# STORM RAINFALL-RUNOFF RELATIONS IN WILSON CREEK WATERSHED, MANITOBA

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by
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# ABSTRACT

Although the intense, short duration summer rainstorms falling on the Wilson Creek Watershed in Manitoba, result in a rapid storm runoff, indicating the possibility of a quick impulse-response linear relationship, the scatter of points on a simple correlation of rainfall-runoff indicates some large effects of other hydrologic parameters. This study attempts to determine the major parameter affecting this storm rainfall - storm runoff relationship.

Three techniques of groundwater separation are considered for derivation of direct storm runoff values. An arbitrary groundwater separation technique with the aid of a composite recession curve is selected in the final analysis.

The findings point out that the antecedent basin moisture, as represented by a depth to groundwater table parameter, is the major parameter affecting the storm rainfall - runoff process in the Wilson Creek Watershed.

A preliminary attempt to derive a unit hydrograph for the basin indicates that both the peak and its time distribution are variable.

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# CHAPTER I

## INTRODUCTION

The operation of flood, erosion, and sediment silting control projects constructed prior to 1957 on several streams originating in the Riding Mountain Escarpment gave indication of future high maintenance costs and pointed out the need for more information on basic causes. This need of discovering the basic causes to the aforementioned problems resulted in the establishment of the Committee on Headwater Flood and Erosion Control in 1957. The Committee was charged with determining the extent, the causes, and the steps required to alleviate the problems of flooding, silting, and erosion caused by action in the headwaters. The Wilson Creek Watershed, located on the eastern slopes of the Riding Mountain, (Figure 1), was selected by the Committee for intensified studies of the abovementioned problems.

Owing to the greater simplicity of conditions and the possibility of obtaining or measuring components of the hydrologic cycle more accurately due to a more dense network of measuring stations, studies of runoff from small drainage basins such as Wilson Creek are better adapted to the determination of the underlying laws and principles of runoff phenomena than studies of larger drainage basins.

The actual program of investigations on Wilson Creek has been discussed fairly extensively in the paper by Mackay and Stanton (1964).

One of the main aspects of the program is the collection of rainstorm and storm runoff data for the establishment of a storm rainfall-runoff relationship. The derivation of a procedure for computing runoff from precipitation provides more insight into the occurrence and control of floods.

The rapid response of runoff to the frequent short duration summer rainstorms on Wilson Creek Watershed, with intensities as high as 6 inches per hour (Newbury et al., 1969) indicates the possibility of a quick impulse-response linear relationship.

Several complex and interdependent processes, however, affect the movement of water from rainfall before it enters streamflow. One of the major problems in determining a storm rainfall-runoff relationship is the separation of the quick response runoff from the long term groundwater flow.

This thesis attempts to discover the major parameter affecting the storm rainfall-runoff relationship in the Wilson Creek Watershed. An initial description of the Wilson Creek storms and the basic data collection in the watershed, in Chapter II, is followed by a general discussion of the factors affecting the runoff phenomena in Chapter III. Several techniques of groundwater separation from the streamflow hydrograph are presented in Chapter IV. The method of chemical base flow separation presently being investigated on the watershed is briefly compared to other methods of base flow separations. The unit hydrograph principle which indicates the time distribution of runoff is discussed. The technique to be used in the thesis for correlation of storm rainfall-runoff is presented along with effects of other parameters.

The data gathered on Wilson Creek Watershed is then analyzed through the aforementioned techniques and a preliminary graphical relationship of storm rainfall-runoff is achieved. A mathematical representation of the graphical relationship is then derived and a comparison between computed and actual flow is obtained. An attempt is also made to determine a unit hydrograph from several storms.

The conclusions presented in the thesis indicate that the antecedent basin moisture as represented by a depth to groundwater table in Well #5 is the major parameter affecting the storm rainfall runoff process in the Wilson Creek Watershed. The findings concluded herein also indicate where future research should be directed or where improvement in the data collection is required.

# CHAPTER II

# THE WILSON CREEK STORMS

## 2.1 General Description of Basin

The Wilson Creek Watershed is situated along the eastern boundary of Riding Mountain National Park, on the Manitoba Escarpment, approximately 150 miles northwest of Winnipeg in the vicinity of the town of McCreary (Figure 1). The headwaters of this pear-shaped, 8.5 square mile watershed, begin at about elevation 2400 feet. From a relatively flat plateau in the upper catchment area, the land falls rapidly, dropping about 1300 feet in four miles. A profile and a geologic cross-section from the headwaters down to the weir may be observed in Figure 2. The sloping portion of the watershed along the escarpment is deeply incised and cut by a large number of drains and coulees tributary to the main water courses.

Cox (1968) divides the Wilson Creek Watershed into four distinct physiographic regions with:

(a) the Western Upland comprised of an undulating plain with numerous beaver ponds, muskeg, and kettle holes.

(b) the Upper Escarpment extending down to approximately 1900 feet elevation and composed entirely of glacial deposits.

(c) the Lower Escarpment containing high rising shale banks and

(d) the Manitoba Lowlands located at the foot of the escarpment in the form of an alluvial fan.

The drainage density of 2.9 for Wilson Creek Watershed was determined using a total stream length of 24.78 miles (Cox, 1968).

The drainage densities of the Bald Hill Creek and Packhorse Creek sub-basins are 2.45 and 3.26 respectively while the drainage density of Wilson Creek basin excluding the Bald Hill and Packhorse Basins is given at 5.15 (Cox, 1968). This increase in value may be caused by a small area in the lower basin accompanied by a considerable meanding of the creek.

A soil survey of the Wilson Creek Watershed in 1958 (Mackay and Stanton, 1964) disclosed that the upper portion consisting of finer textured soils indicates a large contribution to surface runoff while the middle portion, comprising the steep slopes of the escarpment and consisting of very permeable soils may keep surface runoff at a low level.

Detailed studies of the vegetative cover of the watershed, as carried out by J. C. Ritchie in 1958, (Mackay and Stanton, 1964), indicate that the forest cover of the watershed is comprised of both coniferous and deciduous species. The more open decadent forest of hardwoods and spruces is more prominent in upper portion of the watershed. The escarpment is covered predominantly with mixed forest in the upper slopes and deciduous trees in the lower slopes. The lower portion of the watershed is covered by a mixture of hardwood and coniferous forest.

## 2.2 Wilson Creek Watershed Basic Data

### 2.2.1 Rainfall Data Network

The extreme variation in elevation across the escarpment indicated the necessity of establishing a fairly dense network of rain gauges before attempting to achieve a rainfall-runoff relationship. By September, 1969, 34 rain gauges had been installed throughout the watershed (Thomlinson, 1970). The location of both the 26 standard rain gauges and the 8 recording rain gauges are shown in Figure 1.

The total storm rainfall for the basin is determined by the isohyetal method using data from all rain gauges. Rainfall analysis by the isohyetal method may be observed in Figure 24. Sydor (1970) found the Thiessen polygon method to produce similar results.

Although the average seasonal rainfall, from May to September, has averaged only 14.22 inches from 1959 to 1969 (Thomlinson, 1970) rainfall on the basin is frequent and intensities as great as 6 inches per hour have been recorded (Newbury et al., 1969).

To obtain hourly increments of rainfall for each storm, data from the 8 automatic rain gauges is averaged and adjusted by comparison with the storm rainfall value obtained from the isohyetal analysis using all rain gauges.

The hourly rainfall and runoff data for each storm is presented as Appendix A. Hyetographs of storm rainfall have also been plotted with the storm hydrographs and may be observed in Appendix B.

During each annual period from May to September the basin has been averaging 50 days of rainfall for the past 11 years with the months of June and August having an average maximum 11 days and September averaging only 8 days of rainfall (Thomlinson, 1970).

An average of 5 storms per season with 1 inch of rainfall or higher occurred on the watershed with 1961 having a minimum of 1 storm while 1965 contained a maximum of 9 storms (Thomlinson, 1970).

The maximum 48-hour rainstorm from 1959 to 1969 occurred on June 25 to 27, 1969, and produced an average rainfall of 4.93 inches over the watershed (Thomlinson, 1970).

### 2.2.2 Streamflow Data Network

Streamflow records on the Wilson Creek Watershed are collected at six gauging stations. These include Packhorse Creek, Bald Hill Dam, Ridge Dam, and the two weirs on Conway Creek in addition to the main gauging station at the Wilson Creek Weir which provides records of streamflow from the whole basin. The location of the stage recorders at the above sites may be observed in Figure 1.

The Wilson Creek Weir was constructed to obtain a stable cross-section necessary for defining a reliable stage-discharge relationship.

The trapezoidal concrete control structure consists of a base width of 30 feet, side slopes of 3:1, a section length of 20 feet and a 2-foot wide notch to rate low flows.

A continuous record of stage is obtained from a Stevens A-35 water level recorder sitting on top of a bank type well installation connected to the stream by intake pipes. The lowest well intake pipe is extended into the 2-foot low flow notch in the concrete weir.

Sediment deposits at the control section cause difficulties in obtaining accurate low flow records especially below 2 or 3 cfs.

Medium and large flows are not significantly affected. The occasional breakdown of the stage recorder, however, also adds to the problem of obtaining accurate records even at high flows.

Generally speaking, the streamflow at the Wilson Creek responds very quickly to rainfall on the watershed. The streamflow hydrograph at the outlet frequently begins to rise only 2 or 3 hours from beginning of rainfall.

The storm discharge hydrographs exhibit sharp rising limbs, high peaks of very short duration and a fairly quick recession. It was hoped that this quick response of the watershed to bypass storm runoff from each storm rainfall may lead to a quick impulse - quick response type of rainfall-runoff relation at Wilson Creek.

The quick response has produced several streamflow hydrographs of over 100 cfs peak values on the watershed with the storm of June 25 to June 27, 1969 reaching a maximum instantaneous peak of 700 cfs. As a comparison the 11-year average daily discharge during the open water season is approximately only 6.0 cfs (Thomlinson, 1970).

### 2.2.3 Soil Moisture Measurements

Estimates of the moisture content of soil in the basin are generally made weekly using a one-inch tube sampler. The moisture content of the soil samples are estimated by feel at increments of 6 inches up to a depth of 3 feet. These estimates are made at seven sites within the basin.

Laboratory tests have indicated that the soil moisture holding capacity when dry is 3-inches per foot. Once the soil moisture estimate is obtained at each site and the soil capacity is known, the soil moisture deficit may be determined. Values from the seven sites are then averaged to obtain a mean basin soil moisture deficit.

Although the accuracy of this method appears to be questionable, it has provided a fairly reliable estimate for forecasting the possibility of high runoff following a storm rainfall. The estimate of soil moisture deficits prior to some heavy storms have helped to explain the size of the resulting storm runoff.

### 2.2.4 Groundwater Network

Instrumentation to measure groundwater in the basin was not installed until 1965. The present network of wells and piezometer nests are shown on Figure 1.

Wells #1, #2, and #5 are equipped with continuous automatic recorder charts which require changing only once a month. The piezometers are checked on a weekly basis.

Initial reasons for establishing the groundwater investigations were:

(a) the apparent significance of the groundwater recharge and discharge in the overall water balance of the watershed,

(b) to determine the possibility of fairly rapid subsurface flow, especially in the areas of loose shale, and,

(c) to determine the effect of groundwater flow on the sediment movement adjacent to the streams.

In 1968, preliminary studies were undertaken (Newbury, Cherry, and Cox, 1969) to:

(a) determine the hydrochemical characteristics of the surface and groundwater flow systems,

(b) identify groundwater discharge derived from in-basin and out-of basin sources, and

(c) investigate the use of hydrochemical methods of separating stream hydrograph components.

Analysis of the collected data by Newbury et al.(1969) indicates "that the groundwater flow beneath the uplands above the confluence of Packhorse Creek and Bald Hill Creek and beneath the outlet of the basin is characterized by a downward hydraulic gradient."

Observation of Figure 8, indicates greater fluctuations in Wells #1 and #5 than in Well #2. Both Well #1 and #5 show very quick responses to rainfall in their area with Well #5 appearing to be the most sensitive with the largest fluctuations.

Well #1, set in fill, and Well #5, set in shale, are located in recharge areas well above the nearest stream channel. Well #2 is apparently located in a discharge area.

It is interesting to note in Figure 8 that although Well #5 is located in a recharge area while Well #2 is in a discharge area, the water level in Well #5 rises to within 1.3 feet from the ground surface as a result of the large rainstorm in June, 1969 while the water level in Well #2 only rises to within 6 feet from the ground surface.

### 2.2.5 Additional Meteorologic Data

The importance of measuring meteorologic data in addition to rainfall for use in water budget and rainfall-runoff studies has not been overlooked. Instrumentation has been installed on the watershed to measure temperature, relative humidity, barometric pressure, wind, pan evaporation, and solar radiation.

The importance of this additional meteorological data shows up when observing the average pan evaporation for the months of May and September for the period 1961 to 1969. Although the average monthly temperatures during that period were higher in September than in May, thus indicating the possible occurrence of higher evaporation in September also, the actual average pan evaporation of 2.54 inches in September is much less than the 4.36 inches in May.

# CHAPTER III

# FACTORS OF THE RUNOFF PHENOMENA

Generally speaking this chapter deals with a discussion of the runoff phenomena and a qualitative analysis of the factors or parameters which affect runoff.

There is no intention in this thesis to present a quantitative analysis of all these factors and the formulas for deriving their values are thus not presented.

## 3.1 The Runoff Phenomena

There are many variations in "runoff" definitions found in hydrologic literature.

Bruce and Clark (1966) define runoff from an area as the "integrated result of all hydrological and meteorological factors operative in a drainage area."

Hoyt ,(Chow, 1964),described the "runoff phenomena" in terms of a runoff cycle comprised of five phases, which are briefly described in this section.

Phase 1 - Rainless periods. Groundwater level decreases.

Phase 2 - Initial period of rainfall. Little overland flow or evapotranspiration.

Phase 3 - Continuation of rainfall. Overland flow occurs. Groundwater level rises and increases base flow.

Phase 4 - Continuation of rainfall. Natural storage satisfied. Overland flow and subsurface flow continue.

Phase 5 - Period past termination of rain. Evapotranspiration is active. Streamflow sustained by water from channel and subsurface storage.

Chow, (1964) states that "runoff is that part of precipitation which is collected from a drainage basin as it appears at the outlet." An extensive qualitative explanation of the interrelationship of the various hydrologic phenomena before, during, and after a rain in graphical form is presented by Linsley, Kohler, and Paulhus (1949).

## 3.2 Components of the Runoff Phenomena

In most hydrology books streamflow is usually split into surface runoff, subsurface runoff and groundwater runoff.

Surface Runoff, or overland flow, is that part of the runoff which travels over the ground surface and through channels and reaches the basin outlet fairly promptly.

The Subsurface Runoff, also known as interflow, is the runoff due to that part of the precipitation which infiltrates the surface soil and moves laterally through the upper soil horizons towards the stream channels. This portion also enters the streams fairly promptly.

The Groundwater Runoff, or base flow, is that part of the runoff due to deep percolation of the infiltrated water which has passed into the ground, has become groundwater, and has been discharged into the stream. This portion is usually called the long term component of streamflow.

For many practical purposes the surface runoff and the prompt subsurface runoff are usually grouped under the term direct runoff, the portion of streamflow used in rainfall-runoff and unit hydrograph analysis. Direct runoff is obtained by subtracting the groundwater or base flow from the total streamflow.

## 3.3 Factors or Parameters Affecting Runoff

The actual runoff process is very complicated and variable since it is affected by numerous factors. These factors will be considered under three groups -- climatic, physiographic and other hydrologic factors.

### 3.3.1 Climatic Factors

#### (a) Rainfall

The quantity and character of streamflow relies heavily on the total amount of rainfall, but the extent to which it does will depend upon the interaction of other characteristics of rainfall such as:

#### (i) Rainfall intensity

Heavy rain falling in excess of the infiltration capacity of the soil surface will largely contribute to surface runoff and will, therefore, tend to reach the stream very rapidly, while rain falling at lower intensities will be largely absorbed by the soil. Although this may eventually reach the groundwater body, its addition to streamflow will be considerably delayed (Ward, 1967). This indicates that streamflow peaks should vary with the rainfall intensity.

**Kohler** (1964) states that intensity effects are of great importance in semiarid plains region where severe thunderstorms are prevalent and where an inch of runoff may cause serious flooding.

Because of short time of concentration, runoff from small areas such as Wilson Creek Watershed may be very sensitive to changes in rainfall intensity.

(ii) Rainfall Duration

Rainfall duration is significant when considered in relation to the time taken for a drop of rainfall from the farthest point on the watershed to reach the outlet. This duration determines whether the runoff is being contributed from the whole watershed.

Rainfall duration is also important since the infiltration capacity of the soil tends to decrease through a period of rainfall (Ward, 1967). Thus, the longer duration of rainfall will gradually increase surface runoff to the stream.

(iii) Rainfall Distribution

Consideration of areal rainfall distribution is important since it determines whether the runoff contribution is from the whole watershed.

Since rainfall total or intensity are never uniform over the whole watershed, the difference in location of the concentrated higher intensity rainfall between the steeper headwaters and the low lying downstream section will have a different effect on the time distribution and possibly the peak of runoff.

(b) Other climatic factors such as temperature, humidity, wind, and insolation are significant due to their effect on total evaporation, soil moisture and vegetation which in turn affect runoff.

### 3.3.2 Physiographic Factors

Most textbooks of hydrology generally discuss similar physiographic factors. Chow (1964) further subdivides these into the following two groups:

(a) Basin Characteristics

- (i) Geometric factors - size, shape, slope, orientation, elevation.
- (ii) Physical factors - land use and cover, soil type, geologic conditions.

Ward (1967) considers watershed area size the most important factor since it determines the total amount of rainfall to fall on the watershed.

(b) Channel Characteristics

- (i) Carrying capacity - size and shape of cross-section, slope, length, and tributaries.
- (ii) Storage capacity - backwater effect.

Channel characteristics are related mostly to hydraulic properties of the channel which govern the movement of streamflows and determine channel storage capacity (Chow, 1964).

Chow (1964) further adds , however, that peak runoff on small watersheds is more dominantly affected by overland flow than by channel flow.

### 3.3.3 Other Hydrologic Factors

#### (a) Interception

Interception is the process by which precipitation is caught and stored on leaves and stems of the vegetation cover.

Linsley et al. (1949) state that the rate of interception at the beginning of rain is quite high, especially during summer in densely vegetated areas.

Chow (1964) estimates the annual interception by forests to be approximately 25% of annual precipitation.

#### (b) Evapotranspiration

Evapotranspiration deals with evaporation from soil and water and the withdrawal of water from soil by plants which also evaporates into the atmosphere from its leaf surfaces.

Chow (1964) points out the importance of transpiration from plants when he states that while surface evaporation commonly affects only the upper 6 to 15 inches, plants can withdraw water from considerably deeper soil. Riggs (1963) in his discussion of studies in Brandywine Creek, U.S.A., indicates that differences in summer recession curves on that basin are the result of differences in losses to the atmosphere.

During a storm rainfall period, evapotranspiration occurs at an almost negligible rate since the lower atmosphere is either saturated or nearly so.

During rainless periods evapotranspiration may contribute to the gradual lowering of the groundwater table.

### (c) Infiltration

Infiltration is the flow or movement of water from the surface of the ground through the pores and openings of the soil mass, as a result of rainfall on the watershed.

Once the water has infiltrated into the soil mass, its movement through the soil to the groundwater table is known as percolation.

The rate of infiltration is at a maximum when a soil is fairly dry. When water is added from rainfall, the pore spaces in the soil become full and the rate of entry of additional water declines to a low steady rate shortly after beginning of rainfall.

When rainfall rate falling on the ground surface exceeds the infiltration capacity, the rate at which water will be absorbed by a soil surface runoff will occur.

The water which infiltrated into the soil will stay as soil moisture in the ground, move as subsurface flow or percolate to the water table, increasing groundwater flow.

Infiltration indices have been used to estimate an average rate at which rainfall is lost to runoff during specific storms.

Chow (1964) ,however, suggests caution in their use since unequal distribution of rainfall and differences in vegetation cover may affect the derivation and application of these indices.

(d) Soil Moisture

Soil moisture refers to the water in the zone above the water table. The soil moisture content at any time can be expressed as soil moisture deficit in percentage of the field capacity. Field capacity is the amount of water held in the soil after excess gravitational water has drained away and the rate of downward movement has materially decreased.

Since the greater part of soil moisture deficiency is satisfied before significant surface runoff takes place (Linsley et al, 1949) the soil moisture content prior to a rainstorm has a large effect on the amount of the resulting storm runoff.