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A LINEAR RESERVOIR SIMULATION MODEL OF WILSON CREEK WATERSHED

by

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SYNOPSIS

This study has investigated whether a simple mathematical model could be used to produce useful results in flood event simulation. A simplified computer model of the Wilson Creek Watershed that simulates hourly streamflow due to rainfall has been developed. The sequential development of the model is discussed, along with the effect of the various model parameters.

Physically, the model can be thought of as two stacked linear reservoirs with outflows corresponding to the hydrograph components direct runoff and spring flow. Input to the model consists of initial soil moisture content and hourly rainfall data. The model ignores the effects of evaporation, evapotranspiration and interception, assuming them to be negligible in the overall water balance during a rainstorm. The parameters that define the storage and outflow characteristics of each reservoir were determined by minimizing the least squares deviation of the percentage error between the recorded and simulated flood peaks and volumes. Five storms with peak discharges varying from 300 cfs to 1350 were selected for calibration of the model. To verify the model five additional storms were simulated.

The model was found to be capable of a reasonable reproduction of observed streamflow hydrographs. However, an anomaly was encountered in the reproduction of two of the storms. This anomaly requires further study.

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CHAPTER I

INTRODUCTION

1.1 SCOPE OF STUDY

The purpose of this study has been to determine whether a simple mathematical model could be used to produce useful results in flood event simulation. Many hydrologic models, for instance the Sanford Model, have been developed to provide a complete time history of runoff for engineering purposes. A considerable knowledge of the basin hydrology is needed to use these models and several trial runs are necessary to obtain a reasonable reproduction of recorded streamflow. A complete reproduction of runoff is not always needed. The design of engineering structures and flood forecasting is served sufficiently by reproduction of the flood hydrographs resulting from individual rainfall events.This allows a considerable simplification of the model. Experimental data from the Wilson Creek Experimental Watershed have been used to develop such a model.

1.2 DESCRIPTION OF WATERSHED

The Wilson Creek Experimental Watershed is a basin of 8.5 square miles. It is shown on Figure 1. The Wilson Creek Watershed is located on the eastern slopes of the Riding Mountain National Park in Township 20, Range 16 W.P.M. some 150 miles northwest of Winnipeg. The topography of the Watershed is typical of watersheds of the Manitoba Escarpment, which forms a semi-continuous break in topography along a line across the southwestern corner of the Province. The upper portion of the Watershed is located on a relatively flat plateau at an elevation of 2,400 feet. From this plateau the land drops rapidly to an elevation of 1,100 feet in a distance of about four miles. The latter portion of the Watershed is deeply incised by gullies and ravines. The main streams are cut into bedrock shale in valleys that are four to five hundred feet deep.

A surface of unconsolidated glacial drift deposits overlies the shale bedrock formations throughout most of the Watershed. The upper portion of the Watershed is covered with open decadent forest of hardwoods and spruces interspersed with areas of browsed shrub cover. The lower portion of the Watershed is dominated by stands of white birch and aspen.

The climate in this area is sub-humid. The average annual precipitation is about 18 inches of which approximately 14 inches falls as rain during the months of April to October. Throughout the Manitoba Escarpment intense thunderstorms are frequent in the summer. These storms are usually centered over the uplands and often quite local. Rainfall intensities up to four inches per hour have been recorded for short periods of time over the small drainage area of the Watershed. These intensive rainfalls, rather than snowmelt, produce the major flood events on the Watershed (1).

1.3 PREVIOUS STUDIES

A mathematical model of the Wilson Creek Watershed that simulated hourly streamflow from rainfall and evaporation data was developed in 1970 by M. Sydor (2). This model included the simulation of interception, evaporation and evapotranspiration. Basically, the model consisted of three linear reservoirs in series, the outflows represented the hydrograph components: direct runoff, spring flow or interflow and base flow. The synthesized runoff hydrograph was transferred to the downstream end of the Wilson Creek Experimental Watershed by the Muskingum Flood Routing Method taking into account the observed time of travel.

In the development of this model three typical rainstorms were selected for reproduction. The storage capacities and initial amounts in storage prior to the storms were based upon physical observations of the Watershed. The base flow recession coefficients of the groundwater reservoir were determined by conventional hydrograph separation. The parameters that defined the outflow and storage coefficients of the direct runoff and spring flow were optimized to produce a minimum least squares deviation from the observed hydrographs.

The study concluded that the optimized reservoir coefficients produced an adequate simulation of streamflow. In two out of the three storms studied the agreement between actual and synthesized flows was good. However, a third storm revealed an inadequacy of the model in that the direct runoff as modelled did not properly reproduce the storage in ponds, reservoirs, and sloughs from a previous storm. It was recommended that the observed anomaly be given further study.

CHAPTER II

MATHEMATICAL REPRESENTATION OF THE HYDROLOGIC PROCESS

2.1 INTRODUCTION

The development of a mathematical model that simulates streamflow is made much simpler if components of the model can be identified with corresponding natural hydrologic features of the watershed. This also enables the transfer of the model to other watersheds where similar features and conditions exist. Therefore, the study has endeavoured to develop a simple mathematical model in which the components parallel the main natural processes. This chapter describes the hydrologic processes and their conceptual representation. In accordance with the purpose of the study, namely to develop the simplest model that would actually reproduce hourly streamflow, these hydrological processes were drastically simplified.

2.2 HYDROLOGIC PROCESSES

During the initial part of a storm much of the precipitation is intercepted by the vegetative cover, stored and subsequently evaporated. This volume of water is referred to as the interception storage. Once the interception storage capacity is met, the amount of water reaching the soil surface is equal to the rainfall less any evaporation from the vegetative cover. The interception storage capacity of a well-developed forest canopy is estimated to range from 0.03 to 0.06 inches (3). While the interception may be a significant factor in an annual water balance, in major storm events it is of little importance and it may be neglected for the present purpose.

Part of the water which reaches the ground infiltrates into the soil. Infiltration is the movement of water through the soil surface into the soil. It is distinguished from percolation, which is the movement of water through the soil. The water enters the soil surface due to the combined influence of gravity and capillary forces. Both forces also cause percolation. The capillary forces divert the downward-moving gravity water into capillary pores. As the capillary pores at the surface are filled their intake capacity is reduced, and as a result, the infiltration capacity decreases. The infiltration capacity is the maximum rate at which water can enter the soil. Normally, the infiltration capacity decreases gradually with time. The water at the surface cannot infiltrate at a greater rate than it is transmitted downward. Normally, soils are stratified and the subsoil layers are usually less permeable than the surface soil. Thus the infiltration rate is eventually limited to the rate of percolation through the least pervious subsoil stratum reached by the expanding zone of saturation.

When the rainfall intensity exceeds the infiltration capacity, the rainfall excess begins to fill surface depressions. The rainwater retained in puddles and ponds is termed depression storage. When a depression is filled further inflow is balanced by outflow, plus infiltration and evaporation. Once the depressions are filled overland flow begins. The water held in depressions at the end of the rain is either evaporated or absorbed by the soil through infiltration. Depression storage is usually lumped with interception and is treated as an initial loss with respect to storm runoff. Experience suggests that for most basins, the depression storage capacity will be between 0.5 and 2.0 inches (4).

The entire part of storm precipitation which does not appear either as infiltration or as overland flow during or immediately following the storm, is called surface retention. Surface retention includes interception, depression storage, and evaporation, but does not include water temporarily stored en route to the stream.

Evaporation and transpiration (water exuded in the form of vapor by plants) is also taking place during the rainfall period, but at a very limited rate, since the lower atmosphere is saturated or nearly saturated. In this study this component is neglected.

2.3 COMPONENTS OF STREAMFLOW

The water which constitutes streamflow may travel to the stream channel by several paths from the point where it first reached the earth surface. The water that does not infiltrate into the soil flows over the soil surface and reaches the stream soon after its occurrence as rainfall. The balance of the water infiltrates through the soil surface and flows beneath the surface to the stream channel. This water moves more slowly than the surface water and contributes to the sustained flow of the stream after the rainfall has ceased.

The water which travels over the soil surface is referred to as overland flow. Overland flow is the excess precipitation produced by a high-intensity of rainfall which exceeds the infiltration capacity once the detention and interception requirements are met. When surface depressions are filled, surface water begins to move down the slopes following micro-channels which coalesce with others growing larger and larger until the water reaches the main channels. In major runoff events, of interest in design and flood forecasting, overland flow is the most important element in the formation of the flood hydrograph. For many small and moderate storms overland flow may be quite small, since overland flow over a permeable soil can only occur when the rainfall rate exceeds the infiltration capacity. For such storms, overland flow may occur only from relatively impermeable surfaces within the watershed. Usually, the total impervious area is a small percentage of the basin area. Hence, significant amounts of overland flow occur only as a result of high-intensity rainfalls.

Runoff is called interflow if it, after infiltrating into the soil, moves laterally through the upper soil layers until it is intercepted by a stream channel. This water does not percolate down to the groundwater table and become part of the typical groundwater flow system. The proportion of total runoff which occurs as interflow depends on the geology of the basin. A porous surface soil cover underlain by a relatively impervious strata a short distance below the soil surface favours substantial quantities of interflow, whereas a uniform permeable soil encourages downward percolation to the groundwater table. Interflow is probably more significant in storms of moderate intensity, while overland flows is more associated with high-intensity storms.

In the Wilson Creek Watershed, the unconsolidated glacial deposits in which interflow occurs is underlain by shale bedrock formations. The movement of water through the shale fractures that occurs during a storm is referred to as spring flow. In many locations along the shale slopes and stream channels numerous springs occur, which flow freely when heavy rainfall occurs in the watershed. It is assumed that fractures in the shale form interceptors to the vertical and lateral movement within the underlying rock and thus feed the springs. Spring flow is distinguished from groundwater flow proper in that it moves independently of the groundwater table.

The precipitation that infiltrates the soil surface and percolates downward until it reaches the groundwater table may eventually discharge into the stream as base flow, if the water table intersects the stream channel of the basin. The groundwater contribution to the streamflow can increase over several orders of magnitude in a short time. Nevertheless, the maximum contribution to the flow is minor when we deal with major runoff events.

The final component of streamflow is the precipitation that falls directly on the water surface of lakes and streams. This component of streamflow is known as channel precipitation.

2.4 REPRESENTATION OF HYDROLOGIC PROCESSES BY A SERIES OF STORAGE RESERVOIRS

When precipitation falls on a watershed, the water on its way to the stream is temporarily stored either above or below ground and then released. Each area or material the water passes through thus acts as a storage reservoir which retains some of the water for awhile and then releases it partly or entirely to a lower reservoir. The entire watershed can thus be thought of as a series of reservoirs stacked one above the other as shown on Figure 2.

The first reservoir is formed by the vegetative cover. The vegetative cover provides interception storage. Once the interception storage capacity has been reached, the water, minus any evaporation, is passed on to the soil surface.

The soil surface acts as the second reservoir; it will be called the surface reservoir. This reservoir is filled by the water released from the interception storage. The surface reservoir allows part of its storage to be released as overland flow and part to infiltrate into the soil zone below. For overland flow to occur, the flow from the interception storage must exceed the infiltration rate of the soil surface and the depression storage capacity of the soil surface must be satisfied.

Immediately below the surface reservoir is the field reservoir. The field reservoir represents the soil moisture held in the surface deposits. Infiltration from the soil surface acts as input to the field reservoir. The amount of infiltrated water stored in the field reservoir depends on the soil moisture deficit. This is by definition the field capacity (the moisture that cannot drain by gravity from an initially saturated soil) minus the soil moisture content. Once the field capacity of the soil is reached the field reservoir allows part of its storage to be depleted by interflow and part to percolate into the soil layer below. Storage in the field reservoir is also depleted by evapotranspiration.

The fractured shale formations in the Wilson Creek Watershed are represented by a fourth reservoir; it will be called the spring reservoir. The spring reservoir allows part of its storage to be released as spring flow and part to deep percolation.

The groundwater reservoir is the lowest reservoir in the stacked system. This reservoir receives deep percolation water from the spring reservoir. Water stored in the groundwater reservoir is released as base flow to the stream channel and deep percolation to the lower zone as a system loss. The losses take into account the groundwater flow both vertically downward and flow below the Wilson Creek Weir. The groundwater reservoir represents the long term groundwater storage of the complete watershed and is released very slowly.

2.5 LINEAR RESERVOIRS

The rate of outflow from each of the reservoirs discussed in section 2.4 towards the stream channel and the lower lying reservoir is dependent on the amount of water stored in the reservoir. The actual relationship is very complex however, in this study it was assumed that the storage-outflow relationship is linear, so that the storage is directly proportional to the outflow:

$$S(t) = KO(t)$$

The constant K has the dimension of time. It is a measure of the delay imposed by the reservoir on the hydrograph. If the above relationship is combined with the storage equation

$$I(t) - O(t) = \frac{d}{dt} S(t)$$

one gets:

$$I(t) - O(t) = \frac{Kd}{dt} O(t)$$

which can be written in operational form as

$$(1 + KD)\ O(t) = I(t)$$

where D is the differential operator. This equation has the solution

$$O(t)e^{t/K} = \frac{1}{K} \int I(t)e^{t/K}\, dt + \text{constant} \quad \ldots\ldots\ldots\ldots \quad (1)$$

For any given inflow this equation can be solved either analytically or numerically. The case where the inflow into the reservoir has ceased equation (1) can be solved by simple integration. Assuming the limits $I = o$ and $O = S/K$ at $t = o$ equation (1) becomes

$$O = \frac{S}{K} e^{-t/K} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Thus the response of a linear reservoir to the termination of inflow is an exponential decay function. A similar equation may be derived for two linear reservoirs placed in series.

For two unequal linear reservoirs, the outflow from the first reservoir is expressed by equation (2). In routing the flow, this outflow is considered as the inflow to the second reservoir. Using equation (2) as the input function and with τ being the variable, the integral of

$$0(\tau) = \int_0^t u(t-\tau)\ I(\tau)d\tau$$

gives the outflow from the second reservoir as

$$0 = \int_0^t \frac{Se^{-\tau/K1}}{K1} \frac{e^{-(t-\tau)/K2}}{K2} d\tau$$

$$= S\left(\frac{e^{-t/K1}}{K2 - K1} + \frac{e^{-t/K2}}{K1 - K2}\right)$$

Thus the outflow from the second reservoir is a combination exponential decay function.

2.6 ASSUMPTIONS

To simplify the conceptional model as much as possible in compliance with the aim of the study, the following assumptions were made:

a) As the moisture content of the atmosphere is at, or near, saturation during the rainfall period, evaporation and evapotranspiration takes place at a very limited rate and was therefore neglected.

b) As the interception storage capacity of the vegetative cover, estimated to be less than 0.10 inches, is considered to be negligible in the overall water balance of high-intensity rainfalls, interception losses were neglected.

c) Direct runoff produced by rainfall on impervious portions of the basin directly connected to, or adjacent to the channel system, were neglected. It is estimated that less than two percent of the rainfall occurs directly on the channel or is translated directly to the channel. This component of runoff normally occurs prior to the peak discharge and does not contribute significantly to the volume of runoff.

d) The component of base flow was assumed to remain constant through the storm event. Base flow represents the long term storage of the complete watershed and does not fluctuate rapidly.

e) Direct runoff was taken as the sum of overland flow and interflow. The distinction between overland flow and interflow is to some extent arbitrary in any case. Water may start out as overland flow, infiltrate into the soil surface and then complete its trip to the stream as overland flow. Therefore, the total flow in Wilson Creek was assumed to be comprised of three components: 1) direct runoff from the surface deposits of glacial till; 2) spring flow from the subsurface shale bedrock fractures; and 3) base flow from the groundwater system.

CHAPTER III

HYDROGRAPHS STUDIED

3.1 HYDROMETEOROLOGICAL DATA

Precipitation and streamflow records, as well as records of numerous other hydrometeorological data, have been kept for the Wilson Creek Experimental Watershed since 1959. A large amount of data is thus available for analysis. For this study five rainfall events that produced relatively large volumes of runoff were selected for development of the Model.

3.1.1 Precipitation

The areal average of the hourly precipitation was calculated for each storm by means of the Thiessen polygon method using the data of eight recording rain gauges. In this method rainfall at each point of the basin is taken as the rainfall in the nearest rain gauge. Areas nearest to a particular gauge form polygons that are fixed by the geometry of the rain gauge network and the drainage basin. To determine the mean rainfall, each rain gauge observation is multiplied by a coefficient determined as the area of the particular polygon divided by the total area. This procedure was convenient for the storms used in this study since the network is fixed. The calculated mean hourly precipitation multiplied by the drainage area of the watershed represents the volume of the inflow to the Model.

3.1.2 Soil Moisture

The antecedent soil moisture content prior to each storm was estimated from the soil moisture surveys taken weekly in the summer at seven points in the Watershed. A one-inch tube sampler is used to take a soil sample at increments of six inches to a depth of three feet. An experienced operator estimates the moisture content of each sample by touch, which is then recorded. The difference in water content of the soil between the field capacity and the permanent wilting point is about three inches per foot of soil (5). The permanent wilting point is that soil water content at which the soil cannot supply water at a sufficient rate to maintain turgor, and the plant permanently wilts.

The soil moisture estimates have been useful in determining the depth of storm rainfall necessary to produce a significant runoff. Although the method does not provide accurate values of soil moisture content, it has given reliable estimates and helped to explain why some heavy rainstorms have produced relatively little runoff. For example, the 40-hour storm of August 5 to 7, 1966, produced 4.6 inches of rainfall, a maximum hourly intensity of 1.4 inches, and a peak flow of 120 cubic feet per second at the Wilson Creek Weir. By contrast, the 48-hour storm of June 25 to 27, 1969, which produced 4.9 inches of rainfall, a maximum hourly intensity of 0.7 inches, gave a peak flow of 700 cubic feet per second. Although the precipitation of the two storms was similar, there was a great difference in the runoff, presumably because of the moisture content of the soil before the storms. Soil moisture tests before the storms indicated that the soil could absorb more than two inches in the 1966 storm and only 0.75 of an inch in the 1969 storm (5).

3.1.3 Streamflow

Streamflow from the 5400.7 acre Wilson Creek Experimental Watershed is measured at the Wilson Creek Weir. In 1960 Bald Hill and Ridge

Dams were constructed on the headwaters of Wilson Creek. As a result, outflow from 716.2 acres of the Watershed is controlled by the dams. The model developed in this study simulates runoff from the portion of the Watershed which excludes the drainage area of the dams. The recorded outflow from the dams was, however, added to the simulated streamflow hydrographs before being compared with the recorded discharge at the Wilson Creek Weir.

3.2 STORM EVENTS

Five rainfall events with peak discharges ranging from 300 cfs to 1580 cfs were selected for the development of the Model. The five events were selected because of their significant volumes of runoff and availability of soil moisture data, which allowed an estimate of soil moisture conditions prior to the storms. The storms which represent five out of the six largest discharges recorded in the Wilson Creek Experimental Watershed since its inception in 1959, reflect a range of antecedent soil moisture conditions and rainfall intensities and durations. A description of the five storms is as follows:

Event 69-6-1:

From June 25th to 27th, 1969, during a 48-hour period, an average of 4.93 inches of rain fell on the Wilson Creek Watershed. The average maximum hourly rainfall intensity of the storm over the Watershed was 0.41 inches. Prior to the storm, the soil moisture deficit of the Watershed was estimated to be 0.76 inches. At the Wilson Creek Weir a maximum instantaneous discharge of 700 cfs was recorded. A day later at 2100 cst on June 28th an additional 1.51 inches of rain fell during the ensuring 25.5 hours. A secondary peak discharge of 311 cfs was recorded at the Wilson

Creek Weir. The average maximum hourly rainfall intensity of the second storm was 0.16 inches. In this study both storm events have been combined to determine the Model's response to a sequence of rainfall events.

Event 74-5-1:

On May 11th, 1974, an instantaneous peak discharge of 298 cfs was recorded at the Wilson Creek Weir. This was the result of a 22.25 hour rainstorm in which an average of 2.42 inches of rain fell on the Watershed. The soil moisture conditions of the Watershed were at field capacity prior to the storm. The average maximum hourly rainfall intensity of the storm was 0.16 inches.

Event 75-8-2:

From August 23rd to 25th, 1975, during a 53-hour period, an average of 3.06 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.57 inches. At the Wilson Creek Weir a maximum instantaneous discharge of 330 cfs was recorded. The soil moisture deficit prior to the storm was estimated to be 0.76 inches.

Event 75-9-1:

The largest storm ever recorded in Manitoba began over the Wilson Creek Watershed on September 19th, 1975 at 3:30 p.m. During the next 59.5 hours, an average of 9.86 inches of rain fell on the Watershed. The average maximum hourly rainfall intensity of the storm was 0.74 inches. At the Wilson Creek Weir, a maximum instantaneous discharge of 1580 cfs was recorded. This is the largest discharge ever recorded on Wilson Creek. The soil moisture deficit prior to the storm was estimated to be 0.35 inches.

Event 77-7-1:

During a 21.5 hour period from July 10th to 11th, 1977, an average of 5.39 inches of rain fell on the Watershed. The maximum hourly rainfall intensity of the storm was 0.96 inches. A maximum discharge of 540 cfs was recorded at the Wilson Creek Weir. The soil moisture deficit prior to the storm was estimated to be 1.10 inches.

The five storms have been summarized in Table 1 for comparison purposes.

TABLE 1

SUMMARY OF STORM EVENTS

Storm Event	Duration of Rainfall in Hours	Average Rainfall In Inches	Maximum Hourly Rainfall Inches/Hour	Initial Soil Moisture Deficit in Inches	Maximum Instantaneous Discharge in cfs
69-6-1(a)	48	4.93	0.41	0.76	700
69-6-1(b)	25.5	1.51	0.16	0.00	311
74-5-1	22.25	2.42	0.16	0.00	298
75-8-2	53	3.06	0.57	0.76	330
75-9-1	59.5	9.86	0.74	0.35	1580
77-7-1	21.5	5.39	0.96	1.10	540

CHAPTER IV

MODEL DEVELOPMENT

4.1 CRITERIA OF GOODNESS-OF-FIT

In the sequential development of the mathematical model, the agreement between simulated and observed streamflow hydrographs was checked by means of an objective function. This function, which is to be minimized, measures the goodness-of-fit. Many such objective functions are possible. For the purpose of this study, the two most important components of the streamflow hydrograph are the peak discharge and the runoff volume. An objective function was developed that measures the deviation between the simulated and recorded peak discharge and volume using the Principle of Least Squares. This Principle can be stated as follows: The most probable value of a quantity is obtained from a set of measurements by choosing the value which minimizes the sum of squares of the deviation of these measurements. The resultant objective function which is minimized is as follows:

$$F(x) = \sum_{i=1}^{N} \left(\frac{(PSi-PRi)}{PRi} \times 100 \right)^2 + \sum_{i=1}^{N} \left(\frac{(VSi-VRi)}{VRi} \times 100 \right)^2$$

Where:

PRi - is the recorded maximum hourly discharge in cfs;

PSi - is the simulated maximum hourly discharge in cfs;

VRi - is the volume of the recorded streamflow hydrograph in cfs-hours;

VSi - is the volume of the simulated streamflow hydrograph in cfs-hours; and

N - is the total number of storms analyzed.

4.2 OPTIMIZATION PROCEDURE

A systematic search for the optimal value of the storage constants of the linear reservoirs was incorporated in the model. The Direct Pattern Search was employed to optimize the model reservoir constants so as to minimize the objective function. The Pattern Search does not rely on the evaluation of partial derivates but adjusts the parameters stepwise to successively improve trial solutions. The Pattern Search method was introduced by R. Hooke and T.A. Jeeves in 1961. A detailed description of the method is contained in Appendix A.

4.3 MODEL DEVELOPMENT

This section discusses the sequential development of the hourly streamflow simulation model. A model incorporating only a single linear reservoir representing the hydrograph component direct runoff was examined first, as the study's objective was to develop the simplest model possible. However, the results discussed below indicated that at least two linear reservoirs stacked one above the other and representing the hydrograph components direct runoff and spring flow would be needed.

4.3.1 The Single Reservoir Model

In the single linear reservoir model only direct runoff from the surface deposits of glacial till represented by the field reservoir is simulated. The simplest model is one in which direct runoff begins once the field capacity of the field reservoir is reached. The initial soil moisture content of the field reservoir prior to each storm was estimated by the soil moisture deficit readings (field capacity minus the soil moisture deficit). The soil moisture deficit readings allows for an approximation of conditions in the Watershed prior to the storm. This simplistic model referred to as Model A may be represented mathematically as:

$$\text{When} \quad S_t \leq FC \qquad D_t = 0$$

$$\text{When} \quad S_t > FC \qquad D_t = (S_t - FC)AREA/KD$$

Where:

S_t - is the storage volume of the field reservoir in inches at time period t;

D_t - is the direct runoff in cfs at time period t;

FC - is the field capacity of the field reservoir in inches;

KD - is the storage constant of the field reservoir in hours which relates the volume of storage to the direct runoff; and

AREA - is the drainage area in acres of the Wilson Creek Experimental Watershed, excluding Baldhill and Ridge Dams.

These equations were combined with the storage equation, shown on page 10, to mathematically represent the movement of water through the entire Watershed. For the five storms described in section 3.2, the optimal storage constant KD, for Model A, based on minimization of the objective function was determined to be 69.94 hours. The minimum value of the objective function was 21,849. The hourly streamflow hydrographs simulated by Model A are shown on Figures B-1 to B-5, Appendix B.

The peak discharge simulated by Model A was significantly underestimated in all five storms and the rising and recession limbs of the