STREAMFLOW RESPONSES TO RAINFALL EVENTS IN WETLAND, URBAN AND AGRICULTURAL ENVIRONMENTS

STREAMFLOW RESPONSES TO RAINFALL EVENTS IN WETLAND, URBAN AND AGRICULTURAL WATERSHEDS

BY

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ABSTRACT

Through the use of unit hydrographs this paper demonstrates the effect of land uses on the stream discharge of three watersheds located in Southern Ontario. The watersheds represent urban, agricultural and wetland environments. The three different environments each demonstrate different responses to a unit magnitude of uniformly distributed precipitation.

The rainfall events occurred during September and October 1981 and 1986. Three durations of events, six, twelve and twenty-four hours, are studied.

The paper demonstrates that an urban watershed experiences a greater magnitude of peak discharge and faster response time than either of the other two studied watersheds. The unit hydrograph resulting from a wetland showed that the wetland watershed was an important regulator of streamflow.

Special emphasis were placed on the urbanization of agricultural lands as this is the most applicable land use change currently occurring in Southern Ontario.The results from this study will be useful when assessing the magnitude of the potential runoff problem when these agricultural watersheds are urbanized.

ACKNOWLEDGEMENTS

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S.L.C. APRIL, 1989

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CHAPTER ONE
INTRODUCTION

1.1 Land Use Effects on Streamflow

The response of stream discharge to rainfall is dependent on the physical characteristics of the watershed, including slope, elevation, vegetation type and amount, soil type and the geology of the watershed (Manning, 1987). For example, if the basin has a deep permeable soil, overlying impermeable bedrock, the hydrograph will be dominated by subsurface stormflow. Subsurface stormflow delays the peak discharge response in a hydrograph (Burt and Butcher, 1985).

Infiltration capacities of a watershed will also affect a stream's response to a precipitation event (Gray, 1970). Watersheds with a low infiltration capacity will exhibit a rapid response of a large magnitude to a precipitation event. Conversely, a watershed with a high infiltration capacity will have a slow response of a smaller magnitude to a precipitation event of similar intensity and duration. The five main factors that affect infiltration are soil temperature, soil type, precipitation intensity, land use and water quality (Manning, 1987). This study emphasizes the land use aspect. Watersheds in urban environments have low infiltration capacities while watersheds in rural-agricultural environments generally have higher infiltration capacities.

Recent studies have demonstrated that many wetlands are not important regulators of streamflow because the peat layer is either not very thick or it is often saturated (Bay, 1969, Roulet and Woo, 1985). These conditions produce rapid runoff responses in wetland watersheds to precipitation events.

Urbanization modifies the streamflow response of an area to a precipitation event (Hall, 1984, Lazaro, 1979, Gray, 1970). The presence of paved surfaces and numerous buildings will decrease the amount of surface area exposed to infiltration, thus increase the imperviousness of the area. This in turn will decrease the concentration time of the watershed to rainfall (Lazaro, 1979).

Agricultural soils have a larger infiltration capacity than those in urban areas. This results in a discharge of lower magnitude and longer duration in the agricultural environment than in either the urban or wetland environment (Gray, 1970). Interception will be greater in the agricultural areas than in any of the other areas. Interception depends on the spacing, age, size and type of plant (Penman, 1963). Interception and infiltration are both taken into account when the effective rainfall for the unit hydrograph is calculated using the phi index method.

It is predicted that these different land uses will result in the unit hydrograph from each environment being significantly different.

1.2 Unit Hydrograph Approach

Streamflow prediction and forecasting are important aspects of hydrology. The unit hydrograph method has frequently been used for stormwater management, including the prediction of discharge resulting from a known magnitude and duration of precipitation (Wanielista, 1978, Balagh, 1970, Helsinki Symposium, 1980). The unit hydrograph is based on the historical relationship between rainfall and stream discharge. It was first proposed in 1932 by Sherman who defined it as the hydrograph of direct runoff resulting from one unit of effective rainfall.

1.3 Research Objectives

The purpose of this research project is to contrast the streamflow responses of wetland, urban and agricultural watersheds to fall precipitation events. Fall precipitation events were chosen so that snow melt would not have to be considered as it is beyond the scope of this paper.

The streamflow response will be studied through the creation of six, 12 and 24 hour unit hydrographs for each of the three drainage basins. Relatively long duration storms were chosen for study because this paper is concerned with storms that produce significant flooding events and longer duration storms are more likely to produce these types of flood events. An unit hydrograph generalizes the pattern of runoff response to a unit input of rainfall. By comparing the mean response patterns of the unit hydrographs from three different environment one will be able to see the effects of land use on stream discharge.

Results from this study will help in the assessment of land use changes. A change from agricultural to urban land use is currently proposed for the Alder Creek watershed. It is one of the watersheds studied in this paper. Findings of the present research will, therefore, have immediate applications.

CHAPTER TWO
STUDY AREA AND METHODS

2.1 Study Area

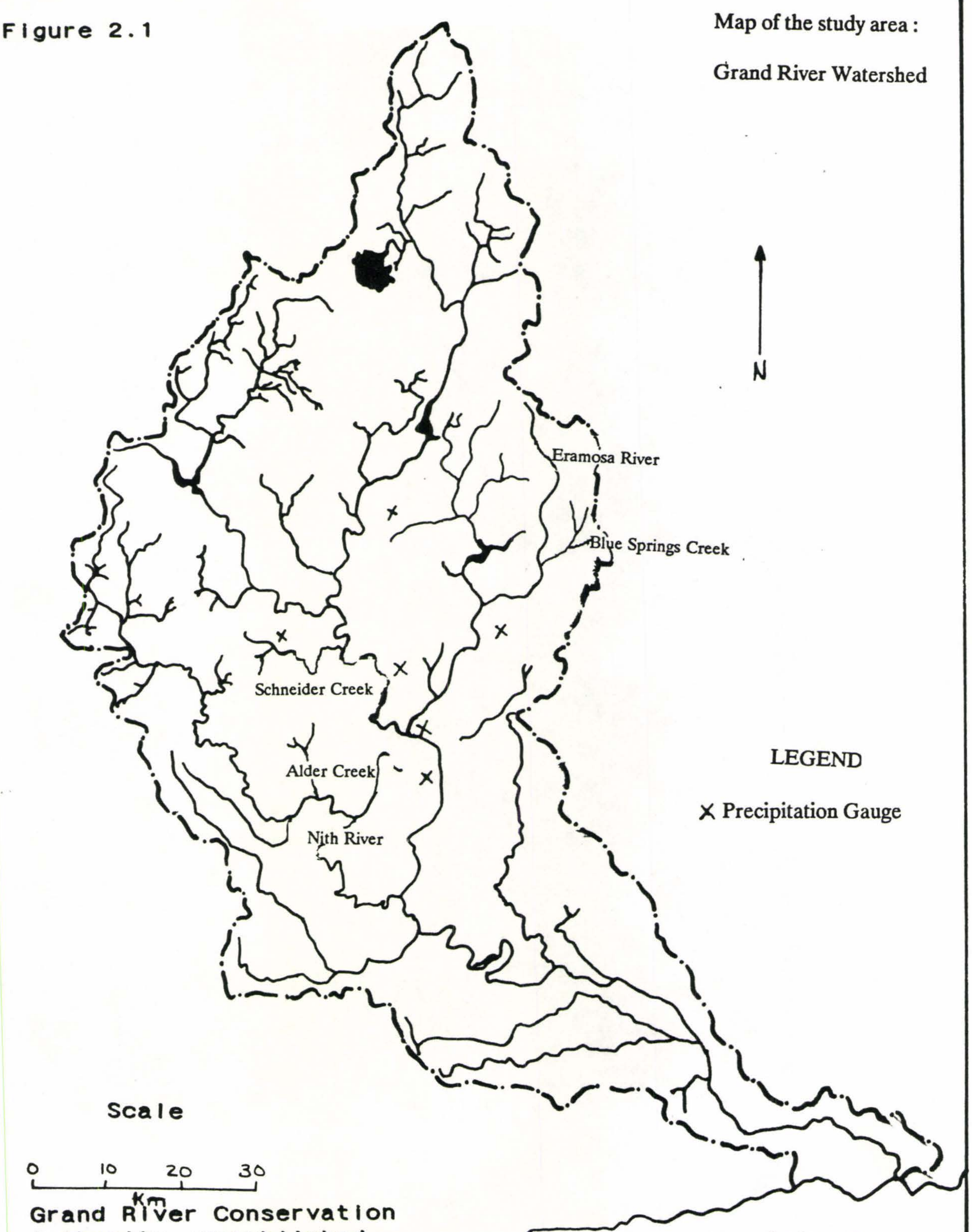
Three watersheds located within the Grand River catchment were chosen for this study. The location of the smaller watersheds within the larger framework of the Grand River catchment can be seen in figure 2.1. The location of the precipitation gauges is identified on figure 2.1. The individual watershed maps (figure 2.1, 2.3, and 2.5) show the location of the discharge gauges.

The area experiences temperate continental climate with a mean annual temperature of 6.7° C and mean annual precipitation of 833.3 mm. Mean precipitation for September and October is 136.8 mm. Mean temperature for the same time period is 19.6°C (Environment, Canada, 1982).

Blue Springs shown in figure 2.2 and figure 2.3, is a wetland watershed covering an area of 44.5 km^2 (Water Survey of Canada). Sixty-five percent of this watershed is classified as wetland according to scheme used by Energy Mines and Resources Canada. Blue Spring is located 8 km East of Guelph, Ontario.

The bedrock in the Blue Springs watershed was formed during the Silurian period 400 million years ago. The bedrock is composed of cream to buff dolomite that is part of the Guelph Formation (Soils of Wellington County, 1971).

Figure 2.1



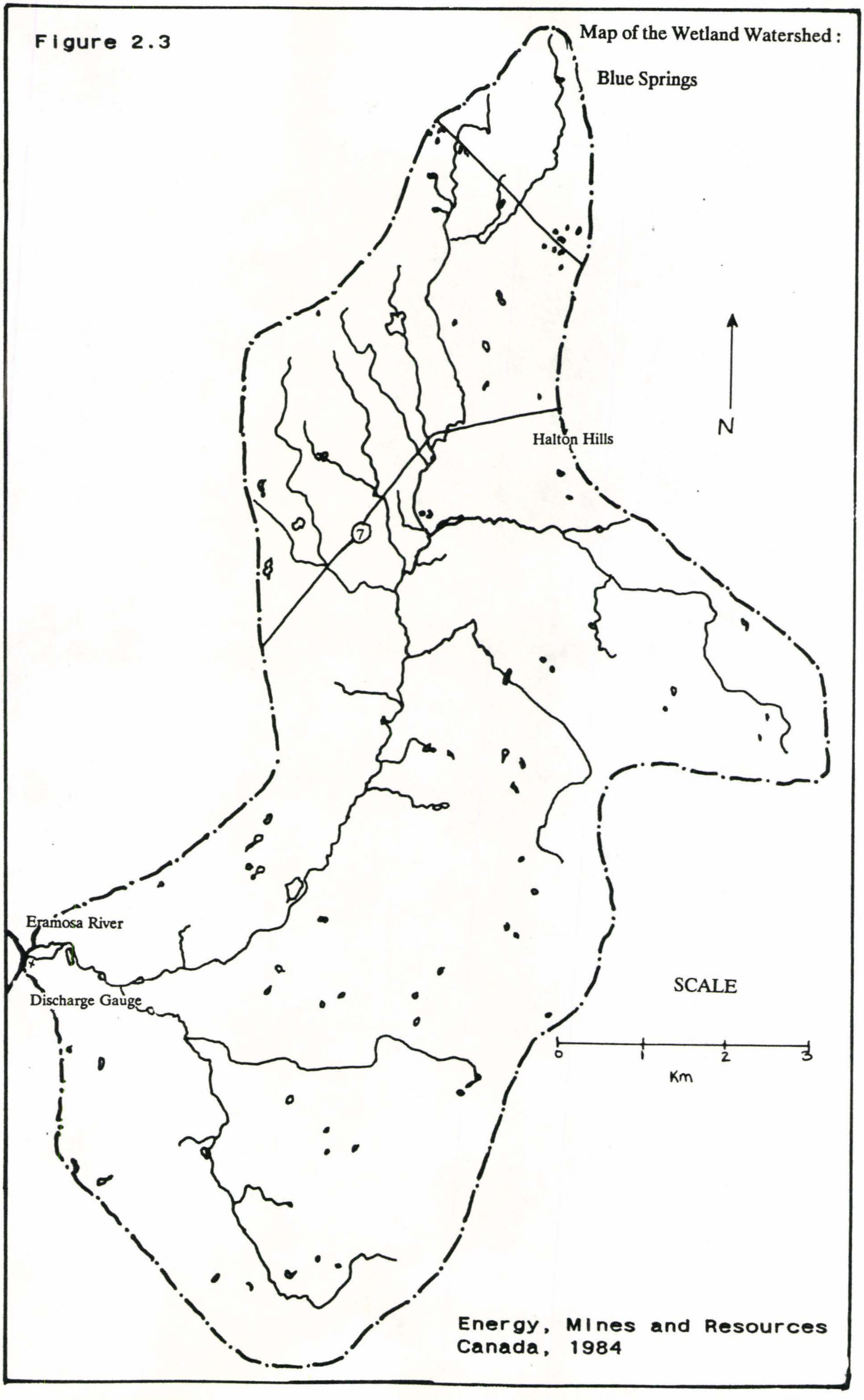
Grand River Conservation Authority, unpublished

The dominant soil association in this watershed is the Freeport-Woolwich. This soil association consists of coarse and medium textured soils, one to three feet deep, overlying fine textured till and lacustrine deposits. The slopes range from very gentle to gentle (2 to 6 % gradient), and the drainage is imperfect to poor (Soils of Wellington County, 1971).

A second prevalent soil in the area is organic. This soil is formed on organic deposits including muck and peat with very poor drainage. The slope gradient is extremely low (Soils of Wellington County, 1971).

Figure 2.2 A photograph showing the Blue Springs watershed.

Figure 2.3



Energy, Mines and Resources Canada, 1984

The urban watershed chosen for this study, Schneider Creek, is located in Kitchener, Ontario, and covers an area of 25.1 km^2 (Water Survey of Canada, 1984). Much of the topography, soil and natural vegetation of this watershed have been altered, as is shown in figure 2.4 and figure 2.5.

The bedrock in Schneider Creek was formed during the Silurian. It is part of the Salina Formation. The rock is buff to brown dolomite and limestone, with local occurrences of shale, anhydrite, gypsum and salt (Soils of Waterloo County, 1971).

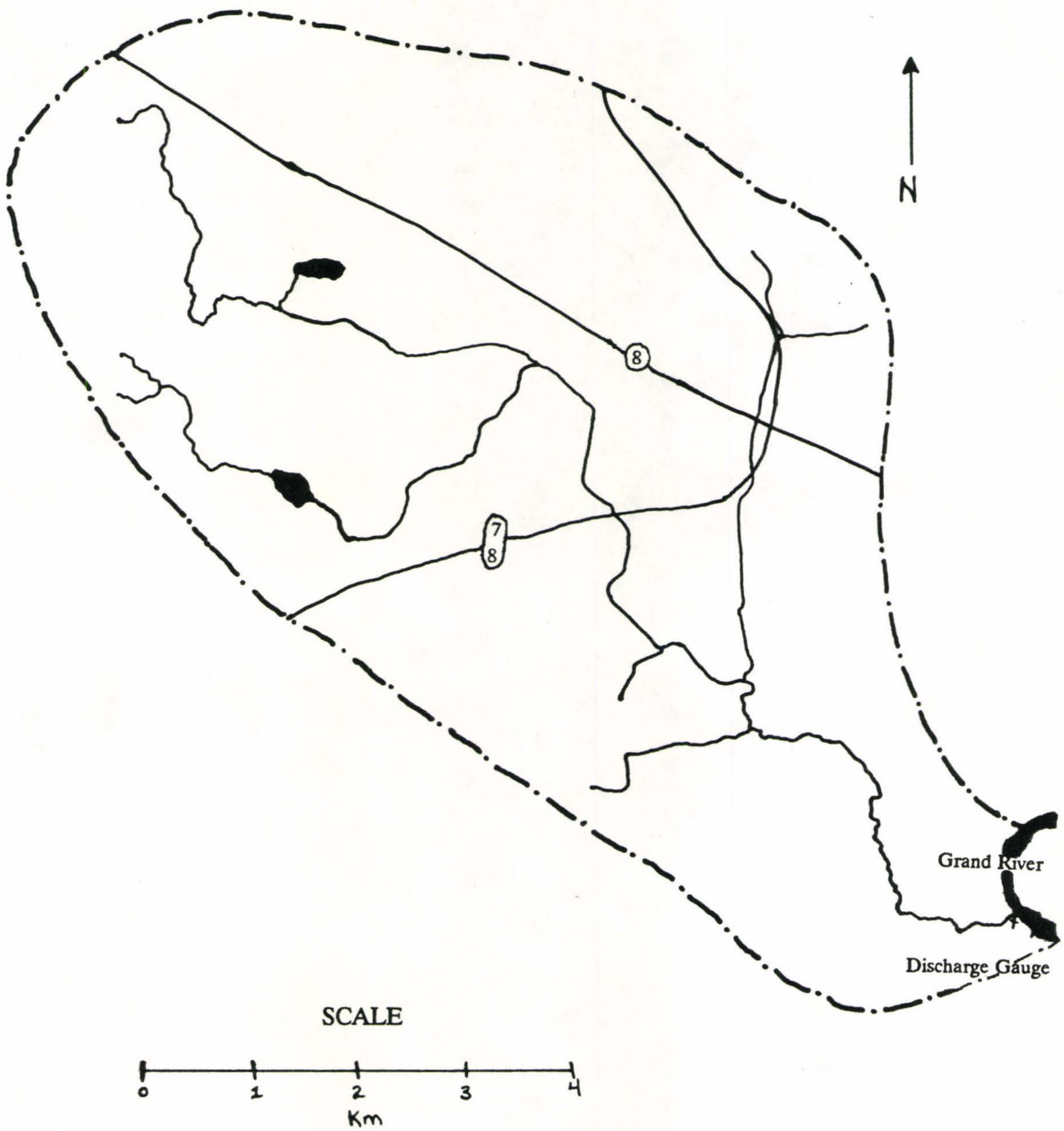
The Burford - Fox soil association comprises the majority of the soil in this urban area. The soil in this association is coarse and medium textured. It is formed on outwash and shallow lacustrine deposits. Near the mouth of Schneider Creek there is a small quantity of soil belonging to the Farmington soil association (Soils of Waterloo County, 1971). This soil is coarse to medium textured and overlies bedrock.

Figure 2.5

Map of the Urban Watershed :

Schneider Creek

Kitchener



Energy, Mines and Resources
Canada, 1986

Figure 2.4 A photograph of the Schneider Creek watershed.

The agricultural watershed, Alder Creek, covers an area of 49.5 km^2, it is located South of Kitchener, Ontario, and can be seen in figure 2.6 and 2.7 (Water Survey of Canada, 1984). Man-made alterations of the flow pattern of this watershed include straightening of some sections of the creek and the development of irrigation ponds. The Water Survey of Canada classifies this as minimal alteration of the natural flow.

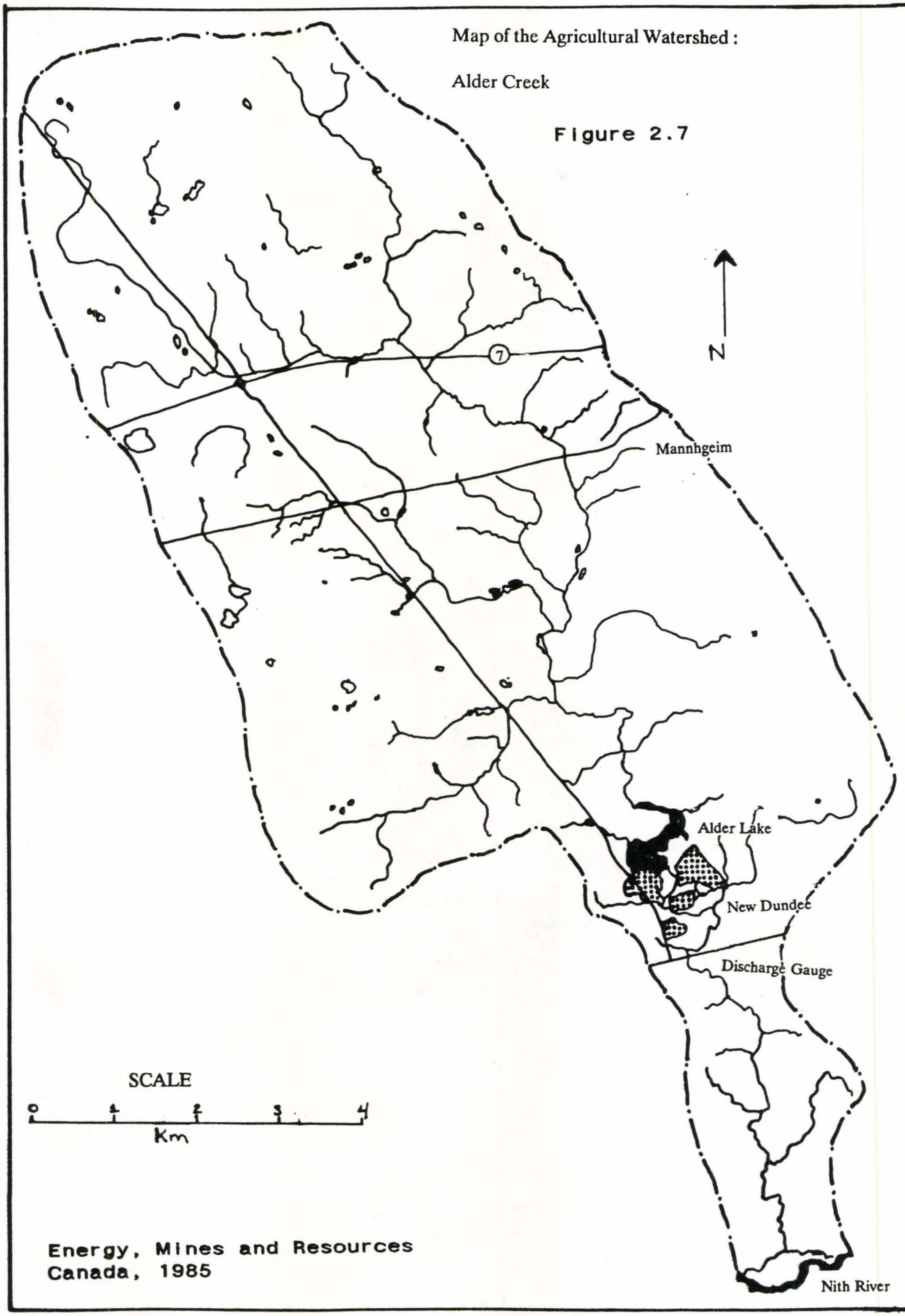
The bedrock in Alder Creek was formed during the Silurian. It represents a portion of the Salina Formation consisting of buff to brown dolomite and limestone. There is also some shale, anhydrite gypsum and salt present (Soils of Waterloo County, 1971).

Fifty percent of the soil present in the Alder Creek watershed is part of the Brant - Waterloo soil association. It is a moderately coarse and medium textured soil that is formed on lacustrine deposits. The slopes are level to very gentle (0 - 3 % gradient). The remaining fifty percent of the soil in the watershed belongs predominantly to the Burford - Fox soil association. This soil is coarse and medium textured and formed on outwash and shallow lacustrine deposits. The topography is level to gently sloping (0 - 6 % gradient). The drainage for both these soil associations ranges from good through imperfect to poor (Soils of Waterloo County, 1971).

Part of the Alder Creek basin is devoted to cash crop farming but much of the area is left to the grazing of livestock. Farms in the range of 130 - 240 acres account for sixty-seven percent of the farms in the entire watershed (Soils of Waterloo County, 1971). There are numerous horse ranches in much of the Alder Creek watershed. In these areas very little of the ground is annually cultivated.

A comparison of the runoff responses to rainfall in these three watersheds, all located within the same climatic, physiographic and geological region, will permit the effects of land use to be assessed.

Figure 2.6 A photograph of the Alder Creek watershed.


Map of the Agricultural Watershed :
Alder Creek
Figure 2.7
N
7
Mannhgeim
Alder Lake
New Dundee
Discharge Gauge
Nith River
SCALE
0
1
2
3
4
Km
Energy, Mines and Resources
Canada, 1985

2.2 Methods

2.2.1 Data Sources

Precipitation data was obtained from the Grand River Conservation Authority. This was the Tab-30 data prepared by the Atmospheric Environment Service, and measured in 0.10 mm intervals at hourly time periods.

Discharge data was obtained from the Water Survey of Canada located in Guelph. This was quarter hour data measured in m^3/s. To use this data with the existing precipitation data hourly averages had to be computed using a Fortran program.

2.2.2 Time Period

Precipitation events were studied in September and October of two years, 1981 and 1986.

2.2.3 Unit Hydrograph

In this paper the unit hydrograph as initially proposed by Sherman in 1932 is the main method used to compare the stream flow responses in the three different environments.

The unit hydrograph is based on a number of assumptions that must be met before the method can be implemented. The assumptions include the following:

1. Effective rainfall is uniformly distributed within the specified period of time.

2. Effective rainfall is uniformly distributed over the basin.

3. The time duration of the hydrograph resulting from effective rainfall of unit duration is constant. This means, for example, that a six hour storm will always result in a twelve hour response in a given basin.

4. Within a given basin the hydrograph resulting from a rain storm of a given duration will reflect all the physical characteristics of the basin. This means that two basins with similar physical characteristics will have the same response to a given storm. This is a poor assumption to make. A unit hydrograph should be completed for each watershed because any different land use between the two environments can result in dramatic differences between stream flow responses.

5. Linearity is assumed. This means that for effective rainfall of different intensities but similar duration the magnitude of runoff at any time is proportional to one another as the rainfall intensities are. Thus, a storm with two times the amount of precipitation results in a hydrograph with two times the discharge. This also means that two separate rainfall events at different but adjacent time periods would result in a unit hydrograph response that

was equal to the summing of the two hydrograph responses. The last assumption is imposed to satisfy the linearity condition required by the linear unity hydrograph theory.

The following steps are those used to create the unit hydrograph.

1. Search the precipitation records for storms of the desired duration with 1 cm or more of rainfall.

2. Obtain the discharge record for the storms chosen in step 1.

3. Create hydrographs of the above data plotting time against discharge.

4. Separate baseflow from surface runoff to determine direct runoff. To do this the recession limbs for all the storms analyzed in a watershed were plotted on semi-logarithmic paper and a lower enveloping curve was determined. This curve was then plotted on a time vs discharge graph to become the master recession limb. The master recession limb was than overlain on the hydrographs obtained in step 3. The point of intersection between the master recession limb and the hydrograph recession limb was taken to be the point below which was baseflow. This section was than removed from the hydrograph and the resulting graph is the direct runoff hydrograph.

5. In a spreadsheet format the baseflow amount is subtracted from the hourly discharge amounts to quantify the direct runoff.

6. Determine the total direct runoff by summing the results from step 5.

7. Determine total effective rainfall using equation 1.

$$ter = \frac{tdr \times tbm \times 100\,cm}{A} \qquad (1)$$

ter = total effective rainfall
tdr = total direct runoff
tbm = time between measurements in seconds
A = area of the basin in m^2

8. Divide the direct runoff values obtained in step 5 by the total effective runoff determined in step 7 to determine the unit coordinates for the unit hydrograph.

9. Plot time against the discharge values obtained in step 8 to create the unit hydrograph.

10. Plot time against rainfall intensity in the upper left hand corner of the unit hydrograph using the phi index method to determine rainfall excess. The phi method is based on the volume of rainfall excess equalling the volume of direct runoff values obtained in step 5.

The above method is a combination of the methods identified in Gray (1970), Hjelmfelt and Cassidy (1975), Linsley et. al. (1949) and Linsley et. al. (1975).

When simple storms, those that are not affected by a prior or subsequent precipitation event, can not be found an alteration of the above method can be used to derive the unit hydrograph from more complex storms. A summary of this method, which was not required in the preparation of this report, can be found in Gray (1970), Linsley et. al. (1949) and Linsley et. al. (1975).

For this paper a minimum number of three storms in each environment and for each time duration were studied to determine average parameters. This is the minimum number of storms required according to Linsley et. al., 1949.

The hypothesis that the wetland, agricultural and urban environments would all demonstrate different discharge responses was tested using the t statistic which was derived using equation 2.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \times \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad (2)$$

Where $\bar{x}_1$ is the mean of sample 1, $\bar{x}_2$ is the mean of sample 2, n_1 is the number of items in sample 1, n_2 is the number of items in sample 2, s_1 is the standard deviation of sample 1 and s_2 is the standard deviation of sample 2.

The t test was computed for time to onset, time to peak, response length and peak discharge for the urban and agricultural environments and the urban and wetland environments.

2.2.4 Peak Flow Prediction

In an attempt to quantify the peak discharge resulting from 6, 12 and 24 hour storms when a change in land use occurs the following method was used.

1. Obtain peak flow values for each environment and each time duration in m^3/s.

2. Divide the peak flow values from step 1 by the area of the basin in m^2 to get a quantity of discharge in m/s.

3. In this paper, attention is focussed on a change of land use from agricultural to urban; thus the next step is to divide the quantity of discharge from the urban environment by the quantity of discharge from the agricultural environment to determine the magnitude of difference.

4. Revised agricultural peaks can than be determined by multiplying the current peak discharges for each duration of storm by the magnitude of difference obtained in step 3.

This procedure was repeated to predict peak flows in the wetland environment resulting from a change in land use from wetland to urban.

CHAPTER THREE
UNIT HYDROGRAPH
RESULTS

The complete set of data that was used to determine the average values for the parameters required to prepare the unit hydrographs as recommended by Linsley et. al., 1949 and 1976 is presented in Appendix 1.

3.1 Six Hour Storm Results

Figure 3.1 displays the average six hour unit hydrographs for the urban, agricultural and wetland environments. The hydrographs that were used to calculate these unit hydrographs are presented in Appendix 2. Table 3.1 contains the information obtained by averaging the responses from at least three storms in each environment to create the six hour unit hydrographs.

Table 3.1 : Data Required for the Six Hour Unit Hydrograph

Location	*Time to Onset	Time to Peak+	Time to Base **	Avg. Peak	Length Response
Schneider Creek	1	7.0	8.6	0.145	15.6
Alder Creek	1.3	12	17.3	0.0163	29.3
Blue Springs	6.7	39.7	133.3	0.066	173

* all time values are hourly measurements
\+ time to peak is measured from onset of rise to peak discharge
** time to base is measured from the time of peak discharge to return to base flow

Schneider Creek (S.C.), the urban environment demonstrates the most rapid rising limb of the three different unit hydrographs. S.C. also experienced by far the highest peak discharge (0.145 m^3/s). The urban watershed required the least amount of time of the three environments to return to baseflow (8.6 hours after peak discharge).

Alder Creek (A.C.) and S.C. both display six hour unit hydrographs that are more symmetrical around the peak discharge than any of the other unit hydrographs for different durations. This means that the length of the rising and falling limbs for each hydrograph are relatively constant. For S.C. the time to reach peak discharge from the onset of the precipitation event is 104.7% of the time to reach baseflow. For AC the value is 76.9%. Blue Springs (B.S.), the wetland watershed, has a six hour unit hydrograph that is asymmetrical around the peak discharge and it is positively skewed.

A.C., the agricultural environment experiences the lowest peak discharge of the three areas studied (0.0163 m^3/s). This watershed requires thirteen hours to reach peak discharge and seventeen hours to return to baseflow resulting in an overall response time of thirty hours after the onset of the precipitation event.

B.S., the wetland environment, requires far more time to respond to a storm of similar duration than does either of the other two environments. This watershed requires nearly 47 hours to reach peak discharge following the onset of a six hour storm. The falling limb of B.S. unit hydrograph takes even longer to return to baseflow requiring 133 after peak discharge was reached.

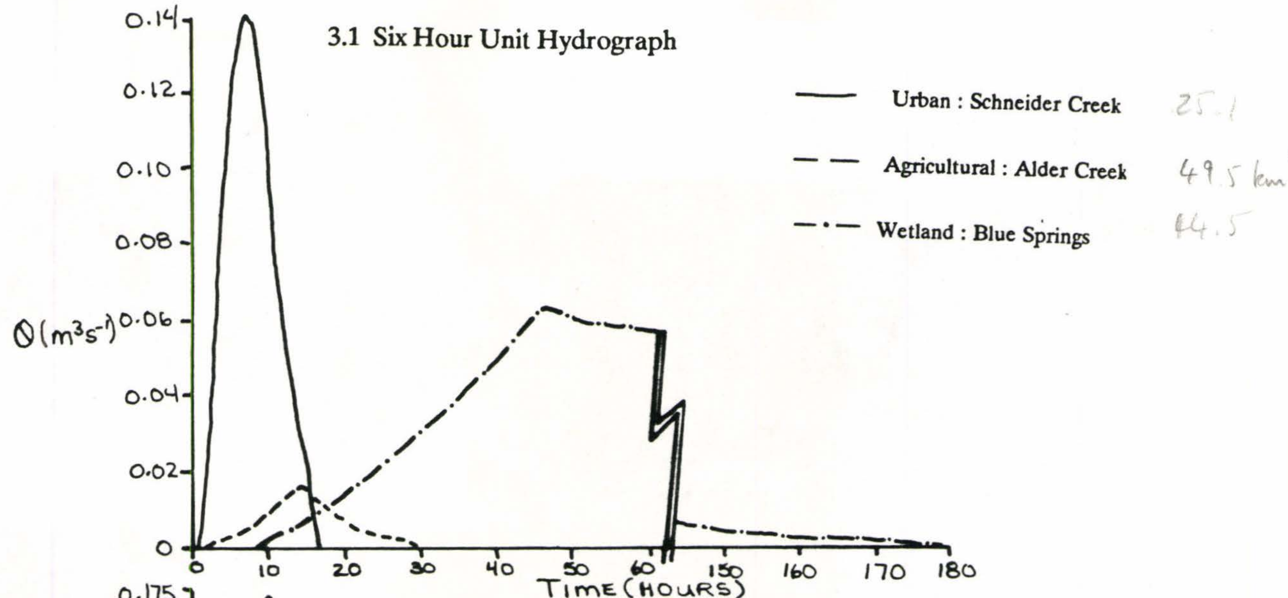
3.2 Twelve Hour Storm Results

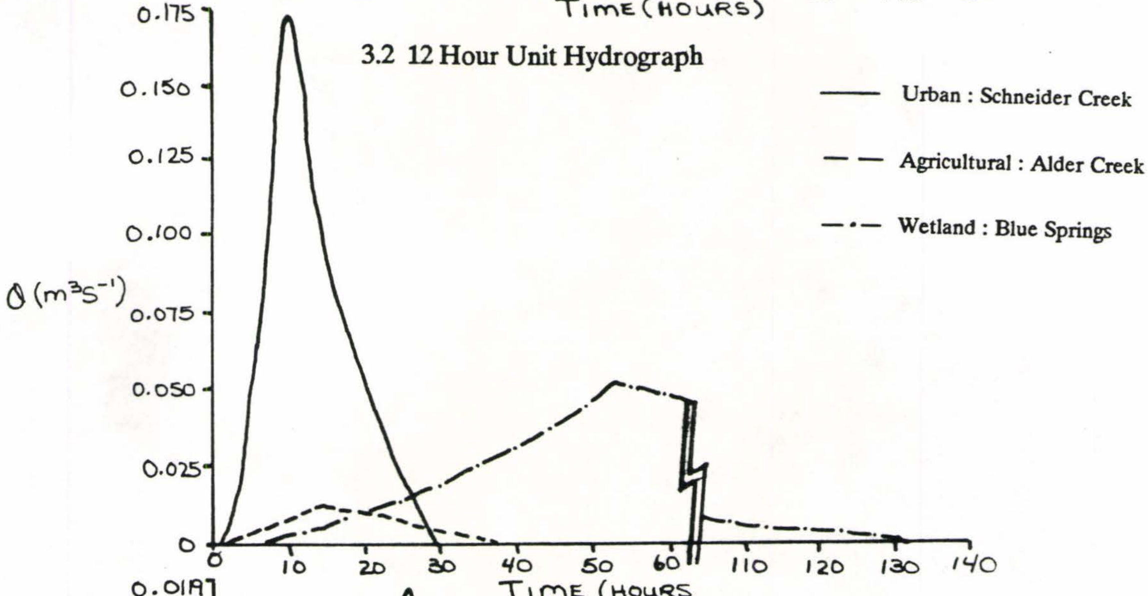
Figure 3.2 displays the average 12 hour unit hydrographs for S.C., A.C. and B.S. and Table 3.2 contains the data that is required to create the 12 hour unit hydrographs. The hydrographs that were used to create these unit hydrographs are displayed in Appendix 3.

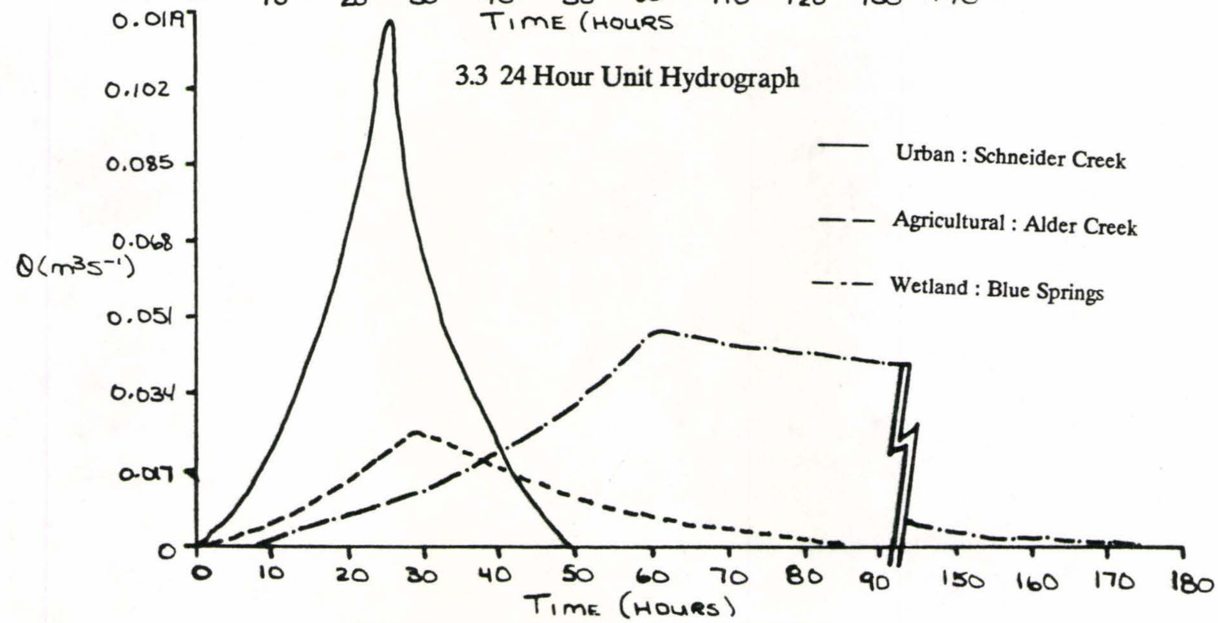
Table 3.2 : Data Required for the 12 Hour Unit Hydrograph

Location	*Time to Onset	Time to Peak +	Time to Base **	Avg. Peak	Length Response
Schneider Creek	1.3	10.1	19.0	0.171	29.2
Alder Creek	1.7	11.3	25.7	0.010	37.0
Blue Springs	7.0	45.7	81.3	0.053	134.0

* all time values are hourly measurements
\+ time to peak is measured from onset of rise to peak discharge
** time to base is measured from the time of peak discharge to return to base flow


3.1 Six Hour Unit Hydrograph
Urban : Schneider Creek
Agricultural : Alder Creek
Wetland : Blue Springs
Q(m³s⁻¹)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0 10 20 30 40 50 60 150 160 170 180
TIME (HOURS)


3.2 12 Hour Unit Hydrograph
Urban : Schneider Creek
Agricultural : Alder Creek
Wetland : Blue Springs
Q (m³s⁻¹)
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0
0 10 20 30 40 50 60 110 120 130 140
TIME (HOURS


3.3 24 Hour Unit Hydrograph
Urban : Schneider Creek
Agricultural : Alder Creek
Wetland : Blue Springs
Q(m³s⁻¹)
0.0119
0.102
0.085
0.068
0.051
0.034
0.017
0
0 10 20 30 40 50 60 70 80 90 150 160 170 180
TIME (HOURS)

S.C. again displays the steepest rising and falling limbs of the three environments. It has the greatest peak discharge of 0.171 m^3/s. The peak discharge for S.C. is greater for the 12 hour storm than for the six hour storm. It also displays the shortest response in all four time categories: onset, peak, base and overall response length.

The S.C. and A.C.'s unit hydrograph response are asymmetrical around the peak discharge as is expected of hydrograph responses. The falling limbs of these unit hydrographs are significantly longer than the rising limbs. A.C. displays the lowest peak discharge values and requires more time than S.C. to respond to rainfall but less time than B.S.. It should be noted also that A.C. reaches its peak discharge within the time required for S.C. to return to baseflow. This was not the case in the six hour unit hydrograph.

B.S. again displays an asymmetrical response to the precipitation event. It requires the longest time of the three environments to respond to a precipitation event, reach peak discharge and to return to baseflow.

3.3 Twenty-four Hour Storm Results

Figure 3.3 displays the average 24 hour unit hydrographs for the three environments and Table 3.3 contains the average data required to create these unit hydrographs. The hydrographs that were derived while determining the 24 hour unit hydrograph are displayed in Appendix 4.

Table 3.3 : Data Required for the 24 Hour Unit Hydrograph

Location	*Time to Onset	Time to Peak+	Time to Base **	Avg. Peak	Length Response
Schneider Creek	1.3	25.0	24.8	0.117	29.8
Alder Creek	1.3	26.7	56.3	0.021	83.0
Blue Springs	7.3	52.0	115.0	0.047	166.3

* all time values are hourly measurements
\+ time to peak is measured from onset of rise to peak discharge
** time to base is measured from the time of peak discharge to return to baseflow

As is the case for the unit hydrographs of six and 12 hour durations, S.C. experiences the most rapid rise to peak discharge and the most rapid return to baseflow. The peak discharge is less for this duration of storm at S.C. than for the other two durations of storms observed. The response observed for the 24 hour storm is similar to that observed for the six hour storm in that S.C. has returned to baseflow before either A.C. or B.S. has reached peak discharge. This was not the case for the 12 hour storm.

A.C. experiences its greatest peak discharge on the 24 hour unit hydrograph. It also experiences a far greater amount of time necessary to return to baseflow. When comparing A.C.'s length of time requirements necessary to return to baseflow there is an increase of eight hours when going from a six to 12 hour storm but an increase of over 40 hours when the storm length is again doubled to 24 hours.

B.S. has a peak discharge for the 24 hour storm that is slightly less than what it experienced in either the six or 12 hour storm. The wetland environment required more than twice as long to return to baseflow from peak discharge than it required to reach peak discharge. This was also the case for the 12 hour storm. It was not the case for the six hour storm when over three times as much time was required to return to baseflow than was required to reach peak discharge.

3.4 Ratios of Runoff Volume

The volume of hydrograph runoff is substantially different in the three different environments. Schneider Creek has the largest volume of runoff for the 12 and 24 hour unit hydrographs. It is followed by Blue Springs and then Alder Creek. For the six hour unit hydrograph Blue Springs has the greatest volume of runoff followed by Schneider Creek and then Alder Creek. The differences in runoff volume are shown as ratios of Schneider Creek, taking into account the size of the individual watersheds, in table 3.4.

Table 3.4 Ratios of Runoff Volume

Location	Duration	Ratio
Alder Creek	6 hours	0.076
Schneider Creek		1.000
Blue Springs		2.847
Alder Creek	12 hours	0.040
Schneider Creek		1.000
Blue Springs		0.802
Alder Creek	24 hours	0.152
Schneider Creek		1.000
Blue Springs		0.756

3.5 Standard Deviations

Table 3.5 contains the results from the implementation of the standard deviation of a sample equation.

Table 3.5 : Standard Deviations of Discharge Values Used to Create the Unit Hydrographs

	Schneider Creek	Alder Creek	Blue Springs
Time to Onset Q	0.00	1.15	3.46
Time to Peak Q	6.00	4.00	4.16
Length of Q Response	6.42	7.02	13.11
Peak Q	0.03	0.04	0.07

Note : Q = discharge (m^3/s)

Table 3.5 shows that time to onset of discharge, time to peak discharge and length of discharge response all demonstrate increasing standard deviations. The magnitude of the variation in these environments indicates that a greater number of storms, (> 3), would likely increase accuracy when creating average unit hydrographs. A single storm when dealing with such a small sample size can have a dramatic effect on the standard deviation. This can be seen in the effect of one 12 hour storm in Blue Springs had on the magnitude of peak discharge (Appendix 3, Blue Springs).

3.6 t - Test Calculation

Table 3.6 contains the results from the application of the t statistic (equation 2). The t - test was used to determine if the unit hydrograph results obtained from the three different watersheds are significantly different.

Table 3.6 : Results from the Calculation of t Values

	Schneider Creek : Alder Creek	Schneider Creek : Blue Springs
Time to Onset Q	- 0.45	- 2.85
Time to Peak Q	- 1.20	- 7.76
Length of Q Response	- 2.49	- 18.67
Peak Q	+ 4.34	+ 4.30

Note : Q = discharge (m^3/s)

The t values displayed above in table 3.5 are tested against a critical value of 2.776 at a confidence level of 0.025 and a two tail test with 4 degrees of freedom (Freund, 1984). Therefore, the time to onset of discharge and time to peak discharge are not significantly different in the urban and agricultural environments. The length of the discharge response and the magnitude of peak discharge are significantly different in these two environments.

The table shows that at this confidence level the four responses between the urban and wetland environment are all significantly different.

CHAPTER FOUR
DISCUSSION

4.1 The Unit Hydrographs

The effect of a basin's physical characteristics on the discharge response of the urban, agricultural and wetland environments is shown in the three unit hydrographs of different durations. S.C. which is dominated by an impermeable surface common in all urban environments has an extremely low infiltration capacity, far less than that experienced in the other two environments. The concentration time in the urban environment is also far less than the concentration time in the wetland and agricultural areas. These two factors result in S.C. having a rapid response to the onset of a precipitation event regardless of the length or magnitude of the event; and a larger peak discharge than the other two environments.

The rapid return of S.C. discharge to baseflow following peak discharge is due in part to the complex storm sewer network in the Kitchener area. This network rapidly drains water from all parts of the drainage basin after the commencement of the precipitation event. Thus, no portion of the basin contributes water to the hydrograph response after the completion of the storm event.

The wetland environment studied in this paper is an important regulator of stream flow. This is evident by the slow response time of the B.S. watershed to a precipitation event. This result is likely due to a thick and/or non-saturated peat layer or a large amount of surface depression storage. B.S. demonstrates its importance in regulating stream flow by the low magnitude of the peak discharge. The low peak discharge indicates that not all areas of the watershed are contributing to peak flow at the same time. Therefore, this watershed has a long concentration time. The infiltration capacity of this soil is much larger than that in the urban environment. This watershed also requires far longer than the urban environment to drain all of its area.

The unit hydrograph response in the agricultural environment displays a concentration time and infiltration capacity between the values for the urban and wetland environment. The lack of paved surfaces will increase the infiltration capacity of the A.C. basin. The response time of the unit hydrograph to the onset of rainfall indicates that although some areas of the watershed immediately contribute to increased discharge, much of the basin does not immediately produce stream discharge.

4.2 Runoff Volume Ratios

Schneider Creek's large volume of runoff can be attributed to the fact that little of the runoff is able to be stored in an urban environment. This is due to the extremely low infiltration capabilities of this type of watershed. Alder Creek has the lowest runoff volume which indicates that it likely has the greatest storage capabilities of the three environments.

Blue Springs had the greatest runoff volume of the three watersheds for the six hour unit hydrographs. This could indicate a problem with the storms used to derive the Blue Springs six hour unit hydrograph. The original streamflow hydrographs used may have had interference from a previous storm.

4.3 t -Test

The t values in table 3.5 display the expected relationship for the urban and wetland environments: that is the discharge response to a precipitation event is significantly different in these two environments.

The hypothesized t value results for response length and magnitude of peak discharge were also obtained for the agricultural and urban environment. That result showed the responses were significantly different. The expected result was not obtained in these environments when time to onset of discharge and time to peak discharge were considered. This is not extremely critical because the major concern of this paper is the prediction of flood events. Major flood damage is more likely to be a result of increased magnitude of peak discharge than time to onset of discharge or time to peak discharge. Although these two criteria are critical in flood forecasting. The reason time to onset of increased discharge

is not significantly different in the agricultural and urban environments is likely due to the low level of accuracy that could be obtained with a one hour minimium time duration. In the urban environment the time to the onset of the rising limb was never greater than two hours and in the agricultural watershed it is never greater than three hours. A shorter time interval would be necessary to distinguish a difference in response times between these two watersheds.

4.4 Problems Implementing the Unit Hydrograph

The assumptions inherent in the unit hydrograph method were not completely satisfied. The first assumption requires uniform spatial distribution of rainfall. This is extremely difficult to assess when there is only one precipitation gauge within a watershed. This can be compensated for by identifying near by precipitation gauges and assessing their data.

The second assumption requires uniform temporal distribution of the effective rainfall. This is also difficult to obtain because few events have uniform intensity throughout their duration.

As stated earlier Linsley et. al., suggest a minimum number of three storms to be aggregated to obtain an average unit hydrograph. This sample size may not be large enough, but it may also be difficult to find many more suitable storms for unit hydrograph derivation.

CHAPTER FIVE
PEAK FLOW PREDICTION

5.1 Peak Flow Predictions Due To Urbanization

Table 5.1 displays the predicted peak discharge values in m^3/s for the agricultural and wetland environments if these areas were to be urbanized. The magnitude of the increase is also shown in this table.

Table 5.1 : Peak Flow Predictions Due To Urbanization

Urbanized Land Use	6 hour		12 hour		24 hour	
	X	Q	X	Q	X	Q
Agricultural	28.4	0.463	54.0	0.540	18.8	0.390
Wetland	6.0	0.396	7.0	0.371	5.0	0.235

Note: X represents the magnitude of increase
Q represents the magnitude of the predicted peak discharge

It is important to note from the above table the level of significance that a change in land use in an agricultural basin has on the discharge levels. The wetland watershed does not increase discharge as dramatically as the agricultural environment.

The above values indicate the magnitude of the problem that results from the urbanization of agricultural or wetland environments. To calculate the values in table 5.1 the peak discharge from Schneider Creek was used to represent an urban environment. Because of this a qualifier must be placed on the calculated values. The qualification is that although these values represent the effect of urbanization they represent the effect of "total" urbanization. This means that for these areas to obtain these peak discharges and magnitudes of increase they would have to experience an urbanization level compatible with that experienced in Kitchener during the time period 1981 and 1986. These values are, therefore, likely an over estimation of the current urbanization problem in the watershed. The values are useful when attempting to predict worst case cenarios for current urbanization.

CHAPTER SIX
ALDER CREEK URBANIZATION

6.1 Problems with Alder Creek Urbanization

Figure 6.1 demonstrates the nearness to the water that present building is permitted on Alder Lake. Alder Lake is a man enhanced lake located north of New Dundee.

Figure 6.1 A photograph of Alder Lake near New Dundee

Construction of new homes is currently occurring downstream of this lake. The homes are being built near to the shores of Alder Creek. Urbanization is also occurring upstream of the lake. Upstream urbanization is increasing the imperviousness of the area, thus increasing the amount of storm runoff. This runoff will rapidly reach Alder Lake after the commencement of a precipitation event. A dam on the lake could prevent flooding of the downstream subdivision but would quickly result in flooding of the homes currently located on Alder Lake. If the upstream runoff is allowed to pass rapidly through Alder Lake and prevent Alder Lake homes from flooding it will result in downstream flooding. A reservoir or other means of short term storage of storm runoff must be implemented in the area before a major flood event occurs and causes significant damage.

CHAPTER SEVEN
CONCLUSION

Urbanization of agricultural and wetland environments is a rapidly expanding trend in Southern Ontario. This paper has identified the magnitude of the problem which must be assessed prior to the urbanization of a watershed.

The unit hydrograph approach is a relatively simple method to determine and quantify a stream's average discharge response to a precipitation event if precipitation and discharge data has been collected for a long period of time in the basin being studied. Since most basins in Southern Ontario have discharge and precipitation records for an extended period of time the unit hydrograph is a suitable method to implement in land use studies.

The unit hydrographs presented in this work indicate that urban environments experience the most rapid response and greatest peak discharge to any of the three durations of precipitation events studied. The wetland environment required the longest amount of time to respond to the precipitation event. The agricultural environment had the lowest peak discharge. These trends can be successfully applied to other watersheds in similar climatic, physiological and geological regions. Extreme caution must be used if attempting to implement the unit hydrographs from this paper to quantify the discharge response in other watersheds because of the assumption which states that the unit hydrograph represents the effect of all the basin's physical characteristics on discharge and no two basins possess ALL the same physical characteristics.

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APPENDIX 1

Parameters to Create Unit Hydrographs

Data Required to Create Blue Springs Unit Hydrograph

Location	Duration	T. to Onset	T. to Peak	T. to Base	Avg. Peak Q	Duration Response
Blue Springs	6 hour	5	38	142	0.068	180
		8	42	130	0.070	172
		7	39	128	0.060	167
	avg.	6.7	39.7	133.3	0.066	173
	12 hour	6	49	87	0.04	142
		8	44	73	0.08	125
		7	44	84	0.04	135
	avg.	7	45.7	81.3	0.053	134
	24 hour	6	62	138	0.029	200
		7	63	122	0.038	185
		9	31	85	0.075	115
	avg.	7.3	52	115	0.047	166.3

Note : T = time (hours)
Q = discharge (m^3/s)

Data Required to Create Schneider Creek Unit Hydrographs

Location	Duration	T. to Onset	T. to Peak	T. to Base	Avg. Peak Q	Duration Response
Schneider Creek	6 hour	1	4	8	0.16	12
		1	7	10	0.145	17
		1	10	8	0.13	18
	avg.	1	7	8.6	0.145	15.6
	12 hour	1	9.6	18	0.14	27.6
		2	10	19	0.183	29
		1	11	20	0.19	31
	avg.	1.3	10.1	19	0.171	29.2
	24 hour	1	25	24	0.11	49
		2	26	25	0.14	51
		1	24	25.6	0.10	49.6
	avg.	1.3	25	24.8	0.117	49.8

Note : T = time (hours)
Q = discharge (m^3/s)

Data Required to Create Alder Creek Unit Hydrographs

Location	Duration	T. to Onset	T. to Peak	T. to Base	Avg. Peak Q	Duration Response
Alder Creek	6 hour	1	10	16	0.014	26
		2	14	19	0.018	33
		1	12	17	0.017	29
	avg.	1.3	12	17.3	0.0163	29.3
	12 hour	1	14	29	0.012	43
		3	13	25	0.008	38
		1	14	23	0.010	37
	avg.	1.7	13.7	25.7	0.010	39.3
	24 hour	1	27	50	0.022	77
		1	25	58	0.015	83
		2	28	61	0.025	89
	avg.	1.3	26.7	56.3	0.021	83

Note : T = time (hours)
Q = discharge (m^3/s)

APPENDIX 2

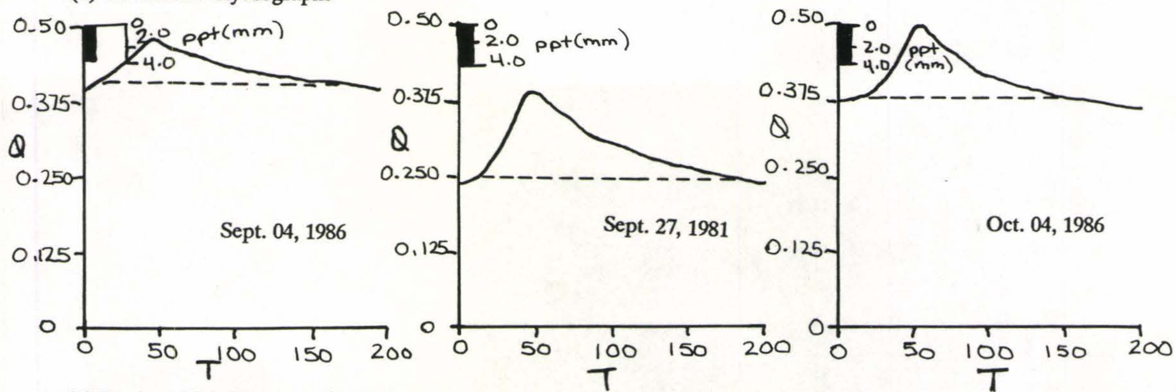
Six Hour Unit Hydrograph Derivation

Appendix 3, 4 and 5 contain the hydrographs that were obtained at the different stages in unit hydrograph derivation. For each basin and each duration graph (a) represents the streamflow hydrograph with the baseflow separation line identified. The precipitation that formed the hydrograph is shown in the upper left hand corner of each graph. Graph (b) represents the derived unit hydrograph (baseflow removed and one unit of rainfall). The effective rainfall is displayed in the upper left hand corner of the individual graphs. Graph (c) shows the three derived unit hydrographs together on one graph. Graph (d) shows the average unit hydrograph obtained by averaging the three graphs displayed on graph (c). In the upper left hand corner of graphs (c) and (d) the average effective rainfall is displayed.

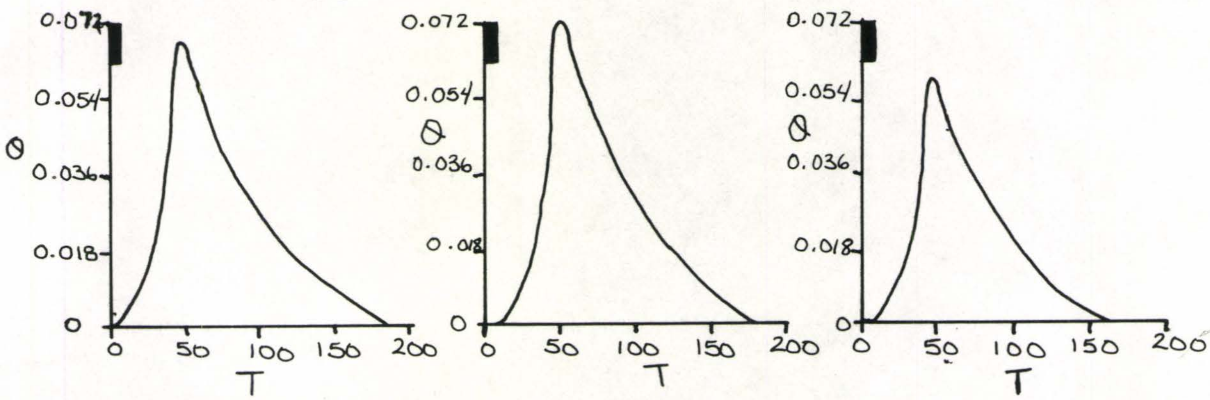
Wetland Watershed : Blue Springs

Six Hour Storms

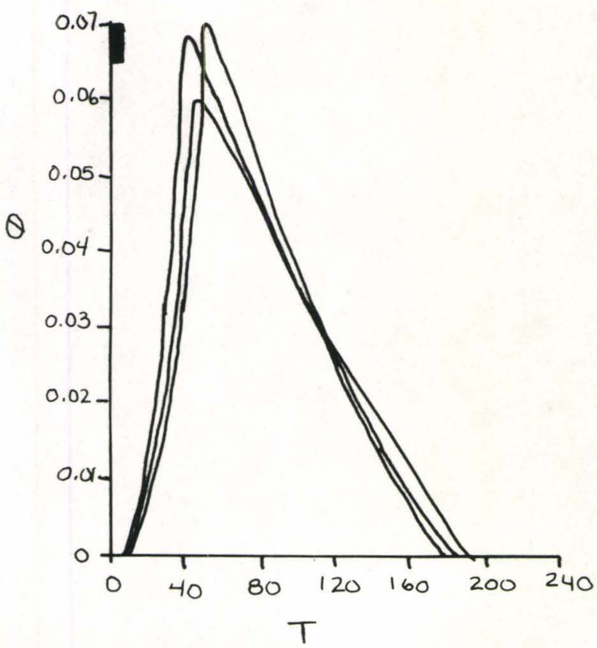
(a) Streamflow Hydrographs



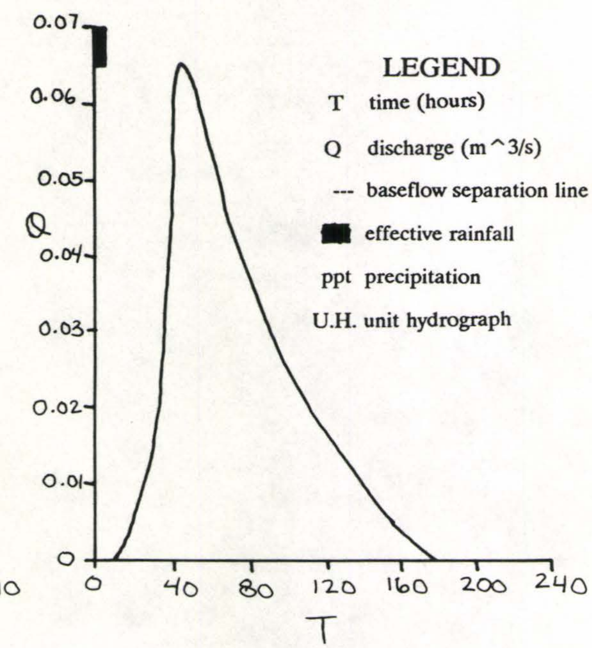
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



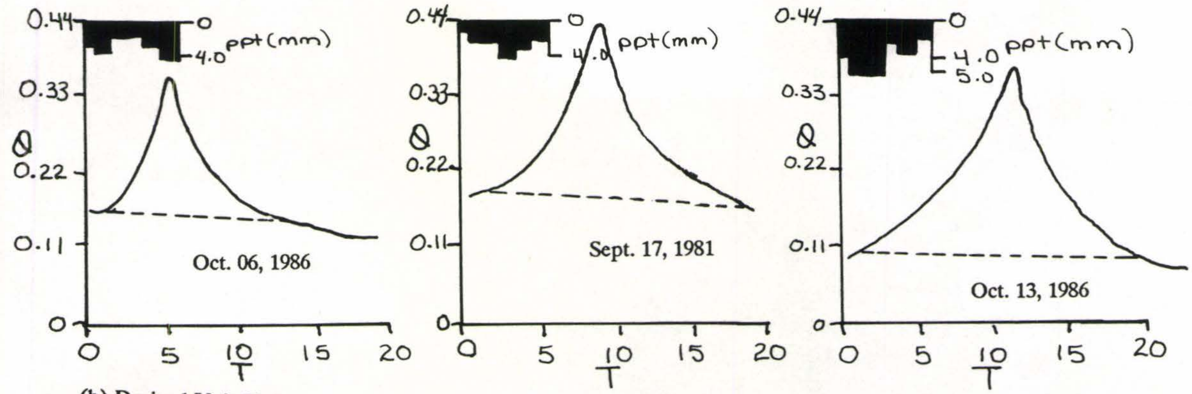
(d) Average U.H.



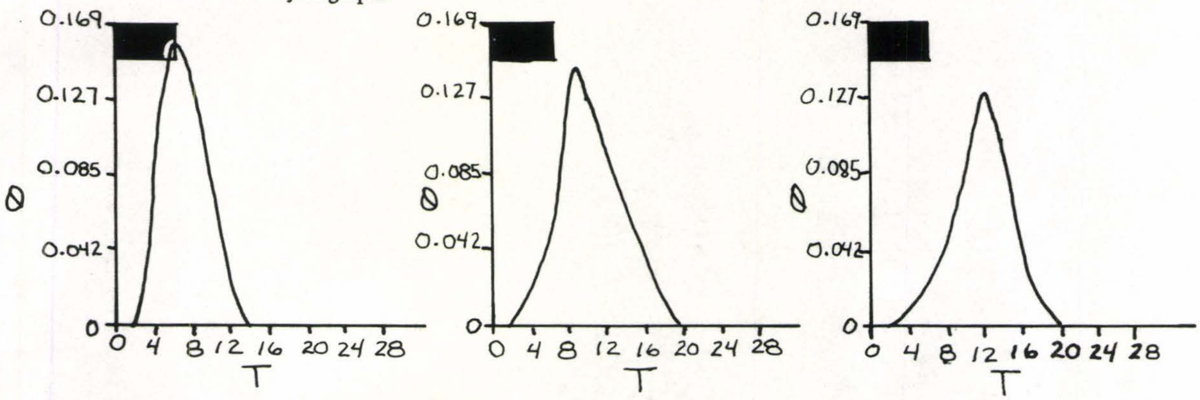
Urban Watershed : Schneider Creek

Six Hour Storms

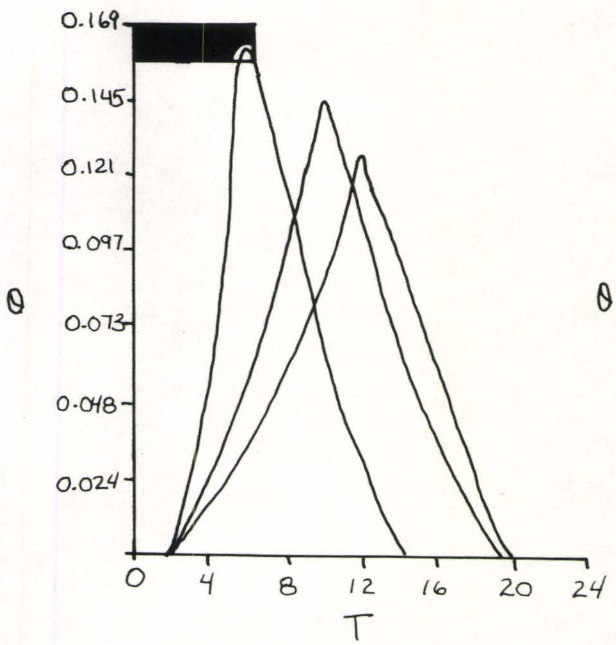
(a) Streamflow Hydrographs



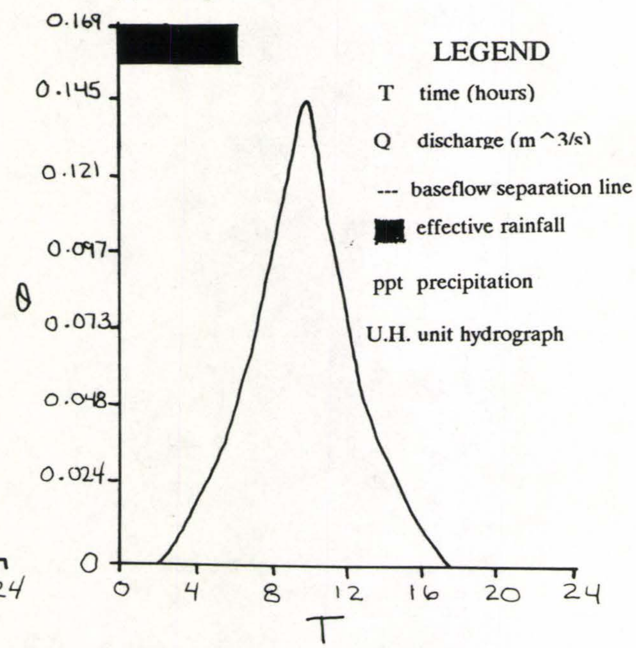
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



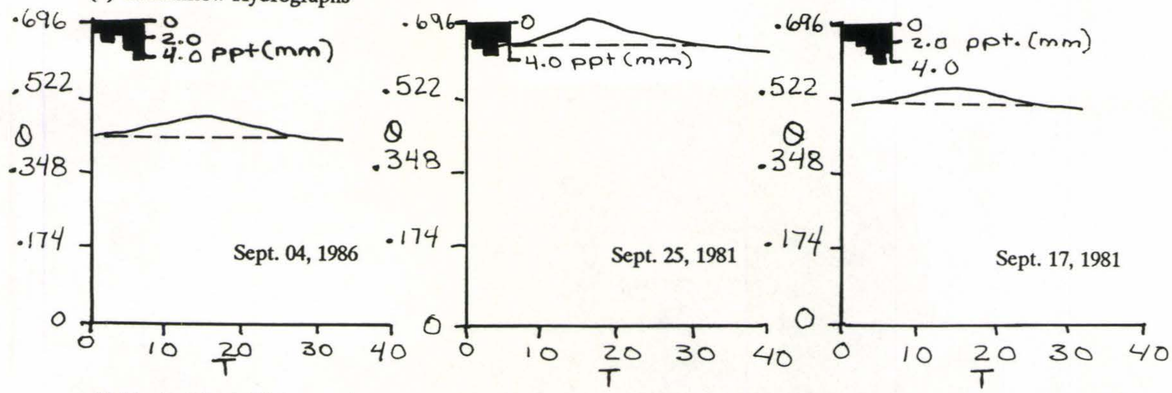
(d) Average U.H.



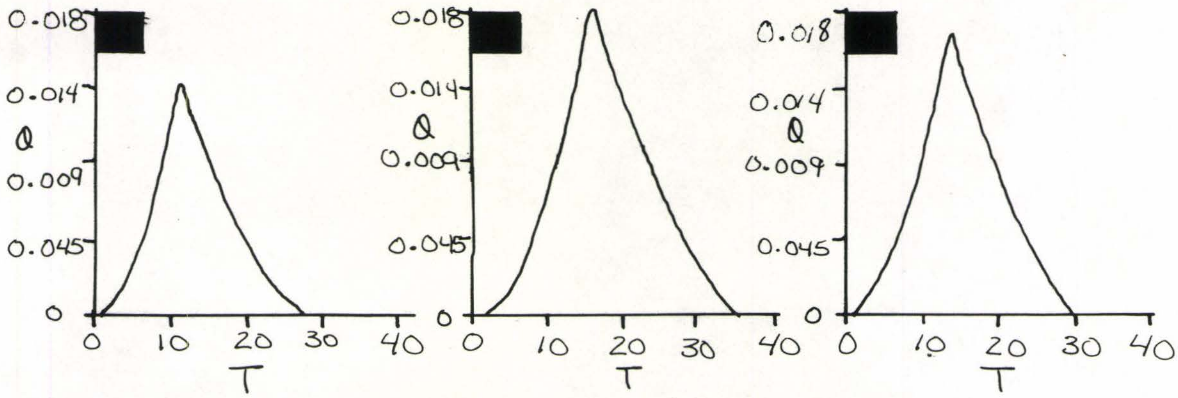
Agricultural Watershed : Alder Creek

Six Hour Storms

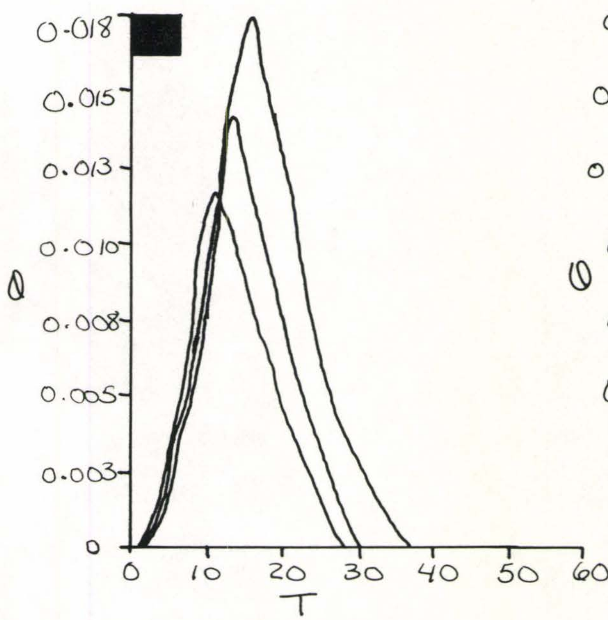
(a) Streamflow Hydrographs



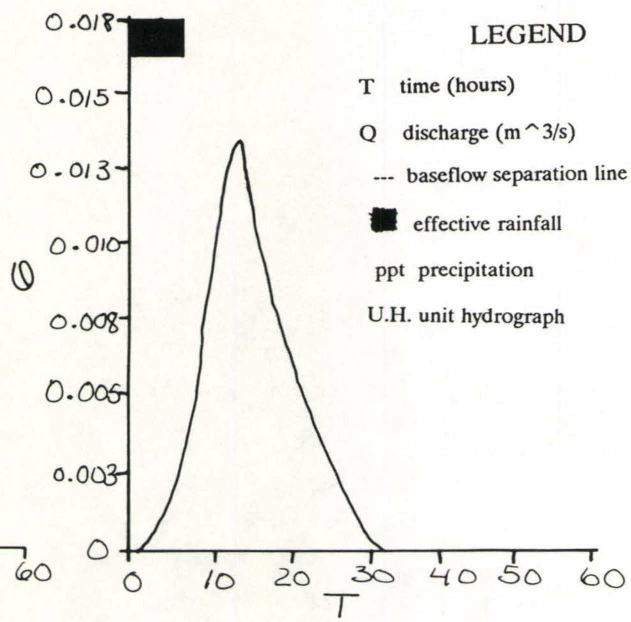
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



(d) Average U.H.



LEGEND

T time (hours)

Q discharge (m^3/s)

--- baseflow separation line

■ effective rainfall

ppt precipitation

U.H. unit hydrograph

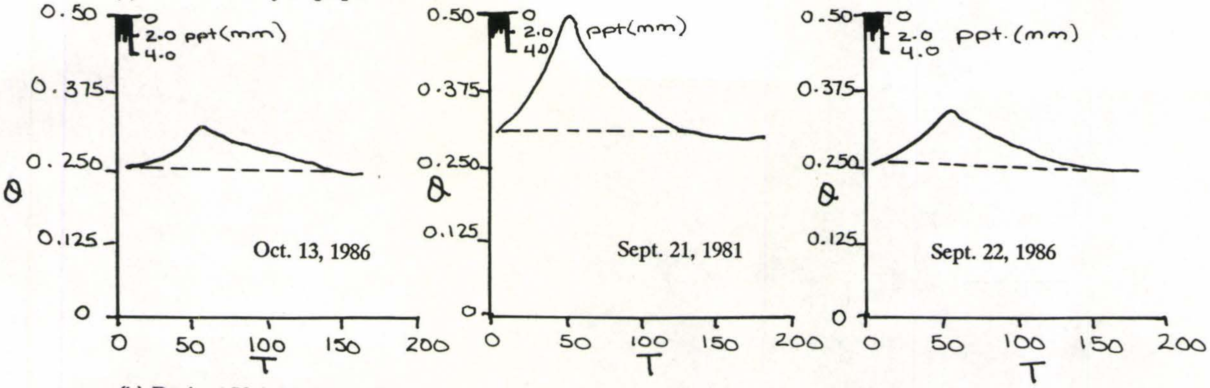
APPENDIX 3

12 Hour Unit Hydrograph Derivation

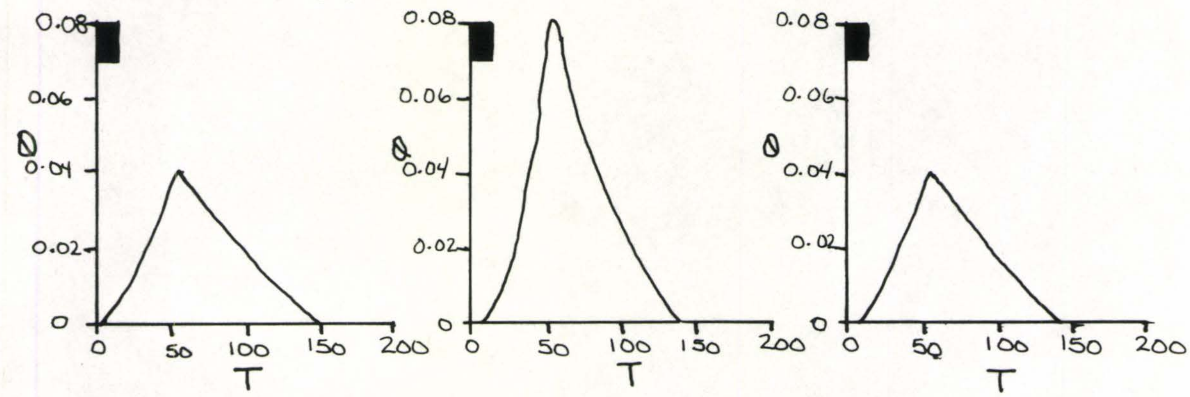
Wetland Watershed : Blue Springs

12 Hour Storms

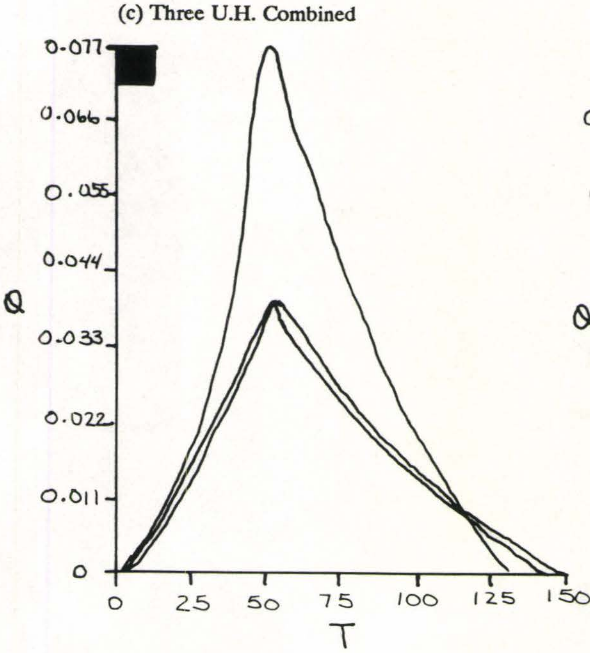
(a) Streamflow Hydrographs



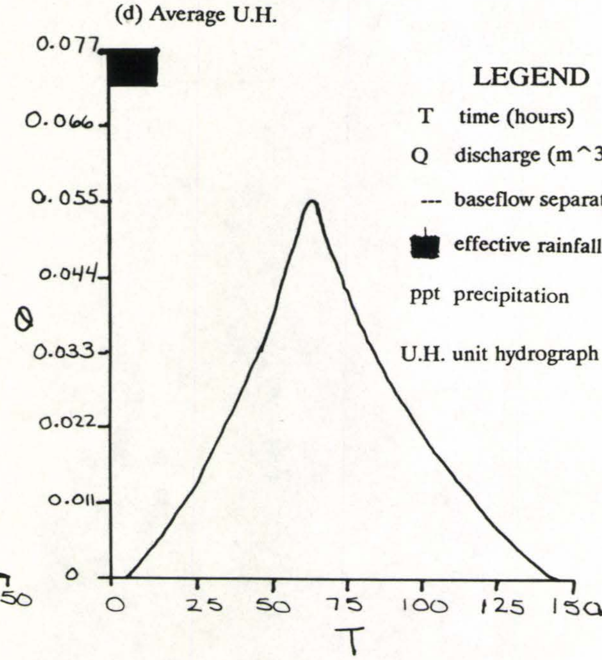
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



(d) Average U.H.



LEGEND

T time (hours)

Q discharge (m^3/s)

--- baseflow separation line

■ effective rainfall

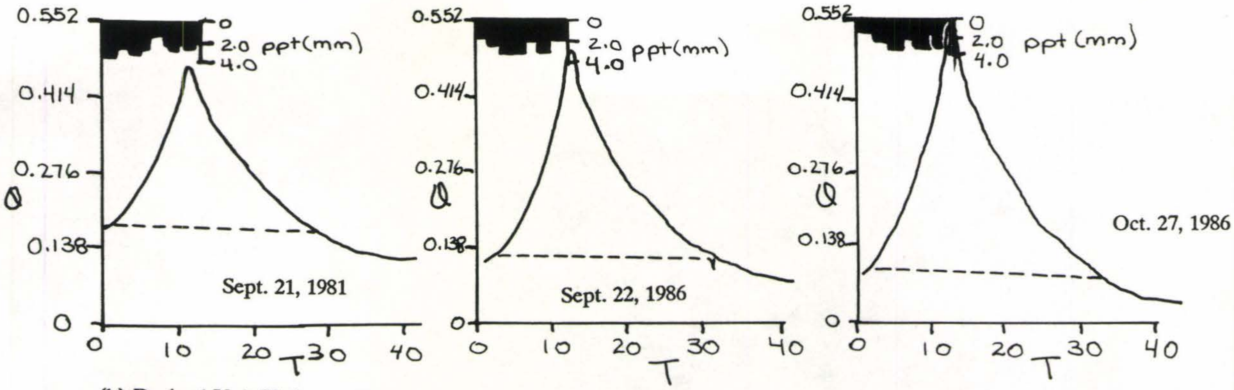
ppt precipitation

U.H. unit hydrograph

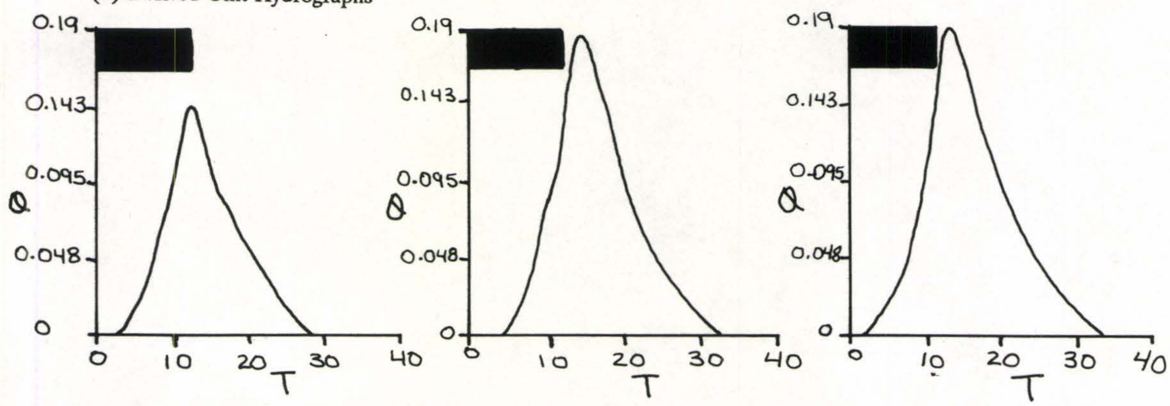
Urban Watershed : Schneider Creek

12 Hour Storms

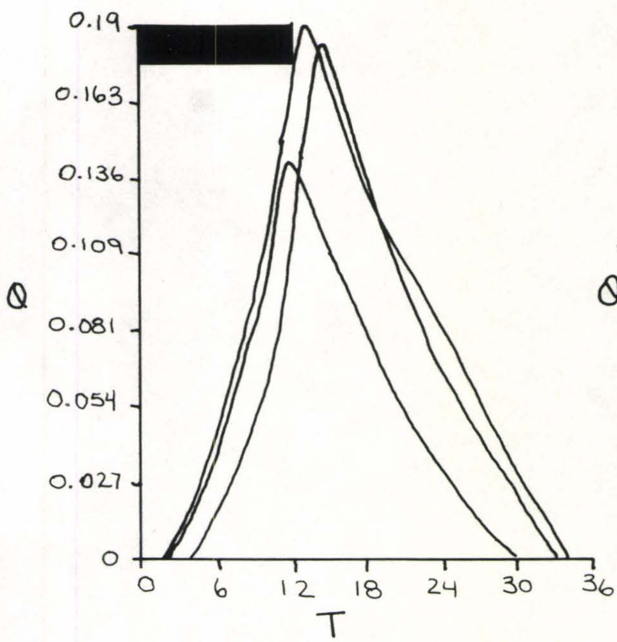
(a) Streamflow Hydrographs



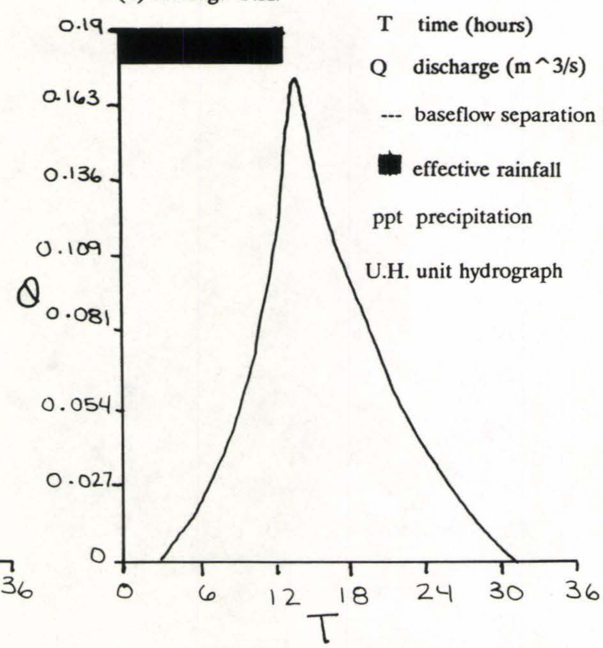
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



(d) Average U.H.



LEGEND

T time (hours)

Q discharge (m^3/s)

--- baseflow separation line

■ effective rainfall

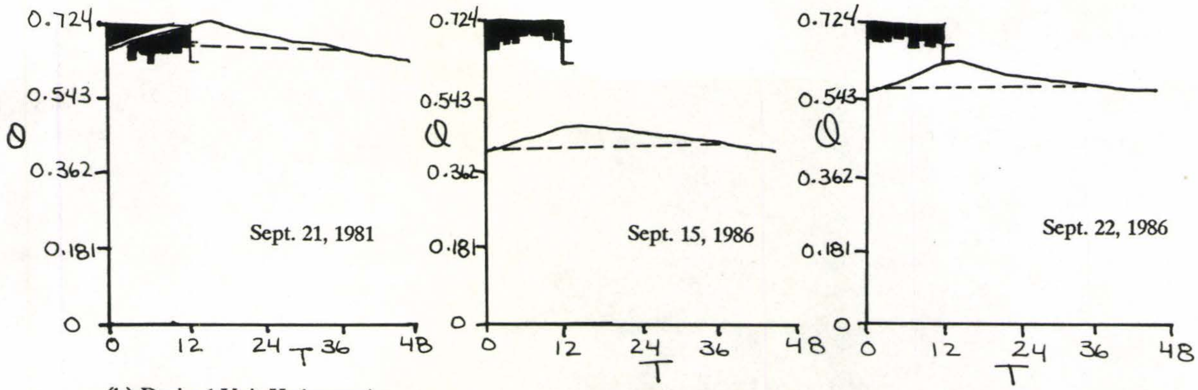
ppt precipitation

U.H. unit hydrograph

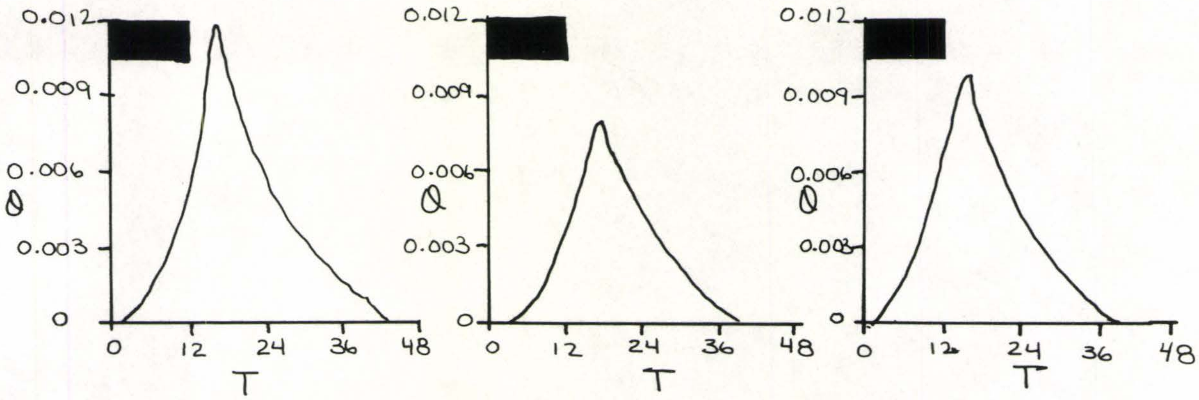
Agricultural Watershed : Alder Creek

12 Hour Storms

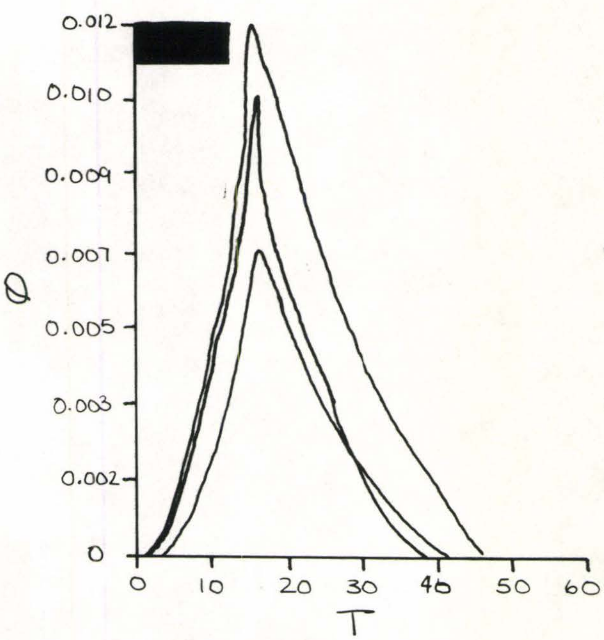
(a) Streamflow Hydrographs



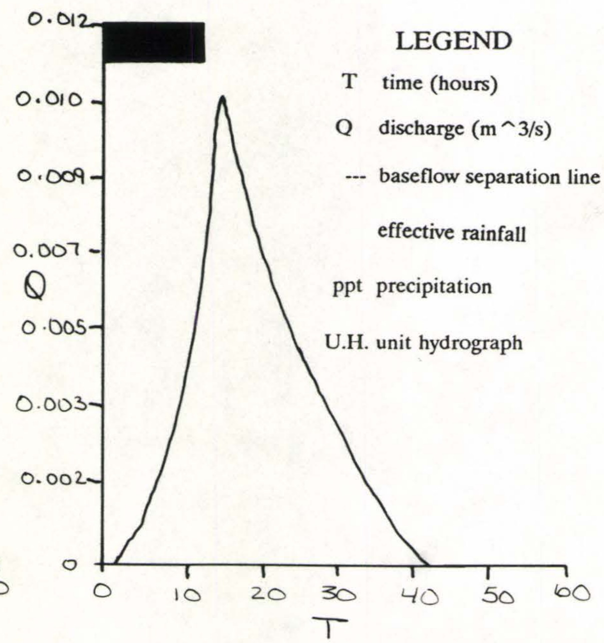
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



(d) Average U.H.



LEGEND

T time (hours)

Q discharge (m ^3/s)

--- baseflow separation line

effective rainfall

ppt precipitation

U.H. unit hydrograph

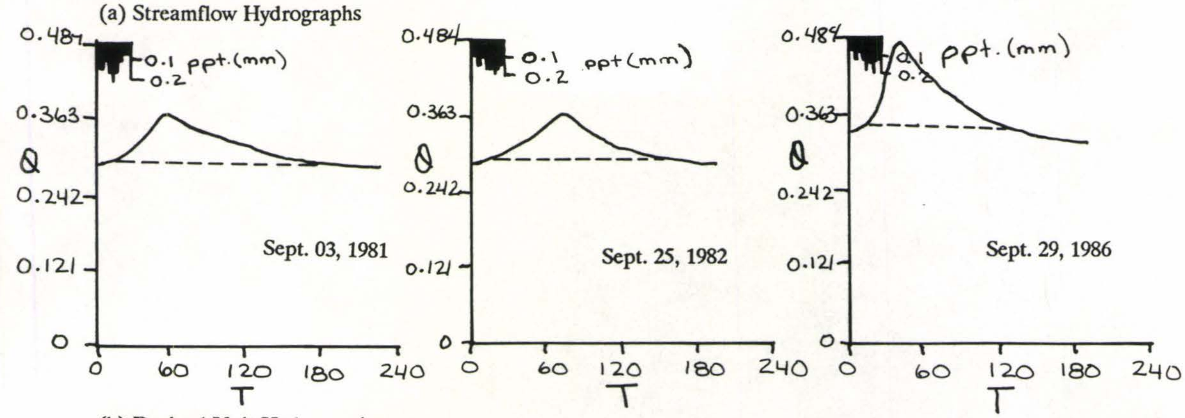
APPENDIX 4

24 Hour Unit Hydrograph Derivation

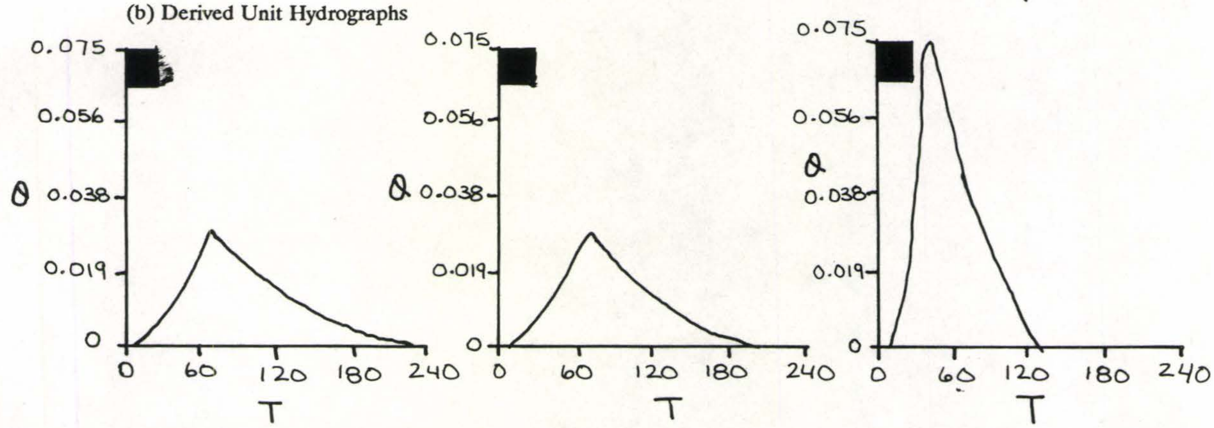
Wetland Watershed : Blue Springs

24 Hour Storms

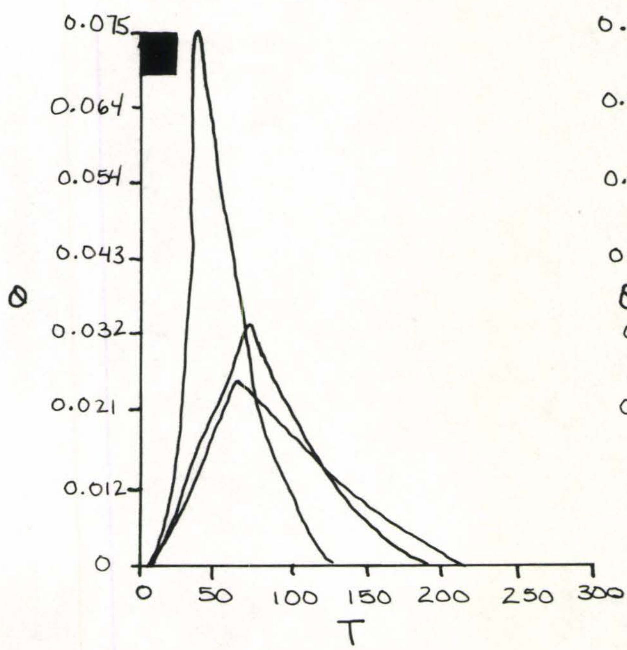
(a) Streamflow Hydrographs



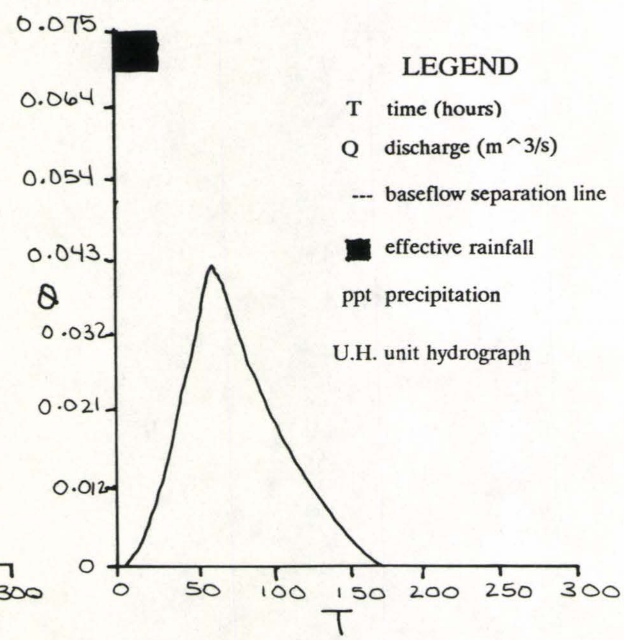
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



(d) Average U.H.



LEGEND

T time (hours)

Q discharge (m^3/s)

--- baseflow separation line

■ effective rainfall

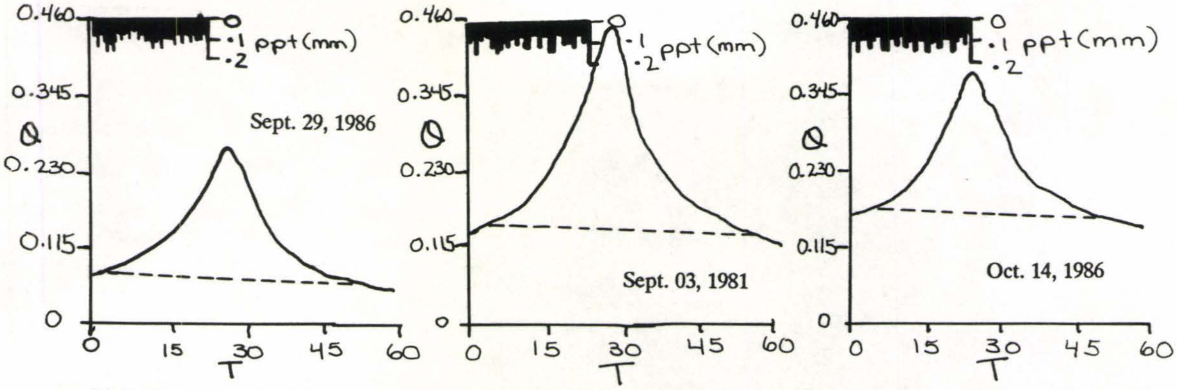
ppt precipitation

U.H. unit hydrograph

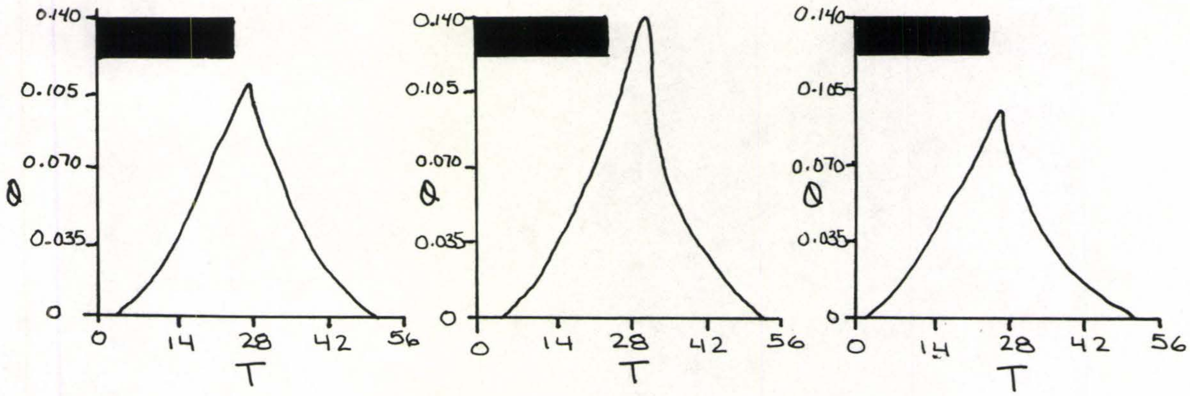
Urban Watershed : Schneider Creek

24 Hour Storms

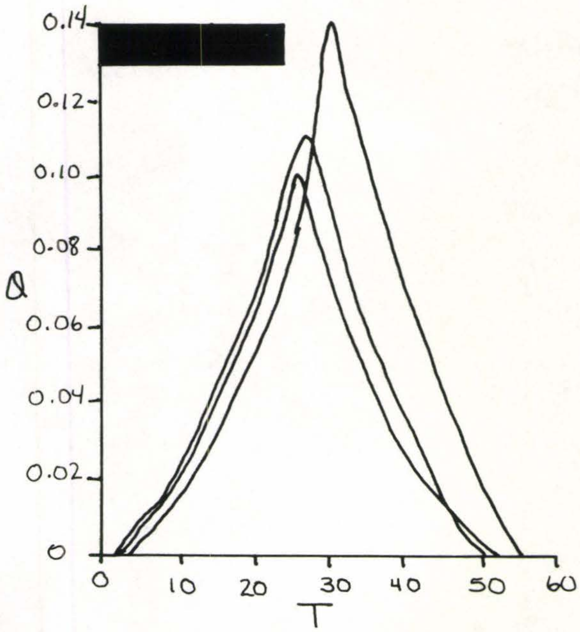
(a) Streamflow Hydrographs

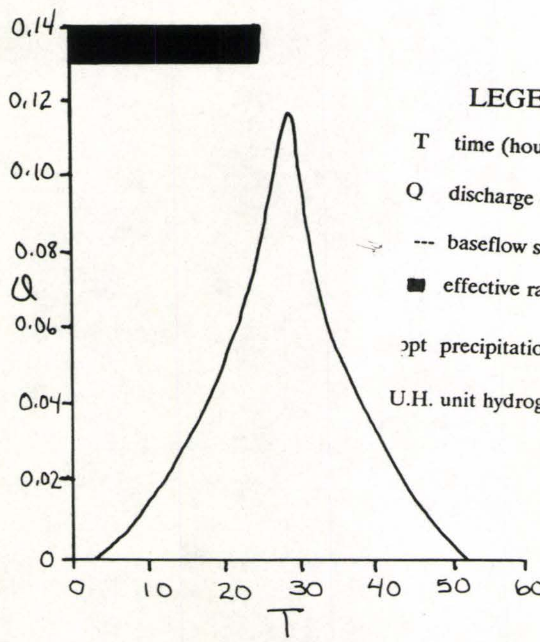


(b) Derived Unit Hydrographs



(c) Three U.H. Combined





LEGEND

T time (hours)

Q discharge (m^3/s)

--- baseflow separation line

■ effective rainfall

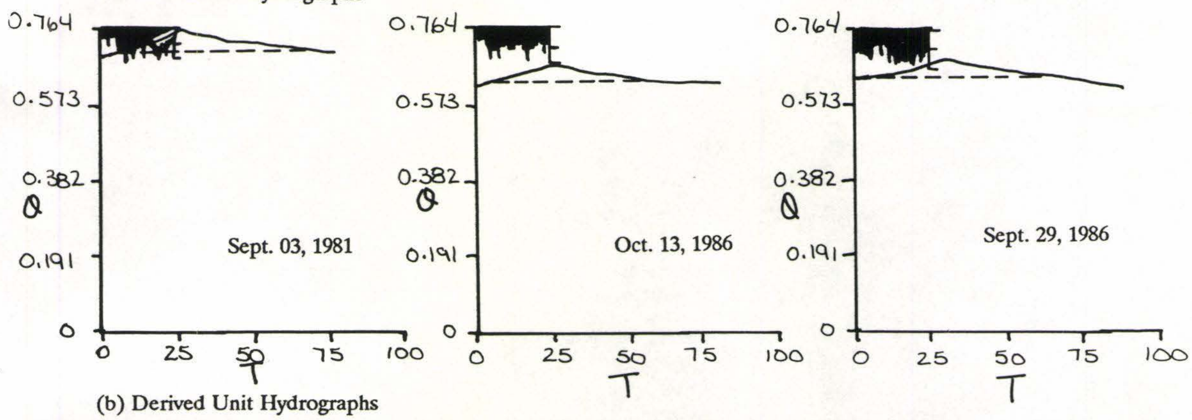
ppt precipitation

U.H. unit hydrograph

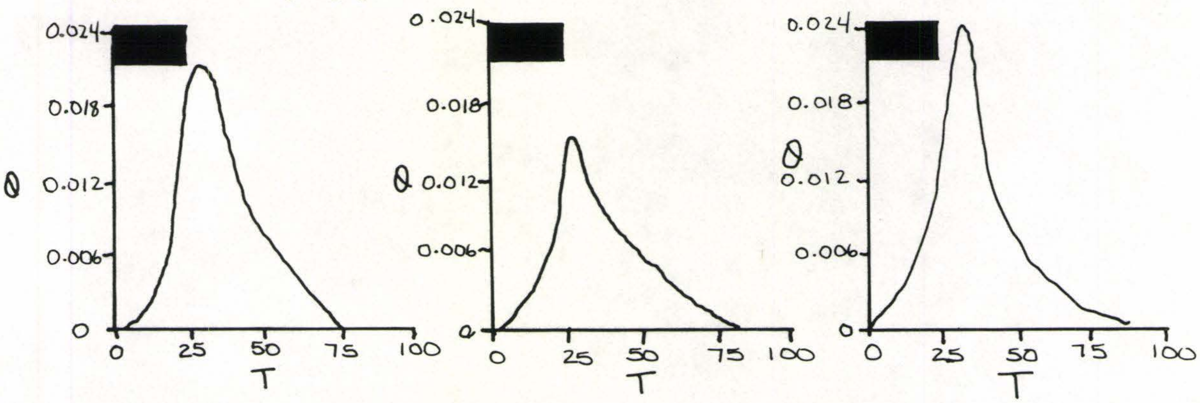
Agricultural Watershed : Alder Creek

24 Hour Storms

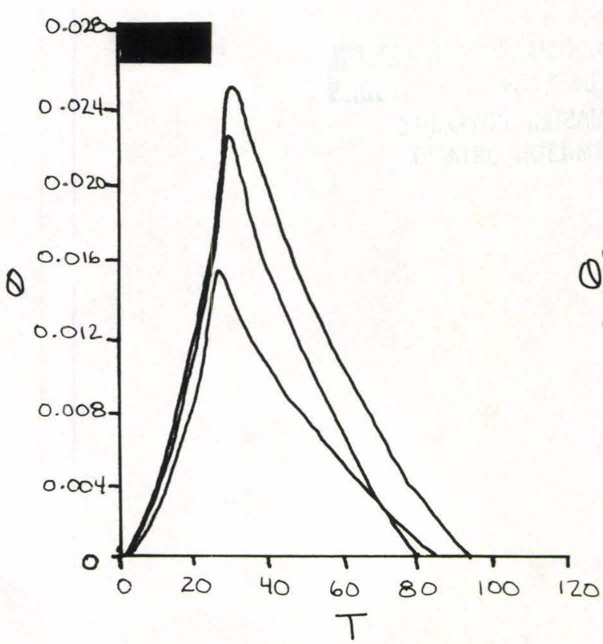
(a) Streamflow Hydrographs



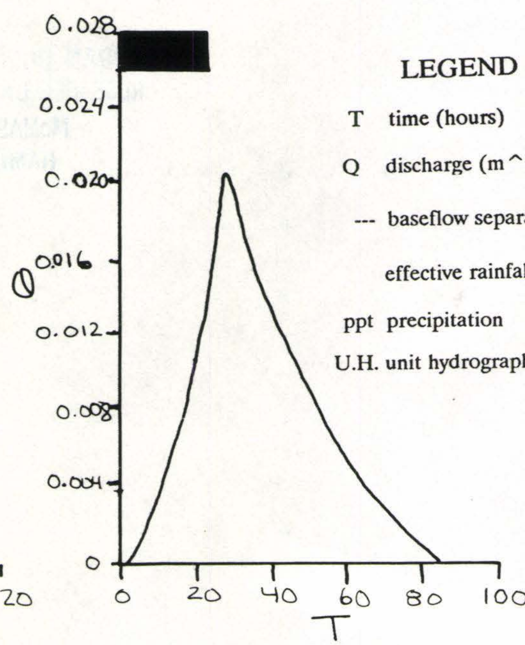
(b) Derived Unit Hydrographs



(c) Three U.H. Combined



(d) Average U.H.



LEGEND

T time (hours)

Q discharge (m^3/s)

--- baseflow separation line

effective rainfall

ppt precipitation

U.H. unit hydrograph