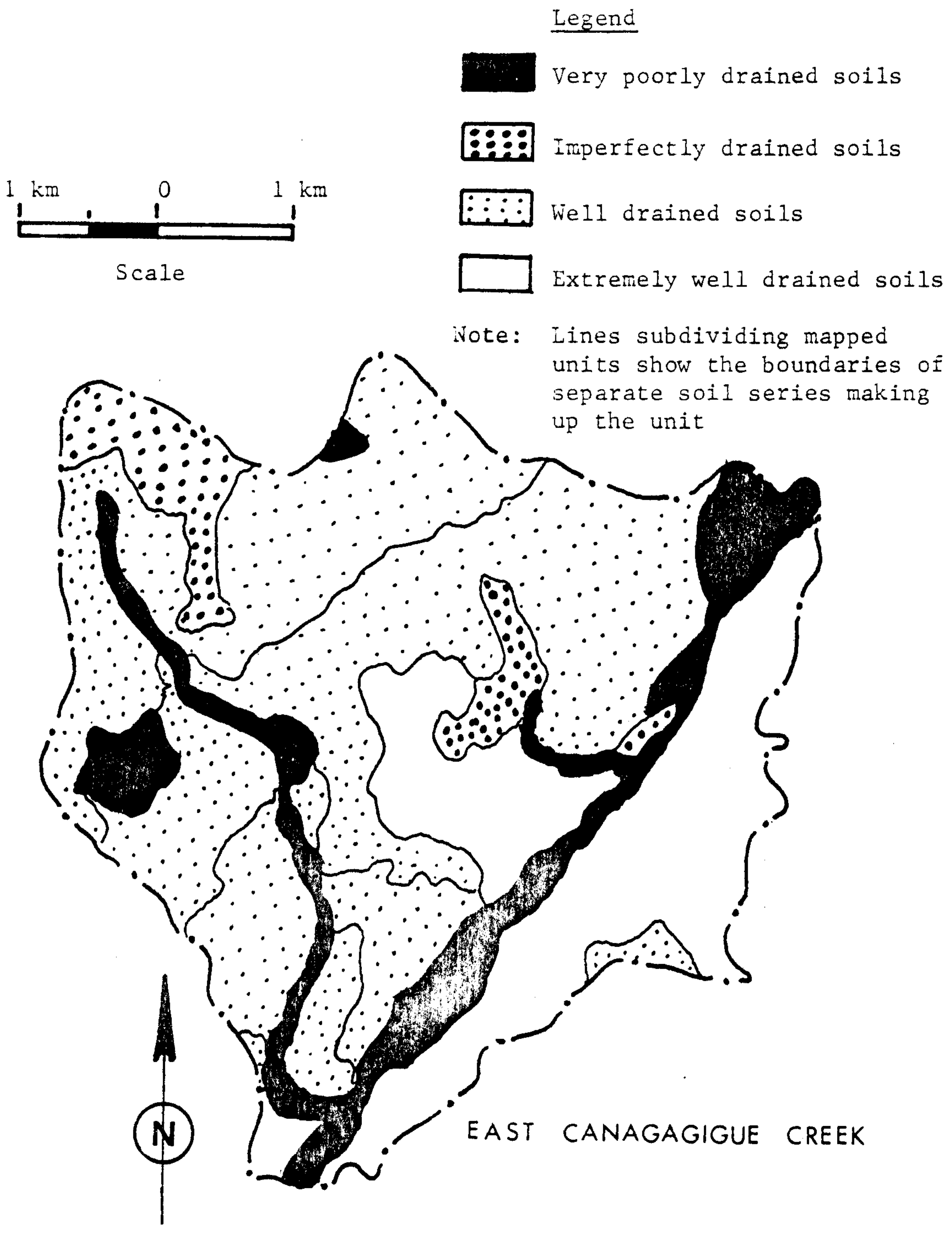

Fig. 8: Soil Map of East Canagagigue Watershed.

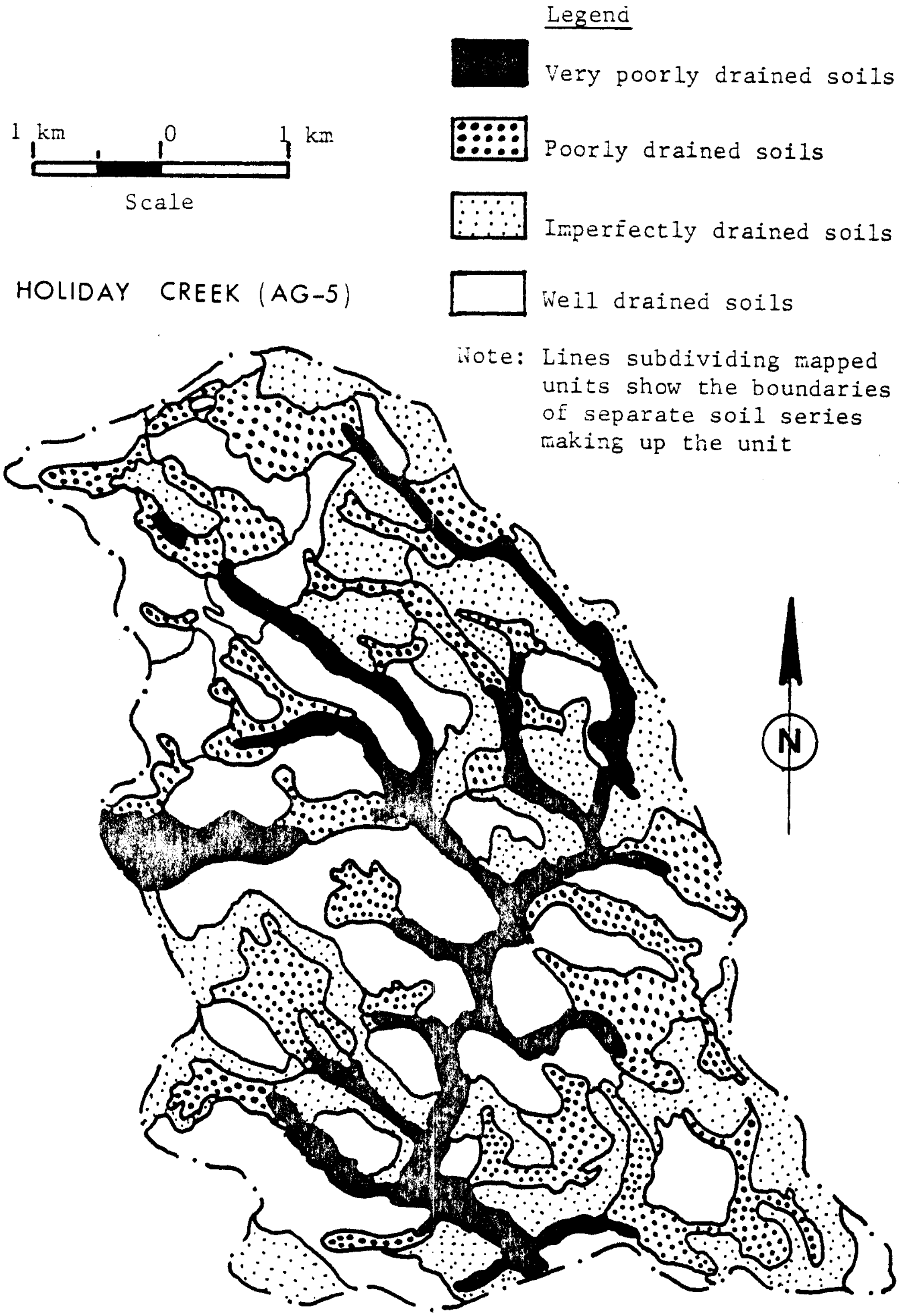

Fig. 9: Soil Map of Holiday Creek
(AG-5) Watershed.

Tiling survey

During the period May - July 1976, a farm-by-farm survey of tile drainage in the Canagagigue (AG-4) watershed was conducted. A separate map was prepared for each lot at a scale of approximately 1:4620. Information from aerial photographs and land owners and tenants was used to determine the fields which were tiled systematically, fields which contained "random" tile lines to specific wet soil depressions, and the outlet locations of tile lines.

An overlay of soil types was prepared for each lot map. From this the proportion of each soil type tiled was determined. The results obtained are summarized in Table 3.

For the predominant soil types of the area, there was not a very significant difference in the proportion tiled. The dominant silt texture of all the major soil series in the Canagagigue (AG-4) watershed appears to have led to a relatively uniform application of tiling to this watershed.

The tiling in this area was accomplished almost entirely without the construction of any municipal (collector) drains. The natural stream channels provided sufficient outlet in most cases. In some locations farmers had undertaken the enlargement of surface channels on their own without invoking the aid of government through the construction of a municipal drain.

Precipitation data

For the period from 1970 through 1973 no recording precipitation data are available for either of the Canagagigue watersheds. For this period hourly precipitation data have been obtained from the Atmospheric Environment Service for the following surrounding stations: Blue Springs Creek, Elora, Fergus Shand Dam, Mount Forest, Stratford OWRC, Waterloo, and Waterloo-Wellington Airport. In addition daily total precipitation data of the following stations were obtained: Arthur, Fergus STP, and Glen Allen. For years 1974 and 1975, precipitation records for a gauge near Floradale just outside the Canagagigue watershed were obtained. PLUARG gauge-4, a recording gauge installed on Canagagigue (AG-4) watershed, provided most of hourly rainfall data for years 1975 - 1976.

The same rain amount, taken from the recording gauge or estimated from the surrounding gauges, was used for most of events analysed on the two Canagagigue watersheds. In three cases the input was different. These three storms were highly localized thunderstorm rainfalls.

Snowmelt rates for Canagagigue watersheds were estimated from the available data of temperature, snow depth and water content in the snow at the nearby Elora Research Station. In most cases, snow depth and temperature plots were made for the days involving snowmelt. A degree hour method was then applied to estimate the snowmelt intensity. In the analysis of the March 1976 storms, however, a heat flux and

Table 3: Summary of Tiling Survey for Canagagigue (AG-4) Watershed

Soil Type	Area in Watershed, km^2	Systematic Tiling		Random Tiling	
		Area, km^2	Percent of soil area	Area, km^2	Percent of soil area
024	6.33	2.60	41.1	0.27	4.3
025	5.89	3.05	51.8	0.29	4.9
026	3.28	1.30	39.7	0.08	2.4
S.C.+D.L.*	2.09	0.31	14.6	0.03	1.4
013	0.52	0.14	26.8	0.01	1.9
037	0.45	0.004	0.9	-	-
005	0.07	0.065	87.3	-	-
Totals	18.63	7.47	40.1	0.68	3.7

* Stream course and depressed land.

radiation method was applied to compute hourly melt. Flowrates at Elmira and Woolwich dam were also analysed to confirm the validity of the melt estimate.

A recording gauge (PLUARG-5) on the Holiday Creek (AG-5) watershed provided most of rainfall data for years 1975-1976. Another standard gauge located at the watershed centre provided a comparison for total rainfall input recorded by the recording gauge. To check the uniformity of a storm, surrounding gauge totals at the stations Stratford, Tavistock, Woodstock, Folders and London Airport were also noted.

The snowmelt rates for Holiday Creek (AG-5) watershed were estimated using a degree hour method from snowdepth, water content and temperature records at London Airport Station.

Stream flow data and baseflow separation

Continuous streamflow records for the Canagagigue (AG-4) and East Canagagigue watersheds are prepared by the Water Survey of Canada for stations 02GA036 and 02GA035 respectively. From the plots of the daily mean flowrates, storm events were selected for those watersheds covering the months of March through December from 1970 to 1976. Hourly flowrates for the selected storms were supplied by Water Survey of Canada. The flowrates supplied were for the downstream gauging station (at cross-section #1) of both watersheds.

Charts of flowrates and rating curves were supplied by Ministry of Environment for the downstream gauging station (cross-section #1) of Holiday Creek (AG-5) watershed. Hourly flowrates for selected storm were derived from the supplied material. The records cover only two years 1975 and 1976.

Intermediate flowrate records for Holiday Creek (AG-5) watershed were obtained from Project No. 17 of the Agricultural Watershed Studies. The records cover mostly the late spring and summer of 1976.

To estimate baseflow flowrates for storm analysis annual plots were made of the mean daily flowrates for all three watersheds. These plots, together with rainfall times, allowed the selection of periods of uninterrupted recession of flowrate which were designated baseflow-flowrate periods. The baseflow recession time constants derived from these periods gave mean values of 6 days, 21 days and 8 days respectively for Canagagigue (AG-4), East Canagagigue, and Holiday Creek watersheds. The time constants for Canagagigue and Holiday Creek varied with season. In summer they were as little as 4 and 6 days respectively while in the late fall they were as large as 10 and 12 days respectively.

By interpolating between baseflow-only periods storm-period variations in baseflow flowrates were estimated. The time constants referred to above were used in the backward-in-time interpolation from the recession portion of hydrographs. The baseflow flowrate peak was normally assumed to occur one day after the peak in observed total flowrate. Figure 10 shows the baseflow separation that was prepared for a storm event on the Canagagigue (AG-4) watershed.

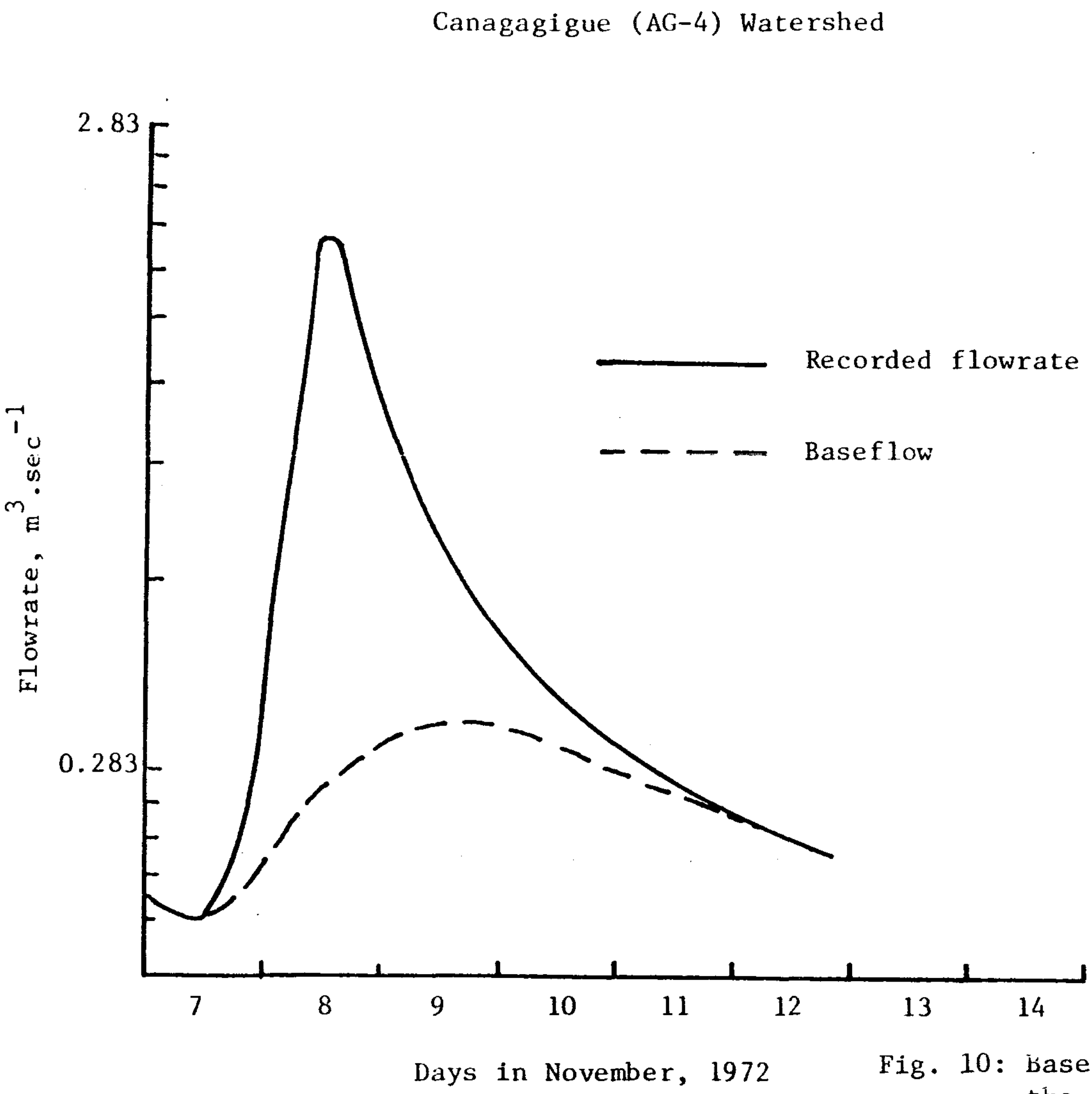

Fig. 10: Baseflow Separation from the Recorded Flowrates on Canagagigue (AG-4) Watershed during November 7, 1972 Storm.

A "storm runoff" hydrograph was prepared for each storm analysed by subtracting the baseflow flowrate from the total observed stream flowrate for each time coordinate during the storm event. The model results were compared with the separated storm runoff hydrograph.

Using the baseflow flowrates estimated over the period from July 1970 through December 1975 for the two Canagagigue watersheds estimates were made of the distribution of total streamflow between baseflow and stormflow. For the Canagagigue watershed, over this period, 30% of total flow was baseflow. For the East Canagagigue 45% of the total streamflow was baseflow. This indicates that this flow component can provide a significant input of dissolved substances into the stream for those substances whose concentrations are high in deeper groundwater flow systems.

The 70% of flow that is storm runoff from the Canagagigue watershed is concentrated seasonally. In the years 1971 through 1975 70% of annual total storm runoff occurred in March and April. This is a mean spring storm runoff depth of 200mm out of an annual mean storm runoff depth of 280mm.

The recession time constants for overland runoff and for subsurface storm runoff were approximated after examination of several storm runoff graphs from each of the three watersheds. The overland runoff constant was estimated from the steepest rate of recession of flowrates after the peak while the time constant for subsurface storm runoff was computed from the recession rates near the end of storm runoff. Estimates of the overland recession constants were 3.9, 3.6 and 6 hours respectively for Canagagigue (AG-4), East Canagagigue, and Holiday Creek (AG-5) watersheds respectively. The subsurface storm runoff constants were 27, 27 and 42 hours respectively.

FLOW CALCULATION PROCEDURES

Model concept used

A deterministic storm-event hydrologic model has been developed in this project. Attention is focused on the areas contributing to overland runoff within storm periods. The choice of an event model considerably simplifies the simulation of soil-water and ground-water. The major disadvantage of this choice is the inability of the model to compute total watershed outputs on seasonal or annual periods. The deterministic model however simulates a storm event completely and it has been possible to test it thoroughly on small agricultural watersheds.

The events analysed are characterized by one or more peaks in the flowrate hydrographs caused by periods of rain and/or snowmelt. A separate event was identified whenever a rise in flowrate occurs after a period of recession during which the flowrate has declined to less than 25% of the preceeding peak value.

Basic model structure

The basic model structure for the GAWSER model is shown in Figure 11. A watershed is divided into several subwatersheds of suitable sizes ($7km^2$ or so). Flowrates are computed for each subwatershed using the techniques described in the next section. The flowrates thus calculated for the upstream subwatershed are routed through channels and added to the next downstream subwatershed. The process is continued until the hydrograph at the most downstream section of the entire watershed has been obtained.

The GAWSER model extends the HYMO model developed by Williams and Hann (1973). Four new commands have been added to the original HYMO and some of its subroutines have been slightly modified. In addition, HYMO has been converted into SI units. The detailed rules of the GAWSER model along with program statements and sample example are given in its Users Manual (Ghate and Whiteley, 1977).

Channel and reservoir routings, adding and printing of hydrographs has been accomplished by adoption of the HYMO model. The flowrate generation method for a subwatershed is developed as explained in the following sections.

Calculation of storm-flow components on each subwatershed

Figure 12 gives the flowchart for subwatershed modeling. The rainfall or snowmelt intensity is the main input. Cumulative rainfall (or snowmelt) is given in 30 minute time steps. (This step length could be increased or decreased). Infiltration capacity rates for each 10 minute interval, (which also could be increased or decreased), are then determined. If the rainfall rate exceeds the infiltration capacity rate then the excess is considered as overland runoff after the deduction of a specified surface depression storage volume from this rainfall excess. The overland runoff from each 30 minute interval

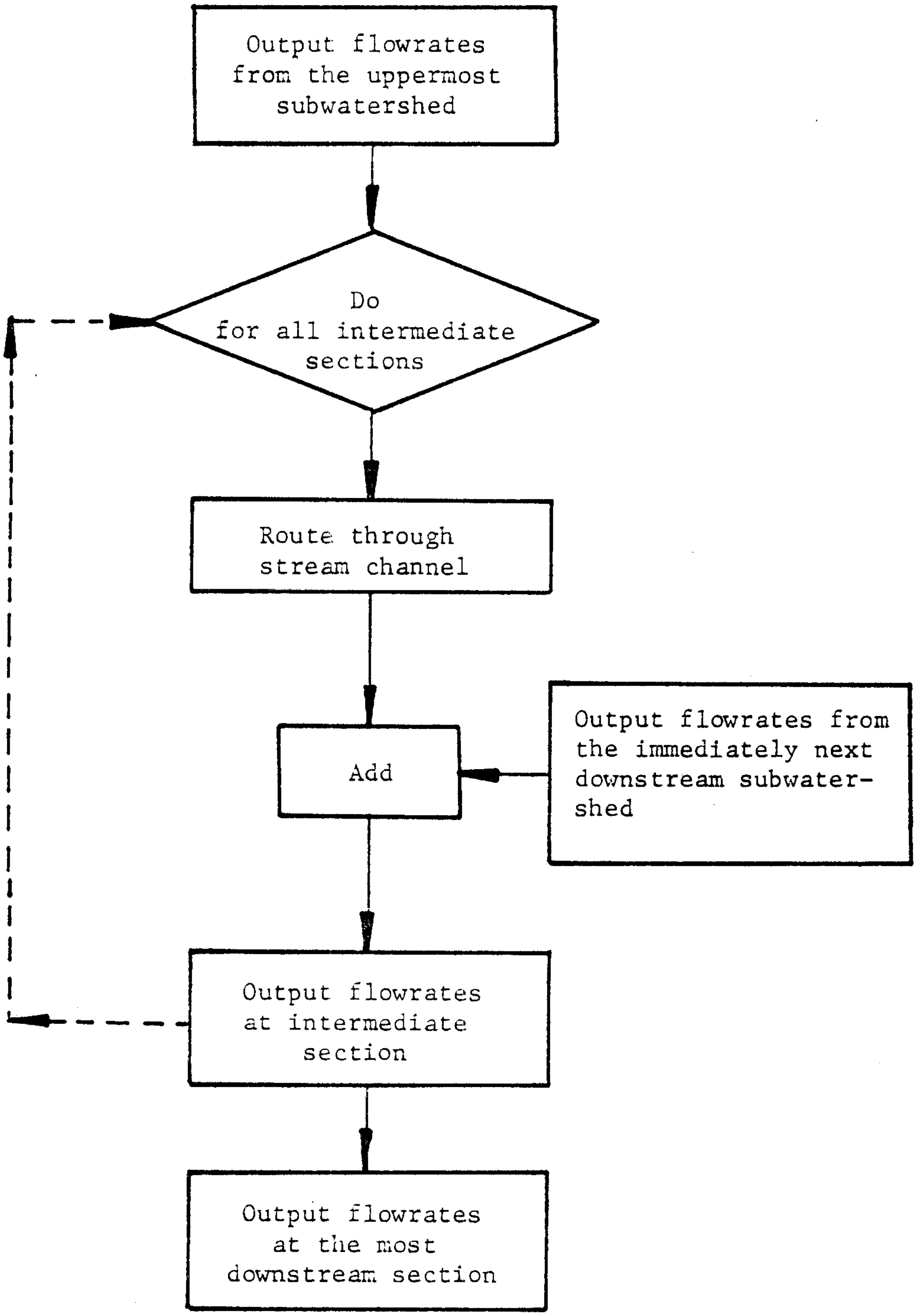

Fig. 11: Flowchart for the Hydrologic Model.

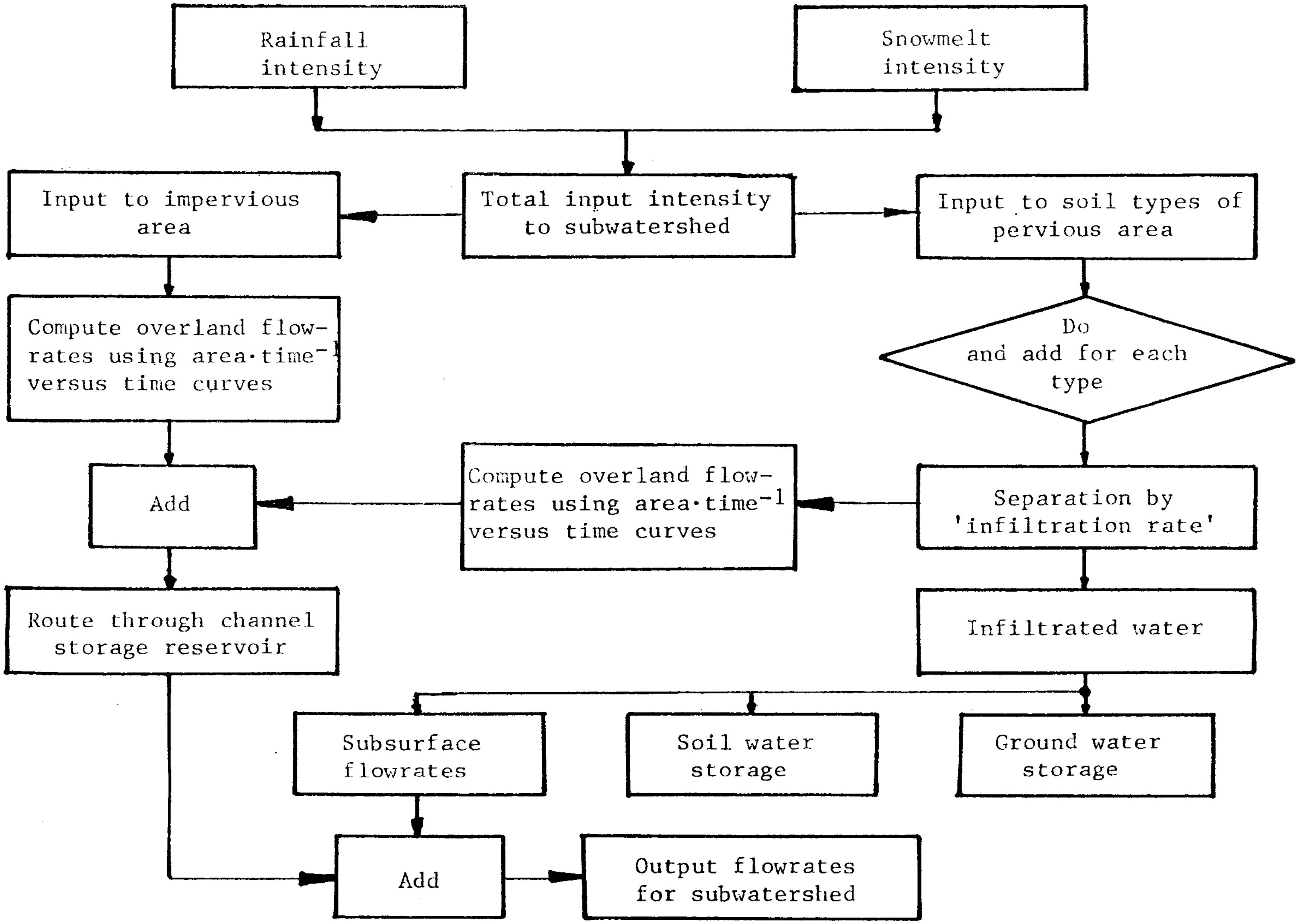

Fig. 12: Flowchart for Subwatershed Modeling.

is converted into discharge rates by convoluting it with an area-time^{-1} versus time curve. Flowrates thus computed are considered as an input to a channel storage reservoir. This input is then routed through a single linear reservoir of a short time constant. This calculation is based on the linear theory of hydrologic systems presented by Dooge (1973).

Infiltrated water is treated as seeping down into the soil layers where some is stored as soil water and some percolates out the bottom. Part of the percolated water is calculated as subsurface storm-event flow to the stream and is converted to flowrate units by multiplying the percolation rate by the area of the contributing zone for each 30 minute time step. The remainder is considered to be accumulation to the groundwater storage, and is not further treated in the model.

Subwatershed surface subdivisions

Each subwatershed is divided into impervious and pervious areas. The impervious area includes roads, lanes, streams and adjoining ditches. Pervious areas aredivided into up to four soil types according to soil properties. Each soil type is divided into two zones one of which contributes to subsurface storm-event flow while the other yields ground water accumulation. Thus there are in all nine soil zones in a subwatershed, the first being impervious while the remaining eight zones are pervious.

Rainfall or snowmelt incident on the impervious area first fills a surface depression storage and then is available as overland runoff. The amount falling on the pervious area is separated into surface runoff and infiltrated components as has been described earlier.

Infiltration and subsurface flow

Each pervious zone is modelled as two soil layers. The top layer has a specified depth, (of up to 30 cm, in the soils examined to date), while the second layer has a depth up to 125 cm. There is an implicit third layer representing ground water storage and transmission which is not part of the model.

Infiltration

The term infiltration is used here to describe the rate of water movement downward through the soil surface. An infiltration equation developed by Holtan et al (1975) is employed to compute infiltration capacity,

$$F = GI. VEG. SA_1^{1.4} + FC.$$

Seepage

The term seepage is used here to indicate water movement downward from the bottom of the top layer into the second layer. The equation used is similar to the one adopted by Holtan et al (1975).

$$E = CS. \frac{G_1 - SA_1}{G_1}$$

Percolation

The term percolation has been used here to indicate water movement out of the bottom of the second soil layer of a soil zone. This water appears as tile drainage (subsurface flow) in soil zones assumed to contribute to this storm flow component or as accretion to groundwater in the other soil zones. The equation adopted to calculate percolation is similar to the one used in seepage calculation.

$$P = D. \frac{G_2 - SA_2}{G_2}$$

The symbols appearing above are defined as:

CS = Maximum seepage rate for a zone, $cm.hr^{-1}$
D = Maximum percolation rate for a zone, $cm.hr^{-1}$
E(t) = Seepage rate for a zone, $cm.hr^{-1}$
F(t) = Infiltration capacity rate for a zone, $cm.hr^{-1}$
FC = Limiting infiltration capacity of a soil zone, $cm.hr^{-1}$
G_1 = Total gravity-draining soil-water capacity of the top layer of a zone, cm
G_2 = Total gravity-draining soil-water capacity of the second layer of a zone, cm
GI = Growth index of crops (seasonal factor), dimensionless
P(t) = Percolation rate for a zone, $cm.hr^{-1}$
$SA_1(t)$ = Space available for additional soil-water storage in the top layer of a zone, cm
$SA_2(t)$ = Space available for additional soil-water storage in the second layer of a zone, cm
VEG = Crop factor, $cm.hr^{-1}/cm^{1.4}$(storage)

Note: Designation (t) indicates parameter which may vary with time during a storm period.

When the space available for soil-water storage in either layer is greater than the gravity-draining storage capacity of that layer then either the seepage (layer one) or percolation (layer 2) is assumed to be zero. Any water entering the layer during this condition is added to stored soil water and decreases SA.

As the soil wets up, P and E increase. When SA_1 and SA_2 are zero (saturated soil) then P = D and F and E are set equal to D. If $SA_2 = 0$ and $SA_1 > 0$, then E is set equal to D. If $SA_1 = 0$ then F is set to CS.

Whenever the calculated infiltration capacity rate exceeds the rainfall intensity then the actual infiltration rate is equal to rainfall intensity.

Evaporation

A fixed rate depending on the season, wetness and atmospheric temperature is assumed for evaporation during the calculation period. No evaporation however, is assumed during the actual rainfall period. Evaporation is deducted from the soil water of the top layer till the available storage reaches half of its maximum storage above wilting point. Thereafter, half the evaporation amount is removed from the soil-water of the top layer and half from the second layer. When the available storage of the top layer reaches its maximum, then the evaporation is taken from the second layer only.

Explanation of Input Parameters

The input parameters outlined in the preceeding section can be explained as follows:

GI: Growth index. This dimensionless index indicates the state of crop maturity. During summer months in Ontario, GI value would be 1.0 when the crop cover is full. The lowest value could be equal to 0.10 or so, when there is no crop or grass cover as in December or March on ploughed fields.

VEG: This is a crop factor and has units as $cm.hr^{-1}$ per $(cm\ of\ storage)^{1.4}$. The value of the crop factor changes depending on the type of crop and condition of soil. A weighted average of different crop practices over the watershed should be taken as the crop index of the watershed. Table 4 derived from USDAHL-74 (Holton et al, 1975) was used to select VEG index for the watersheds. Table 5 shows the crop practices followed on Canagagigue (AG-4) and Holiday Creek (AG-5) watersheds during 1975. These are taken from survey results from project 16 of the Agricultural Watershed Studies. The VEG index assumed for Canagagigue and East Canagagigue was 0.30 and for Holiday Creek it was 0.35 for most of the storms analyzed.

Other parameters in the infiltration and subsurface flow equations are related to soil properties and could vary for each soil type. Soils in each watershed were classified into four soil types as stated earlier. Each type was divided into two zones, one contributing to subsurface (tile) flow and the other to groundwater accumulation. The soil parameters were given for each zone of the soil as follows:

FC: Limiting infiltation capacity of a zone, $cm.hr^{-1}$. This is the same as infiltration capacity after prolonged wetting. Well drained soil will have higher value than poorly drained soil. This value would also have seasonal variations.

CS: Maximum rate of seepage from top layer to second layer, $cm.hr^{-1}$.

D: Maximum rate of percolation from second layer to the third layer (ground water or tile storage), $cm.hr^{-1}$. CS and D are related to GA_1 and GA_2 (gravity water storages for top and second layers of soil, respectively) by the recession constant of the soil. Total recession constant in hours for a zone would be sum of GA_1/CS and GA_2/D of a zone. For the ground water contribution the recession constant of top layer (GA_1/CS) would be much smaller than corresponding second layer (GA_2/D). In the current version

Table 4: Estimates* of crop factor VEG of infiltration equation in cm.hr^{-1}/cm$^{1.4}$

Crop	Poor Condition Soil	Good Condition Soil
Fallow	0.069	0.21
Row crops	0.069	0.14
Small grains	0.14	0.21
Hay:		
Legumes	0.14	0.275
Sod	0.275	0.41
Pasture:		
Bunchgrass	0.14	0.275
Temporary (sod)	0.275	0.41
Permanent (sod)	0.55	0.69
Woods and forests	0.55	0.69

Table 5: Crop practices on Canagagigue (AG-4) and Holiday Creek (AG-5) watersheds during year 1975

Canagagigue (AG-4)		Holiday Creek (AG-5)	
Crops	Percent area	Crops	Percent area
Corn in rotation	19	Potatoes	3
Winter wheat	9	Continuous corn	19
Small grains (oats, barley)	33	Corn in rotation	20
Meadows in rotation	22	Small grains (oats, barley)	16
Permanent pasture	10	Meadows in rotation	24
Root land (trees, swamp)	7	Permanent pasture	4
		Root land (trees, swamp)	14

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* Derived from ARS-Tech. Bulletin No. 1518 by Holtan et al (1975).

of the GAWSER model the values are selected so that the total average recession constant for zones contributing to tile drainage would be equal to subsurface recession constant, while the total average recession constant for zones contributing to groundwater would be equal to or less than the baseflow recession constant.

SA_1: Initial storage available in top layer of a zone, cm at time zero.

SA_2: Initial storage available in second layer of a zone, cm at time zero. SA_1 and SA_2 can be estimated from previous rainfall and evaporation data. These indicate antecedent moisture conditions before the beginning of a storm.

GA_1: Gravity water storage for top layer, cm. It is the difference between the water content of the layer at saturation and at .33 bar tension. Assumed values of upper layer gravity storage capacity values (GA_1) during storms for zones 2 and 9 for the watersheds are shown in Figures 13 to 15. Zone 2 has well drained soil for Canagagigue and Holiday Creek watershed. Zone 2 of East Canagagigue has extremely well-drained soil. Zone 9 has very poorly drained soils in all watersheds.

GA_2: Gravity water storage for second layer, cm. It is the difference of water content of the layer at saturation and .33 bar tension.

Numerical value of GA_2 for zones contributing to ground water would be much higher than for the zones contributing to subsurface (tile) flow. This is due to a greater layer depth for zones contributing to ground water.

Computation of Area.time^{-1} versus time curves

Area.time^{-1} versus time curves are important input data for the hydrologic model. These curves were estimated for each soil type for every subwatershed. The following procedure was adopted to get these curves.

(1) The watershed and subwatershed boundaries were determined.

(2) The number of significant reaches in each subwatershed were fixed.

(3) Representative valley cross-sections were chosen for each stream reach. The cross-sections were surveyed and also the slope and reach length information of the stream were obtained from topographic maps.

(4) Rating curves were computed for the cross-sections and the travel time obtained for the reaches, using commands COMPUTE RATING CURVE and COMPUTE TRAVEL TIME of the GAWSER model respectively.

(5) A suitable flowrate for the storm was assumed at the most downstream cross-section of the watershed.

(6) The flowrate output of a subwatershed was taken to be in the proportion of 0.7th root of its area,

$$\text{i.e. } q_i = q\left(\frac{A_i}{A}\right)^{0.7}, \text{ where:}$$

q is the flowrate at the most downstream section of the watershed,

q_i is the output flowrate from the i^{th} subwatershed,

A is the total watershed area,

A_i is the area of the i^{th} subwatershed, and

0.7 was the index used.

(7) From the computed output flowrates from different subwatersheds, appropriate flowrate values were selected at intermediate valley cross-sections.

(8) The travel time along the stream was estimated starting from the downstream end, using the travel time information.

(9) The impervious area (comprising areas of roads, streams and adjoining ditches) in each subwatershed was computed from map lengths and suitably chosen widths.

(10) The total time required for water travel from the upstream to the downstream sections in a subwatershed was already computed as in step 4. The travel time at several points along the stream length was also established as indicated in step 8. A water velocity of 40 $m.min^{-1}$ was used to compute the travel time for water moving along the road-side ditches from the end of a road to the nearest stream points. The total travel time for water moving from the most remote end of the road system was thus the sum of travel times required for water flowing along a road side ditch to the stream-point and from the stream-point to the downstream section of the subwatershed. In this way the base time for impervious areas was established.

(11) Some equal travel time step points on the impervious area in the subwatershed were established at ½ hour intervals. The impervious area closer in travel time to the outlet than the first step point would be the area for the first travel time step. The area included in the second time step was the impervious area between the one hour and the half an hour points and so on.

(12) The $area.time^{-1}$ values were computed by dividing the area within a travel step by travel time step (taken as ½ hour in this model). An appropriate dividing scale was selected to make the values easily readable. In simulation of all the three watersheds of this project, the scale chosen was 0.02 for impervious area and 0.5 for the

pervious area. The values of area.time^{-1} were divided by the scale. These quotients were the ordinates for the scaled area.time^{-1} versus time curves. The unit used was km^2.hr^{-1}/scale.

(13) The ordinates were plotted against time. A shape (triangular, rectangular or trapezoidal) was selected which most closely represented the actual plot. Figure 16 for example, shows the actual and approximated curves for the impervious area of subwatershed #306 of Holiday Creek (AG-5) when watershed output flowrate is 1.5 m^{-3}.sec^{-1}. This completed the curves for impervious areas.

(14) The same shape for the area.time^{-1} versus time plots as was used for impervious areas was assumed for the pervious soil types of the watershed. The ordinate values varied due to change of size of area and also base time for the curves.

(15) The location of the various pervious soil types was noted and an average distance of the soil type from the stream was estimated.

(16) The travel time required for the overland runoff to reach a stream was calculated for each soil type assuming a velocity of 4 m.min^{-1} for overland flow.

(17) The time required for the overland runoff to reach a stream was added to the travel time as computed in step 8. This was the base time for the soil type under consideration for the specified subwatershed.

(18) Knowing the area of the soil type, the base time for the area.time^{-1} versus time curves and the curve shape (steps 13, 14), the area.time^{-1} versus time plots were then plotted.

(19) The data from these curves was prepared as required for command COMPUTE DISTRIBUTION of the GAWSER model.

Choice of initial soil water storage values

In order to run the GAWSER model it is necessary to have values for the available soil water storage (SA_1 and SA_2 respectively for the upper and lower soil layers) at the start of each storm. In order to use consistent values in terms of storms which occurred in sequence and also in terms of seasonal variation in soil-water storage conditions a simple evaporation model was used to compute the soil-water status for each watershed for each year in which storms were to be analyzed for each day from the end of snowmelt runoff to the middle of December. The soil was assumed to be at field capacity at the start of each year's calculation.

The soil-water values given by the evaporation calculations for the day of the storm to be analyzed were used as the initial values for the well-drained soil zones at the start of calculations. Available soil-water storage amounts for the other soil zones were assumed to be smaller than for the well-drained soils. Some adjustments were made in the values of

Fig. 13: Assumed Upper-layer, Gravity-storage, Capacity values (GA-1) for Various Storms on Canagagigue (AG-4) Watershed.

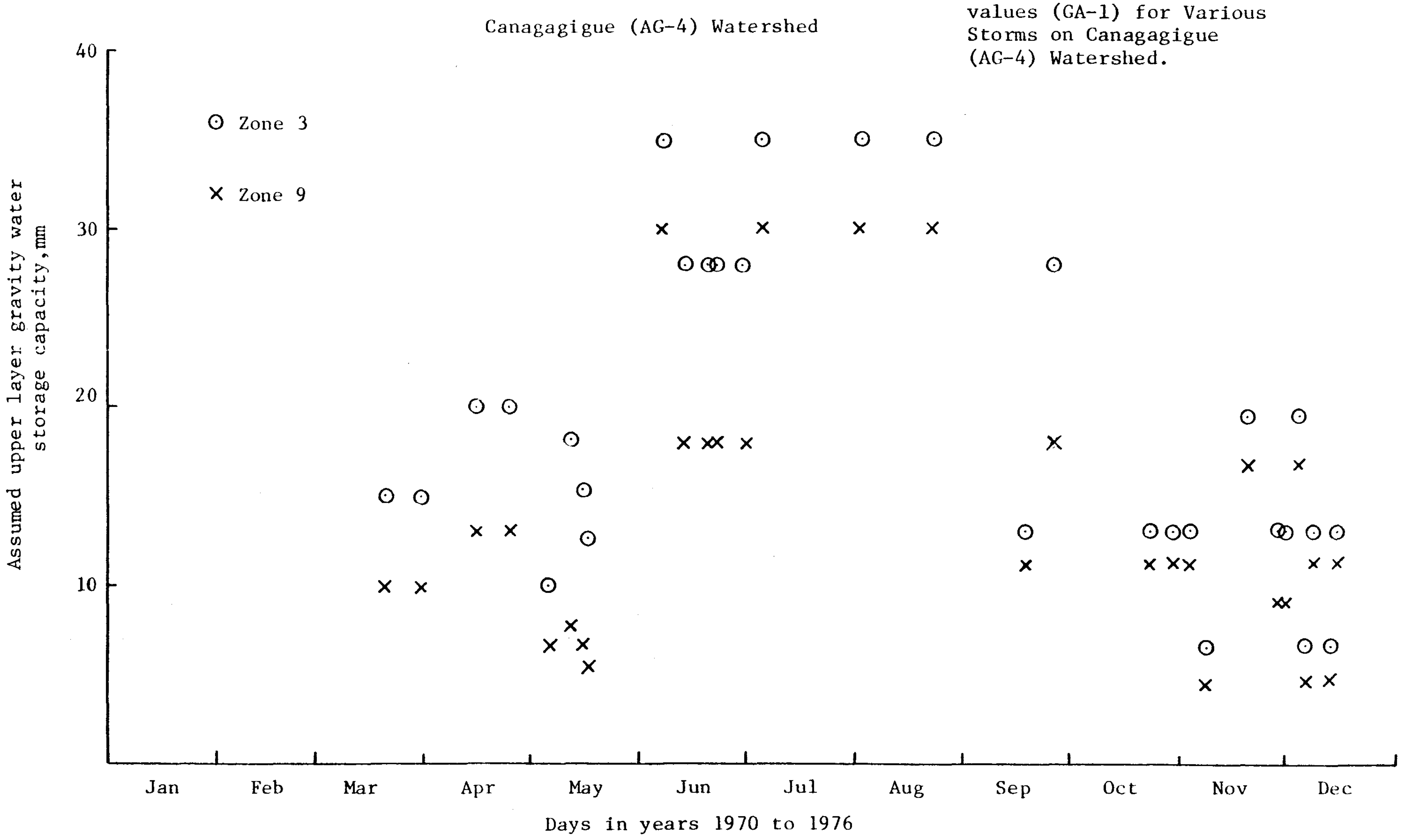


Fig. 14: Assumed Upper-layer, Gravity-storage, Capacity values (GA-1) for Various Storms on East Canagagigue Watershed.

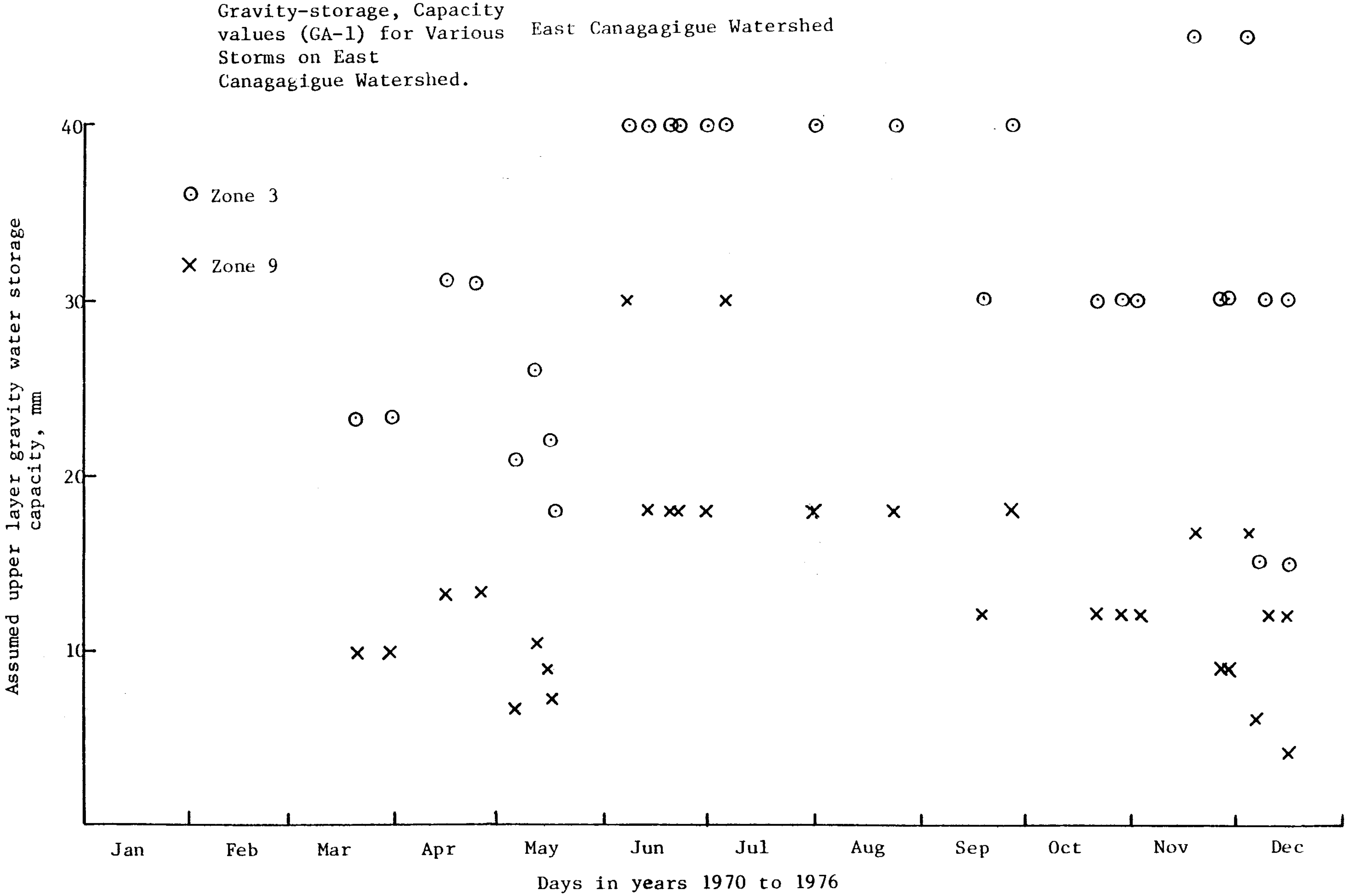


Fig. 15: Assumed Upper-layer, Gravity-storage, Capacity values (GA-1) for Various Storms on Holiday Creek (AG-5) Watershed.

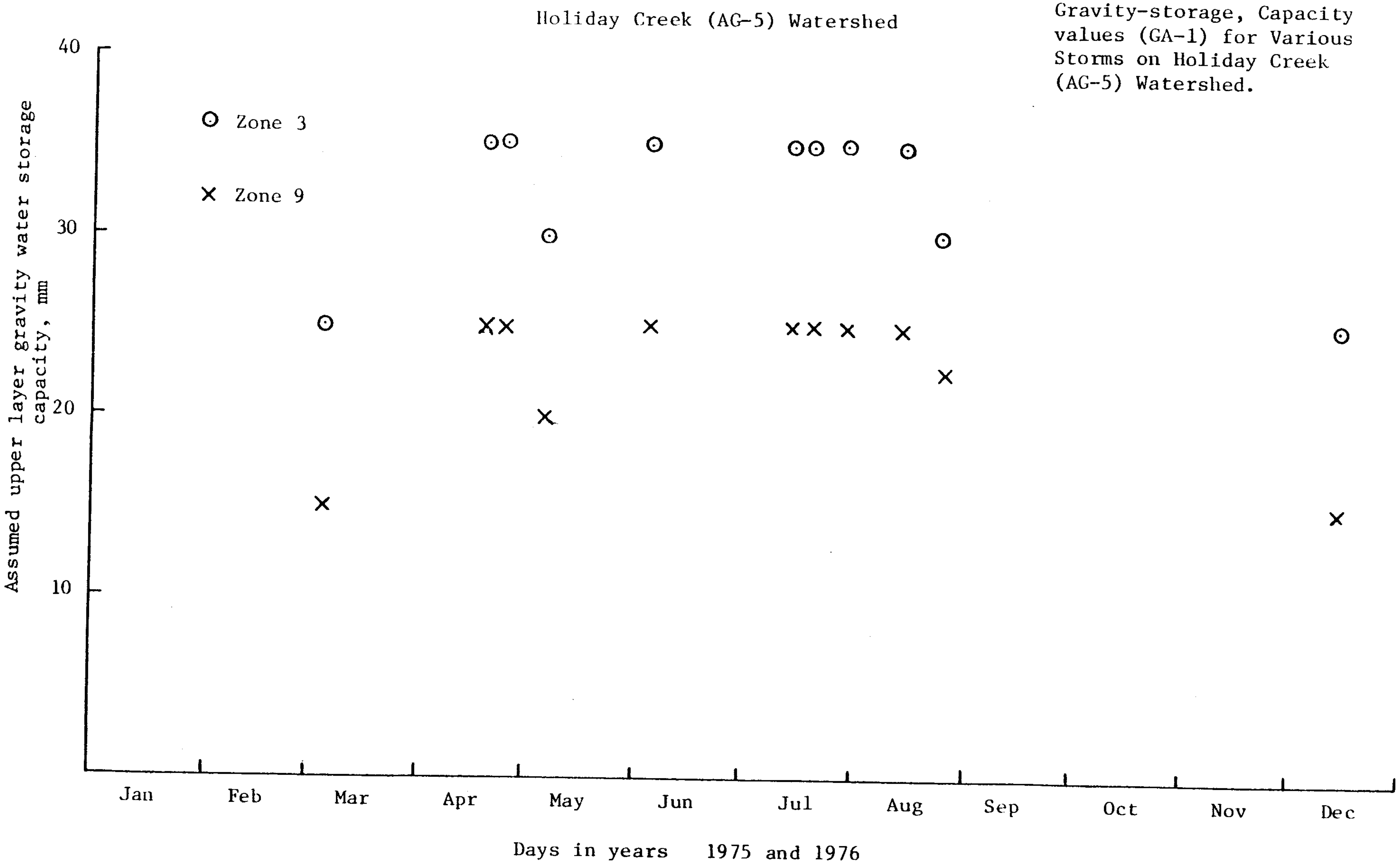
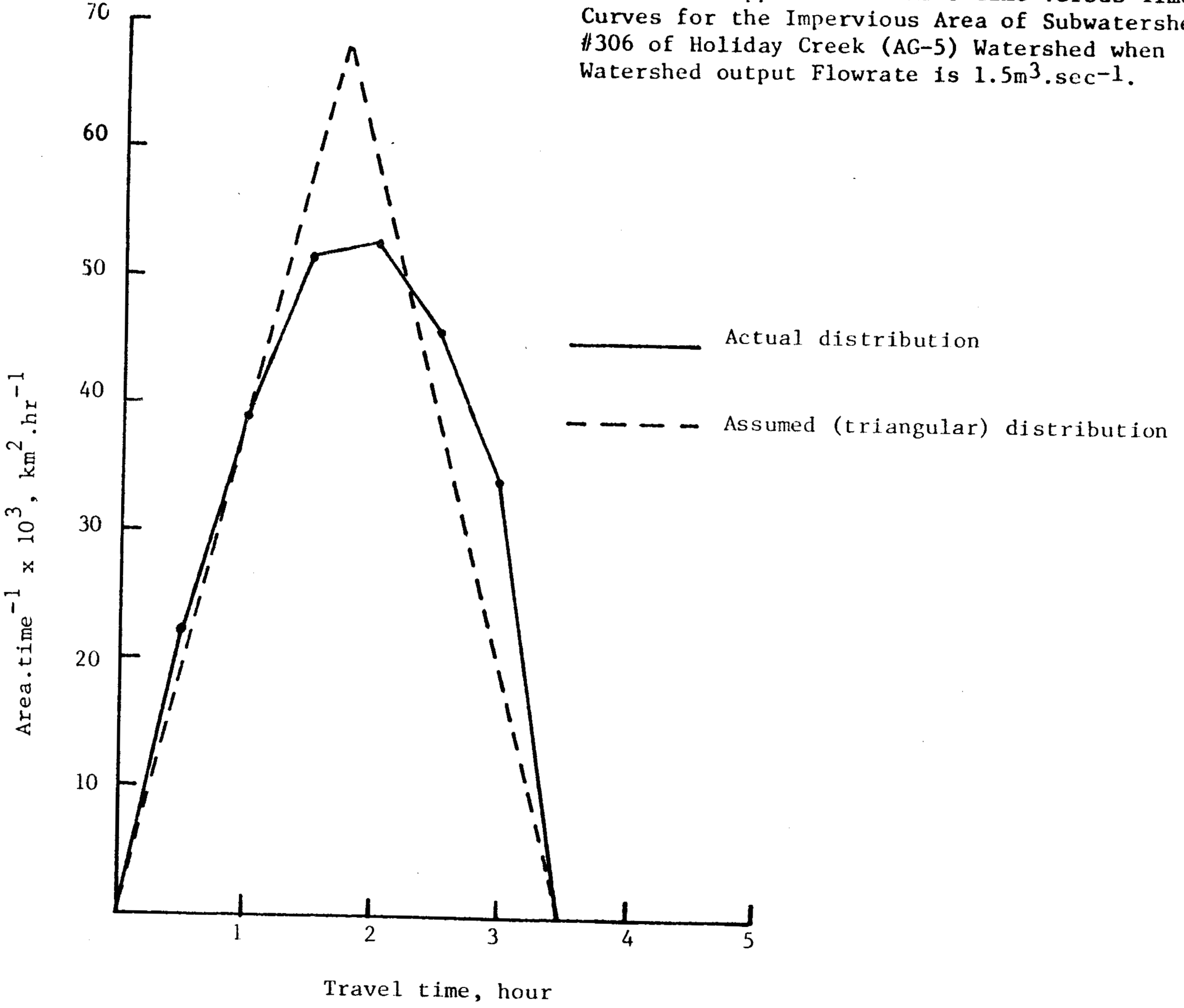


Figure 16 Actual and Approximated Area Time versus Time Curves for the Impervious Area of Subwatershed #306 of Holiday Creek (AG-5) Watershed when Watershed output Flowrate is 1.5m^3.sec^{-1}.



SA_1 and SA_2 for the less well-drained soils if needed to obtain reasonable agreement between observed and computed storm runoff hydrographs.

The justification for the areal distribution of available soil water storage used is that poorly-drained soils near streams have been shown to be consistently wetter than better drained soils of the same texture further removed from streams (Henninger et al, 1976). The difference between drainage types is largest during periods when soil water content is high and is smallest during extended dry periods. Figures 13 to 15 illustrate both the seasonal variability in SA_1 values for one soil type and the difference between well-drained and poorly-drained soils that was assumed for the three watersheds.

One further change that was made between storms was in the assumed depths of the soil layers. It was found necessary to use smaller soil depths for both the first and second layers for storms during and immediately after snowmelt and again for storms in later November and December than was used for the storms in the intervening months. While no direct physical justification is known for this reduction in effective layer depth it is assumed to relate to either the existence of a water table (either a perched or regional watertable) sufficiently close to the soil surface to affect infiltration or to a change in soil structure which allows only a thin surface layer to control infiltration. Frozen soil is not an explanation as the reduced soil layer thicknesses were required for storms for which the soil was clearly unfrozen.

DATA ANALYSIS AND INTERPRETATION

Hydrograph simulation

GAWSER has been applied to storm events which occurred on three agricultural watersheds. They include a variety of events. Some were high intensity and non-uniform, others low intensity and uniform and a few were storms with a snowmelt component. The period of analysis covered events in March through December. Thirty storms were analysed on the Canagagigue (AG-4) watershed and twenty-nine on the East Canagagigue watershed covering years from 1970 to 1976. The eleven events analysed on Holiday Creek (AG-5) covered only the two years 1975 and 1976.

Figures 17 to 19 show observed and simulated hydrographs obtained for Canagagigue, East Canagagigue and Holiday Creek watersheds respectively. They are the May 5, 76 event on Canagagigue (AG-4), the December 3, 70 event on East Canagagigue and the August 13, 76 event on Holiday Creek (AG-5) watersheds.

Tables 6 to 8 show the detailed comparison of observed and computed hydrograph characteristics for the storms analysed on Canagagigue, East Canagagigue and Holiday Creek watersheds respectively. The characteristics include peak flowrate, time to peak, storm runoff and groundwater accumulation. Table 9 shows the comparison of observed and computed values of peak and time-to-peak for downstream and intermediate gauging stations on Holiday Creek (AG-5) watershed for some storms.

A graphical comparison of observed and computed values of peak flowrate and storm runoff is shown in Figures 20 to 25 for the watersheds. The equal value line in all these plots indicates where points would lie if simulated results coincide exactly with the observed values.

These tabulated and graphically illustrated simulation results do confirm the reliability of the developed model. The results related to peak and storm runoff are quite satisfactory. The other two results time to peak and grounwater accumumlation however, do have some discrepancies. The interpretation of these results has been given in the following sections.

Time to Peak

Time to the peak flowrate is an important parameter of a flowrate hydrograph. This time could be measured in a variety of ways such as:

(i) Time from the start of rainfall to the time of peak flowrate

(ii) Time from the center of the mass rainfall to the peak runoff rate time.

(iii) Time from the beginning of the highest intensity of rainfall to the peak.

The first approach sometimes gives rise to very long times and produces occasionally misleading results, the second approach is cumbersome and time

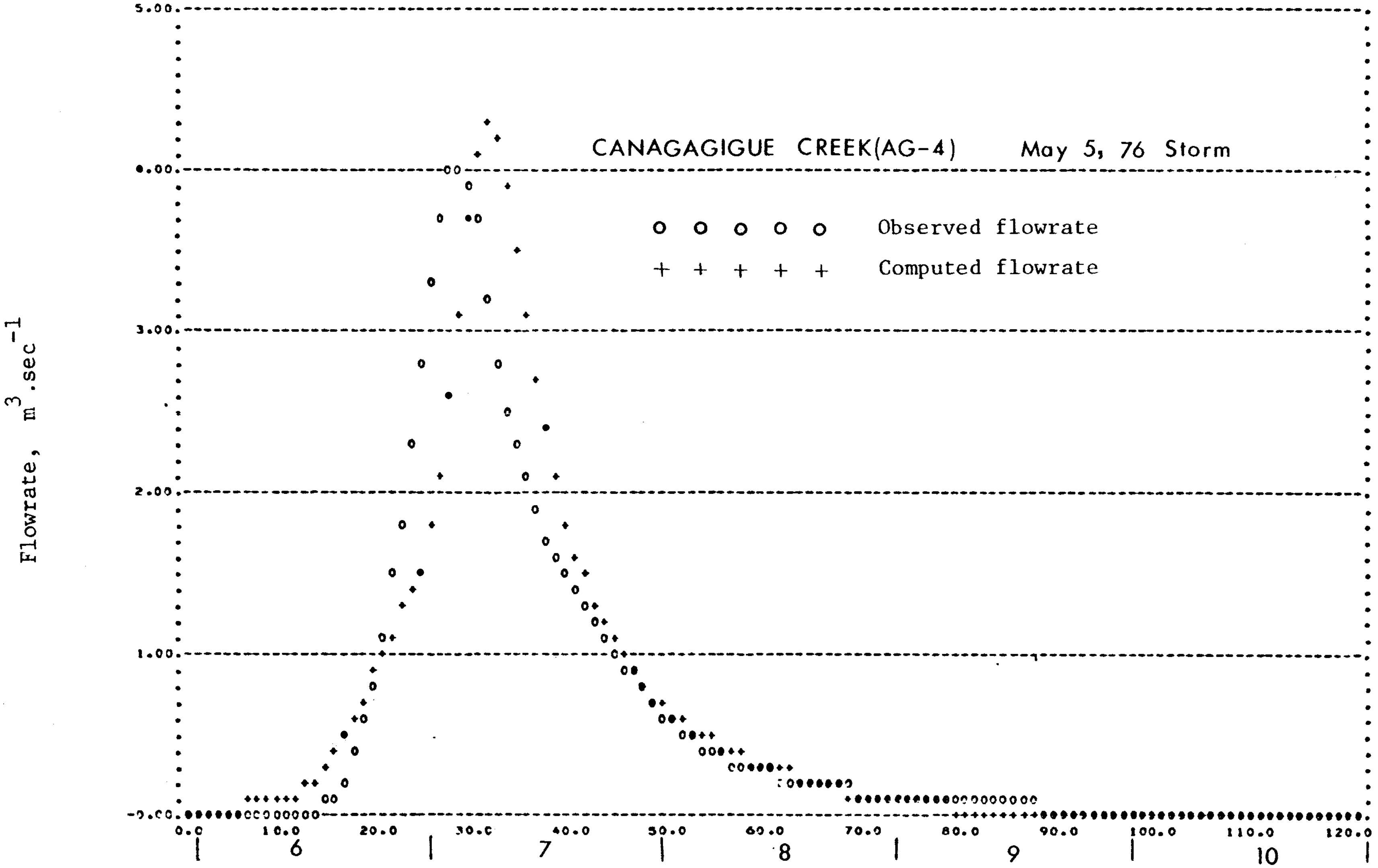


Fig. 17: Comparison of Observed and Simulated Flowrates Due to May 5, 1976 Storm on Canagagigue (AG-4) Watershed.

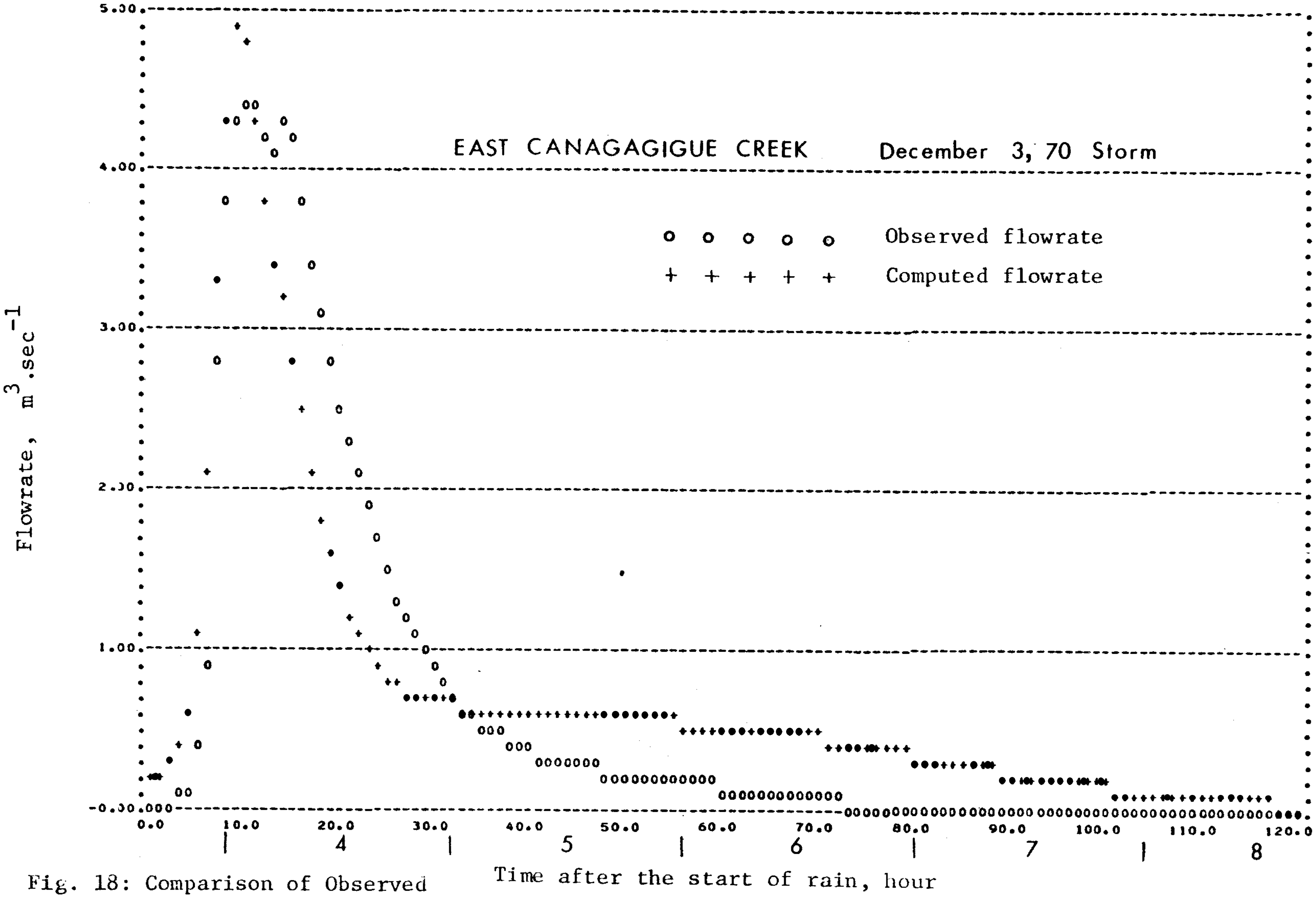


Fig. 18: Comparison of Observed and Simulated Flowrates Due to December 3, 1970 Storm on East Canagagigue Watershed.

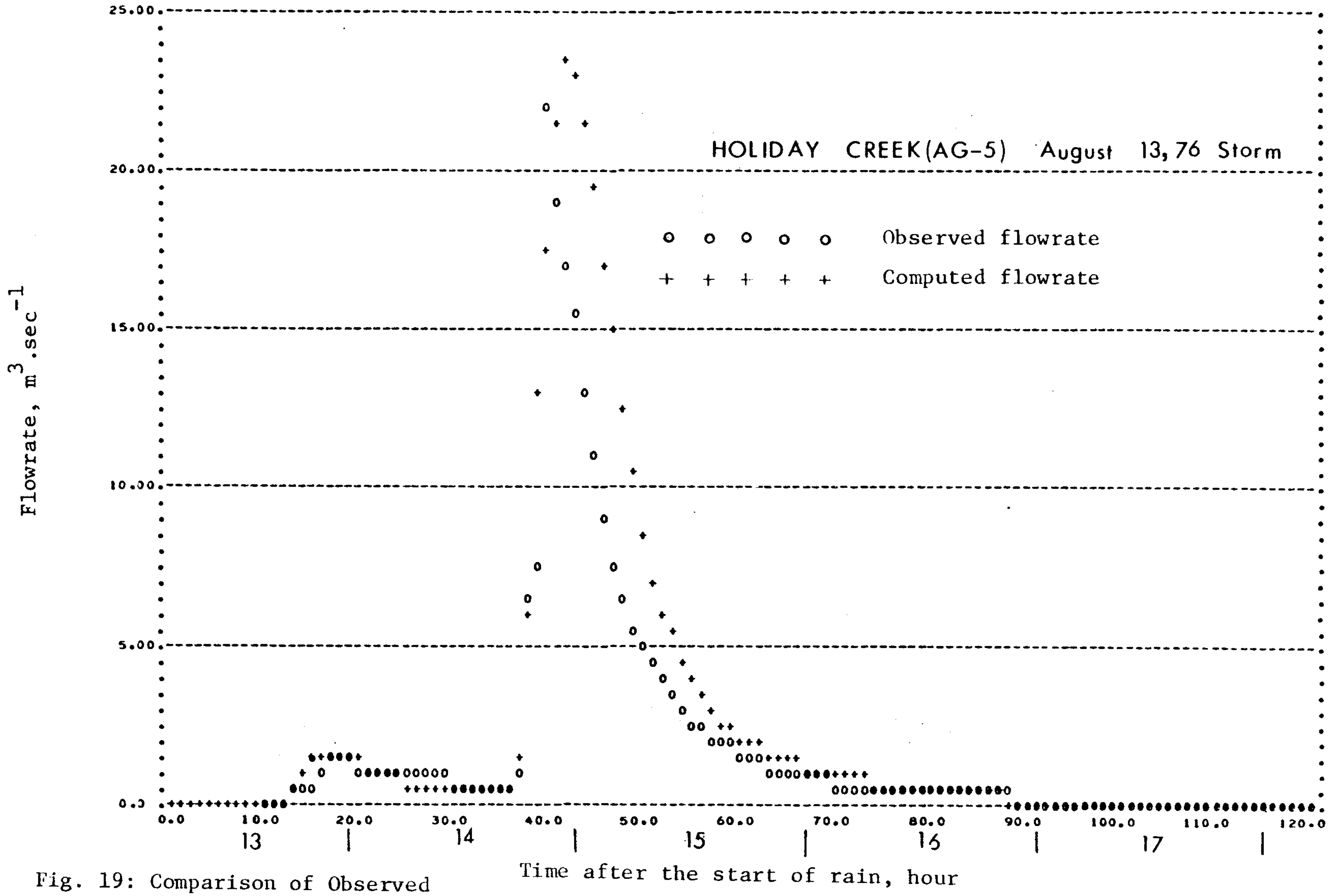


Fig. 19: Comparison of Observed and Simulated Flowrates Due to August 13, 1976 Storm on Holiday Creek (AG-5) Watershed.

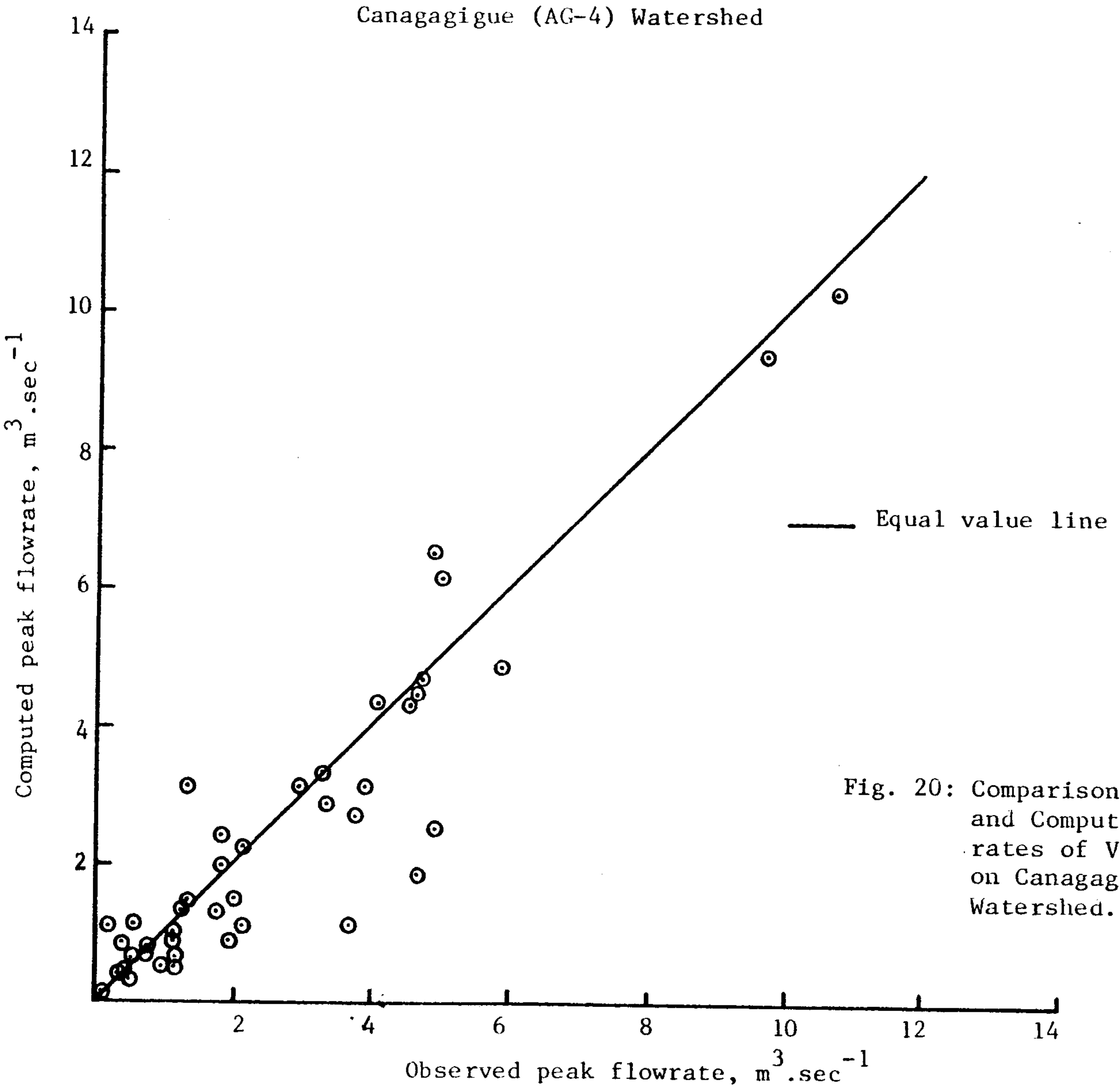


Fig. 20: Comparison of Observed and Computed Peak Flowrates of Various Storms on Canagagigue (AG-4) Watershed.

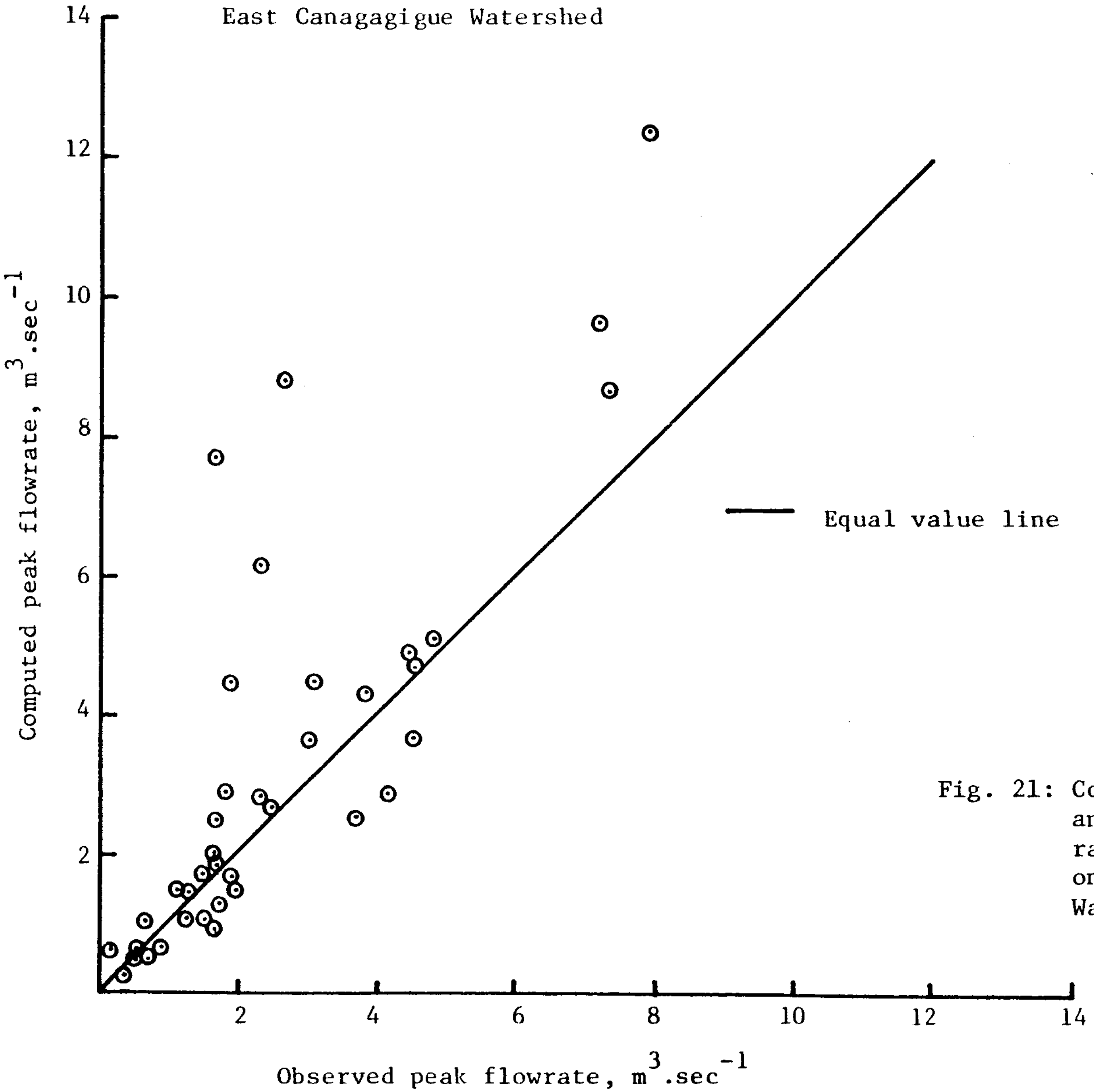


Fig. 21: Comparison of Observed and Computed Peak Flowrates for Various Storms on East Canagague Watershed.

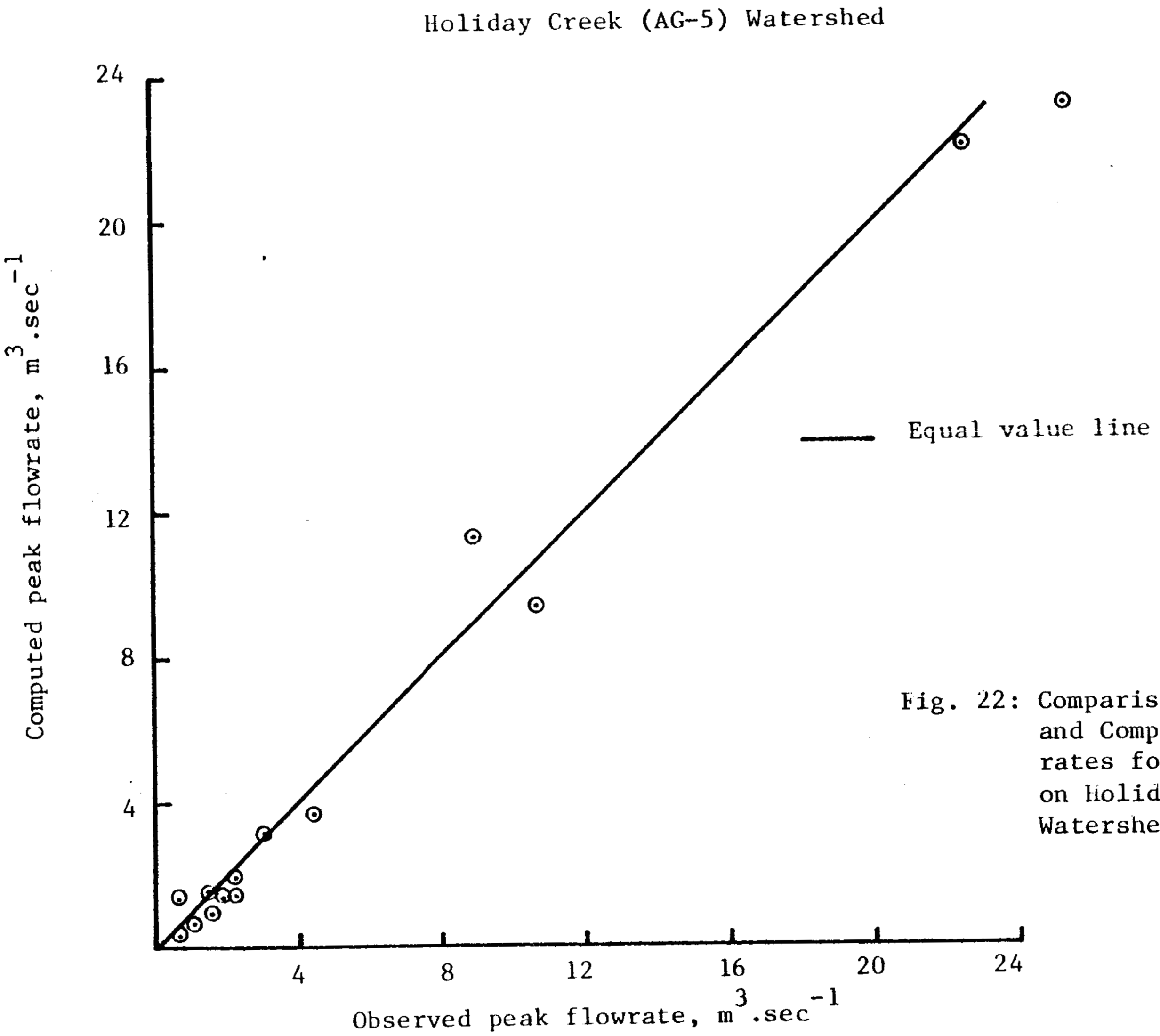


Fig. 22: Comparison of Observed and Computed Peak Flowrates for Various Storms on Holiday Creek (AG-5) Watershed.

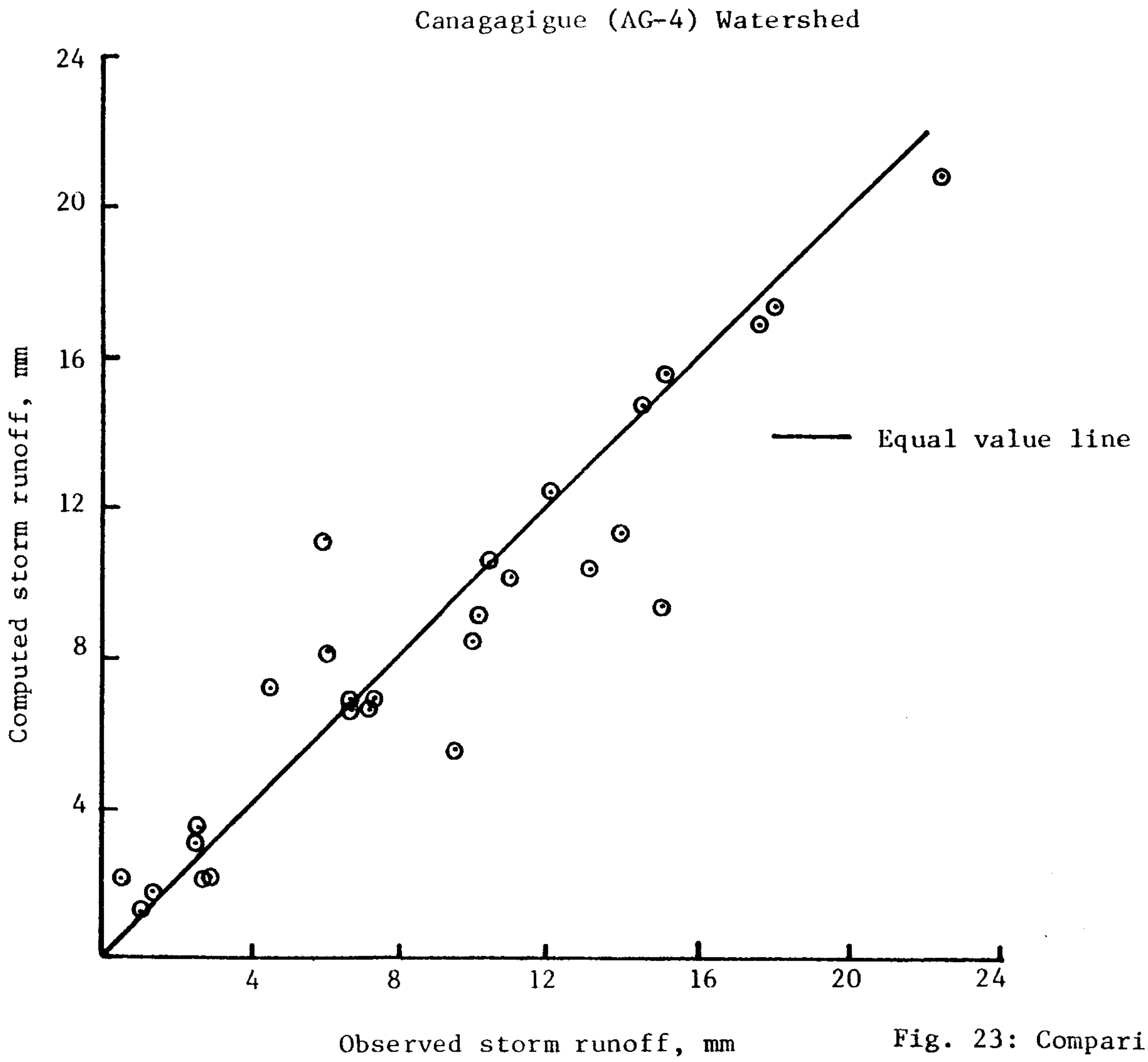


Fig. 23: Comparison of Observed and Computed Storm Runoff for Various Storms on Canagagigue (AG-4) Watershed.

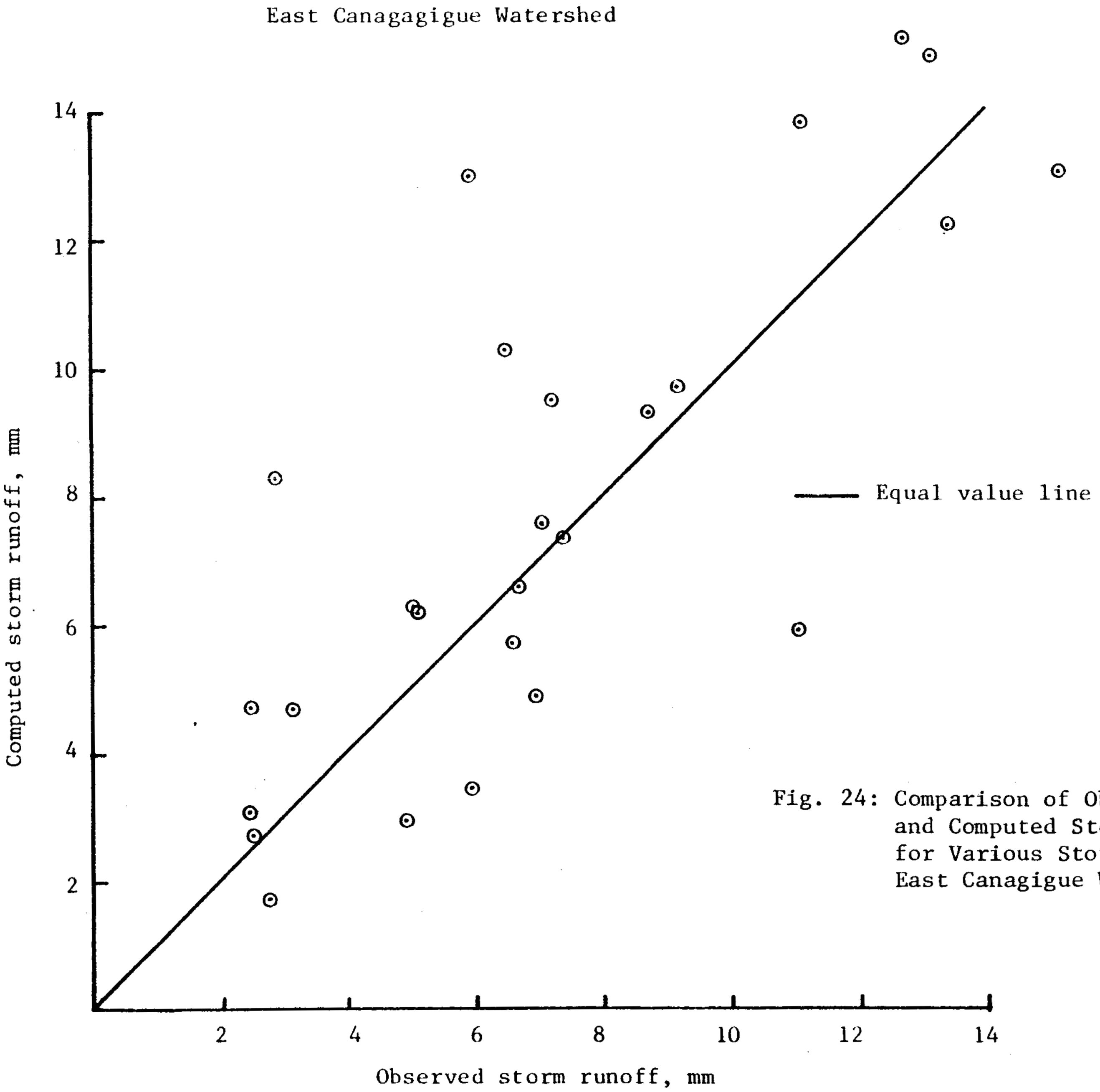


Fig. 24: Comparison of Observed and Computed Storm Runoff for Various Storms on East Canagigue Watershed.

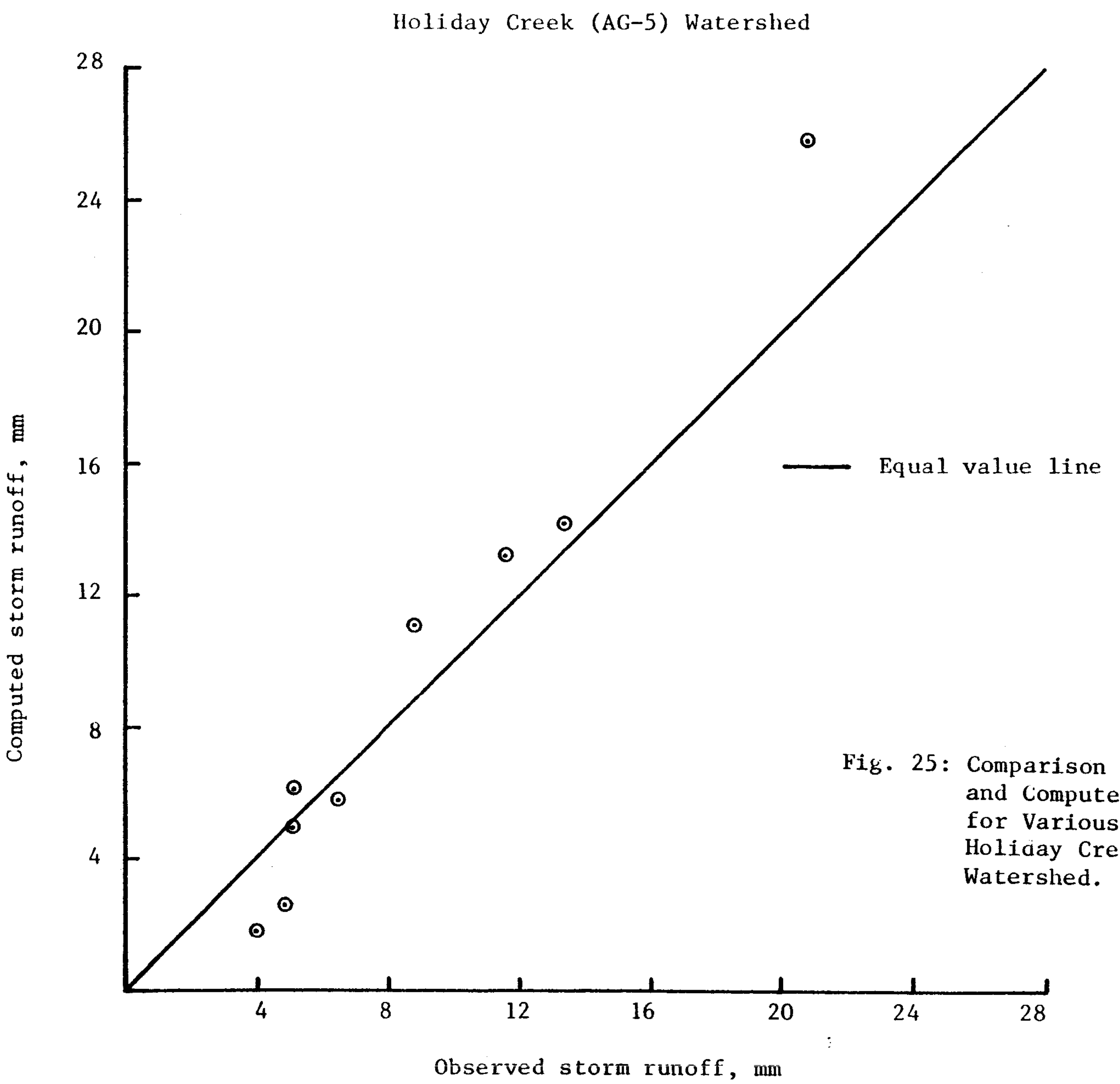


Fig. 25: Comparison of Observed and Computed Storm Runoff for Various Storms on Holiday Creek (AG-5) Watershed.

Table 6: Observed and Computed Hydrograph Characteristics on Canagagigue (AG-4) Watershed for Various Storms

Date	Rain and Snow-melt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Ob-served	Com-puted	Ob-served	Com-puted	Ob-served	Com-puted	Over-land	Sub-surface	Ob-served	Com-puted
Mar 19, 76	220[@]	5.84	4.83	11.0	6.0	206	202	116	86.0	15.7	17.7
		22.4	21.1	5.0	6.5						
		3.76	2.79	2.0	5.5						
		4.90	6.50	8.0	5.5						
		10.7	10.3	3.0	5.5						
		9.61	8.40	2.0	4.0						
		3.30	3.31	3.0	5.5						
Mar 30, 76	20[@]	0.47	0.44	2.0	5.0	14.5	14.8	2.0	12.8	4.8	5.6
		1.98	1.50	10.0	9.0						
		0.91	1.10	15.0	15.0						
Apr 15, 76	24	2.92	4.18	2.0	5.0	4.6	9.7	7.0	2.7	3.4	2.1
Apr 15, 76	21[&]	2.92	3.16	2.0	4.5	4.6	7.3	4.8	2.5	3.4	1.7
Apr 24, 76	43[@]	3.96	3.16	11.0	8.5	22.4	20.9	7.5	13.4	9.2	11.5
		1.87	0.96	2.0	6.5						
		1.25	1.36	7.0	7.0						
May 5, 76	27	4.08	4.35	2.0	6.0	15.1	15.5	8.0	7.5	6.1	7.0
May 11, 74	23	2.08	2.23	3.0	5.5	12.2	12.4	3.4	9.0	2.0	8.3
		1.56	-	9.0	-						
May 15, 74	25[#]	4.24	-	3.0	-	13.2	10.4	7.0	3.4	2.3	5.0
		4.65	4.41	4.0	6.0						

continued .....

Table 6 (continued)

Date	Rain and Snow-melt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Ob-served	Com-puted	Ob-served	Com-puted	Ob-served	Com-puted	Over-land	Sub-surface	Ob-served	Com-puted
May 16, 74	56	22.8	18.2	1.0	5.0	46.9	51.1	39.1	12.0	3.9	3.8
Jun 7, 71	37	0.53	1.18	5.0	5.0	2,9	2.2	2.2	0.0	0.7	0.0
Jun 13, 76	29	3.71	1.12	3.0	5.5	2.8	2.2	2.2	0.0	0.2	0.0
Jun 19, 75	32	4.96	2.53	3.0	6.0	9.5	5.6	4.6	1.0	0.6	0.5
Jun 21, 72	63	0.36	0.89	8.0	5.0	6.6	6.9	2.7	4.2	1.8	2.6
		0.37	-	9.0	-						
		0.35	0.45	7.0	8.0						
		0.37	0.80	9.0	7.5						
Jun 30, 76	49	4.52	4.29	2.0	5.0	10.0	8.5	8.2	0.3	2.5	0.0
Jul 5, 71	51	0.42	0.62	3.0	3.5	1.0	1.3	1.3	0.0	0.5	0.0
Aug 1, 73	46	0.18	1.14	13.0	5.5	0.5	2.2	2.2	0.0	0.0	0.0
Aug 23, 75	108	1.31	3.18	5.0	8.0	6.0	11.2	7.2	4.0	1.6	4.2
		0.74	0.81	2.0	7.5						
Sep 18, 75	35	0.44	0.38	12.0	16.0	7.4	6.9	1.0	5.9	4.9	9.8
		0.98	0.55	5.0	6.5						
		0.22	0.40	8.0	6.5						
Sep 26, 70	20	0.39	0.48	5.0	5.5	1.4	1.8	0.9	0.9	0.6	0.4
Oct 22, 72	62	1.06	1.64	8.0	6.0	6.1	8.2	5.2	3.0	4.1	1.9
		-	1.03	-	4.0						
Oct 28, 72	19	0.54	0.53	11.0	8.0	2.5	3.1	0.8	2.3	5.5	3.6
Nov 2, 72	12	0.64	0.72	7.0	6.5	2.6	3.5	1.0	2.5	5.1	4.6

continued .....

Table 6 (continued)

Date	Rain and Snow-melt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Ob-served	Com-puted	Ob-served	Com-puted	Ob-served	Com-puted	Over-land	Sub-surface	Ob-served	Com-puted
Nov 7, 72	16	-	1.39	-	12.5	6.7	6.7	3.3	3.4	8.1	6.6
		1.71	1.39	10.0	10.0						
Nov 17, 70	20@	1.90	0.67	19.0	10.0	7.2	6.7	5.8	0.9	6.8	12.1
Nov 26, 70	25@	1.11	0.56	9.0	6.5	14.0	11.4	1.5	9.9	7.6	14.1
		2.06	1.14	6.0	6.5						
Nov 28, 73	19	1.78	2.00	9.0	5.0	11.0	10.2	3.7	6.5	5.4	9.8
Dec 3, 70	28	4.74	4.69	6.0	7.5	18.0	17.4	8.8	8.6	2.8	20.5
		5.10	-	10.0	-						
Dec 5, 75	24@	5.02	6.19	4.0	5.0	17.6	16.9	13.3	3.6	5.2	8.2
Dec 6, 71	47@	1.31	1.49	8.0	8.5	10.2	9.2	2.7	6.5	2.5	1.7
Dec 13, 75	15@	3.38	2.91	3.0	5.5	15.0	9.4	4.7	4.7	5.7	5.7
Dec 15, 71	29	1.76	2.40	11.0	8.0	10.6	10.5	4.8	5.7	4.3	12.1

@ Includes snowmelt

Fifty percent more than recorded amount

& Average; amounts on subwatersheds vary

Table 7: Observed and Computed Hydrograph Characteristics on East Canagagigue Watershed for Various Storms

Date	Rain and Snow-melt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Ob-served	Com-puted	Ob-served	Com-puted	Ob-served	Com-puted	Over-land	Sub-surface	Ob-served	Com-puted
Mar 19, 76	$220^{@}$	1.95	4.51	9.0	5.0	102.	182.	108	74.0	15.1	35.8
		13.3	25.5	6.0	6.0						
		2.72	8.81	6.0	5.0						
		7.87	12.8	4.0	5.5						
		7.13	9.64	3.0	3.5						
		3.03	4.53	4.0	5.5						
Mar 30, 76	$20^{@}$	0.69	1.03	3.0	-	12.7	15.1	1.4	13.4	4.2	5.5
		1.93	1.55	14.0	6.0						
Apr 15, 76	24	0.35	0.28	5.0	6.0	6.7	6.6	4.1	2.5	3.6	3.6
		4.56	3.68	3.0	4.0						
Apr 24, 76	$43^{@}$	4.11	2.97	11.0	7.0	16.0	17.7	5.0	12.7	7.4	14.2
		1.26	1.11	5.0	5.0						
		1.17	1.46	8.0	5.0						
May 5, 76	27	3.82	4.36	3.0	5.0	11.1	13.8	8.3	5.5	6.8	9.2
May 11, 74	23	2.49	2.70	5.0	4.0	13.4	12.2	3.2	9.0	2.0	9.3
		1.93	1.69	10.0	3.0						
May 15, 74	21	3.96	-	3.0	-	11.0	9.1	4.8	4.3	6.6	5.7
		4.59	4.75	4.0	5.5						
May 16, 74	56	24.9	24.1	1.0	4.0	38.6	50.4	38.1	12.3	2.5	4.4

continued .....

Table 7 (continued)

Date	Rain and Snowmelt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Observed	Computed	Observed	Computed	Observed	Computed	Overland	Subsurface	Observed	Computed
Jun 7, 71	37	2.34	2.85	2.0	3.5	4.8	3.0	2.9	0.1	2.5	0.0
Jun 13, 76	44[#]	4.84	5.13	4.0	4.0	6.6	5.7	5.6	0.1	2.9	0.0
Jun 19, 75	32	3.66	2.53	4.0	4.0	5.9	3.4	2.6	0.8	1.4	0.0
Jun 21, 72	63	1.79	1.24	4.0	3.5	6.9	4.9	2.3	2.6	4.8	2.8
		0.56	0.65	6.0	6.5						
Jun 30, 76	61[$]	7.26	-	4.0	-	15.1	13.0	9.9	3.1	5.1	3.8
		7.29	8.66	4.0	4.0						
Jul 5, 71	51	1.65	2.04	3.0	3.5	2.4	4.7	2.4	2.3	1.6	2.1
Jul 31, 73	61	1.69	7.73	6.0	4.5	2.9	8.3	8.3	0.0	0.0	0.0
Aug 23, 75	108	3.03	3.63	1.0	7.0	5.1	6.3	6.0	0.3	2.3	0.1
		0.19	0.62	1.0	4.0						
Sep 18, 75	35	0.31	0.34	14.0	9.5	3.1	4.7	1.1	3.6	4.7	9.1
		0.52	0.53	6.0	9.5						
		-	0.35	-	6.5						
Sep 26, 70	20	1.64	0.99	4.0	4.0	2.8	1.7	1.1	0.6	1.5	0.1
Oct 21, 72	68	1.69	2.53	6.0	5.5	6.5	10.3	5.3	5.0	5.9	17.4
		-	1.90	-	4.5						
Oct 28, 72	19	0.70	0.54	11.0	6.0	2.5	2.8	0.7	2.1	4.2	2.4
Nov 2, 72	12	0.56	0.78	7.0	4.5	2.4	3.1	0.7	2.4	4.7	3.7
Nov 17, 70	20[@]	0.86	0.64	18.0	12.0	5.1	6.2	0.6	5.6	6.7	10.3

continued .....

Table 7 (continued)

Date	Rain and Snow-melt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Ob-served	Com-puted	Ob-served	Com-puted	Ob-served	Com-puted	Over-land	Sub-surface	Ob-served	Com-puted
Nov 26, 70	15@	0.74	0.57	8.0	5.0	8.7	9.3	1.1	8.2	12.8	15.0
		1.57	1.08	7.0	5.5						
Nov 28, 73	19	1.44	1.79	6.0	3.5	7.2	9.5	2.2	7.3	9.1	10.1
Dec 3, 70	28	4.47	4.95	7.0	5.5	13.1	14.8	6.3	8.5	6.0	22.8
Dec 5, 75	24@	2.32	6.19	4.0	4.5	5.9	13.0	8.4	4.6	5.4	9.1
Dec 6, 71	47@	0.56	-	14.0	-	9.2	9.7	2.0	7.7	3.8	7.6
		1.29	1.48	10.0	7.0						
Dec 13, 75	15@	1.80	2.96	6.0	4.5	7.0	7.6	3.4	4.2	5.5	8.0
Dec 15, 71	29	1.77	1.84	7.0	6.5	7.4	7.4	1.8	5.6	4.7	9.8

@ Includes snowmelt

Fifty percent more than recorded amount

$ Twenty-five percent more than recorded amount

Table 8: Observed and Computed Hydrograph Characteristics on Holiday Creek (AG-5) Watershed for Various Storms

Date	Rain and Snow-melt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Ob-served	Com-puted	Ob-served	Com-puted	Ob-served	Com-puted	Over-land	Sub-surface	Ob-served	Com-puted
Mar 3, 76	69[@]	25.3	23.2	12.0	6.5	48.6	56.2	30.8	25.4	13.3	11.5
Apr 18, 75	40	10.7	9.41	5.0	5.5	21.8	25.8	9.4	16.4	5.8	11.1
Apr 24, 76	47	3.02	3.16	8.0	5.5	3.8	11.3	8.8	7.5	9.9	8.6
May 6, 76	45	4.40	3.68	6.0	5.5	11.5	13.3	4.6	8.7	9.8	10.4
Jun 3, 75	46	0.93	0.76	4.0	5.0	4.7	2.6	1.4	1.2	3.3	1.4
		0.84	-	-	-						
		0.64	0.35	5.0	4.5						
Jul 14, 76	27	1.75	1.36	4.0	7.0	3.9	1.9	1.7	0.2	0.3	0.0
Jul 20, 76	61	8.9	11.3	7.0	5.5	13.3	14.2	13.5	0.7	0.3	0.1
Jul 29, 76	32	1.59	1.64	9.0	6.0	5.0	5.0	1.5	3.5	0.9	0.8
Aug 13, 76	85[#]	1.53	0.91	9.0	7.0	28.7	34.4	26.3	8.1	3.6	14.5
		22.5	22.1	4.0	6.0						
Aug 13, 76	88[&]	1.53	1.92	9.0	7.0	28.7	37.9	29.9	8.0	3.6	14.4
		22.5	23.8	4.0	6.5						
Aug 24, 75	61	2.13	1.45	3.0	6.0	5.1	6.1	3.0	3.1	1.4	2.3
		1.63	-	5.0	-						
		0.64	1.38	11.0	6.0						

continued .....

Table 8 (continued)

Date	Rain and Snowmelt mm	Peak, $m^3.sec^{-1}$		Time to peak, hour		Storm runoff, mm		Computed runoff, mm		Groundwater, mm	
		Observed	Computed	Observed	Computed	Observed	Computed	Overland	Subsurface	Observed	Computed
Dec 13, 75	19[@]	2.16	2.00	6.00	5.0	6.4	5.8	2.1	3.7	6.5	8.1

@ Includes snowmelt

Seventy percent of recorded amount

& Average; amounts on subwatersheds vary

Table 9: Observed and Computed Hydrograph Characteristics on Holiday Creek (AG-5) Watershed at H1, H2 and Downstream Gauging Stations for Various Storms

Date	Station H1(Cross-section #4)				Station H2(Cross-section #14)				Downstream Gauging Station (Cross-section #1)			
	Peak,$m^3.sec^{-1}$		Time to peak, hour		Peak,$m^3.sec^{-1}$		Time to peak, hour		Peak,$m^3.sec^{-1}$		Time to peak, hour	
	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed
Apr 24, 76	N.A.	0.75	N.A.	4.5	0.98	0.87	5.0	5.5	3.02	3.16	8.0	5.5
May 6, 76	1.01	0.88	4.5	4.5	1.15	0.99	5.0	5.5	4.40	3.68	6.0	5.5
Jul 14, 76	1.10	0.35	1.0	4.5	0.58	0.42	5.5	6.0	1.75	1.36	4.0	7.0
	0.63	-	7.5	-								
Jul 20, 76	3.45	-	1.0	-	2.42	3.28	3.0	6.0	8.91	11.3	7.0	5.5
	2.97	2.83	3.0	5.0								
Jul 29, 76	N.A.	0.40	N.A.	5.0	0.69	0.49	3.5	6.0	1.59	1.64	9.0	6.0
Aug 13, 76#	0.79	0.24	5.5	5.0	0.94	0.26	4.5	6.0	1.53	0.91	9.0	7.0
	10.6	5.48	0.5	5.0	5.97	6.02	1.5	6.0	22.5	22.1	4.0	6.0
Aug 13, 76&	0.79	1.22	5.5	5.0	0.94	0.55	4.5	5.0	1.53	1.92	9.0	7.0
	10.6	10.4	0.5	5.0	5.97	7.29	1.5	5.5	22.5	23.8	4.0	6.5

Seventy percent of recorded amount

& Average; amounts on subwatersheds vary

N.A. : Not available.

consuming. The third approach is easy and logical and was used here.

It was assumed that a peak flowrate is probably produced by the highest intensity of the rainfall. In case of multiple bursts, multiple peaks result. Each peak was associated with the preceeding maximum intensity period.

A comparison between observed and computed time to peak gave the following results. The average observed times to peak for Canagagigue (AG-4), East Canagagigue and Holiday Creek (AG-5) watersheds were 6.3, 6.1 and 6.6 hours respectively. Their computed times to peak were 6.7, 5.3 and 5.9 hours respectively.

The scatter around the mean was quite significant for observed times of all watersheds. The standard deviations for the observed times to peak were 4.1, 3.6 and 2.8 hours respectively for the three watersheds. The standard deviations for the computed times to peak were less at 2.4, 1.8 and 0.8 hours respectively.

Small variations for the computed results can be easily explained. The program uses a method of convoluting rainfall amounts with area.time^{-1} versus time curve for a sub-watershed to calculate the generated flowrate. The response was therefore uniform and non-seasonal. The watershed however, responds in a seasonal fashion.

Overall, the summer storms produce a sharp peak, normally earlier than computed, but reverse was observed during other seasons, barring a few exceptions. This suggests that some seasonal modifications might be necessary in selection of area.time^{-1} versus time curves. This could result in a slightly better match between the computed and observed peaks.

Storm runoff

Storm runoff has two components overland and subsurface runoffs. The total amount of runoff shows a very seasonal trend and so do its two components in their relative amounts.

The storm runoff varies with rainfall and snowmelt input and season. It was generally observed that storms occuring during the months of June through August (summer storms) produce less runoff than the spring or winter storms.

Several examples could be cited. June 7, 71 (37 mm) and August 23, 75 (108 mm) storms produced respectively 2.2 and 11.2 mm runoff on Canagagigue (AG-4) and 3.0 to 6.3 mm runoff on East Canagagigue. In contrast May 5, 76 (27mm) and December 13, 75 (15 mm) storms produced respectively 15.5 and 9.4 mm runoffs on Canagagigue and 13.8 to 7.6 mm on East Canagagigue. Holiday Creek (AG-5) watershed also showed similar trend. May 6, 76 (45 mm) storm on Holiday Creek (AG-5) produced 13.3 mm runoff, while August 24, 75 (61 mm) produced only 6.1 mm runoff.

Even very big summer storms produced comparatively small runoff amounts.

The August 13, 76 storm on Holiday Creek was very intense and highly localized. Average rainfall amount on the watershed was estimated to be 88 mm. It however, computed only 37.9 mm storm runoff in contrast to 56.2 mm runoff produced by a smaller, less intense storm event of March 3, 76 (69 mm).

In the summer months, there is a fairly large soil-water deficit in the soil. Vegetative cover is dense over the watersheds. These result in high rate of infiltration capacity and more water is stored as soil-water. During other months the reverse is true. March through May and December storms tend to produce maximum storm runoff.

Relative amounts of overland and subsurface runoff components also show a very strong seasonal trend. Overland runoff is relatively much larger than subsurface runoff during most summer storms. Some summer storms produce almost no subsurface runoff. Winter, spring and sometimes fall storms do not exhibit a large proportional difference between these components.

All three watersheds gave similar computed responses. Three summer storms which occurred on June 19, 75, August 1, 73 and August 23, 75, produced 4.6, 2.2 and 7.2 mm of overland storm runoff and 1.0, 0.0 and 4.0 mm of subsurface storm runoff respectively on Canagagigue watershed. On East Canagagigue the same storms produced 2.6, 8.3 and 6.0 mm of overland storm runoff and 0.8, 0.0 and 0.3 mm of subsurface storm runoff respectively. The July 20, 76 and August, 76 storms on Holiday Creek produced 13.5 and 29.9 mm overland runoff and 0.7 and 8.0 mm subsurface runoff respectively.

During Spring and Fall months the proportion was different. The April 24, 76, October 28, 72 and December 13, 75 storms produced 7.5, 0.8 and 4.7 mm of overland storm runoff and 13.4, 2.3 and 4.7 of subsurface storm runoff respectively on the Canagagigue watershed. The amounts were 5.0, 0.7, 3.4 and 12.7, 2.1 and 4.2 mm respectively on East Canagagigue watershed. On Holiday Creek watershed, the March 3, 76 storm produced 30.8 mm of overland storm runoff and 25.4 mm of subsurface storm runoff.

Due to a high soil-water deficit, most of infiltrated water is retained in the soil during summer causing small subsurface response. In spring and winter and also when the conditions are very wet in summer, very little infiltrated water is retained and most comes out as subsurface storm runoff or percolation to groundwater.

Areal distribution of overland runoff

Overland runoff calculated for various zones of the watersheds during different storm events has been tabulated in Table 10 to 12. Zone 1 of each watershed represented the impervious area. The other zones are pervious. Zones 2 and 3 have well drained soils (in case of East Canagagigue extremely well drained soils) and zones 8 and 9 have very poorly drained soils. The areal distribution of soil types is shown in Figures 7 to 9 and summarized in Table 2. The choice of zone properties is described on pages 29 to 34.

The great variation of overland runoff on the Canagagigue watershed can be pictorially described as given in Figures 26 to 34. Figure 26 shows the

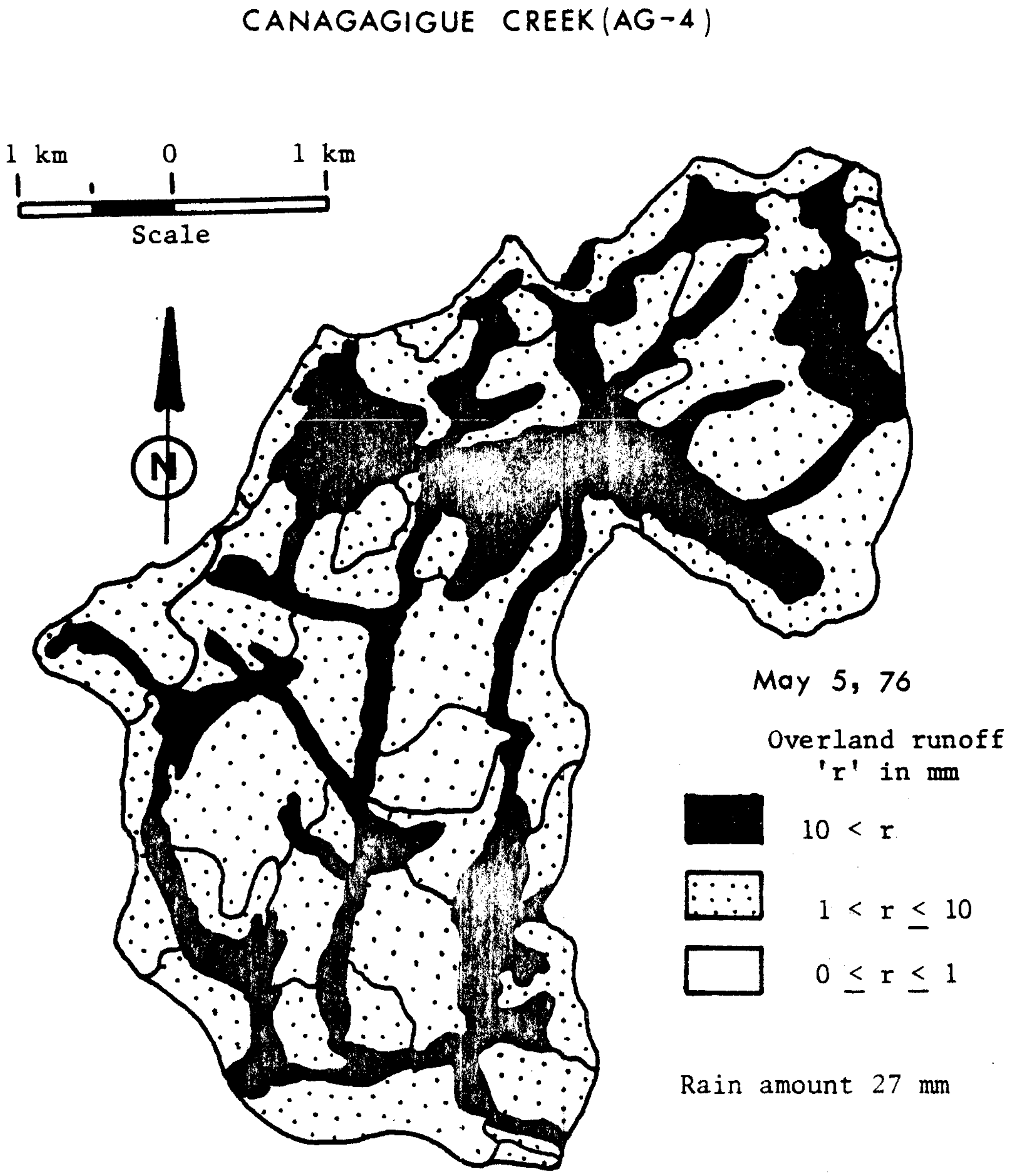


Fig. 26: Areal Distribution of Overland Runoff Produced During May 5, 1976 Storm on Canagagigue (AG-4) Watershed.

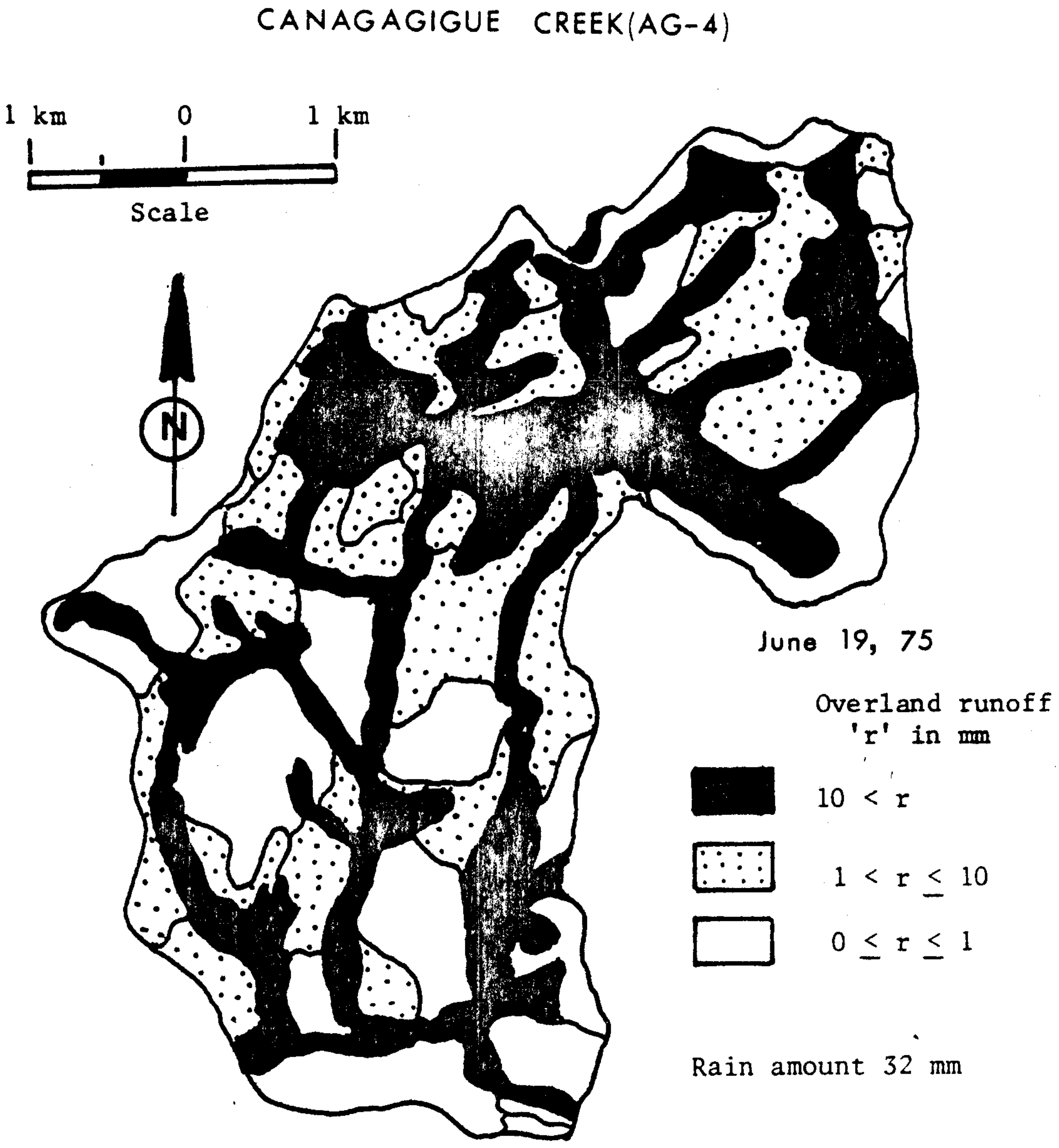


Fig. 27: Areal Distribution of Overland Runoff Produced During June 19, 1975 Storm on Canagagigue (AG-4) Watershed.

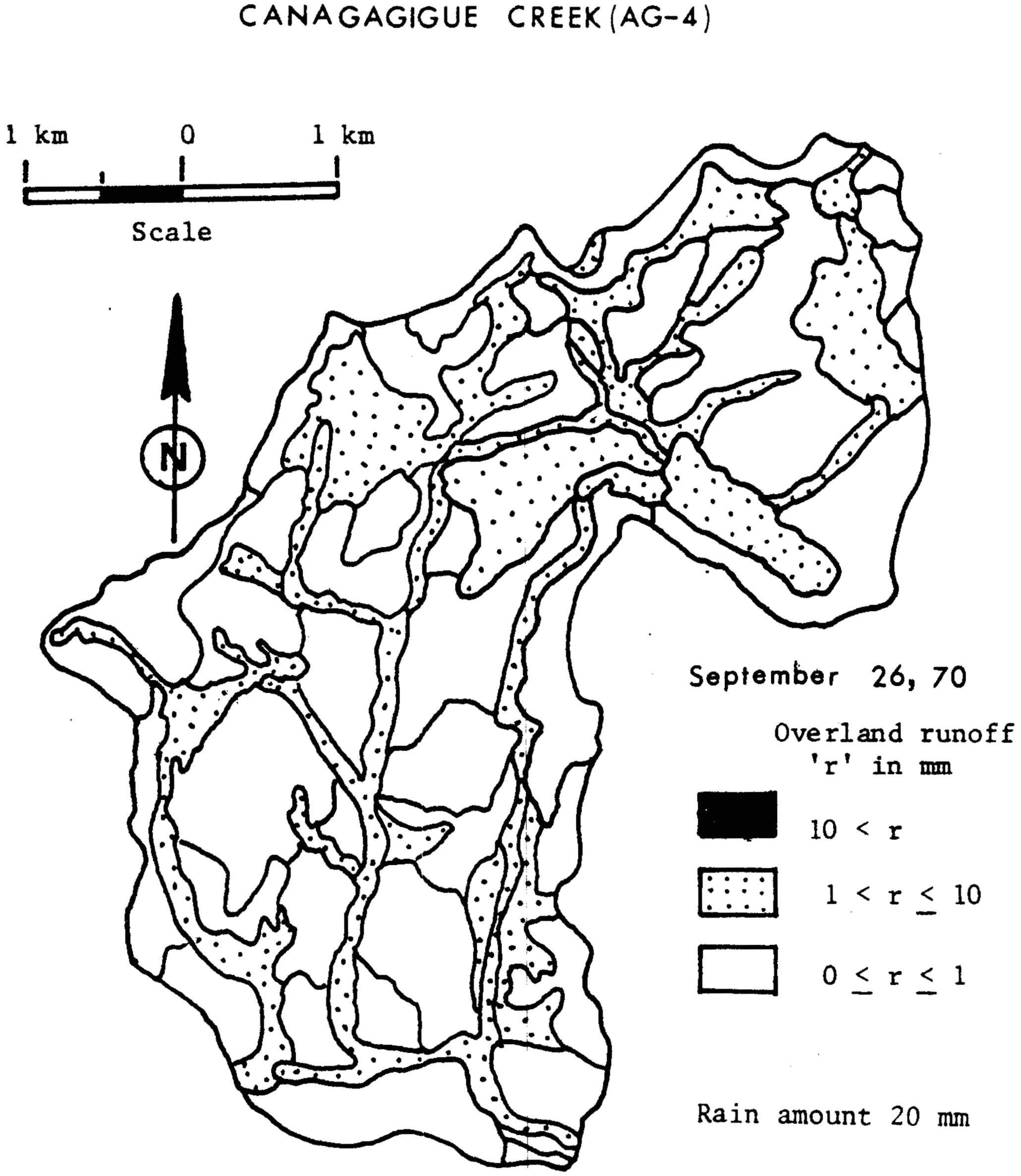


Fig. 28: Areal Distribution of Overland Runoff Produced During September 26, 1970 Storm on Canagagigue (AG-4) Watershed.

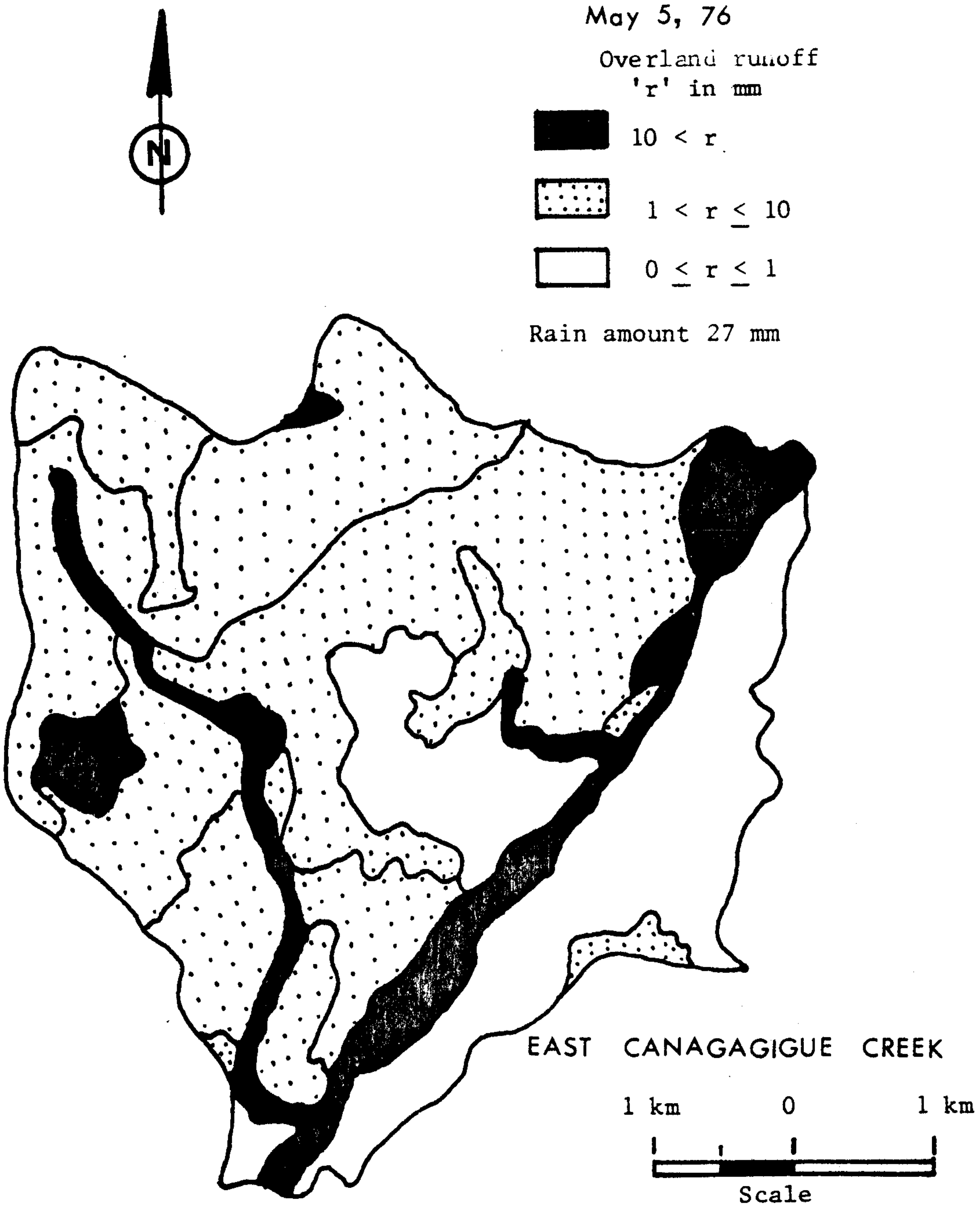


Fig. 29: Areal Distribution of Overland Runoff Produced During May 5, 1976 Storm on East Canagagigue Watershed.

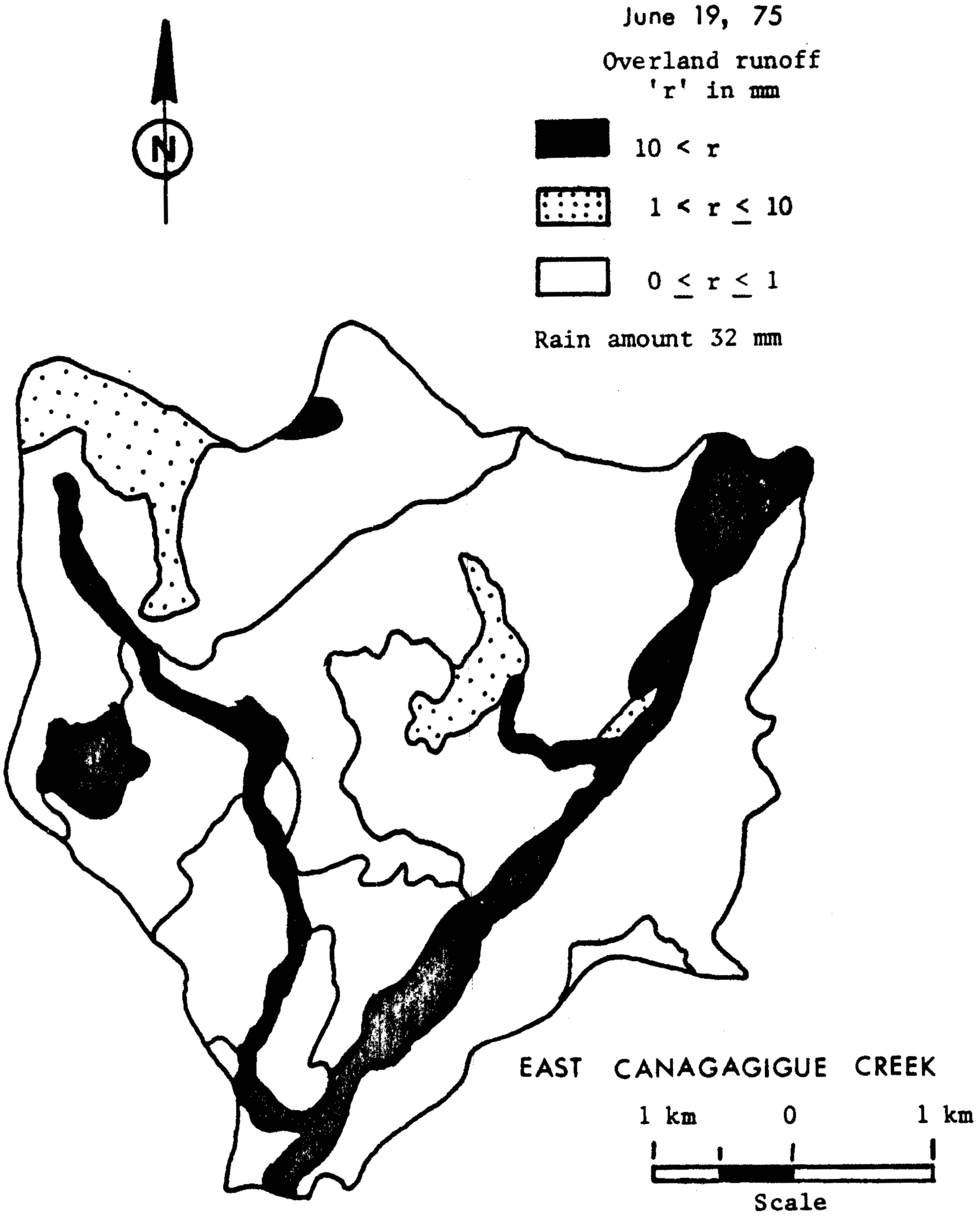


Fig. 30: Areal Distribution of Overland Runoff Produced During June 19, 1975 Storm on East Canagagigue Watershed.

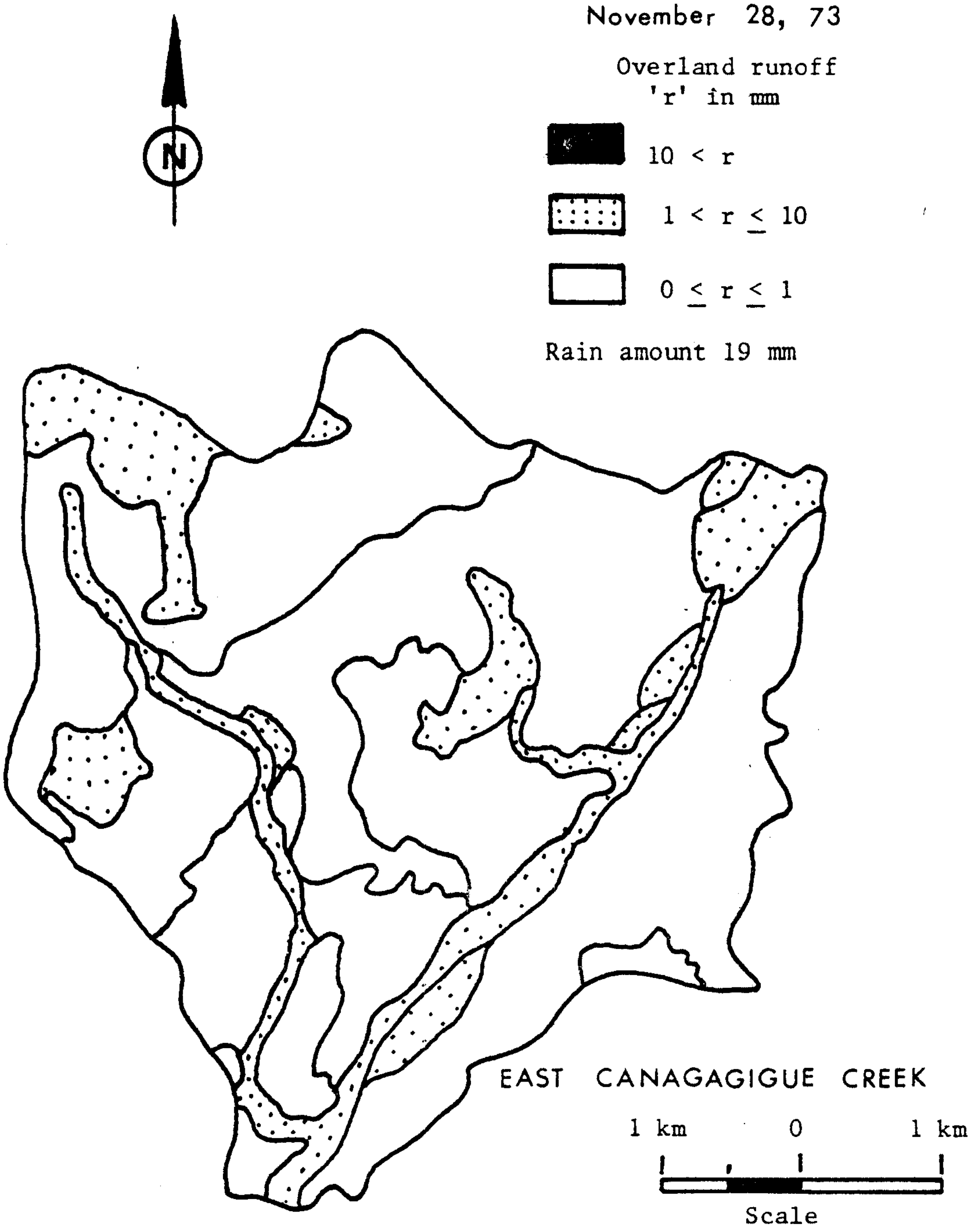


Fig. 31: Areal Distribution of Overland Runoff Produced During November 28, 1973 Storm on East Canagagigue Watershed.

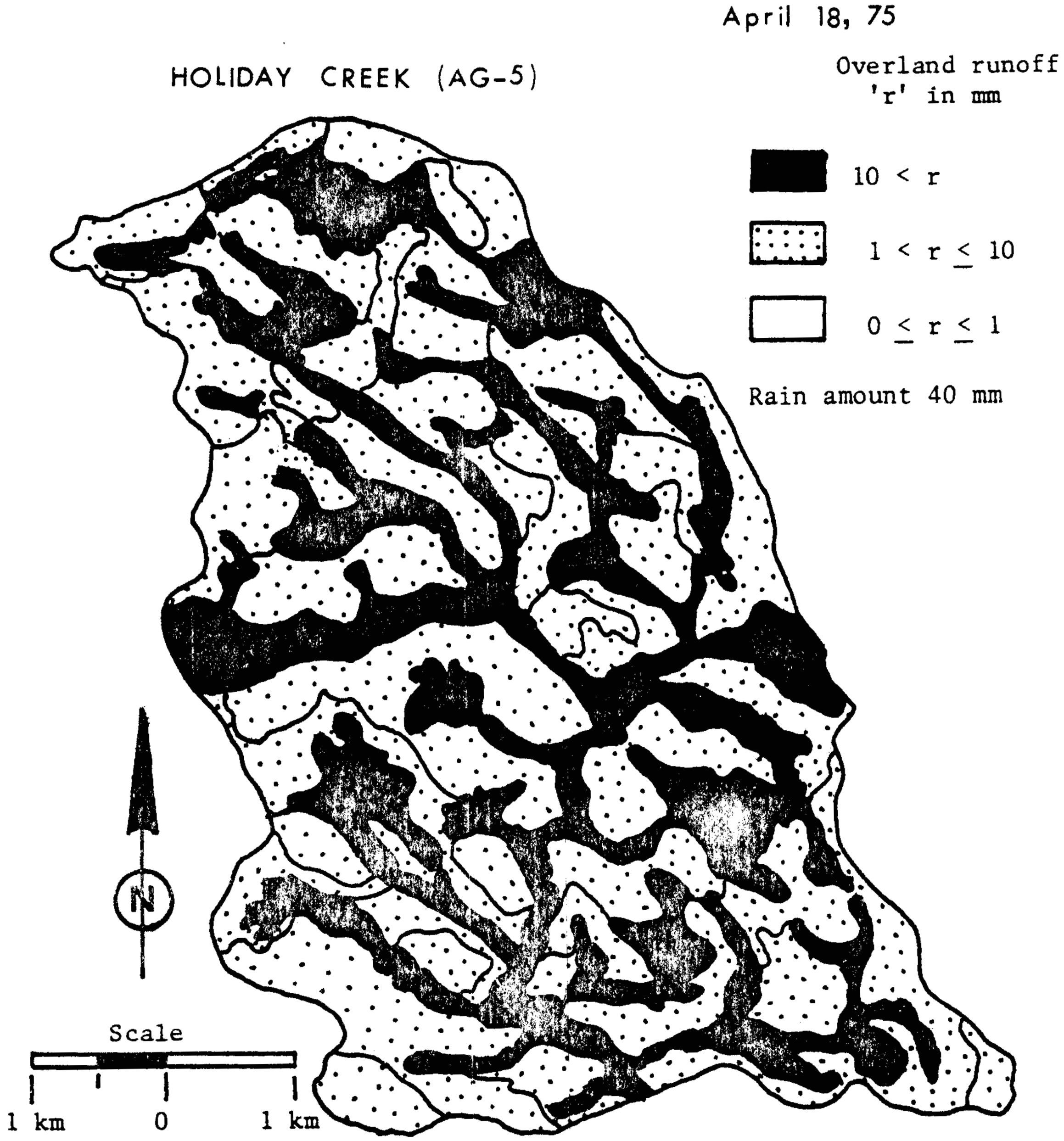


Fig. 32: Areal Distribution of Overland Runoff Produced During April 18, 1975 Storm on Holiday Creek (AG-5) Watershed.

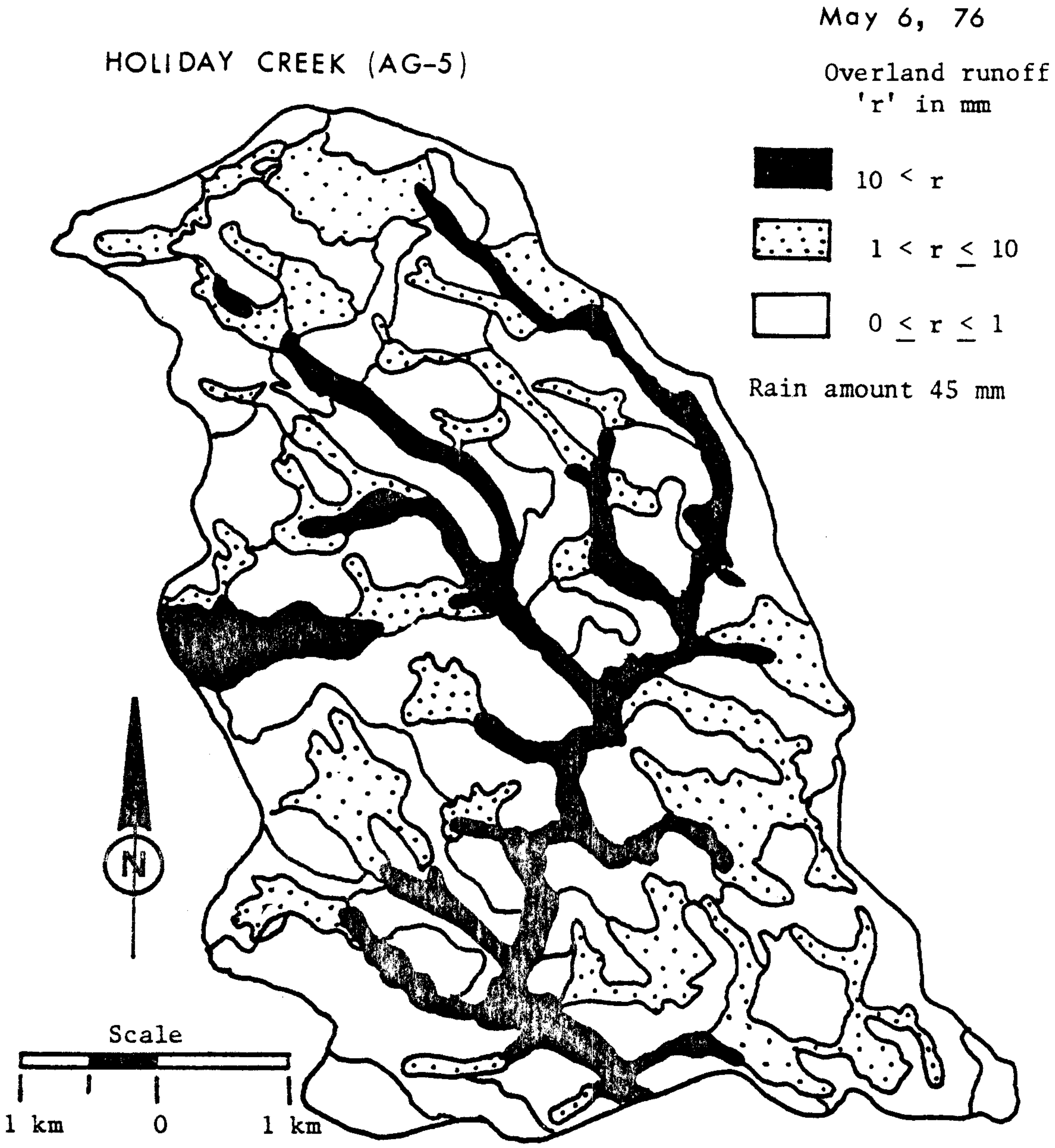


Fig. 33: Areal Distribution of Overland Runoff Produced During May 6, 1976 Storm On Holiday Creek (AG-5) Watershed.

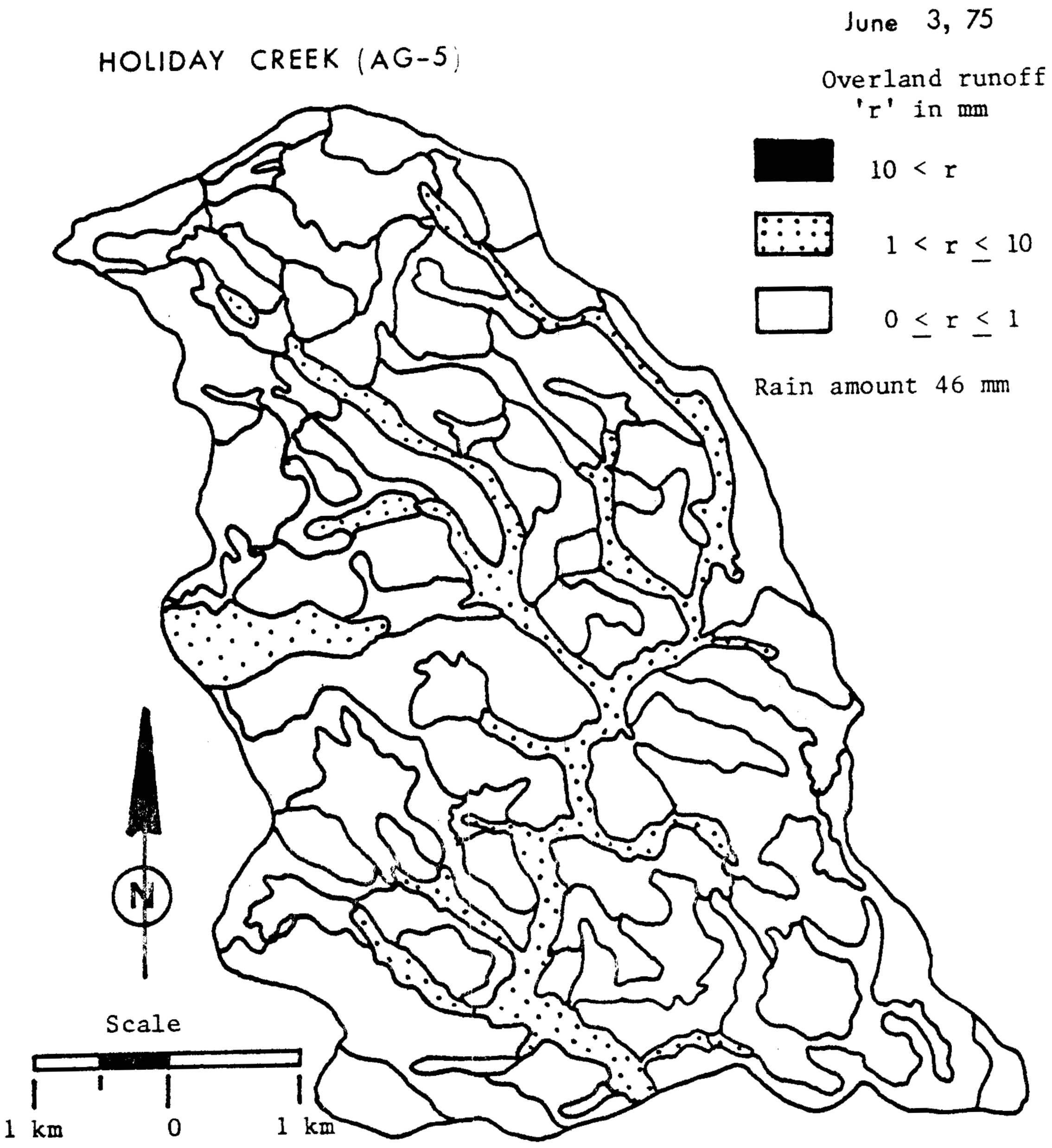


Fig. 34: Areal Distribution of Overland Runoff Produced During June 3, 1975 Storm on Holiday Creek (AG-5) Watershed.

Table 10: Overland Runoff from Different Zones of Canagagigue (AG-4) Watershed During Various Storms

Date	Rain and Snowmelt, mm	Overland Runoff for Zones, mm								
		1	2	3	4	5	6	7	8	9
Mar 19, 76	220[@]	220	96.4	97.8	108	106	138	141	138	141
Mar 30, 76	20[@]	19.5	0.5	0.5	0.9	0.9	3.3	3.3	3.3	3.3
Apr 15, 76	24	24.0	2.5	2.5	5.8	5.8	11.9	11.9	11.9	11.9
Apr 24, 76	43[@]	43.0	2.9	2.9	3.6	3.6	13.3	13.3	13.3	13.3
May 5, 76	27	27.0	5.3	5.3	5.0	5.0	12.5	12.4	12.5	12.4
May 11, 74	23	23.0	0.0	0.0	1.0	1.0	7.3	7.30	8.7	8.7
May 15, 74	25[#]	25.0	2.3	2.3	3.4	3.4	14.4	14.4	14.4	14.4
May 16, 74	56	56.0	34.0	31.4	37.3	36.0	46.6	46.0	46.7	46.0
Jun 7, 71	37	37.0	0.0	0.0	0.0	0.0	3.9	3.9	3.9	3.9
Jun 13, 76	29	24.0	0.0	0.0	0.0	0.0	5.0	5.0	5.0	5.0
Jun 19, 75	32	32.0	0.0	0.0	1.0	1.0	11.0	11.0	11.0	11.0
Jun 21, 72	63	63.0	0.0	0.0	0.0	0.0	2.9	2.9	2.9	2.9
Jun 30, 76	49	49.0	1.3	1.3	3.4	3.4	17.4	17.4	17.4	17.4
Jul 5, 71	51	45.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug 1, 73	46	26.2	0.0	0.0	0.0	0.0	4.7	4.7	4.7	4.7
Aug 23, 75	108	106.0	0.0	0.0	0.0	0.0	13.7	13.7	13.7	13.7
Sep 18, 75	35	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep 26, 70	20	20.0	0.0	0.0	0.0	0.0	1.2	1.2	1.2	1.2
Oct 22, 72	62	62.0	0.0	0.0	0.0	0.0	11.0	11.0	11.9	11.0
Oct 28, 72	19	18.8	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
Nov 2, 72	12	12.0	0.0	0.0	0.0	0.0	2.2	2.2	2.2	2.2

continued .....

Table 10 (continued)

Date	Rain and Snowmelt, mm	Overland Runoff for Zones, mm								
		1	2	3	4	5	6	7	8	9
Nov 7, 72	16	16.0	1.3	1.3	1.1	1.0	6.9	6.8	6.9	6.8
Nov 17, 70	20@	16.5	0.0	0.0	0.0	0.0	2.0	2.0	0.6	0.6
Nov 26, 70	25@	17.1	0.0	0.0	0.0	0.0	4.8	1.8	2.8	0.0
Nov 28, 73	19	19.0	0.4	0.4	1.3	1.3	8.4	9.2	8.4	9.2
Dec 3, 70	28	28.0	7.0	3.6	6.9	3.0	18.0	16.6	18.0	16.6
Dec 5, 75	24@	24.0	11.0	10.9	11.2	11.0	17.0	18.3	17.0	18.3
Dec 6, 71	47@	23.3	0.0	0.0	0.0	0.0	8.0	4.8	8.0	4.8
Dec 13, 75	15@	15.0	3.7	3.7	3.7	3.7	6.1	6.1	6.1	6.1
Dec 15, 71	29	29.0	0.0	0.0	1.7	0.6	13.5	9.8	13.5	9.8

@ Includes snowmelt

\# Fifty percent more than recorded amount

Table 11: Overland Runoff from Different Zones of East Canagagigue Watershed During Various Storms

Date	Rain and Snowmelt, mm	Overland Runoff for Zones, mm								
		1	2	3	4	5	6	7	8	9
Mar 19, 76	220[@]	220	47.6	48.4	95.0	145	105	143	148	190
Mar 30, 76	20[@]	19.5	0.0	0.0	0.5	0.5	0.9	0.9	3.3	3.4
Apr 15, 76	24	24.0	0.0	0.0	2.5	2.5	5.8	5.8	11.9	11.9
Apr 24, 76	43[@]	43.0	0.1	0.1	2.9	2.9	3.6	3.6	13.4	13.4
May 5, 76	27	27.0	0.0	0.0	4.5	4.5	4.4	4.1	14.2	13.2
May 11, 74	23	22.9	0.0	0.0	1.5	1.5	2.9	2.9	9.3	14.4
May 15, 74	16	16.0	0.0	0.0	1.0	1.0	1.5	1.5	6.6	6.7
May 16, 74	56	55.9	23.4	23.4	39.2	45.2	40.9	44.6	45.7	47.9
Jun 7, 71	37	36.6	0.0	0.0	0.0	0.0	0.0	0.0	12.3	12.3
Jun 13, 76	44[#]	43.5	1.8	1.8	2.9	2.9	4.0	4.0	14.6	14.6
Jun 19, 75	32	32.0	0.0	0.0	0.0	0.0	1.0	1.0	11.0	11.0
Jun 21, 72	63	63.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.8
Jun 30, 76	61[$]	61.0	4.0	4.0	5.5	5.5	7.8	7.8	26.4	26.4
Jul 5, 71	51	50.8	0.0	0.0	0.0	0.0	0.0	0.0	5.9	5.9
Jul 31, 73	61	41.0	3.7	3.7	7.5	7.5	6.5	6.5	12.4	12.4
Aug 23, 75	108	108.0	0.0	0.0	0.0	0.0	0.0	0.0	19.3	19.3
Sep 18, 75	35	35.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep 26, 70	20	20.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.3
Oct 21, 72	68	68.0	0.0	0.0	4.9	0.0	0.4	0.0	18.4	14.1
Oct 28, 72	19	18.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0

continued .....

Table 11 (continued)

Date	Rain and Snowmelt, mm	Overland Runoff for Zones, mm								
		1	2	3	4	5	6	7	8	9
Nov. 2, 72	12	12.2	0.0	0.0	0.0	0.0	0.0	0.0	2.2	2.2
Nov 17, 70	20@	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6
Nov 26, 70	25@	17.1	0.0	0.0	0.0	0.0	0.0	0.0	3.1	11.1
Nov 28, 73	19	19.0	0.0	0.0	1.2	0.4	1.3	1.3	8.6	7.0
Dec 3, 70	28	27.9	0.0	0.0	8.5	3.6	7.2	3.0	18.6	11.7
Dec 5, 75	24@	24.0	0.0	0.0	9.5	9.5	9.3	9.3	14.3	13.4
Dec 6, 71	47@	23.3	0.0	0.0	1.4	0.0	0.0	0.0	8.0	4.6
Dec 13, 75	15@	15.0	0.0	0.0	3.4	3.4	3.5	3.5	6.4	6.4
Dec 15, 71	29	29.0	0.0	0.0	0.0	0.0	0.1	0.0	12.0	9.7

@ Includes snowmelt

Fifty percent more than recorded amount

$ Twenty-five percent more than recorded amount

Table 12: Overland Runoff from Different Zones of Holiday Creek (AG-5) Watershed During Various Storms

Date	Rain and Snowmelt, mm	Overland Runoff for Zones, mm								
		1	2	3	4	5	6	7	8	9
Mar 3, 76	69@	69.0	24.4	24.4	27.4	27.4	36.2	36.2	36.2	36.2
Apr 18, 75	40	45.0	1.4	1.4	5.0	5.0	17.5	17.5	17.5	17.5
Apr 24, 76	47	47.0	0.0	0.0	0.0	0.0	7.2	7.2	7.2	7.2
May 6, 76	45	45.0	0.0	0.0	0.0	0.0	8.4	8.4	11.6	11.6
Jun 3, 75	46	44.0	0.0	0.0	0.0	0.0	0.3	0.3	2.1	2.1
Jul 14, 76	27	25.0	0.0	0.0	0.0	0.0	2.5	2.5	3.4	3.4
Jul 20, 76	61	59.0	4.8	4.8	5.5	5.5	23.3	23.3	25.9	25.9
Jul 29, 76	32	32.0	0.0	0.0	0.0	0.0	1.5	1.5	3.1	3.1
Aug 13, 76	85#	82.7	28.1	28.1	20.5	20.5	33.9	33.9	33.9	33.9
Aug 24, 75	61	59.0	0.0	0.0	0.0	0.0	7.2	7.2	7.2	7.2
Dec 13, 75	19@	18.7	0.0	0.0	0.1	0.1	4.5	4.5	4.4	4.4

@ Includes snowmelt

Seventy percent of recorded amount

distribution due to May 5, 76 storm. Similar distributions have been obtained for several other storms (mostly spring storms). It can be seen that most of the runoff has been produced by poorly and very poorly drained soils. Also, it could be noticed that remaining areas produce some runoff during these large spring storms. The distribution obtained for the June 19, 75 storm is shown in Figure 27. In this case, and others similar, the well-drained areas produce very little overland runoff. The distribution shown in Figure 28 is due to the September 26, 70 storm. Several other summer and fall storms were similar. The amount of overland runoff has been quite small in these cases, most contributions coming from very poorly drained soils only.

In a similar way responses of the East Canagagigue watershed are shown in Figure 29 to 31 and of Holiday Creek (AG-5) watershed in Figures 32 to 34. Figures 26 to 29 show the distribution due to the same May 5, 76 storm on Canagagigue and East Canagagigue watersheds. It can be seen that similar soils on both these watersheds respond in a similar fashion. An area in the Eastern portion of the East Canagagigue watershed produced little overland runoff, since it contains sandy soils (extremely well drained).

Some big storms such as that of March 19, 76 on both Canagagigue watersheds and August 13, 76 storm on Holiday Creek watershed generate large amounts of overland runoff from all soils. Their distribution would appear as a solid black figure. The reverse is found in cases of small storms or storms with a very dry initial watershed condition such as July 5, 71 and September 18, 75 storms on both Canagagigue watersheds. For these and many summer rainstorms the distribution would be shown by a blank figure.

An attempt has been made to compare the overland runoff results computed by the model with the observations made and reported by Mr. L.J.P. van Vliet, in the October, 76 report of PLUARG Project No. 16. Two of the best matches are shown in Figure 35 and 36. These figures show the comparisons for April 18, 75 and August 13, 76 storms respectively.

The observed runoff reported in the October, 76 report of Project 16, illustrates the areas falling under different contributing area classes as follows: 0%, 1-10% (low), 11-25% (medium), 26-50% (high) and >50% (very high). 0% indicates no runoff contribution while >50% indicates a large amount of runoff contribution from the area.

To quantify these subjective observations, storms were classified as short duration (less than 20 hours) or long duration (greater than 20 hours) storms. For short duration storms, the following amounts were attributed to the various classes. Runoff amount up to 1 mm was considered as non-observable and hence was considered as equal to 0% class. Other classes were attributed to the following amounts for short storms: 1 to 10%: >1 to 3 mm; 11 to 25%: >3 to 8 mm; 26 to 50%: > 8 to 15 mm; and >50%: > 15 mm. The amounts attributed to these five classes for a long duration storms were: 0 to 2 mm, > 2 to 6 mm, > 6 to 12 mm, > 12 to 20 mm and > 20 mm.

Figure 35 is the comparison for a short duration storm (April 18, 75) and Figure 36 shows the comparison for a long duration storm (August 13, 76). It could be noted that there is a fairly reasonable correspondence between the computed and estimated (from observation) results.

This correspondence could be greatly improved if the watershed would be further divided into small area zones, and also if the observation techniques would be made in a more quantitative fashion.

Groundwater accumulation

Estimates of groundwater accumulation during a storm are made in an indirect fashion in this model. The model assumes that a portion of pervious area contributes to subsurface flow and the remaining to groundwater. This was the way chosen to allow for a portion of the water percolating through the bottom layer of the soil to be treated as subsurface flow and the rest as groundwater accumulation. Tables 13 to 15 show the proportion of the soil types contributing to subsurface flow and to groundwater accumulation during various storms on the watersheds. Also tabulated are initial groundwater conditions and assumed limiting infiltration capacities for various zones on the watersheds.

Seasonal variations were observed in the proportion of soils contributing to subsurface storm runoff and groundwater flow. Compared to the contribution to groundwater, areal contribution to subsurface flow was more in March, almost equal in April and May and always less in the remaining months.

The tiling survey done on the Canagagigue watershed indicated that about 40 percent of the watershed area has been tiled. This estimate is fairly close to the percent area contributing to subsurface flow during June through December. The percent varied from 32 to 44. The March 19, 76 storm on Canagagigue had a maximum area contribution (82%) to subsurface flow. The areal contribution to subsurface storm flow increased considerably as wetness of soil increased. May 11, 15 and 16 are three storms which occurred in sequence on Canagagigue during 1974. The areal proportions to subsurface storm flow were 52, 61 and 78 percent respectively.

No tiling survey data are available for East Canagagigue and Holiday Creek watersheds. The model results on those watersheds- however, resemble closely the results on Canagagigue.

The amount of observed groundwater was established from recorded hydrograph estimates of baseflow rate and an estimate of a recession constant for the groundwater. It was assumed that the groundwater system acts as a linear reservoir. The match between computed and observed amounts of groundwater input are reasonable during drier period. During wet period and notably at snowmelt time, the agreement is poor. One reason could be the high sensitivity of results to rainfall and infiltration capacity rates during this period. Tables 6, 7 and 8 contain the model-computed groundwater amounts and the hydrograph-observed values.

Table 13: Assumed Model Parameters of Canagagigue (AG-4) Watershed During Various Storms

Date	Limiting infiltration capacity (Fc) of various zones, mm.hr^{-1}				% of total area to subsurface flow	% of total area to ground water	Initial ground water flowrate m^3.sec^{-1}
	2,3	4,5	6,7	8,9			
Mar 19, 76	2.0	1.5	1.0	1.0	81.8	15.4	0.17
Mar 30, 76	2.0	1.5	1.0	1.0	66.3	30.9	0.19
Apr 15, 76	5.0	3.0	2.0	2.0	52.4	44.8	0.20
Apr 24, 76	2.0	1.5	1.0	1.0	55.0	42.2	0.25
May 5, 76	4.0	2.5	1.5	1.5	52.4	44.8	0.11
May 11, 74	5.0	3.0	1.5	1.5	52.4	44.8	0.06
May 15, 74	5.0	3.0	1.5	1.5	61.2	36.0	0.09
May 16, 74	6.0	4.5	2.0	2.0	76.9	20.2	0.14
Jun 7, 71	6.0	4.5	2.0	2.0	40.9	56.3	0.0
Jun 13, 76	6.0	4.5	2.0	2.0	40.9	56.3	0.0
Jun 19, 75	6.0	4.5	2.0	2.0	40.9	56.3	0.0
Jun 21, 72	6.0	4.5	2.0	2.0	40.9	56.3	0.06
Jun 30, 76	6.0	4.5	2.0	2.0	40.9	56.3	0.0
Jul 5, 71	6.0	4.5	2.0	2.0	40.9	56.3	0.0
Aug 1, 73	6.0	4.5	2.0	2.0	36.4	60.7	0.0
Aug 23, 75	6.0	4.5	2.0	2.0	36.4	60.7	0.0
Sep 18, 75	5.0	3.0	2.0	2.0	36.4	60.7	0.03
Sep 26, 70	6.0	4.5	2.0	2.0	36.4	60.7	0.06
Oct 22, 72	6.0	4.5	2.0	2.0	32.2	65.0	0.05

continued .....

Table 13 (continued)

Date	Limiting infiltration capacity (Fc) of various zones, mm.hr^{-1}				% of total area to subsurface flow	% of total area to ground water	Initial ground water flowrate m^3.sec^{-1}
	2,3	4,5	6,7	8,9			
Oct 28, 72	3.0	2.0	1.0	1.0	32.2	65.0	0.09
Nov 2, 72	3.0	2.0	1.0	1.0	37.0	60.1	0.15
Nov 7, 72	3.0	2.0	1.0	1.0	37.0	60.1	0.18
Nov 17, 70	6.0	4.5	2.0	2.0	32.2	65.0	0.07
Nov 26, 70	3.0	2.0	1.0	1.0	41.2	55.9	0.11
Nov 28, 73	3.0	2.0	1.0	1.0	41.0	56.1	0.11
Dec 3, 70	6.0	4.5	2.0	2.0	32.2	65.0	0.20
Dec 5, 75	3.0	2.0	1.0	1.0	32.2	65.0	0.11
Dec 6, 71	6.0	4.5	2.0	2.0	32.2	65.0	0.04
Dec 13, 75	3.0	2.0	1.0	1.0	44.0	53.2	0.06
Dec 15, 71	6.0	4.5	2.0	2.0	32.2	65.0	0.07

Table 14: Assumed Model Parameters of East Canagagigue Watershed During Various Storms

Date	Limiting infiltration capacity (Fc) of various zones, mm.hr^{-1}				% of total area to subsurface flow	% of total area to ground water	Initial ground water flowrate m^3.sec^{-1}
	2,3	4,5	6,7	8,9			
Mar 19, 76	3.0	2.0	1.5	1.0	69.8	27.1	0.18
Mar 30, 76	3.0	2.0	1.5	1.0	61.1	35.8	0.24
Apr 15, 76	9.0	5.0	3.0	2.0	48.0	48.9	0.13
Apr 24, 76	3.0	2.0	1.5	1.0	48.0	48.9	0.15
May 5, 76	9.0	3.0	2.0	1.0	48.0	48.9	0.19
May 11, 74	9.0	3.0	2.0	1.0	48.0	48.9	0.08
May 15, 74	9.0	3.0	2.0	1.0	51.1	45.8	0.10
May 16, 74	9.0	3.0	2.0	1.0	68.6	28.4	0.12
Jun 7, 71	10.0	6.0	4.5	2.0	33.6	63.3	0.02
Jun 13, 76	10.0	6.0	4.5	2.0	33.6	63.3	0.04
Jun 19, 75	10.0	6.0	4.5	2.0	33.6	63.3	0.06
Jun 21, 72	10.0	6.0	4.5	2.0	33.6	63.3	0.0
Jun 30, 76	10.0	6.0	4.5	2.0	33.6	63.3	0.04
Jul 5, 71	10.0	6.0	4.5	2.0	40.5	56.4	0.01
Jul 31, 73	10.0	6.0	4.5	2.0	33.6	63.3	0.0
Aug 23, 75	10.0	6.0	4.5	2.0	33.6	63.3	0.0
Sep 18, 75	10.0	5.0	3.0	2.0	29.1	67.8	0.03
Sep 26, 70	10.0	6.0	4.5	2.0	29.1	67.8	0.02
Oct 21, 72	10.0	6.0	4.5	2.0	31.6	65.3	0.04

continued .....

Table 14 (continued)

Date	Limiting infiltration capacity (Fc) of various zones, mm.hr^{-1}				% of total area to subsurface flow	% of total area to ground water	Initial ground water flowrate m^3.sec^{-1}
	2,3	4,5	6,7	8,9			
Oct 28, 72	9.0	3.0	2.0	1.0	31.9	65.0	0.08
Nov 2, 72	9.0	3.0	2.0	1.0	33.0	63.9	0.11
Nov 17, 70	10.0	6.0	4.5	2.0	31.6	65.3	0.07
Nov 26, 70	9.0	3.0	2.0	1.0	33.0	63.9	0.10
Nov 28, 73	8.0	3.0	2.0	1.0	42.4	54.6	0.13
Dec 3, 70	10.0	6.0	4.5	2.0	31.6	65.3	0.17
Dec 5, 75	8.0	3.0	2.0	1.0	33.0	63.9	0.07
Dec 6, 71	10.0	6.0	4.5	2.0	31.6	65.3	0.03
Dec 13, 75	5.0	2.0	1.5	1.0	33.0	63.9	0.06
Dec 15, 71	10.0	6.0	4.5	2.0	31.6	65.3	0.06

Table 15: Assumed Model Parameters of Holiday Creek (AG-5) Watershed During Various Storms

Date	Limiting infiltration capacity (Fc) of various zones, mm.hr^{-1}				% of total area to subsurface flow	% of total area to ground water	Initial ground water flowrate m^3.sec^{-1}
	2,3	4,5	6,7	8,9			
Mar 3, 76	1.5	1.2	0.8	0.8	66.6	31.0	0.30
Apr 18, 75	6.0	4.5	2.0	2.0	51.2	46.3	0.23
Apr 24, 76	5.0	3.5	1.5	1.5	44.6	52.9	0.11
May 6, 76	5.0	4.0	1.0	1.0	44.6	52.9	0.20
Jun 3, 75	6.0	4.5	2.0	2.0	36.1	61.4	0.04
Jul 14, 76	6.0	4.5	2.0	2.0	47.5	50.0	0.0
Jul 20, 76	6.0	4.5	2.0	2.0	47.5	50.0	0.0
Jul 29, 76	6.0	4.5	2.0	2.0	47.5	50.0	0.04
Aug 13, 76	6.0	4.5	2.0	2.0	37.7	59.8	0.04
Aug 24, 75	6.0	4.5	2.0	2.0	37.7	59.8	0.0
Dec 13, 75	3.0	2.0	1.0	1.0	32.5	65.1	0.20

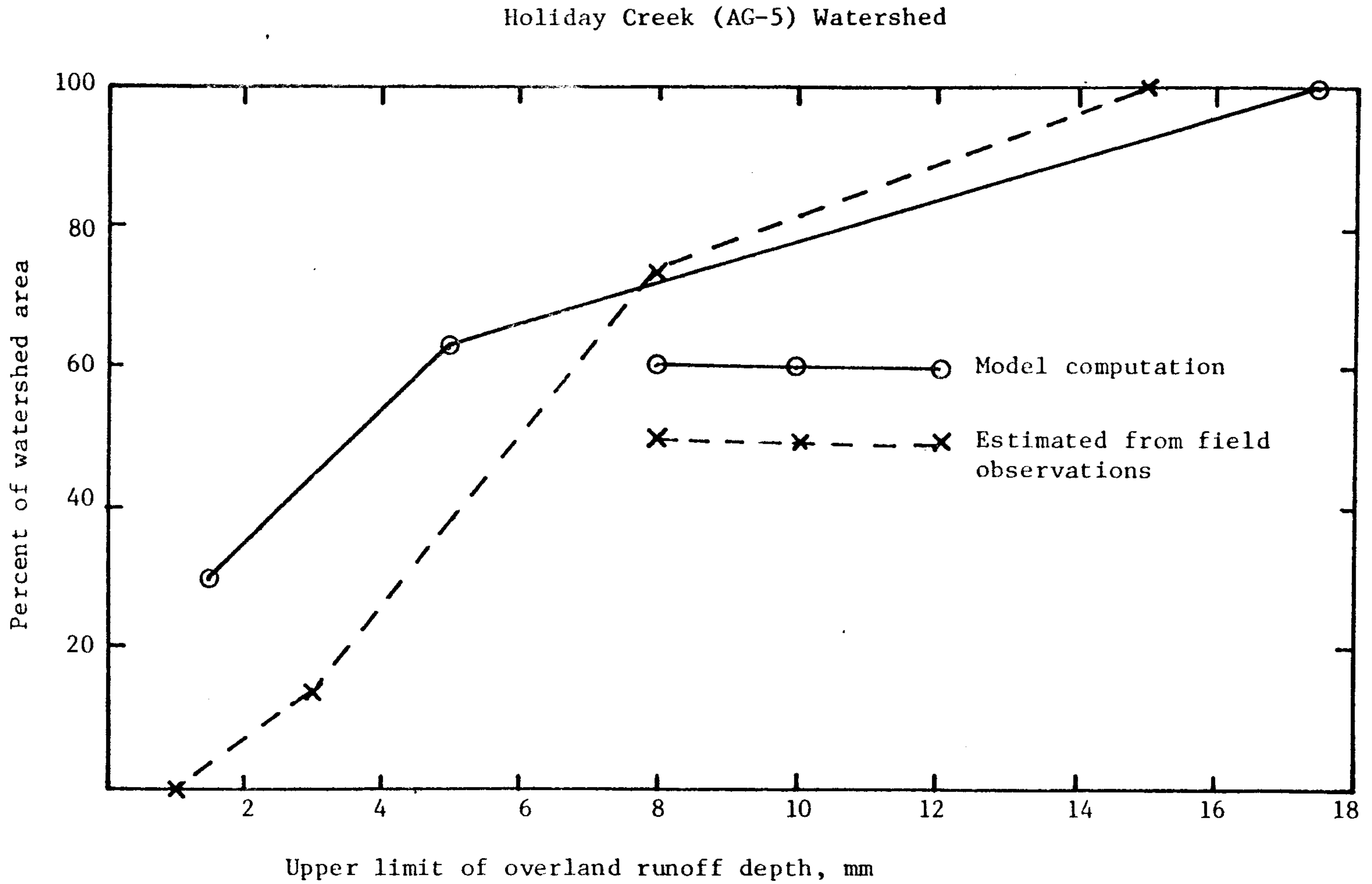


Figure 35: Comparison of estimated (field) and computed (model) overland-runoff depths produced during the April 18, 1975 storm on Holiday Creek (AG-5) watershed.

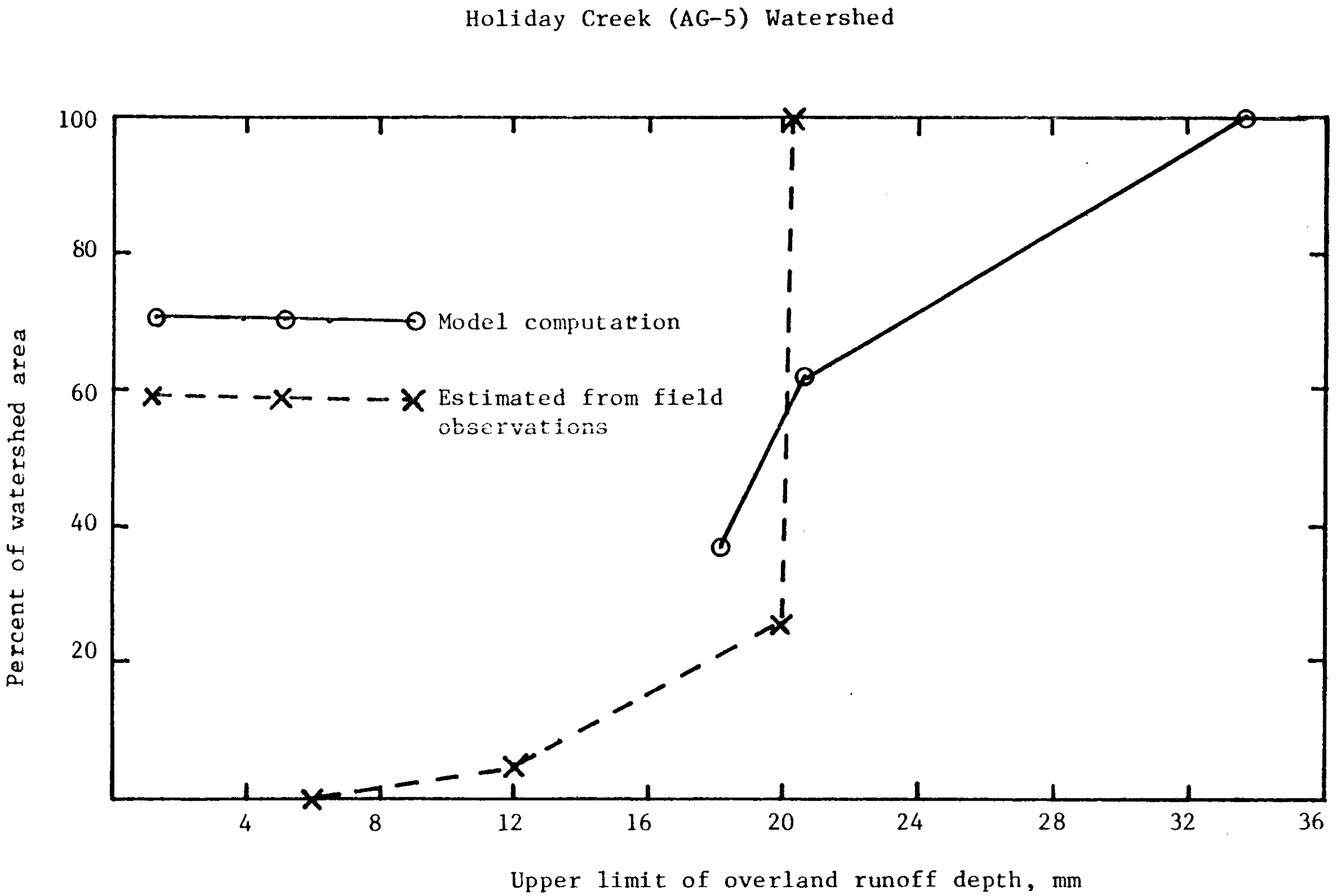


Figure 36: Comparison of estimated (field) and computed (model) overland-runoff depths produced during the August 13, 1976 storm on Holiday Creek (AG-5) watershed.

It is felt that this area needs more research including methods of estimating groundwater contribution from recorded data. Since the objective of the model was not an accurate prediction of groundwater accumulation, no further modifications were made in this model.

Water balance summaries

Storm-event water-balance summaries for the watersheds are given in Tables 16 to 18. The effective input is the rain and snowmelt amounts after deducting a small interception amount. The output consists of overland runoff, net subsurface storm runoff, net input to groundwater, evaporation and any depression storage assumed for the watershed. The net amount of either subsurface storm runoff or groundwater accumulation is the sum of the difference between the storage capacities at the beginning and end of the storm and the amount produced during the analysis period.

The last column of the table gives apparent soil-water storage increase due to the storm. It can be seen that the amount is large for most summer storms or storms with dry initial conditions. This is due to large amounts of soil-water deficit at the beginning of the storm. The negative amount in this column indicates very wet initial conditions for the storms.

Infiltration capacity

Infiltration capacity rates computed at the beginning and end of storm periods for the watersheds are given in Tables 19 to 21. Zones 2 and 3 have well drained soils, zones 4 and 5 have imperfectly drained soils, zones 6 and 7 have poorly drained soils and zones 8 and 9 have very poorly drained soils in Canagagigue (AG-4) and Holiday Creek (AG-5) watersheds. The sequence in East Canagagigue watershed is however, extremely well drained, well drained, imperfectly drained and very poorly drained soils.

Infiltration capacity varied with both soil type and season. Well drained and extremely well drained soils had higher infiltration capacity than very poorly drained soils. The capacity was maximum during the summer months and minimum during winter for all soil types.

Well drained soils of Canagagigue watershed had infiltration capacity ranging from 30 to 84 $mm.hr^{-1}$ during the months of June through August at the beginning of a storm. The rates dropped to 7 to 12 $mm.hr^{-1}$ during September - October, 3 to 9 $mm.hr^{-1}$ during November - December and 3 to 6 $mm.hr^{-1}$ during March through May. East Canagagigue had the same response. Well drained soils of Holiday Creek watershed differed slightly during March through May. The capacity varied from 3 to 12 $mm.hr^{-1}$.

It should be noted that the summer values are very much different from the values during other months. The reasons are a dense vegetative cover and commonly a large amount of soil-water deficit in the top soil layer.

Table 16: Storm Event Water Balance Summaries for Canagagigue (AG-4) Watershed

Date	Effective input, mm	Output Components, mm					Total output, mm	Apparent soil-water storage increase mm
	Rainfall and Snowmelt A	Overland runoff B	Net sub-surface runoff C	Net ground water storage D	Evaporation for period of analysis E	Depression storage F	(B+C+D+E+F) G	(A-G)
Mar 19, 76	$220^{@}$	116	85.6	17.5	0.0	0.5	219.6	0.4
Mar 30, 76	$20^{@}$	2.0	11.4	5.6	0.0	0.5	19.5	0.5
Apr 15, 76	24	7.0	2.9	2.1	4.4	0.5	16.9	7.1
Apr 15, 76	$21^{\&}$	4.8	2.6	1.7	4.4	0.5	14.0	7.0
Apr 24, 76	$43^{@}$	7.4	13.8	11.5	7.7	0.5	40.9	2.1
May 5, 76	27	8.0	7.3	6.1	12.0	0.0	33.4	-6.4
May 11, 74	23	3.4	9.1	8.3	4.7	0.5	26.0	-3.0
May 15, 74	$25^{\#}$	7.0	7.0	5.0	2.2	0.5	21.7	3.3
May 16, 74	56	39.1	10.1	3.8	8.7	0.5	62.2	-6.2
Jun 7, 71	37	2.2	0.0	0.0	18.8	1.0	22.0	15.0
Jun 13, 76	29	2.2	0.0	0.0	8.9	1.9	13.0	16.0
Jun 19, 75	32	4.6	1.0	0.5	10.5	1.0	17.6	14.4
Jun 21, 72	63	2.7	4.1	2.6	30.2	1.9	41.5	21.5
Jun 30, 76	49	8.2	0.3	0.0	17.3	1.0	26.8	22.2
Jul 5, 71	51	1.3	0.0	0.0	9.4	2.1	12.8	38.2
Aug 1, 73	46	2.2	0.0	0.0	11.1	2.5	15.8	30.2
Aug 23, 75	108	7.2	4.0	4.2	15.2	2.0	32.6	75.4
Sep 18, 75	35	1.0	5.9	9.8	12.0	0.5	29.2	5.8
Sep 26, 70	20	0.9	0.9	0.4	14.2	1.5	17.9	2.1

continued .....

Table 16 (continued)

Date	Effective input, mm	Output Components, mm					Total output, mm (B+C+D+E+F)	Apparent soil-water storage increase mm
	Rainfall and Snowmelt A	Overland runoff B	Net sub-surface runoff C	Net ground water storage D	Evaporation for period of analysis E	Depression storage F	G	(A-G)
Oct 22, 72	62	5.2	3.0	1.9	6.0	1.0	17.1	44.9
Oct 28, 72	19	0.8	2.1	3.6	6.7	0.5	13.7	5.3
Nov 2, 72	12	1.0	2.4	4.6	5.4	0.5	13.9	-1.9
Nov 7, 72	16	3.3	3.3	6.6	5.0	0.5	18.7	-2.7
Nov 17, 70	20[@]	0.9	5.7	11.9	0.0	1.6	20.1	-0.1
Nov 26, 70	25[@]	1.5	9.7	14.1	0.0	2.0	27.3	-2.3
Nov 28, 73	19	3.7	6.3	9.8	0.0	0.5	20.3	-1.3
Dec 3, 70	28	8.8	8.1	20.5	0.0	0.5	37.9	-9.9
Dec 5, 75	24[@]	13.3	3.4	8.2	0.0	0.5	25.4	-1.4
Dec 6, 71	47[@]	2.7	6.3	1.7	0.0	2.60	13.3	33.7
Dec 13, 75	15[@]	4.7	4.5	5.7	0.0	0.0	14.9	0.1
Dec 15, 71	29	4.8	5.4	12.1	0.0	0.5	22.8	6.2

[@] Includes snowmelt

[#] Fifty percent more than recorded amount

[&] Average; amounts on subwatersheds vary

Table 17: Storm Event Water Balance Summaries for East Canagagigue Watershed

Date	Effective input, mm	Output Components, mm					Total output, mm (B+C+D+E+F)	Apparent soil-water storage increase mm
	Rainfall and Snowmelt A	Overland runoff B	Net sub-surface runoff C	Net ground water storage D	Evaporation for period of analysis E	Depression storage F	G	(A-G)
Mar 19, 76	220[@]	107	73.5	35.8	0.0	0.5	216.8	3.2
Mar 30, 76	20[@]	1.4	10.1	5.5	0.0	0.5	17.5	2.5
Apr 15, 76	24	4.1	3.0	3.6	4.4	0.5	15.6	8.4
Apr 24, 76	43[@]	5.0	13.0	14.2	7.7	0.5	40.4	2.6
May 5, 76	27	5.5	7.8	9.2	12.0	0.0	34.5	-7.5
May 11, 74	23	3.2	8.7	9.3	4.7	0.5	26.4	-3.4
May 15, 74	21[$]	4.8	5.5	5.7	2.2	0.5	18.7	2.3
May 16, 74	56	38.1	10.2	4.4	9.1	0.5	62.3	-6.3
Jun 7, 71	37	2.8	0.1	0.0	8.1	1.0	12.0	25.0
Jun 13, 76	44[#]	5.6	0.1	0.0	8.9	1.9	16.5	27.5
Jun 19, 75	32	2.6	0.6	0.0	22.1	1.0	26.3	5.7
Jun 21, 72	63	2.3	2.5	2.8	30.3	1.9	39.8	23.2
Jun 30, 76	61[$]	9.9	3.0	3.8	17.3	1.0	34.0	27.0
Jul 5, 71	51	2.4	2.4	2.1	9.4	1.9	18.2	32.8
Jul 31, 73	61	8.3	0.0	0.0	10.0	2.6	20.9	40.1
Aug 23, 75	108	6.0	0.2	0.1	15.1	1.9	23.3	84.7
Sep 18, 75	35	1.1	3.6	9.1	11.9	0.5	26.2	8.8
Sep 26,70	20	1.1	0.7	0.1	6.9	1.5	10.3	9.7

continued .....

Table 17 (continued)

Date	Effective input, mm	Output Components, mm					Total output, mm (B+C+D+E+F)	Apparent soil-water storage increase mm
	Rainfall and Snowmelt A	Overland runoff B	Net sub-surface runoff C	Net ground water storage D	Evaporation for period of analysis E	Depression storage F	G	(A-G)
Oct 21, 72	68	5.3	5.4	17.4	5.3	1.9	35.3	32.7
Oct 28, 72	19	0.7	2.0	2.4	6.7	0.5	12.3	6.7
Nov 2, 72	12	0.7	2.2	3.7	5.4	0.5	12.5	-0.5
Nov 17, 70	20[@]	0.6	5.5	10.3	0.0	0.8	17.2	2.8
Nov 26, 70	25[@]	1.1	7.8	15.0	0.0	1.0	24.9	0.1
Nov 28, 73	19	2.2	6.9	10.1	0.0	0.5	19.7	-0.7
Dec 3, 70	28	6.3	8.2	22.8	0.0	0.5	37.8	-9.8
Dec 5, 75	24[@]	8.4	4.2	9.1	0.0	0.5	22.2	1.8
Dec 6, 71	47[@]	2.0	7.6	7.6	0.0	2.7	19.9	27.1
Dec 13, 75	15[@]	3.4	3.6	8.0	0.0	0.0	15.0	0.0
Dec 15, 71	29	1.8	5.4	9.8	0.0	2.7	19.7	9.3

@ Includes snowmelt

\# Fifty percent more than recorded amount

$ Twenty-five percent more than recorded amount

Table 18: Storm Event Water Balance Summaries for Holiday Creek (AG-5) Watershed

Date	Effective input, mm	Output Components, mm					Total output, mm	Apparent soil-water storage increase mm
	Rainfall and Snowmelt A	Overland runoff B	Net sub-surface runoff C	Net ground water storage D	Evaporation for period of analysis E	Depression storage F	(B+C+D+E+F) G	(A-G)
Mar 3, 76	69[@]	30.8	24.0	11.5	2.9	0.5	69.7	-0.7
Apr 18, 75	40	9.4	12.0	11.1	8.9	0.5	41.9	-1.9
Apr 24, 76	47	3.8	7.4	8.6	7.8	0.5	28.1	18.9
May 6, 76	45	4.6	8.9	10.4	12.1	0.5	36.5	8.5
Jun 3, 75	46	1.4	0.9	1.4	17.5	2.0	23.2	22.8
Jul 14, 76	27	1.6	0.2	0.0	22.8	2.0	26.6	0.4
Jul 20, 76	61	13.5	0.7	0.1	22.2	2.0	38.5	22.5
Jul 29, 76	32	1.5	3.1	0.9	22.0	0.5	28.0	4.0
Aug 13, 76	85[#]	26.3	8.2	14.5	15.7	2.0	66.7	18.3
Aug 13, 76	88[&]	29.9	8.1	14.4	15.7	2.0	70.1	17.9
Aug 24, 75	61	3.0	3.1	2.3	15.5	2.0	25.9	35.1
Dec 14, 75	19[@]	2.1	3.7	8.1	3.8	0.5	18.2	0.8

[@] Includes snowmelt

[#] Seventy percent of recorded amount

[&] Average; amounts on subwatersheds vary

Table 19: Initial and Final Infiltration Capacities for Pervious Zones of Canagagigue (AG-4) Watershed During Various Storms

Date	Initial Infiltration Capacity, mm.hr^{-1}				Final Infiltration Capacity mm.hr^{-1}			
	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9
Mar 19, 76	2.8	2.5	1.4	1.4	2.6*	2.2	1.3	1.3
Mar 30, 76	2.8	2.5	1.4	1.4	2.5	2.0	1.2	1.2
Apr 15, 76	8.2	6.3	2.9	2.9	5.9	4.3	2.3	2.3
Apr 24, 76	4.0	3.8	2.1	2.1	2.7	2.3	1.3	1.3
May 5, 76	4.7	3.5	1.9	1.9	4.0	2.5	1.5	1.5
May 11, 74	6.4	4.5	1.7	1.6	5.7	3.6	1.5	1.5
May 15, 74	6.3	4.4	2.0	2.0	5.0	3.0	1.5	1.5
May 16, 74	5.8	3.7	1.7	1.7	5.0	3.0	1.5	1.5
Jun 7, 71	43.4	43.1	29.7	29.7	24.4	24.1	14.8	14.8
Jun 13, 76	35.3	32.7	14.7	14.7	21.3	19.0	6.6	6.6
Jun 19, 75	29.5	23.5	7.8	7.8	17.2	12.7	3.4	3.4
Jun 21, 72	39.0	39.6	26.8	26.8	12.2	13.2	4.2	4.2
Jun 30, 76	35.7	29.8	11.6	11.6	13.5	10.2	2.8	2.8
Jul 5, 71	50.1	52.5	35.0	35.0	17.0	18.3	7.1	7.1
Aug 1, 73	61.1	64.6	47.7	47.7	23.4	25.2	16.3	16.3
Aug 23, 75	84.2	86.3	64.0	64.0	17.5	19.4	10.1	10.1
Sep 18, 75	11.9	12.1	7.6	7.6	6.9	6.0	3.1*	3.1*
Sep 26, 70	21.3	24.2	15.9	15.9	11.7	13.4	7.2	7.2
Oct 22, 72	16.8	16.8	9.6	9.6	6.2	4.8	2.1*	2.0

continued .....

Table 19 (continued)

Date	Initial Infiltration Capacity, mm.hr^{-1}				Final Infiltration Capacity mm.hr^{-1}			
	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9
Oct 28, 72	6.8	6.6	3.4	3.4	3.8	3.3	1.2*	1.2*
Nov 2, 72	4.6	3.9	2.3	2.3	4.2	3.7	1.9	1.9
Nov 7, 72	3.6	2.8	1.3	1.3	3.0	2.0	1.0	1.0
Nov 17, 70	7.8	7.0	3.3	3.3	6.8	5.8	2.6*	2.6*
Nov 26, 70	3.9	3.2	1.3	1.3	3.7	3.1	1.3	1.3
Nov 28, 73	3.9	3.2	1.4	1.4	3.1*	2.2*	1.0	1.0
Dec 3, 70	6.8	5.5	2.2	2.2	6.0*	4.5*	2.0	2.0
Dec 5, 75	3.3	2.4	1.1	1.1	3.0	2.0	1.0	1.0
Dec 6, 71	9.2	7.3	3.6	3.6	6.2*	4.6*	2.0*	2.0*
Dec 13, 75	3.2	2.2	1.2	12.	3.0	2.0	1.0	1.0
Dec 15, 71	8.2	6.4	2.8	2.8	6.0	4.5	2.0	2.0

* Average of two zones

Table 20: Initial and Final Infiltration Capacities for Pervious Zones of East Canagagigue Watershed During Various Storms

Date	Initial Infiltration Capacity, mm.hr^{-1}				Final Infiltration Capacity mm.hr^{-1}			
	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9
Mar 19, 76	5.4	2.8	2.5	1.4	3.8*	2.4*	1.9*	1.2*
Mar 30, 76	5.4	2.8	2.5	1.4	4.2	2.5	2.1	1.1
Apr 15, 76	13.0	8.2	6.3	2.9	10.2	5.9	4.3	2.3
Apr 24, 76	6.6	4.0	3.8	2.1	4.8	2.7	2.4	1.2
May 5, 76	10.7	3.6	2.9	1.4	9.3	3.0	2.0	1.0
May 11, 74	10.5	3.4	2.6	1.2	9.9	3.2	2.2	1.0
May 15, 74	10.3	3.5	2.6	1.4	9.4	3.0	2.0	1.0
May 16, 74	9.8	3.3	2.3	1.2	9.0	3.0	2.0	1.0
Jun 7, 71	37.7	43.4	43.1	17.7	21.2	24.6	24.1	8.6
Jun 13, 76	52.0	43.2	40.4	18.2	30.9	23.0	20.5	6.6
Jun 19, 75	30.6	29.5	23.5	7.8	18.8	17.2	12.7	3.4
Jun 21, 72	46.6	39.0	39.6	26.8	21.8	12.3	13.3	4.2
Jun 30, 76	37.4	35.7	29.8	11.6	11.9	8.9	7.0	2.2
Jul 5, 71	50.3	50.1	52.5	23.6	19.1	17.0	18.3	4.0
Jul 31, 73	75.0	66.0	69.5	52.4	28.4	22.3	23.6	14.9
Aug 23, 75	104.0	84.2	86.3	63.0	24.8	13.2	14.0	4.9
Sep 18, 75	31.6	11.9	12.1	7.6	18.7	7.3	6.1	3.5
Sep 26, 70	29.6	17.4	19.3	12.4	20.4	10.5	11.2	6.6
Oct 21, 72	22.9	16.8	16.8	9.6	12.0	6.1*	4.6*	2.0

continued .....

Table 20 (continued)

Date	Initial Infiltration Capacity, mm.hr^{-1}				Final Infiltration Capacity, mm.hr^{-1}			
	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9
Oct 28, 72	20.4	6.8	6.6	3.4	15.4	3.8	3.3	1.2*
Nov 2, 72	16.4	4.6	3.9	2.3	14.2	4.3	3.8	2.0*
Nov 17, 70	16.5	7.8	7.0	3.3	14.1	6.8	5.8	2.6*
Nov 26, 70	12.1	3.9	3.2	1.3	11.5	3.7*	3.0	1.2*
Nov 28, 73	10.8	3.9	3.2	1.4	9.5	3.1*	2.2*	1.0
Dec 3, 70	12.8	6.8	5.5	2.2	11.8	6.0*	4.5*	2.0
Dec 5, 75	9.4	3.3	2.4	1.3	8.0	3.0	2.0	1.0
Dec 6, 71	17.4	9.3	7.3	3.6	11.8	6.1*	4.6*	2.0
Dec 13, 75	5.8	2.2	1.8	1.2	5.2	2.0	1.5	1.0
Dec 15, 71	14.9	8.2	6.4	2.8	11.4	6.0	4.5	2.0

* Average of zones

Table 21: Initial and Final Infiltration Capacities for Pervious Zones of Holiday Creek (AG-5) Watershed During Various Storms

Date	Initial Infiltration Capacity, $mm.hr^{-1}$				Final Infiltration Capacity $mm.hr^{-1}$			
	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9	Zones 2,3	Zones 4,5	Zones 6,7	Zones 8,9
Mar 3, 76	2.8	2.5	1.4	1.4	1.7	1.4	0.9	0.9
Apr 18, 75	8.3	6.8	3.3	3.3	6.3	4.8	2.2	2.2
Apr 24, 76	9.8	8.3	3.5	3.5	6.1	4.6	1.6	1.6
May 6, 76	12.0	10.5	4.6	3.5	6.2	4.9	1.4	1.2
Jun 3, 75	48.0	39.8	22.0	19.2	22.0	16.2	7.5	7.1
Jul 14, 76	63.4	57.4	27.9	25.5	38.5	32.8	11.8	10.6
Jul 20, 76	76.0	74.5	40.1	35.3	23.0	22.0	10.9	9.5
Jul 29, 76	49.0	42.6	26.4	22.2	21.7	17.0	6.9	5.9
Aug 13, 76	49.0	47.5	30.8	30.8	8.9	7.6	4.4	4.4
Aug 24, 75	62.6	57.9	40.1	35.3	14.3	12.1	5.9	5.8
Dec 13, 75	4.4	3.4	1.7	1.7	3.6	2.6	1.2	1.2

The high infiltration capacity rates mostly limit the overland flow response of areas of well-drained soils in summer. Generally, spring and winter storms show some similarity in their respone with more frequent overland flow generation which has little resemblance to a summer storm response.

Infiltration capacity rates for very poorly drained soils also vary seasonably. The values were smaller than for well drained soils. Infiltration capacity rates for extremely well drained soils of East Canagagigue watershed were higher than those of well drained soils.

Infiltration capacities drop during a storm due to infiltrated water and recover after input stops. This is clearly illustrated by Figures 37 to 41. Recovery of infiltration rates between storms has been shown by dotted lines.

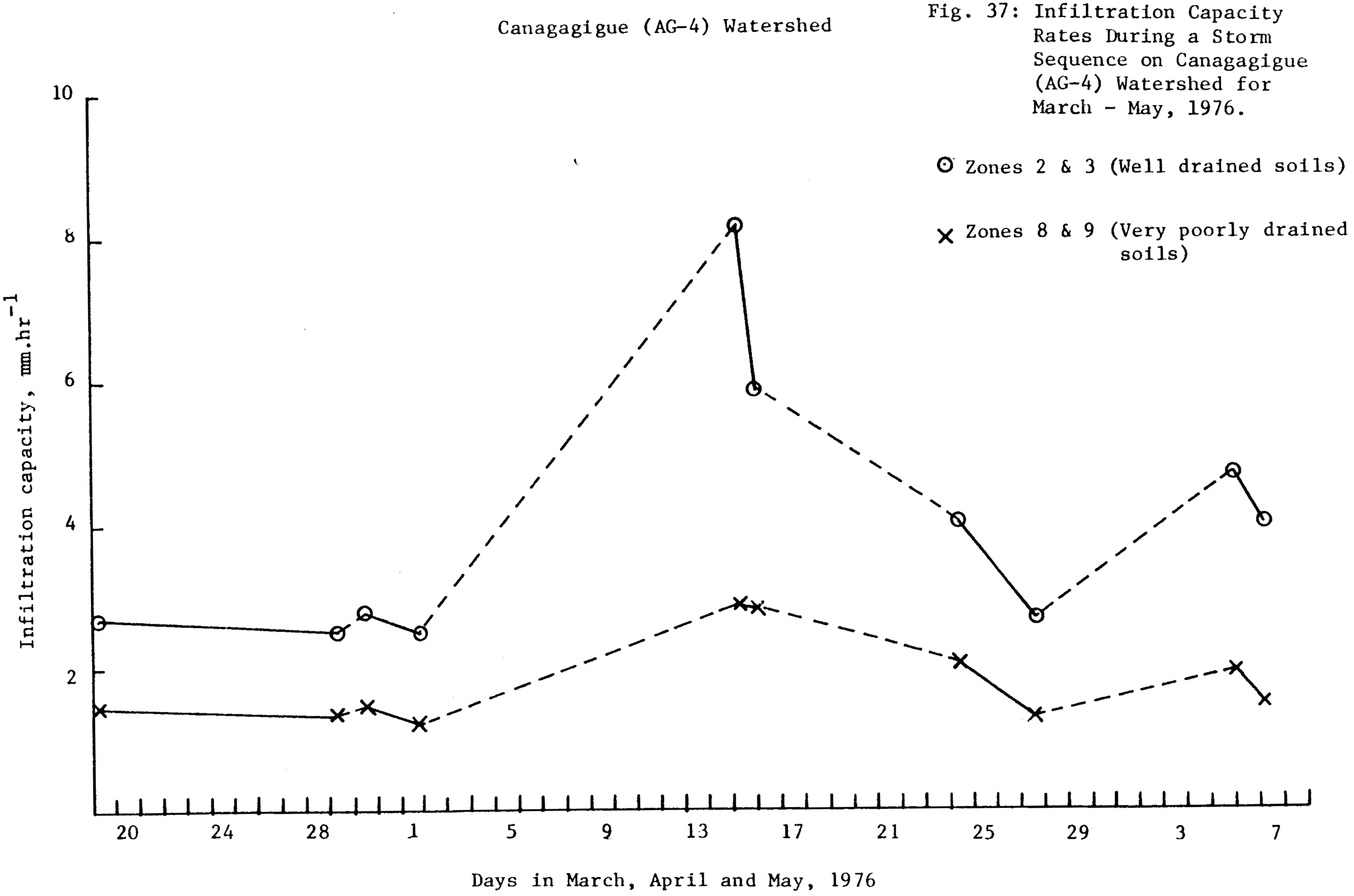
Figure 37 shows the infiltration capacity rates for several storms which occurred in succession on Canagagigue watershed. The first storm (March 19, 76) is a snowmelt event and a very slow and small drop in infiltration capacity during the storm is noticed. It indicates that the soil was very wet and the limiting infiltration capacity state was reached. After the end of each storm some recovery of infiltration capacity (showed by dotted line) was noticed. The April 24 storm had lower rates than April 15 storm because of rainfall which occurred on April 21st (7 mm) and April 22nd (3 mm).

Infiltration capacity rates for October - November, 1972 storms could be explained similarly (Figure 38). The drop in the infiltration capacity rates for November 7, 72 storm seems to be an erroneous result since there was no rainfall recorded between November 4 and November 6. The rates and the drop in the rates are very small. It could be stated that such discrepancies in the infiltration capacities could occur during the wet season due to high sensitivity of the model to small changes in the selected parameters. The errors, however, are not large and do not indicate any serious errors either in computed values or selected parameters.

It is worth noting that the infiltration capacity rates drop very rapidly during a storm having drier initial conditions. The rate change is much more gradual during storms with wet initial conditions.

Figures 39 and 40 show the infiltration capacities for May, 74 and November - December, 70 storms on East Canagagigue. The erroneous drop in infiltration capacity (instead of recovery) after November 17, 70 storm could be attributed, as before, to the sensitivity of model parameters during wet seasons. The amount and effect of the error are small and hence ignored. Figure 41 shows the infiltration capacities during July, 76 storms on Holiday Creek (AG-5) watershed.

Fig. 37: Infiltration Capacity Rates During a Storm Sequence on Canagagigue (AG-4) Watershed for March - May, 1976.



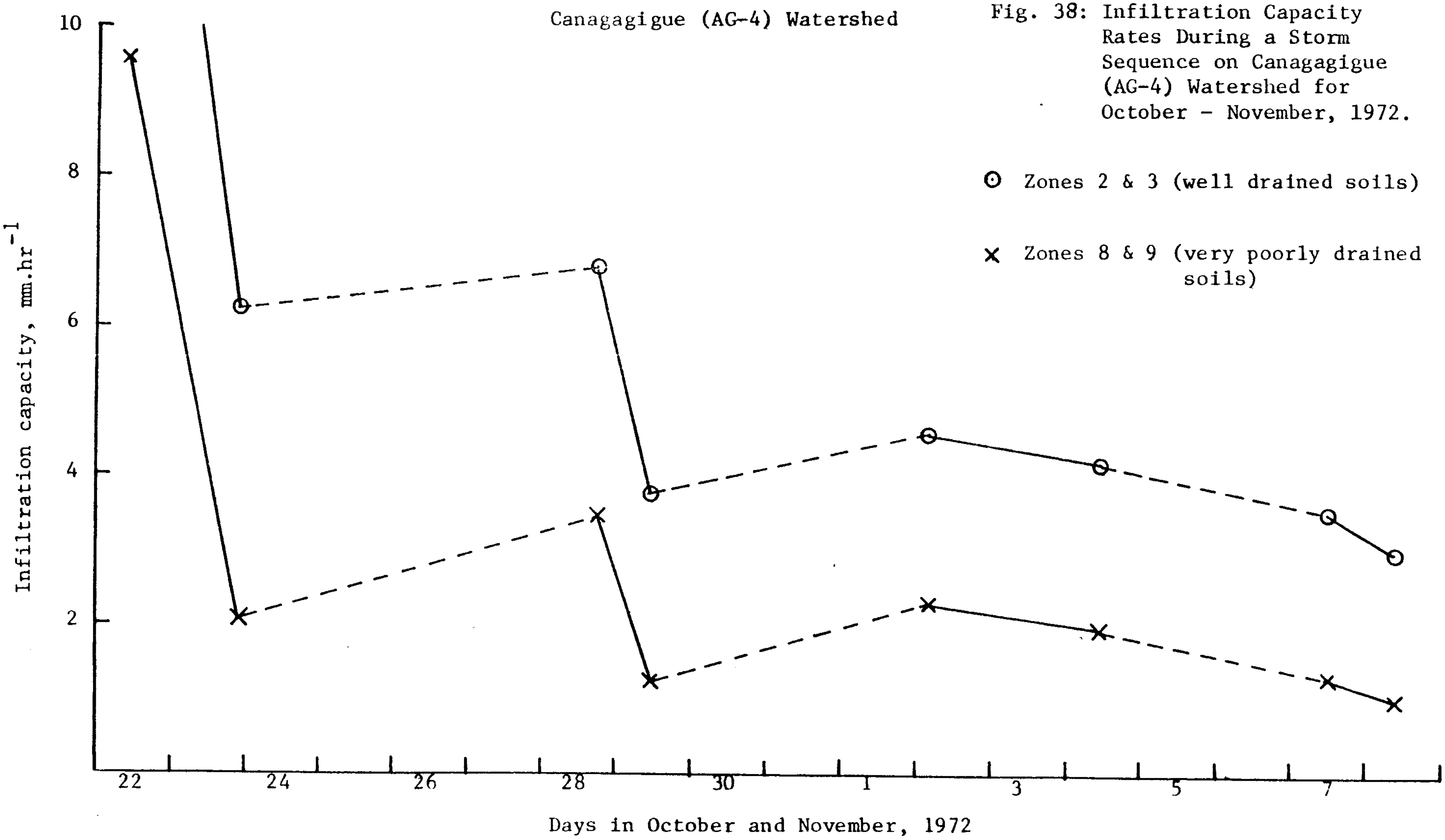


Fig. 38: Infiltration Capacity Rates During a Storm Sequence on Canagagigue (AG-4) Watershed for October - November, 1972.

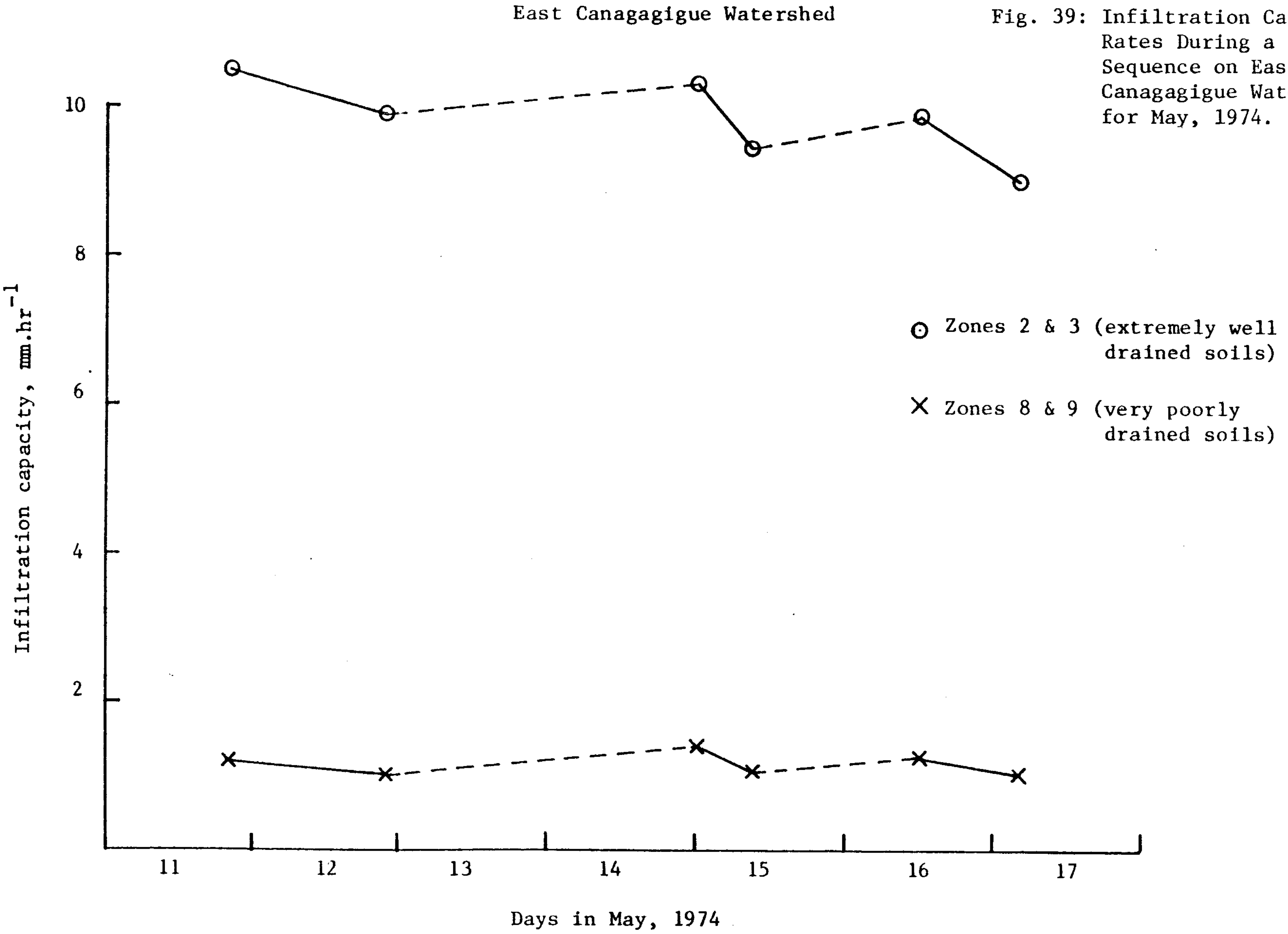
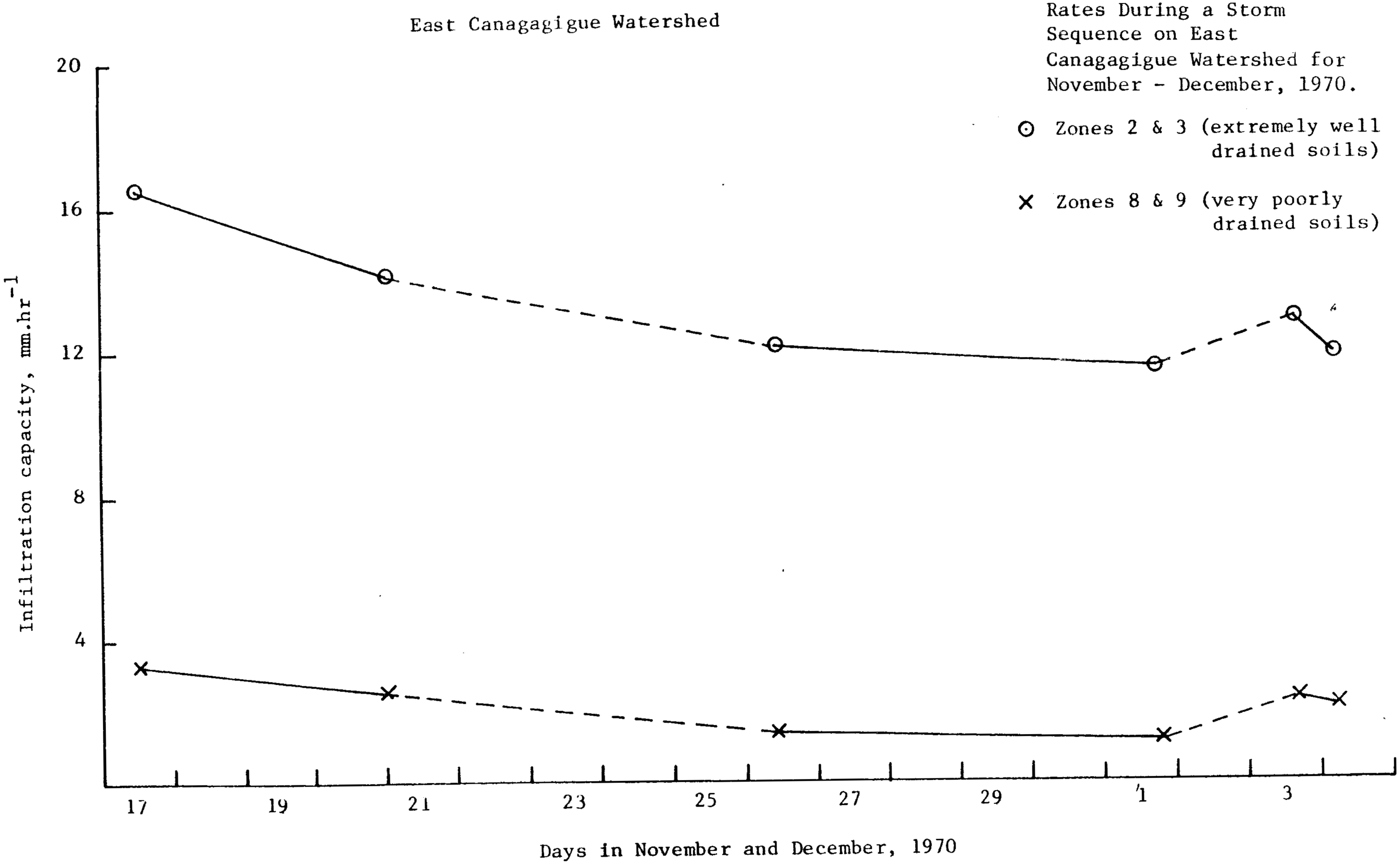


Fig. 39: Infiltration Capacity Rates During a Storm Sequence on East Canagagigue Watershed for May, 1974.

Fig. 40: Infiltration Capacity Rates During a Storm Sequence on East Canagagigue Watershed for November - December, 1970.



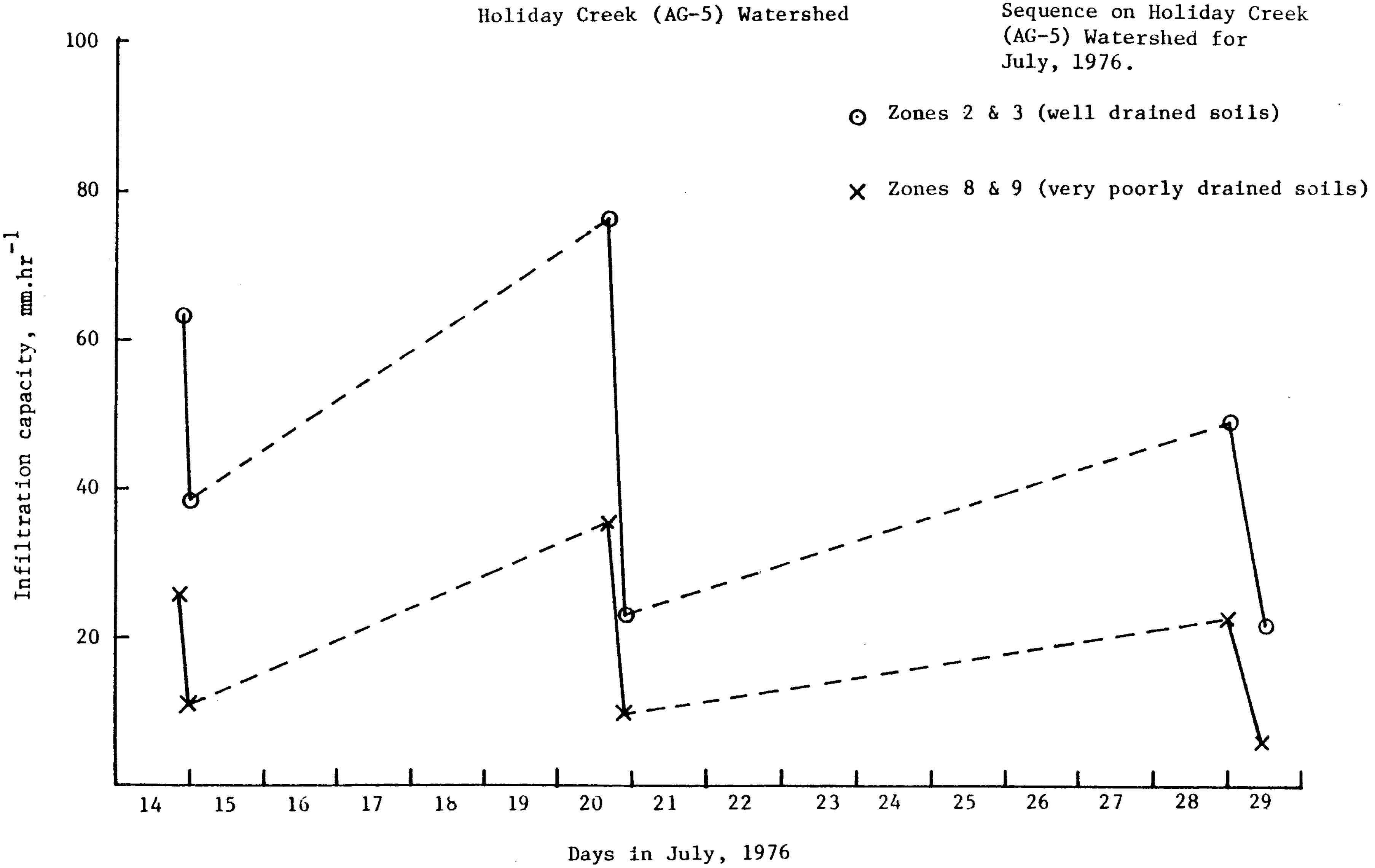


Fig. 41: Infiltration Capacity Rates During a Storm Sequence on Holiday Creek (AG-5) Watershed for July, 1976.

Meeting of project objectives

An event-oriented hydrologic model has been developed. The model, GAWSER, simulates flowrate hydrographs at the outlet of agricultural watersheds of a size around 25 Km^2. The model provides estimates of the amount of overland and subsurface storm runoff generated by the road, stream and ditch surfaces in a watershed, and by up to four different types of soil. An estimate of the amount of water percolating to deeper groundwater storage as a result of a storm rainfall or snowmelt event is also provided.

The model has been extensively tested on three agricultural watersheds by the simulation of storms occurring in the months from March through December. Nearly thirty storms were simulated on the Canagagigue and East Canagagigue watersheds and about one third that number on the Holiday Creek Watershed. From this application of the model the following points can be made.

- The impermeable areas of watersheds, which are about 2.5% of total, consistently provide overland runoff to the watershed outlet for nearly all rain events. On watersheds such as Canagagigue where flow ceased in the main stream during extremely prolonged dry periods, moderate and sometimes large rain amounts on the impermeable areas may not produce storm runoff which reaches the watershed outlet.

- The poorly-drained soils, which are generally closest to the water courses, make the most frequent and the largest contributions to overland storm runoff to streams. This result from the model study is largely based on the assumption that well-drained soils will be drier than poorly drained soils at the start of most storms. This is an appropriate assumption.

- The well-drained silt-loam soils studied generated overland runoff infrequently. The very-well-drained sandy soils which cover a portion of East Canagagigue watershed generate overland flow even less frequently. Nevertheless very large rainstorms such as the August 1976 storm on Holiday Creek or the May 1974 storm on Canagagigue create overland runoff even from well-drained soils.

- The much reduced infiltration capacities which apply to all soil types under very wet conditions in early spring and again in late fall and early winter allow overland runoff to be generated by low-intensity rains. This low infiltration capacity is present even under unfrozen soil conditions.

The general pattern of results from the model study, as outlined above, particularly the identification of areas near streams as the most important source of overland runoff, agrees with field observations made in other of the watershed studies. Dr. M. Miller requested and obtained overland (surface) runoff-amount estimates for use in estimating phosphorous contributions from agricultural watersheds. These estimates were based on the results outlined in this report for the three watersheds studied.

The project did not provide as much information on snowmelt-period runoff generation as had been anticipated as the start of the project. It turned out that streamflow flowrates for the two Canagagigue watersheds had quite large possible errors during spring breakup due to ice effects on the flowrate versus height relationships. Furthermore, field information on snow amounts at various times during the snowmelt period were not available for any of the three watersheds. These data deficiencies, and a lack of time to devote to overcoming them, prevented any extensive examination of snowmelt-period runoff generation.

In view of the large amount of total annual streamflow which occurs during snowmelt-period events on Ontario watersheds tributary to the Great Lakes we recommend that further studies be conducted on overland and subsurface storm runoff generation processes during snowmelt periods. The presence of snow and the effects of frozen soil must be considered. We believe that studies of runoff from snowmelt periods could be combined with studies of erosion during snowmelt about which there appears to be little quantitative information.

Another area which was observed to be in need of further study is the influence of tile drains on infiltration properties of soils. For this study it was assumed that tiling had no effect on the properties of the surface soil layer. This assumption needs further examination to determine whether tiling enhances the infiltration capacity of a soil.

RELATION OF FINDINGS TO PLUARG OBJECTIVES

The findings of this study support the view that soil areas near streams are the most active zones in a watershed in contributing overland runoff to streams. These zones, generally identified as poorly drained in soil classification mapping, produce overland runoff more frequently than well-drained soils farther from streams and also produce larger amounts of overland runoff per unit of surface area than do well-drained soils.

These frequently active runoff generation zones can be expected to be potential contributors of sediment and dissolved nutrients to streams if these substances are available and free to move across the soil surface. These zones should be examined to see what preventative and remedial measures should be applied to them to restrict the entry of sediment and other undesirable substances into the overland runoff these soils generate.

In the examination of remedial measures several outcomes of this and other studies should be kept in mind. There is a strong seasonal variation in overland runoff generation. Events during the period from late May through September generally produce little overland runoff even from the most active zones because of large soil water deficits and high infiltration capacities. Any remedial measures which were applied during this season <u>only</u> will be limited in their effect on annual stream-borne loading because of this normal lack of significant overland runoff during the summer.

Most streamflow in total, and most storm runoff, occurs in and immediately after the snowmelt period in the watersheds studied. The possibility of widespread overland flow generation is high during this period and although the active zones near streams will still likely produce the highest per-unit-area overland runoff amounts their overall contribution may not be predominant because of sizeable contributions from the larger-in-area zones farther from the streams. The observation also applies to very large storm rainfalls such as the May 1974 rains which produced flooding on the Grand River watershed. Remedial measures applied to small proportions of the watershed area are unlikely to significantly change the amount of overland runoff generated by snowmelt period storms or large summer storms.

The contribution of subsurface storm runoff to the total amount of storm runoff is significant in the watersheds studied. This flow component could be a significant contributor of any dissolved substances which are free to move through soil to tile drains or sidehill seeps. Remedial measures applied only to overland storm runoff will not directly alter the properties of this flow component and may indirectly increase its effects in some cases as, for example, when higher infiltration rates are created through more soil-surface protection by vegetation.

The previously-listed conclusions about the application of remedial measures are based on results from the three watersheds examined. It must be recognized that the extrapolation of the results and conclusions beyond the three watersheds, with their particular blend of agricultural practices and their predominately silt loam soils, is subject to considerable uncertainty. The concept of soil areas near the streams being the most obvious candidate sources for overland runoff and pollution should be farily general in application.

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