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# APPLIED HYDROLOGY

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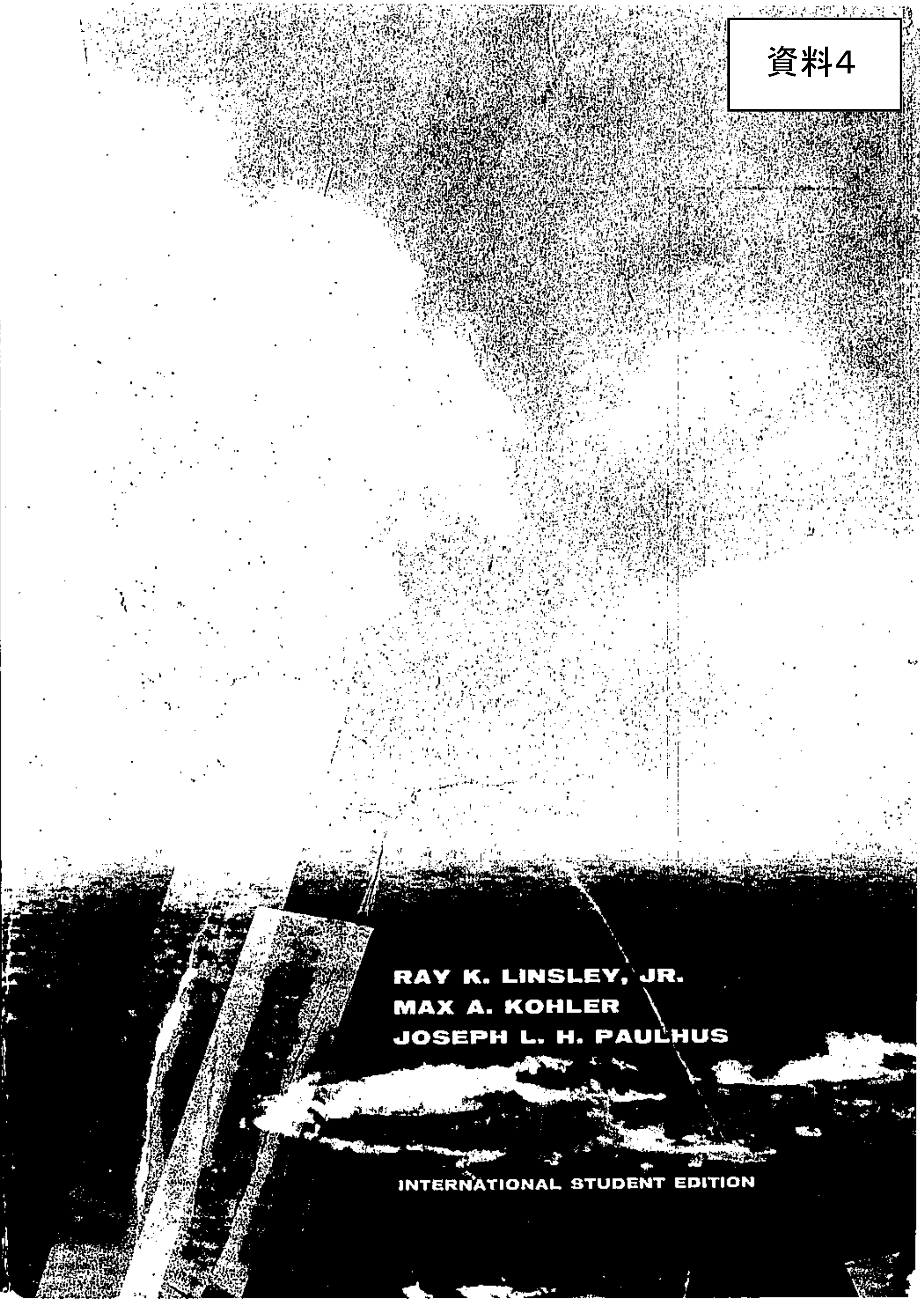

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# APPLIED HYDROLOGY

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McGRAW-HILL BOOK COMPANY, INC.
New York Toronto London
KŌGAKUSHA COMPANY, LTD.
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TOSHO INSATSU
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TOKYO, JAPAN

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# PREFACE

There is abundant evidence that some principles of hydrology were known and applied at the dawn of history. Modern hydrology, however, is a product of the current century. In fact, the bulk of current theory and practice stems from the great expansion in flood-control and reclamation programs since 1935. During this period the useful application of hydrology has been demonstrated in many fields, such as highway and airport drainage, small water-supply projects, storm-sewer design, and others.

As a result of the rapid growth in activities within the field of hydrology during recent years, many technical papers have been written for scientific periodicals, and numerous special bulletins have been issued by several agencies. These numerous papers on a subject which is still young, as applied sciences go, display considerable lack of standardization of terminology, nomenclature, and techniques. Persons not engaged in the full-time practice of hydrology often find it difficult to orient themselves in the field.

This book is designed to meet the demand for a convenient text reference for general data, basic theory, and methods of application. The emphasis throughout has been on the presentation of methods for practical application of hydrology and on data which present the means and ranges of variation of the key elements in hydrology. Basic data are limited to the continental United States except in so far as foreign data have been judged pertinent to the practice of hydrology in this country. Techniques and problems discussed are those which are characteristic of hydrology in the United States. It is the hope of the authors that this book will prove useful as a text to the student in the field and a valuable reference and guide to those engineers who devote all or part of their professional efforts to hydrologic problems. No claim is made that it presents a complete coverage of the field. Much basic theory readily available from other sources has not been included, in the interest of conserving space. Many highly specialized and unusual applications of hydrology have been omitted in favor of detailed presentation of the more generally applicable techniques. It is believed, however, that ample references have been supplied for those who wish to carry their study beyond the scope of this book.

Every effort has been made to adopt a standardized terminology and nomenclature and to present well-established procedures. To this end the from storm to storm, depending on the flow at the point of rise. As an alternate, line *AB* is drawn from the point of rise to an intersection with the recession *N* days after the crest. The time base can thus be limited to a reasonable length and will not vary beyond the variation in duration of rise. If the *initial flow*, the discharge at the beginning of rise, is high because of a previous storm, neither of these two methods gives results which are particularly realistic. The line *ACB* has been generally adopted as a plausible, if arbitrary, mode of separation. The line *AC* represents an extension of the recession existing prior to the storm to a point under the peak of the hydrograph. From this point a straight line *CB* connects with the hydrograph at a point *N* days after the crest or after the end of runoff-producing rain. Values of *N* vary with slope and drainage area. Approximate values of *N* for various drainage areas are listed in Table 15-2. While variations in slope and other factors will result in deviations from these values, the selection of *N* is not particularly critical in most studies. In mountainous areas, values of *N* shown in the table should be slightly reduced, while, for long, narrow basins or basins on flat slopes, values of *N* may be increased as much as 50 per cent.

TABLE 15-2. Values of *N* for Various Drainage Areas (non America)

| Drainage Area, Square Miles | *N*, Days |
|---|---|
| 100 | 2 |
| 500 | 3 |
| 2000 | 4 |
| 5000 | 5 |
| 10000 | 6 |

**Analytical separation into two components.** A groundwater depletion curve can be constructed for a basin by any of the methods discussed earlier in this chapter. It should be prepared by use of data selected from periods sufficiently long after any rain to justify the assumption that they represent groundwater flow exclusively. Beginning after a storm, when the recession is known to represent only groundwater flow, and computing successively earlier ordinates from the groundwater depletion, it will be found that the groundwater recession eventually falls below the observed recession. The point of departure (Fig. 15-8) may be taken as the end of direct runoff, and the depletion curve, extended back from this point, represents the recession of the groundwater hydrograph. The time of groundwater peak and the shape of the rising limb must be selected arbitrarily. A prepared template is useful in making this type of separation.

A modification[1] of the foregoing procedure is useful in separating the

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[1] Linsley, R. K., and W. C. Ackermann, A Method of Predicting the Runoff from Rainfall, *Trans. ASCE*, Vol. 107, pp. 825-835, 1942.

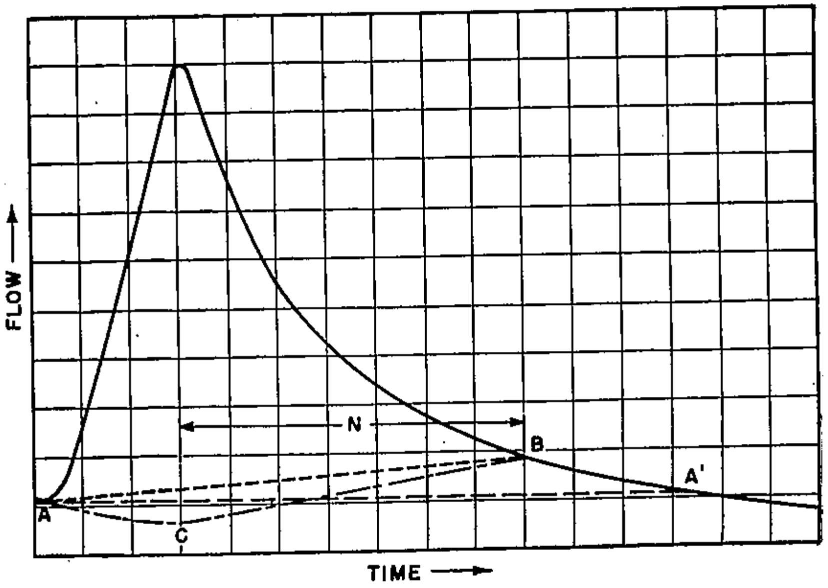


FIG. 15–7. Arbitrary methods for hydrograph separation.

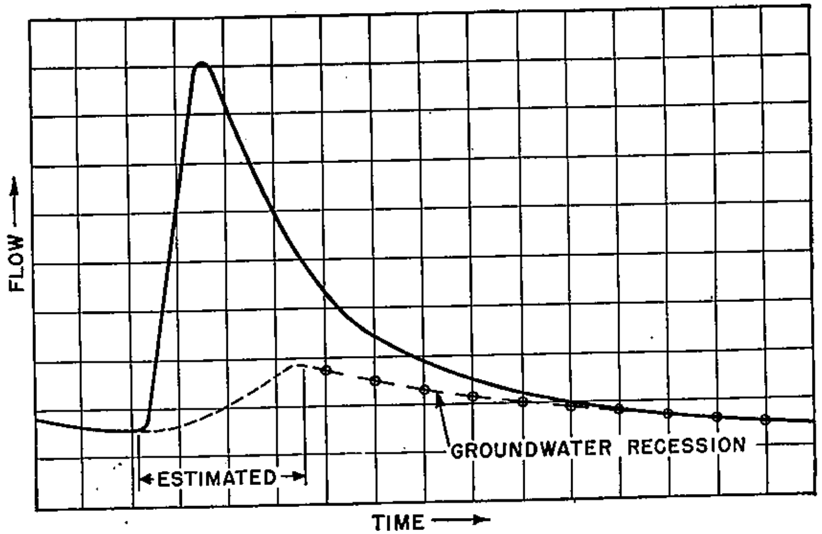


FIG. 15–8. Use of groundwater depletion for simple hydrograph separation.

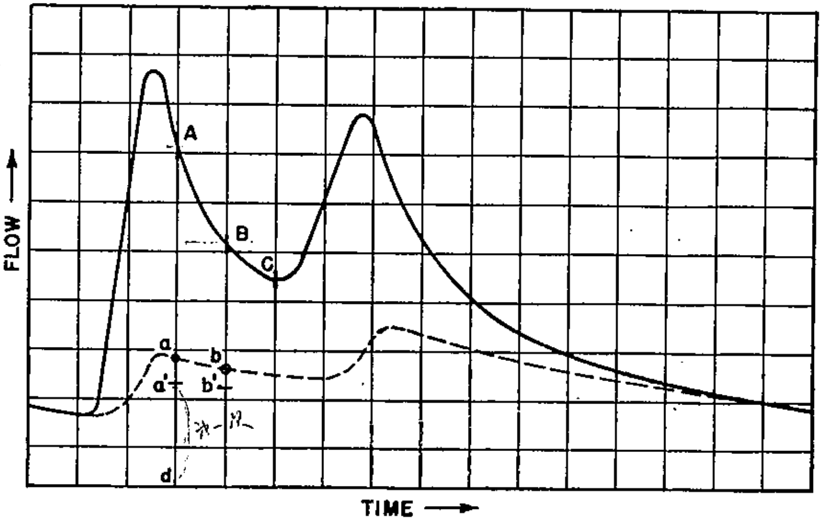


FIG. 15-9. Analysis of a complex hydrograph.

runoff from complex storms. Figure 15-9 shows two storms so close together that direct runoff does not end between the storms. The groundwater recession cannot be extended to a time earlier than the peak of the second storm. A depletion curve for direct runoff is therefore required; such a curve can be constructed by using ordinates between the groundwater recession and the total hydrograph for several storms. Both the direct-runoff and groundwater depletion curves are then replotted to show the change in discharge per unit time as a function of initial discharge (Fig. 15-10). A point on the groundwater hydrograph beneath the recession *AB* (Fig. 15-9) may be located as follows:

1. Determine the change in discharge *AB* (in unit time), and read a first estimate of direct runoff corresponding to this rate of change from Fig. 15-10.

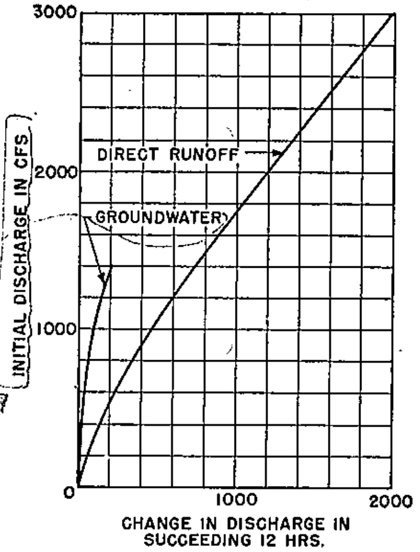
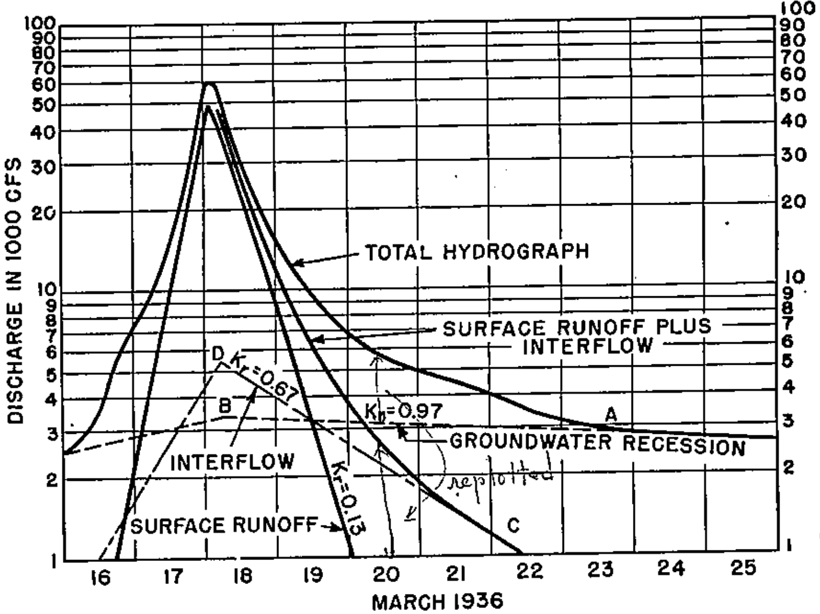


FIG. 15-10. Rate of change in flow curves for Valley River at Tomotla, North Carolina.

2. Subtract the estimated direct runoff *Aa'* from the total ordinate *Ad*. The balance *a'd* is a first approximation to the groundwater ordinate.
3. Determine the change in discharge corresponding to a groundwater flow *a'd* from Fig. 15-10, and subtract this from the total change *AB*. The remainder is essentially the change in discharge for direct runoff and may be used to determine a new value of initial direct runoff *Aa*. The ordinate *ad* represents groundwater flow.



$q_t = q_0 k_r^t$

FIG. 15-11. Separation of hydrograph components using semilogarithmic plotting for Stony Creek at Johnstown, Pennsylvania.

Following the procedure outlined above, a segment of the groundwater hydrograph underneath the recession of the first storm may be determined. The balance of the groundwater hydrograph must be sketched arbitrarily. The direct-runoff recession of the first flood event can be extended under the second rise by use of the direct-runoff depletion.

**Analytical separation into three components.** For research studies in which it is desired to approximate the distribution of flow from each hydrograph component, an analytical procedure devised by Barnes[1] may be adopted. The procedure is displayed in Fig. 15-11, where the storm hydrograph has been plotted on semilogarithmic paper. The groundwater reces-

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[1] Barnes, B. S., Structure of Discharge Recession Curves, *Trans. Am. Geophys. Union*, Vol. 20, pp. 721-725, 1939.

sion *AB* can be approximated by a straight line and, as such, can be extended back under the hydrograph. The residual ordinates above the groundwater hydrograph represent the combined surface runoff and interflow. This combined hydrograph is replotted and a straight line fitted to the interflow recession *CD*. This recession can now be extended as a straight line to separate interflow from surface runoff. The rising limb of the groundwater and interflow graphs must be estimated as in all other procedures. In all logarithmic plottings, considerable care must be exercised to avoid large errors developing in the very condensed scales at high flows.

# 16

# RUNOFF RELATIONS

In most hydrologic studies concerned with design, river forecasting, land use, etc., it is necessary to develop relations between precipitation and runoff, possibly using other factors as parameters. Moreover, precipitation records are generally longer than those of discharge and, therefore, precipitation-runoff relations can be used to extrapolate or interpolate discharge records.

Runoff relations may be classified in two ways, (1) according to whether the precipitation is all in the form of rain or whether snow is involved and (2) according to whether the relation deals with individual storms or the total volume of runoff over an extended period of time. The nature of the precipitation is of little significance in considering long-period runoff. Therefore, runoff relations may be segregated into (1) storm-period rainfall-runoff relations; (2) short-period runoff relations involving rain and/or snow; and (3) extended-period precipitation-runoff relations. This chapter treats runoff relations according to this classification. However, before considering the numerous types of relationships, the general aspects of runoff are first discussed in order that the reader may become thoroughly familiar with the interrelations of the relevant hydrologic phenomena.

## THE RUNOFF CYCLE

The *hydrologic cycle* (Chap. 1) is the term applied to the general circulation of water in its various states from the seas to the atmosphere, to the ground, and back to the seas again. The *runoff cycle* is the descriptive term applied to that portion of the hydrologic cycle between incident precipitation over land areas and subsequent discharge through stream channels or direct return to the atmosphere through evapo-transpiration.

The following discussion of the runoff cycle is similar to that presented by Hoyt.[1] However, instead of considering the cycle to be comprised of five rather arbitrary phases, depending upon the rainfall characteristics, the

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[1] Hoyt, W. G., An Outline of the Runoff Cycle, *School of Engineering, Pennsylvania State College Tech. Bull.* 27, pp. 57-67, 1942.

# 17

# RUNOFF DISTRIBUTION

The previous chapter discussed methods of computing the total volume of runoff associated with a particular combination of storm rainfall and antecedent weather. In certain problems, such as those involving the quantities of water available for power or irrigation storage, this volume estimate may be sufficient. More commonly, however, the estimate of runoff volume is only the first step in the determination of the outflow hydrograph from a basin. This chapter discusses techniques of determining the time distribution of flow from small and moderate drainage areas (generally under 5000 square miles).

**The unit hydrograph.** The discussion of hydrograph shape in Chap. 15 leads naturally to the hypothesis that identical storms with the same antecedent conditions produce identical hydrographs. This principle was expressed by Sherman[1] in introducing his theory of the *unit hydrograph*, or *unit graph*. He pointed out that all hydrographs resulting from rainfalls of a given duration have the same time base. If the rainfall distribution in the storms is similar with respect to time and area, the ordinates of each hydrograph will be proportional to its volume of runoff. The unit graph itself is the graph resulting from 1.00 in. of runoff. If the theory is sound, the hydrograph for any other similar storm of the same duration will be established by multiplying the ordinates of the unit graph by the storm runoff.

The unit hydrograph has proved to be a highly effective and simple tool for hydrologic work. It can readily be agreed that, within the limitations of a fixed duration and similar rate and areal distribution of rainfall, the hydrographs of various storms will be substantially similar in shape with ordinates approximately proportional to the runoff volumes. Obviously, this cannot be rigorously true, for the effect of channel storage varies with stage and the unit graphs of very large floods will necessarily differ somewhat from those for small rises. The unit hydrograph assumes that the time bases of all floods caused by rainfalls of equal duration are the same. A direct-runoff recession curve will show, however, that the time required for flows to recede to some fixed value increases with the initial flow. Since recessions approach zero asymptotically, a practical compromise is possible without excessive error.

[illegible]

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[1] Sherman, L. K., Streamflow from Rainfall by the Unit-graph Method, *Eng. News-Record*, Vol. 108, pp. 501-505, 1932.

There are limitations to the use of unit graphs which must be recognized. Reasonably similar rainfall distribution from storm to storm over very large areas is rare. Hence, unit graphs are best suited to areas under about 2000 square miles, although they have been applied to fairly large areas with varying success. Odd-shaped basins, particularly those which are long and narrow, commonly have very uneven rainfall distribution, and hence unit graphs are not well adapted to such basins. In mountainous areas subject to orographic rainfall, the areal distribution is very uneven, but the pattern tends to remain the same from storm to storm, and unit graphs may be successfully applied.

It is almost impossible to identify typical intensity patterns from storm to storm, and uniform rainfall rates over an extended period of time are uncommon. This is not so serious as it might seem at first, for nature effectively smooths a very uneven raingraph. Much of the variation in rainfall intensity is smoothed out in the course of surface detention during overland flow and further leveled by valley storage in the streams. Hence, short-period variations in rainfall intensity have little effect on the accuracy of the unit-graph method. Relatively long-period variations such as the successive bursts of rainfall accompanying a series of frontal passages must be reckoned with. This can be done by treating each such burst as an individual storm and applying the proper duration unit graph. As used in this paragraph, "short" and "long" are relative terms. On a drainage area of a few square miles, the short bursts of rain from one or more thunderstorms occurring within an hour or less may result in several streamflow peaks and may require the adoption of a time unit measured in minutes. On a basin as large as 2000 square miles, 12 or even 24 hr may be an adequate unit. アメリカで Experience has shown that the time unit should approximate one-fourth the basin lag for practical application.

**Derivation of the unit hydrograph from isolated storms.** The unit graph can be most easily derived from the hydrograph of an isolated storm which meets the general requirements outlined in the previous section. The steps in the derivation are as follows (Fig. 17-1):

1. Separate the groundwater flow, and measure the volume of direct runoff from the storm.
2. Divide the ordinates of direct runoff by the runoff volume (expressed in inches over the drainage area). The resulting hydrograph is a unit graph for the basin.
3. Determine the effective duration of runoff-producing rain for which the unit graph is applicable by a study of the rainfall records.

General storms with runoff in excess of 1 in. are more satisfactory than smaller storms because the reduction to 1 in. tends to diminish the errors in the unit graph. When possible, unit graphs for several similar storms should be determined and averaged to obtain a mean graph for the basin. If several unit hydrographs for the same duration are superimposed so that the beginnings of rainfall excess coincide, the peaks will not necessarily coincide. If several hydrographs are averaged by averaging concurrent ordinates, the resulting average graph has a broader, and quite possibly a

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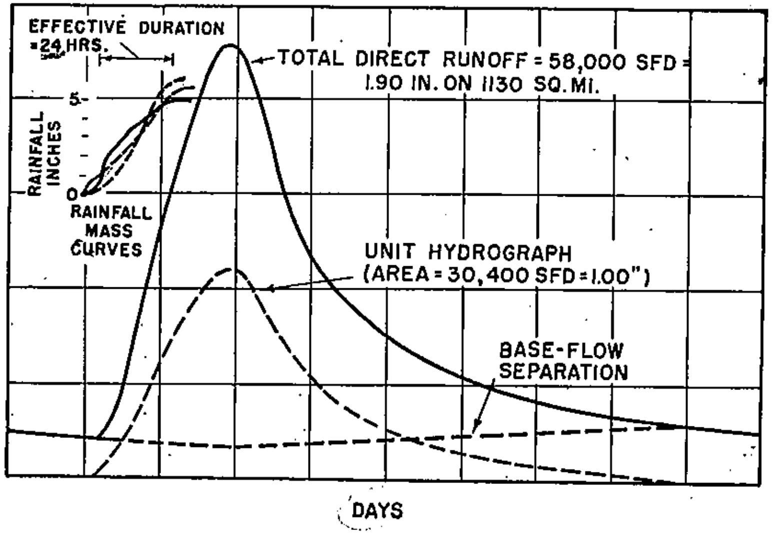

FIG. 17–1. Derivation of a unit hydrograph from an isolated storm.

lower, peak than any of the individual graphs (Fig. 17-2). The correct average unit graph should be obtained by locating the average peak height and time and sketching a mean graph having an area equal to 1 in. of runoff and resembling the individual graphs as much as possible.

If the available storms show a wide variation in areal distribution of rainfall, it is necessary to develop several unit graphs and note on each the general nature of the rainfall distribution causing it. The effect of varying distribution or of nonuniform intensity is evident from Fig. 15-3.

In basins with two concentrations of area, the characteristic hydrograph may exhibit two peaks. Variations in rainfall distribution and intensity commonly cause a wide variation in the relative magnitudes of the two crests. Frequently, it is necessary to treat such basins in two portions or to use other methods of runoff distribution for accurate work.

[illegible]心

**Unit hydrographs from complex storms.** If no better data are to be found, unit hydrographs must be developed from the records of complex storms. If the storms are sufficiently separated so that there are two peaks (Fig. 15-9), the groundwater separation can be made and the two storms may be separated by use of a direct-runoff depletion curve. The unit hydrographs may then be developed from each storm, using the procedure outlined for isolated storms.

If the only data available represent an extended period of rainfall and the hydrograph cannot be broken down into portions contributed by each burst of rain, a more specialized analysis is required. Figure 17-3 represents a hydrograph resulting from three consecutive periods of rain. Using the techniques of Chap. 16, we may compute the runoff to be expected from each period of rain. The total so computed should equal the total volume under the hydrograph (with base flow subtracted). If the observed and computed volumes do not check, the error should be prorated to the several periods in proportion to their respective runoff volumes or by some other rule. Letting $U_1$, $U_2$, $U_3$, etc., equal the unit-graph ordinates at times 1, 2, and 3, and $Q_1$, $Q_2$, $Q_3$, etc., represent the direct runoff from rain during each of the periods, then, since only $Q_1$ can affect the hydrograph during period 1, the discharge $q_1$ at the end of this period is

$$q_1 = Q_1U_1 \tag{17-1}$$

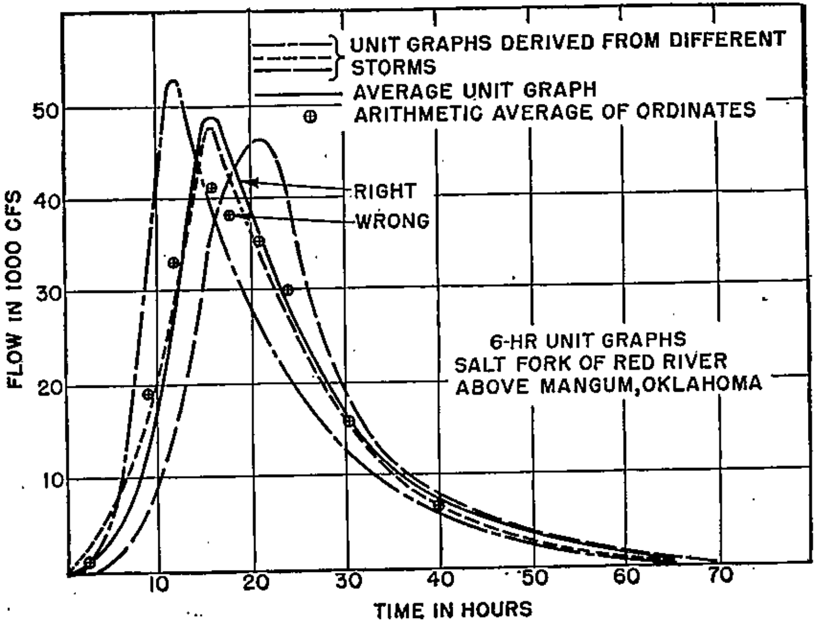

FIG. 17–2. Construction of an average unit graph. *(Data from U.S. Bureau of Reclamation.)*

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# APPLIED HYDROLOGY

LINSLEY・KOHLER・PAULHUS

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## ■序文（PREFACE）

歴史の黎明より、幾つかの水文学の原理が用いられてきたことは、多くの証拠が示すところであるが、現代の水文学は今世紀の産物である。事実、現在における理論と実践の多くは、1935年以降に急速に行われるようになった洪水調節と干拓事業に拠るところが大きい。この期間に、高速道路や空港での排水、小規模な水供給事業、合流式下水道の設計などの様々な分野において、水文学が適用され役立ってきた。

近年の水文学分野における取り組みが急速に成長した結果、多くの技術論文が科学系定期刊行物に書かれ、多くの専門の報告書がいくつかの関係機関によって出版された。まだ歴史の浅い現代水文学の応用が進むにつれ、この分野に関する数々の論文が書かれるようになり、用語・術語、技術の標準化が著しく欠けていることが明らかになった。水文学に専門的に従事していない人にとって、この分野に親しむのは難しい。本書は、水文学に関する一般的情報、基本的な理論、実践手法のため、使い勝手の良い参考書となることを目的に作成されている。本書を通して強調したことは、水文学の実用的な適用手法の提示と、水文学で鍵となる要素の変動について、その中間値や幅を示すデータを提示することである。基礎的なデータについては、アメリカ合衆国のデータに限定しているが、この国の水文学の適用に適切と判断された場合に限って諸外国のデータも用いている。本書で論じられている技術や課題はアメリカ合衆国特有のものである。

本書が水文学を専攻する学生にとって実用的な教科書であるとともに、多少なりとも水文学の課題に職業的に取り組む技術者にとって貴重な参考資料であり指針となることが筆者の望みである。本書が水文学の分野すべてを網羅しているという主張はしない。別の出典より容易に手に入る基本的な理論については、ページ数を抑えるためその多くを掲載していない。高度に専門的で稀な水文学の適用については、より一般的な適用手法を詳細に紹介することを優先するためその多くを割愛している。しかし、この本の範疇を越えてもっと勉強したい読者にとって、豊富な説明を提供できたのではないかと信じている。

## ■２つの流出成分への分析分離（P. 400　Analytical separation into two components）

ある流域の地下水流出の逓減曲線は、この章で前述したどの方法を用いても作成することができる。それらに用いるデータは、そのデータが降雨の影響を受けておらず、専ら地下水流出のみを示しているという仮定を正当化できるほどに、降雨が終わって十分に時間が経過した後のデータとすべきである。降雨終了後より始め、流量逓減曲線が地下水流出のみを示すものであることが明らかな場合、地下水流出量の逓減から時系列的に遡りながら連続して縦距（縦座標）を計算すれば、地下水の流出逓減曲線は、最終的には、実測流出量の逓減曲線を離れて下回ることがわかる。出発点(図 15-8)を直接流出の終わりに取り、この点より後ろ（左方向）に伸びた逓減曲線は、地下水のハイドログラフの逓減を示している。このとき、地下水流出のピーク生起時刻と上昇カーブの形状は任意で取られなくてはいけない。用意したテンプレートは、このタイプの分離を行う際に有効である。

上述の分離方法を修正したものは（リンスレーらによる）、複雑な降雨の流出量を分離する際に役立つ。図 15-9 は、二つの降雨がとても近い間隔で起こったため、直接流出が二つの降雨の間で終わらない波形を示している。地下水流出の逓減曲線は二つ目の降雨のピークより前まで伸ばすことができない。それゆえ、直接流出の逓減曲線は、地下水流出の逓減曲線と複数の降雨による総流出量ハイドログラフの間の領域で作成されるような曲線であることが必要である

直接流出と地下水流出の逓減曲線を再度プロットすると、単位時間当たりの流出量の変化は、初期流出量の関数として表されることがわかる（図 15-10）。逓減区間 AB（図 15-9）の下の地下水流出のハイドログラフ上の点は次のように位置づけられる：

1．　AB の流出量の変化量を求め（単位時間あたり）、図 15-10 より、その変化量に対応する直接流出量の１次推計量を読み取る。
2．　直接流出量の推計値 Aa'を総流出量 Ad より引く。差し引きの a'd が地下水流出量の１次近似値となる。
3．　図 15-10 より、地下水流出量 a'd に対応する流出量の変化量を求め、これを総変化量 AB より引く。残りは、基本的に直接流出量の変化量であり、初期の直接流出量 Aa の新たな値を決定するために使用される。縦距 ad が地下水流量を表す。

上記に示した手順に沿って、最初の洪水による流出量の逓減部に対応する地下水のハイドログラフが定められる。地下水流出のハイドログラフのバランスは任意に描かれなければならない。最初の洪水による直接流出の逓減は、直接流出の逓減曲線を用いることにより、２回目の出水の立ち上がりの下まで引き伸ばされる。

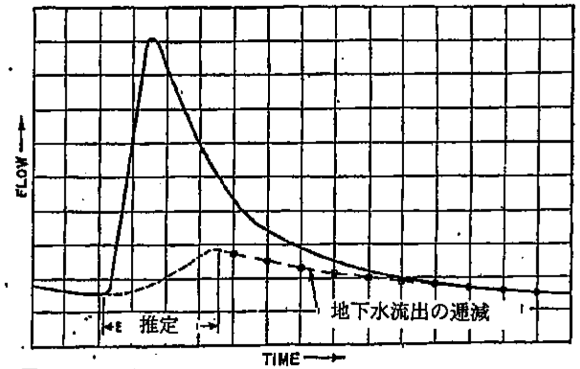


図 15-8　一山ハイドログラフの地下水流出逓減線の作成

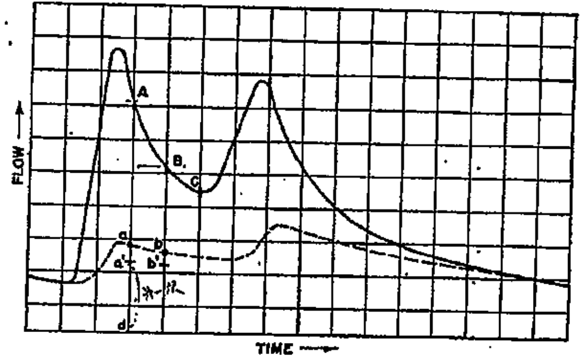


図 15-9　複数山ハイドログラフの解析手法

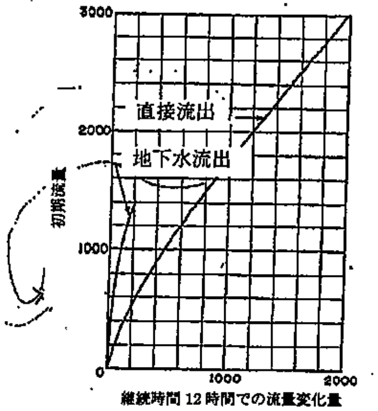
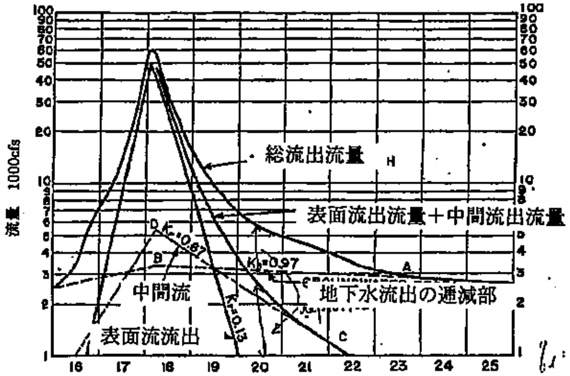


図 15-10　流出曲線の変化率
（ノースカロライナ州トモティアのバレー川）

## ■3つの流出成分への分析分離 (P. 403　Analytical separation into three components)

それぞれのハイドログラフから流量分布の近似値を求めるような研究においては、バーネス（1）の編み出した分析手段が用いられる。手順は図 15-11 に示す通りで、洪水流量ハイドログラフが片対数方眼紙にプロットされている。地下水流出の逓減 AB は直線で近似されており、それ自体はハイドログラフより下で時間的に遡って延長して描くことができる。地下水流出ハイドログラフより上の残りの流量高（縦座標値）は、表面流出流量と中間流出流量（interflow）を合わせたものである。この合算されたハイドログラフは、プロットし直すと中間流流出量（interflow）の逓減 CD に適合する直線となる。この逓減は直線として表現され、表面流流出から中間流流出を分離することができる。地下水流出と中間流流出のグラフの上昇部分は、その他のすべての方法と同じように推定される。対数方眼紙へのプロットの際には、流出量の大きいところで凝縮されたスケールを使用する場合に大きなエラーが発生しないように、細心の注意を払わなければならない。

(1)バーネス･B･S：「流出低減曲線の構造」トランス.AM.地球物理協会　第 20 巻 p 721-725(1939 年)



1936 年 3 月

図 15-11　片対数方眼紙へのプロットを用いたハイドログラフの成分分離
（ペンシルバニア州ジョンズタウンのストーニー川）

## ■流出量配分 (P. 444　Runoff Distribution)

前章では、洪水降雨と先行気象の特定の組み合わせに関連した総流出ボリュームの計算方法を議論した。たとえば発電電力供給や灌漑用水供給に使用可能な水量の用水使用可能量を算出するような特定の問題の場合には、そうしたこの総量の計算推測で十分である。しかしながら、より総合的には、総流出ボリュームの推定作業は、流域の流出ハイドログラフを決める作業の中で、何よりも他の作業に先駆けて、まず第一番に優先してなされる作業である。この章では、小規模ないし中規模程度の流域（およそ 5000 平方マイル以下（12,949 平方 km 以下））の流量ハイドログラフを決める技術について示す。

### 単位図法 The unit hydrograph：

１５章におけるハイドログラフの形についての話からは、同一様の降雨が同一ので同じ流域湿潤条件で発生すればであれば、同一のハイドログラフとなるという仮説が自然に生まれる。この原理は、Sherman がこの原理については、彼の学説である単位流量図（*unit hydrograph*）もしくは単位図（*unit graph*）でを紹介するときに言及された紹介している。彼は、与えられたある一定期間の降雨から得られるすべてのハイドログラフは、同じ基底時間長（time base）になると指摘している。もし時間的・空間的に降雨分布が似ているとすれば、それぞれのハイドログラフの縦距（流出量）はも流出ボリュームに比例するだろう。単位図(Unit graph)自体は、１インチ（１インチ＝２．５４cm）の降雨から生じた流出流量グラフである。もしこの説が合理的であれば、同じ降雨時間の、ほかの同じ降雨期間のよく似た降雨によるのいずれのハイドログラフも、降雨量に単位図の縦距をかけることで作ることができる。

(1)シャーマン･L･K：「単位図法により流出解析」工学；News-Record　第 108 巻 p 501-505(1932 年)

水文学的な作業・検討において、単位流量図（unit hydrograph）は非常に効果的で簡単なツールであることが証明されている。ある固定された降雨期間で、同様の降雨の時空間分布という条件下であれば、様々な降雨のハイドログラフは大体似た形になり、流出量は流出ボリュームに大体比例するといえる。もちろん、河道貯留の効果は段階により様々であり、たいへんとても大きい洪水の unit graph は、小さい洪水のものとは必然的に違うため、厳密には真実であるとは言えない。単位流量図（unit hydrograph）は同様の降雨継続期間に生じた洪水の基底時間長（time base）は同じであると仮定している。しかしながら、直接流出量の逓減曲線は、流量がある値にまで逓減するのに要する時間が初期流量の大きさに応じて増加することを示している。逓減曲線は漸近的にゼロに近づくため、実際の適用を許したとしても大きな誤差は生じないであろう。

単位図（unit graph）の使用に限界があることは認識されなければならない。大規模な範囲において、降雨のたびごとに適度に類似した降雨分布が起こることはほとんどない。そ

のため、単位図（unit graph）はかなり大きな地域での適用での成功例はあるものの、2,000平方マイル以下の地域に最も適している。特異な形の流域、とくに細長い流域形状では、一般に降雨分布は不均等であり、そのため単位図（unit graph）はこのような流域にはうまく適用できない。山岳地帯では地形性降雨に支配されるが課題となるため、降雨の空間分布は非常に不均等であるが、そのパターン時間分布は降雨のたびごとに同じ傾向にあるため単位図(unit graph)を使用してもよい。

降雨ごとの典型的な降雨強度類型を見分けることはほぼ不可能であり、長時間にわたって均一な降雨は通常ない。これは見た目一見したよりも重大ではない。というのも、とても不均一なハイドログラフを自然が効果的になだらかにするからである。大体の降雨強度の変化は、地表流の地表面貯留でなだらかになり、渓谷の流れなどの貯留によりさらになだらかになる。このため、短期間の降雨量の変化は単位図（unit graph）の手法の正確さにほとんど大きな影響を与えない。比較的長期間の変化、たとえば数々の前線通過による集中豪雨などは考慮されるべきである。これはそれぞれの豪雨をひとつの降雨として扱い、適切な降雨継続時間の単位図（unit graph）を用いることで計算できる。この段落で使われている「短い」「長い」というのは相対的な用語である。数平方マイルの流域面積で、1時間以内にひとつかそれ以上の雷雨により複数の短時間豪雨が発生した短い降雨が1時間以内で起こった場合、いくつかの流量ピークが生起するので、分単位で計測された時間単位を用いる必要がある。2,000平方マイル程度の大きな流域においては12時間か24時間が適当な時間単位となる。実際の適用においては、時間単位は洪水到達時間（basin lag）のおよそ1/4とすべきことが経験上知られている。

### ■単一降雨一雨洪水からの単位流量図の作成

（P. 445 Derivation of the unit hydrograph from isolated storms）

単位図（unit graph）は前述の一般的な条件を満たす単一一雨降雨の流量ハイドログラフから最も簡単に導くことができる。手順は以下のとおりである（図17-1）。

1. 地下水流出を分離し、直接流出量のボリュームを計測する
2. 直接流出量高を求める（流域全域においてインチで表す）。結果作成されたハイドログラフが流域の単位図（unit graph）となる。
3. 降雨記録調査によって、単位図（unit graph）が適用可能なできる、流出に寄与する降雨の効果的な継続時間を決める。

1インチへの逓減が単位図（unit graph）の誤差を消してしまう傾向にあるため、流出高が1インチ以上の一般的な降雨は、少規模の降雨に比べて理想的である。出来れば、流域の平均的なグラフを作成するため、いくつかの似た洪水の単位図群（unit graphs）を決め、平均しておくべきである。同じ降雨継続期間のいくつかの単位図（unit hydrograph）を有効降雨（rainfall excess）の開始が初期が同時となる生起するように重ねるとしても、ピークは必ずしも同時生起しないだろう。もし、いくつかの単位図で同時刻の縦距を平均して、平均単位図を作成するとしたら、得られた平均単位図のピークは、どの個別の単位図よりピークがつぶれ低くなるだろう（図17-2）。　正確精確な平均的な単位図（unit graph）では、ピーク流出高とピーク生起時刻はそれぞれの諸量を平均して設定し、グラフ形状は1インチの降雨の流出と流出ボリュームが等しくなるように、かつ、個別のグラフにできるだけ似せて設定されるべきである。

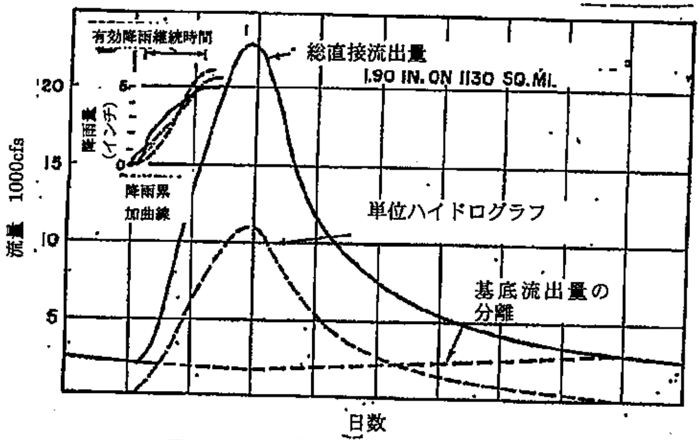


図17-1　一雨降雨からの単位流量図の作成

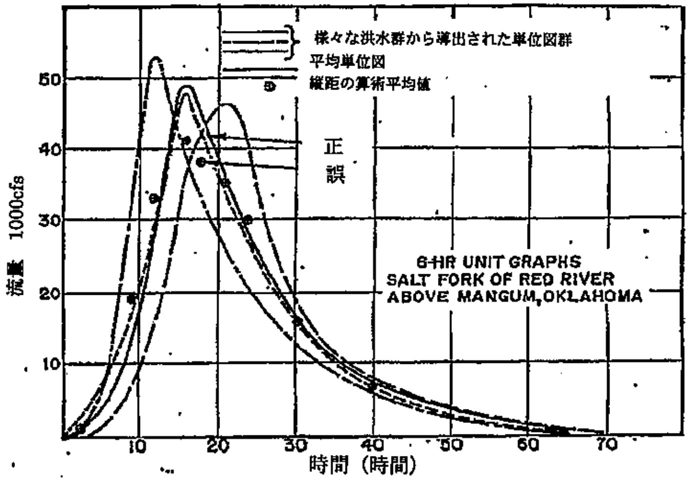


図17-2　平均単位図の作成（データ出典：アメリカ合衆国干拓局）