Unit hydrographs developed for selected drainage basins in northcentral and northwestern Montana
by Ola Kaarstad

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Civil Engineering
Montana State University

Abstract:
Unit hydrographs for 12 watersheds in northcentral and northwestern Montana were derived.

The data used were obtained from the June 1964 rainstorm and following floods.

A computer program was used to derive the unit hydrograph of "best fit" using a unit time of 1 hour for 8 and a unit time of 20 min. for 4 of the watersheds. For convenience of manipulating the shape of the unit hydrographs to obtain a "best fit", the equation defining the instantaneous unit hydrograph was used in the program.

The results were divided into 3 groups based upon the "goodness of fit" to peaks and magnitudes of peaks between the computed and the actual complex hydrographs, and upon overall goodness of fit.

The results were: Group 1; Excellent results.

Waterton River near Waterton Park, Alberta Sullivan Creek near Hungry Horse South Fork Flathead River near Hungry Horse Sun River at Gibson Reservoir near Augusta Group 2; Good results. . - South Fork Milk River near Babb South Fork Milk River at Del Bonita Cut Bank Creek at Cut Bank Dearborn River near Craig Lone Man Coulee near Valier Group 3; Poor results.

Waterton River near International Boundary Badger Creek near Browning South Fork Judith River near Utica The unit hydrographs obtained were compared with unit hydrographs derived from 3 synthetic unit hydrograph formulas developed by other geographic areas. Snyder's formulas appeared to give the best results, although as might be expected, none of the 3 gave good agreement.

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List of Contents

List of Tables

List of Figures

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CHAPTER I

INTRODUCTION

The prediction of flood peaks and flood hydrographs is important in many areas of water resource and hydraulic engineering practice. If the maximum flood which may occur during a particular period of time can be accurately estimated, levees can be built to required elevation, rip-rap of adequate size can be laid out, dam spillways can be adequately designed, bridge openings and piers can be designed properly and culverts of adequate but economical size can be chosen.

In most geographic areas rain is probably the most important flood producing factor, especially for smaller watersheds, 1000 sq. mi. or less. It is therefore of great value to be able to predict the flood-flow which will be caused by a certain volume of rain distributed in time in a certain way.

There are several methods available for flood prediction. Some are for rain only, while others are for floods produced from snowmelt alone or in combination with rain. The following is a listing of the most commonly used methods for flood prediction today.

1. Frequency analysis (flood peaks)
   a) Annual floods
   b) Partial duration series or floods above a base

2. Comparisons of historical floods in a drainage area basin with maximum flood experience in the immediate area as well as in other areas
   a) Envelope curves (Creager equation)
   b) Maximum flood equations (Meyer formula)

3. Unit hydrograph approach
   a) Empirically derived

b) Synthetically derived
c) Digital similation (Stanford Watershed Model(1))

Of the above mentioned methods the unit hydrograph approach is most used. In this method the characteristics of the watershed are expressed in the shape of the unit hydrograph, which represents the time distribution of the surface runoff produced by a storm of short duration. These characteristics are those that affect overland flow, since the definition of the unit hydrograph includes only overland flow. In order to apply a unit hydrograph to a given rain, however, it is also necessary to know the magnitude of the "losses" of rain on a watershed, such as infiltration, wetting and detention storage, so excess rain can be estimated closely.

There appear to have been few if any, unit hydrographs derived for any Montana drainage areas. The objective of this study is to derive some unit hydrographs for selected drainage areas in Montana. In order to do so the author searched records of isolated rainstorms with corresponding runoff data. No suitable storms of this kind were found. In the search for data the extensive rainstorm of June 1964 appeared to be one that had sufficient rainfall and runoff data. Although the 1964 storm was not the kind preferred for the derivation of unit hydrographs, it was decided to use it as a basis for an attempt to derive some unit hydrographs for the area of Montana covered by this storm. Because of the complexity of the storm a trial and error procedure was necessary, and the instantaneous unit hydrograph method was decided upon, modified so as to use rainfall of 20 minutes or 1 hour's length as unit time instead of instantaneous rainfall. Unit hydrographs have been derived for 12 drainage areas. The unit hydrographs derived are compared with synthetic unit hydrographs derived for the same drainage areas by the formulas of Snyder, Soil Conservation Service and Gray.

CHAPTER II

UNIT HYDROGRAPH DEVELOPMENT

Although Folse (2) as early as 1929 started to work with separation of base flow and overland flow, rain loss due to variable infiltration, depression storage and wetting, and also derived physical constants which in effect were the successive ordinates for a 24 hour unit hydrograph, it is Sherman's name that is connected to the development of the unit hydrograph theory.

Sherman (3) proposed his theory of the unit graph in 1932, defined as the hydrograph resulting from 1 inch of excess rain occurring during a unit time period (of 1 day, 12 hours, 6 hours, ...) and evenly distributed over the drainage basin. Definitions in connection with rainfall and runoff are given below.

1. Excess rainfall is defined as that rain in excess of wetting the ground and the plants, evaporation, depression storage and infiltration, which reaches the streams as overland flow or surface runoff.

2. Excess rainfall rate is defined as excess rainfall in inches per hour.

3. Surface or overland runoff is defined as that part of stream flow which reached the stream channel over the surface of the land.

4. Interflow is defined as water flowing between the surface and the groundwatertable toward the streams.

5. Baseflow is defined as water flowing to the streams from the groundwater.

Sherman defined his well-known theory of unit hydrograph for surface runoff only.

When the unit hydrograph for one unit time is known, a flood resulting from a complex rainstorm can be computed.

Some basic assumptions are associated with the unit hydrograph idea, Chow (4).

1. The excess rainfall is uniformly distributed within its duration.

2. The excess rainfall is uniformly distributed throughout the whole area of the drainage basin.

3. The base time or duration of hydrograph of direct runoff due to excess rainfall of unit duration is constant.

4. The ordinates of the excess runoff hydrograph of a common base time are directly proportional to the total amount of direct runoff.

5. For a given drainage basin the hydrograph of runoff due to a given period of rainfall reflects all the combined physical characteristics of the basin.

Regarding assumption 1. it is well-known that rainfall is more likely to have a nonuniform than a uniform distribution, Bernard (5). For large drainage basins in particular the rainfall distribution over the area is usually not uniform. Regarding assumption 5. the physical characteristics will change with season and man-made adjustments. From the above comments about the basic assumptions, it will be seen that they probably never can be met perfectly under natural conditions. However, by careful selection of data so as to meet the assumptions closely, the results although subject to a certain degree of error, are acceptable for engineering purposes.

Unit Hydrograph Analysis

For the derivation of the unit hydrograph it is necessary to have a recorded flood hydrograph and a record of the associated hourly recorded rainfall. Chow (4) points out that care should be taken to make sure that the above mentioned assumptions, especially 1. (uniform excess rainfall distribution throughout the unit time period) and 2. (uniform excess rainfall distribution over the drainage area) are met as closely as possible, and states:

> A hydrograph resulting from an isolated, intense, short duration storm of nearly uniform distribution in space and time is the most desireable. If such single peaked, well-defined hydrographs are not available, it is necessary to derive the unit hydrograph from a complex storm.

Bernard (5) states that the runoff following the storm must have been uninterrupted by low temperatures, ice and snowmelt.

Linsley et al. (6) states that a unit hydrograph is best derived from the hydrograph of a storm of reasonable uniform intensity and with a runoff volume close to an inch or above.

The derivation of a unit hydrograph from a single simple storm is quite straightforward. After the base flow and the interflow are separated, leaving a surface runoff hydrograph, the amount of surface runoff is represented by the area under the resulting surface runoff hydrograph. If each ordinate is divided by the total amount of surface runoff, the resulting hydrograph represents a one-inch volume of runoff. If possible the unit hydrograph should be computed from several storms and an average unit hydrograph derived.

If a complex storm must be used, the method of Collins (7) can be used. It includes 4 steps: 1. assume a unit hydrograph and apply it to all excess rainfall blocks except the largest; 2. subtract the resulting hydrograph from the actual hydrograph, and reduce the residual to unit hydrograph terms; 3. compute a weighted average of the assumed unit hydrograph and the residual unit hydrograph, and use it as the revised approximation for the next trial; 4. repeat the previous 3 steps until the residual unit hydrograph does not differ by more than a permissible amount from the assumed hydrograph.

A concept nearly associated with the unit hydrograph theory is the S-hydrograph, Morgan and Hullinghorse (8). The S-hydrograph is defined as the direct runoff from a continuous uniform excess rain during a long period of time. From a S-hydrograph the unit hydrograph of an excess rain of any unit time can be derived. Fig. 1 shows how the S-hydrograph is formed and how to derive a unit hydrograph from it. The procedure is to construct the S-hydrograph from an assumed uniform continuous rainfall, then offset the S-hydrograph for the desired duration of excess rain t_0. By taking the differences between the original and the offset S-hydrographs, and dividing the differences by rainfall rate times t_0, the desired unit hydrograph is obtained.

Instantaneous Unit Hydrograph

When the duration of excess rainfall becomes infinitesimally small, the resulting unit hydrograph is called the instantaneous unit hydrograph, Chow (4).

Several investigators have proposed models that with or without their knowledge build upon the principles of the instantaneous unit hydrograph. A committee report by the Boston Society of Civil Engineers in 1930 (9), indicated that an instantaneous storm could give information about the watershed characteristics. Clark (10) connected this idea to the unit hydrograph idea in 1945 for the first time.

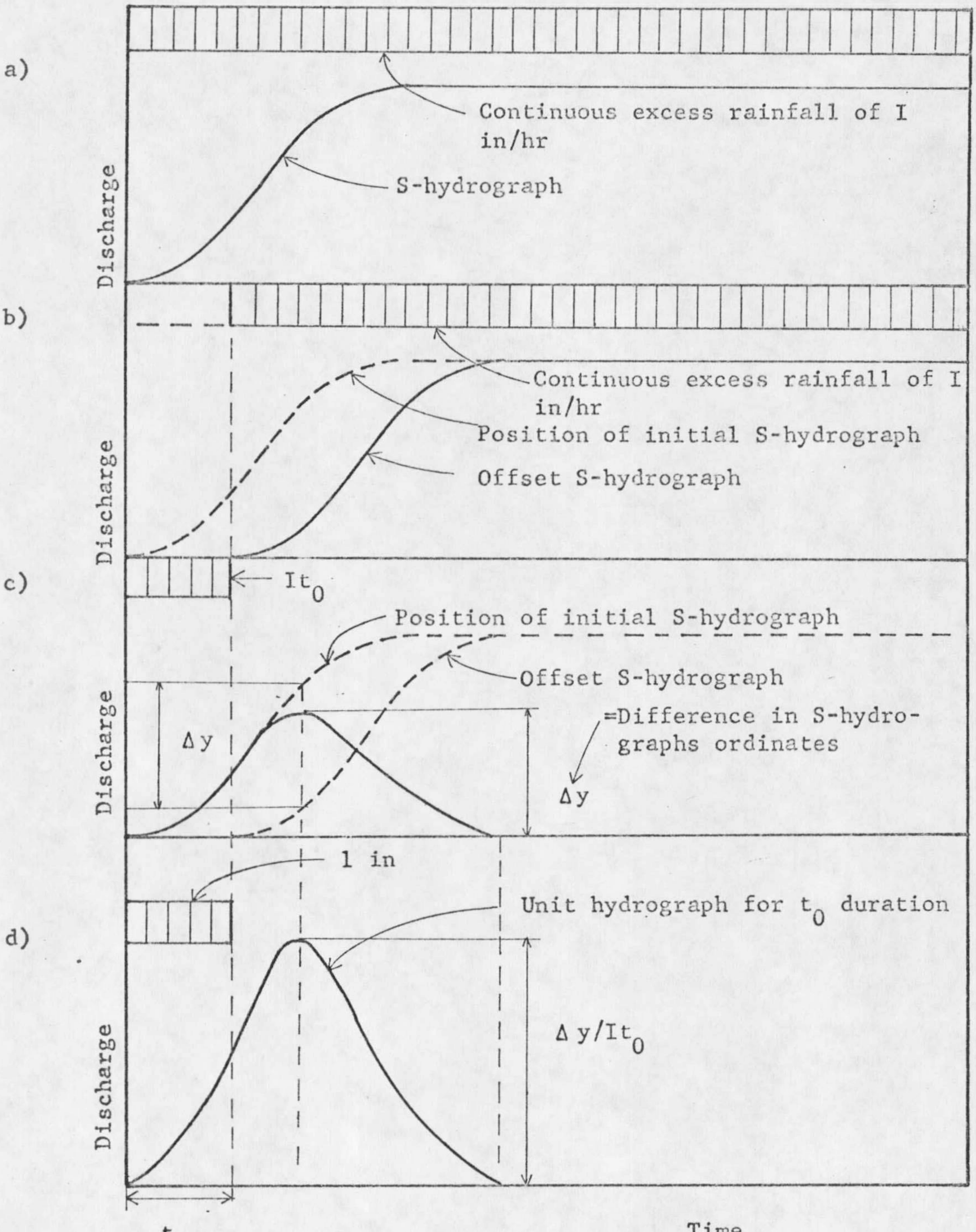

FIGURE 1. - Derivation of a unit hydrograph of desired length of excess rain duration from a S-hydrograph.