Runoff Hydrograph هيدروغراف السيح (1)

<u>Runoff</u>: the draining or flowing off the precipitation from a catchment area through a surface channel.
هو جريان أو تصريف التساقط من الكابية وخلال قناة سطحية موجودة فيه.
It thus represents the output from catchment in a given unit of time. وعليه فأنه يمثل الناتج من الكابية في وحدة الزمن

$$R = P - ET - IL - INF - DS \quad (1)$$

R = Runoff (السيح), P = receiving precipitation (الأمطار الساقطة على الكابية), ET = evapotranspiration (النتح)

IL = initial loss (الفواقد الأولية), INF = infilitration (الترشيح), and DS = detention storage (الحجز السطحي)

The excess precipitation moves over the land surfaces to reach smaller channels. This portion of runoff is called overland flow بعد تحقق الفواقد فالزيادة في التساقط تتحرك حتى تصل إلى القنوات الصغيرة وهذا الجزء من السيح يسمى جريان فوق سطح الأرض.

This flow involves building up a storage over the surface and draining off the same. يتضمن هذا الجريان بناء خزين فوق سطح الأرض وتصريفه.

The flow during overland discharge is laminar regime. The flow travels from small channels to bigger ones till the flow reach catchment outlet. The mode of flow where it travels all the time over the surface as <u>overland</u> flow and through channels as <u>open-channel</u> flow and reach outlet of catchment is called Surface runoff.
يسمى الجريان فوق سطح الأرض والحاصل في القنوات والواصل إلى مخرج الكابية بالسيح السطحي

A part of precipitation that infilters and moves laterally through upper crusts of the soil and return to surface at locations away from the point of entry into the soil this component of runoff is known as interflow الجريان البيني, subsurface storm flow الجريان تحت السطحي, storm seepage تسرب العاصفة, or quick return flow الجريان العاصف السريع & through flow. الجريان الخلالي
أنظر الشكل (1).

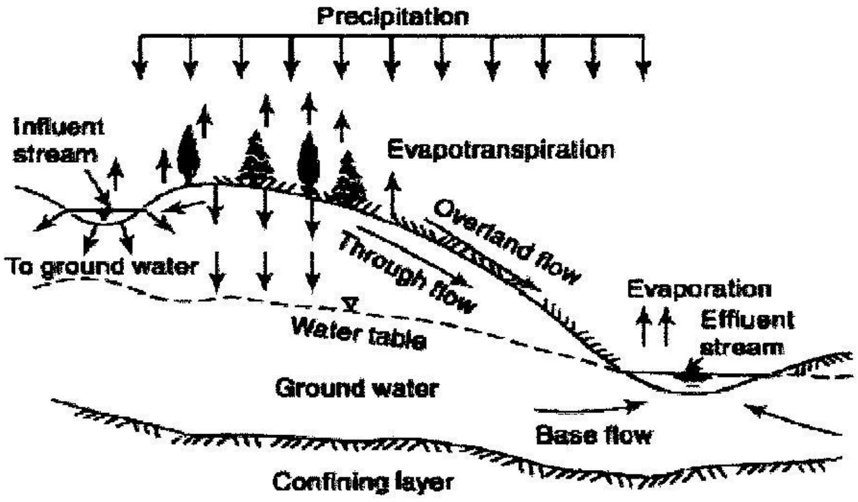

Fig. 1 – Different routes of runoff مسارات السيح

The interflow sometimes is classified as prompt interflow جريان بيني سريع i.e, the interflow with least time lag (the difference between the time of interance and the time of soil leaving).

Another route of the infiltrated water is to undergo deep percolation and reach the groundwater storage. The groundwater follows a complicated and long path of travel and ultimately reach the surface. The groundwater flow provides the dry-weather flow in perennial streams. (الدائمة)

The surface runoff is classified into :-

1. Direct runoff السيح المباشر (storm runoff)
2. Base flow الجريان القاعدي

Hydrograph

It is a plot of the discharge in a stream against time chronologically. هو مخطط للتصريف المائي مع تعيين نقاط ضد الزمن بشكل تسلسلي

1. Annual Hydrograph : shows the variation of daily or weekly or 10 days mean flow over year.
2. Monthly hydrograph : shows variation of daily mean flow over month
3. seasonal hydrograph : shows variation of discharge in a season.
4. Flood hydrograph (Storm Hydrograph) : due to a storm and representing stream flow of the storm over the catchment X

وسندرس النوع الأخير بالتفصيل لاحقاً.

water year السنة المائية

The annual hydrograph shows the seasonal variation of the discharge over a year and forms a basic data for further analysis. Each country has fixed a define 12-month period to begin & end. In USA the water year starts 1st october to 30th september, In India is from 1 June to 31 May whereas In Iraq starts from 1 March and end at 30th september. In Egypt starts at 1 August to 31 July.

Runoff Characteristics of Streams خصائص السيح الجداول

A study the annual hydrographs of stream enable to classify the streams in three classes;

(1) Perennial stream: الجداول الدائمة

It always carries some flow (Fig 2)
There is a considerable amount of groundwater flow throughout the year even during dry Season (How?)

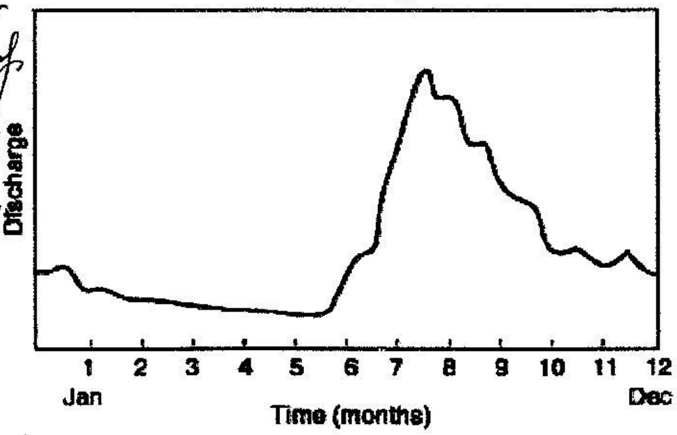

Fig. 2 Perennial stream

(2) Intermittent stream الجداول المتقطعة

The contribution of groundwater is limitted. In wet season, the water table is above the streambed. In dry season the water table is below streambed an the stream dries up, unless storms that can produce a short-duration flow

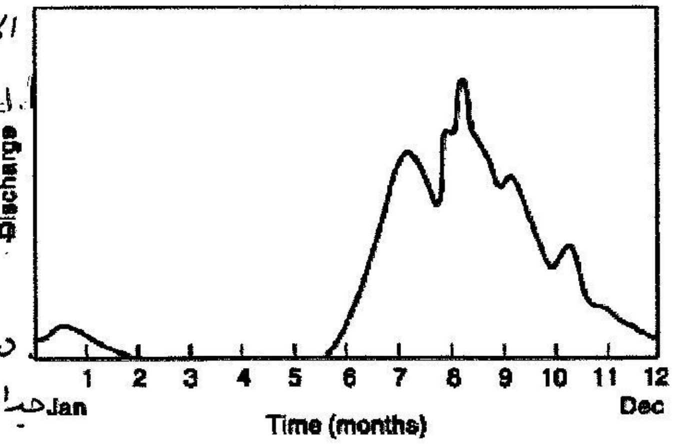

Fig. 3 Intermittent stream

(3) Ephemeral Stream جداول السيول

The base flow does not have any Contribution. The stream becomes dry soon ~~after~~ the end of storm flow.
The annual hydrograph of such stream show series of short-duration flactuations of Storm.

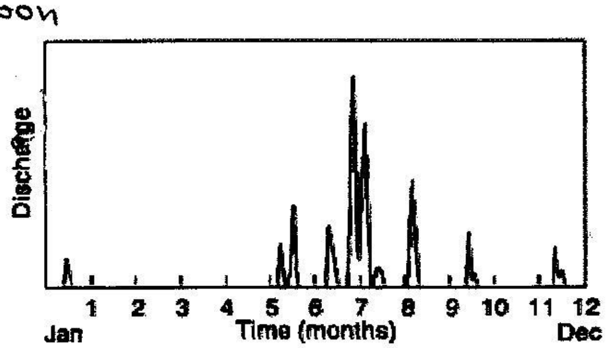

Fig. 4 Ephemeral stream

Rainfall-runoff Correlation

$R = aP + b$, a & b can be found by regression of Linear type as in regression of stage-discharge relation.

Flood Hydrograph (الهيدروغراف الفيضاني (العاصف))

Consider a concentrated storm producing a fairly uniform rainfall of duration D over a catchment. After the initial losses and inflitration losses are met, the rainfall excess reaches the stream through overland and channel flow. A certain amount of storage is built up in the overland and channel flow. This storage gradually depletes after cessation (توقف) of the rainfall.

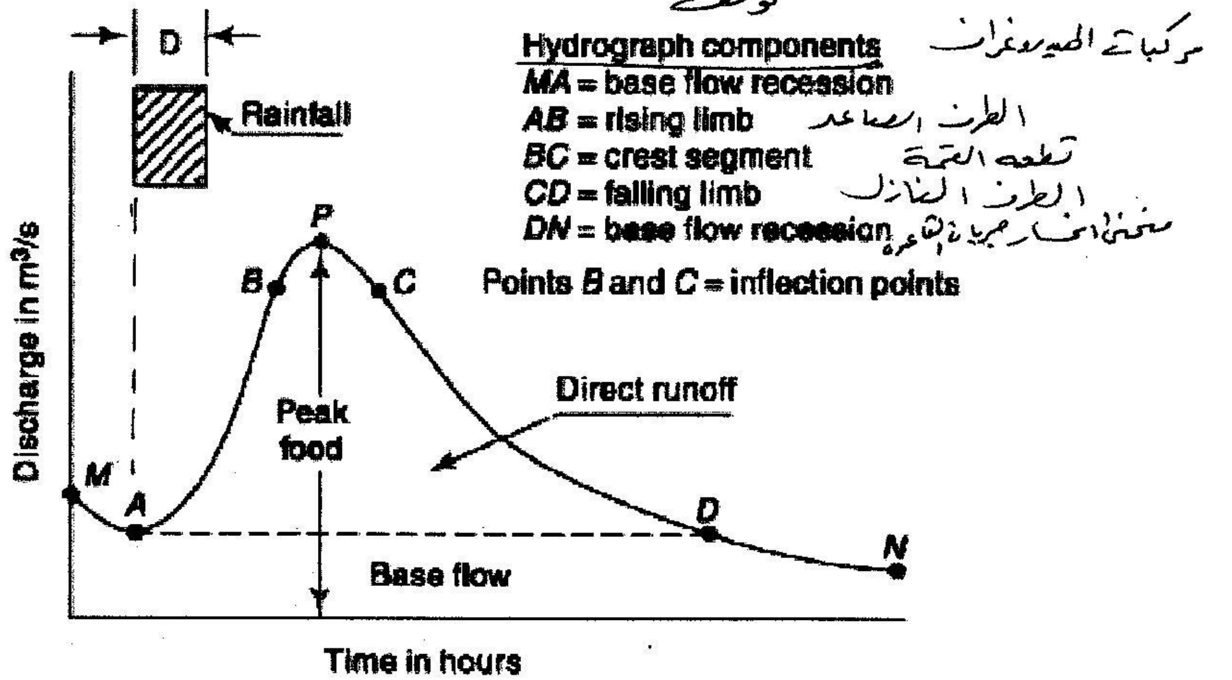

Fig. 5 – Elements of a Flood Hydrograph

There is a time lag between the occurrence of rainfall in the basin and the time when that water passes a gauging station at basin outlet. The runoff measured at stream-gauging station will give a typical hydrograph shown in Fig (5) above.

الزمن بين مركز كتلة الهيدروغراف ___ وذروة التصريف (P) يطلق عليه زمن التخلف Lag time (T_L). حيث مركز الكتلة (المساحة) هو:

$$X_c = \frac{\int x\,dA}{\int dA} = \frac{\sum x_i A_i}{\sum A_i} \qquad (2)$$

إن الهيدروغراف يمثل حالات السيح باشكالها الثلاث (السيح السطحي، الجريان البيني والجريان القاعدي) وكذلك تتضمن خصائص الحوض Basin وخصائص العاصفة المطرية وهي حصيلة من التداخلات المعقدة.

Factors affecting Hydrograph — العوامل المؤثرة على الهيدروغراف (5)

A) Physiographic factors — عوامل الجغرافية الطبيعية

(1) Basin characteristics:

(a) shape (b) size (c) slope (d) Nature of valley (e) elevation (f) drainage density

(2) Infiltration characteristics:

(a) land use and cover (b) soil type and geological condition (c) lake & storage

(3) Channel characteristics:

(a) roughness (b) storage capacity

(B) Climatic factors — العوامل المناخية

(1) Storm characteristic:

(a) intensity (b) duration (c) storm movement

(2) Initial loss

(3) Evapotranspiration

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1. Shape of the Basin

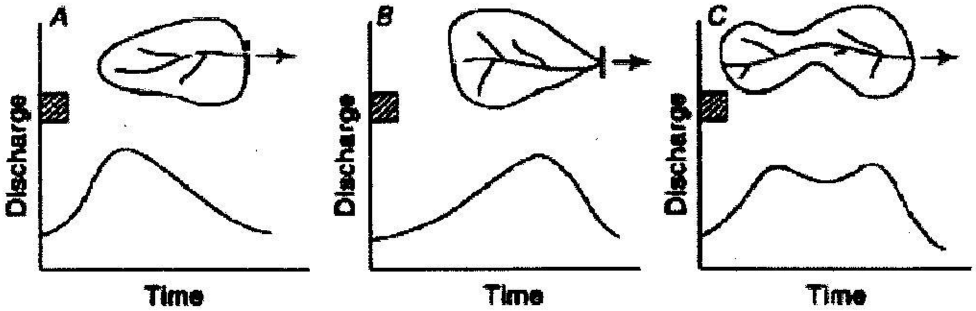


Fig. 6 Effect of Catchment Shape on the Hydrograph

2. Size:

Small catchment → overland flow is dominant.

Large catchment → Channel flow is dominant.

$Q_p \propto A^n$ $n \approx 1/2$ $(n<1)$ } $t_p \propto A^m$; $m \approx 0.2$

$T_{Base}|_{small} < T_{Base}|_{large}$ — للوادي الكبيرة

3. Slope

Large slope → quick depletion of storage (steeper recession limb)

Large slope → large peak of discharge.

4. Drainage density كثافة البزل

high density → large peak
low density → low peak
as shown in Fig (7)

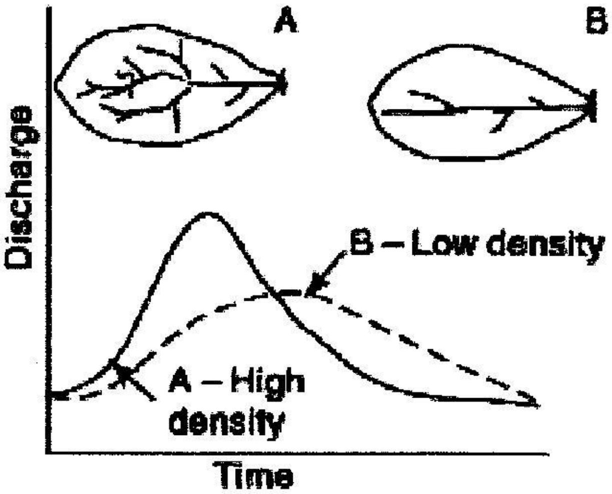


Fig. 7 Role of Drainage Density on the Hydrograph

5. Land use

Vegetation cover increases the infiltration and causes a considerable retardance in overland flow.

⇒ V.C. → Low peak especially in catchment of $A < 150 km^2$.

Components of Hydrograph — مركبات الهيدروغراف

1- Rising Limb — الطرف الصاعد from start to inflection ①
2- Crest segment — قطعة الذروة between two inflections
3- Recession Curve — منحنى الانحسار from inflection ② to ground water flow

—

Hydrograph Separation فصل الجريان في الهيدروغراف

Method 1

Joining the beging of surface runoff to apoint of the end of direct runoff on the rising limb. (A ⟶ B)

Point B canbe evaluated by an empircal equation calculated from peak as;

$$N = 0.83\ A^{0.2} \qquad (3)$$

A: drainage area Km^2, N: period in days

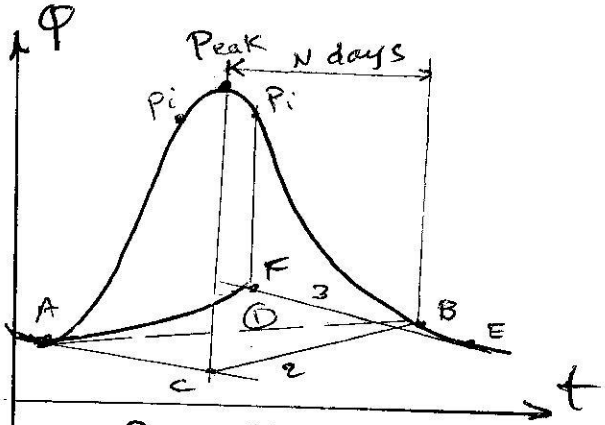


Fig. 8 – Base flow separation

Method 2

Extend the hydrograph curve prior to point A till it intersects the ordinate drawn from peak point (point C). This point is jointed to point B.

Method 3

The recession curve is extended backwards till it intersects the ordinate from inflection point at point F. Joining point A and F by an arbitrary smooth curve

Storage of Water in the Basin الخزين المائي في الجابية

The storage of water in the basin exists as;

(i) surface storage (surface detention & channel storage) الخزن السطحي (الحجز السطحي + خزن القناة)

(ii) interflow storage الخزن البيني

(iii) Groundwater storage (base-flow storage) الخزن القاعدي

Bannes, in 1940, showed that the recession of storage can be expressed as;

$$Q_t = Q_o K_r^t \qquad (4)$$

Q_t = discharge at a time t.

Q_o = discharge at time $t = 0$.

Equation (4) is equivalent to:

$$Q_t = Q_o e^{-at} \qquad (5)$$

where $a = -\ln K_r$

K_r : recession constant ($K_r < 1$), this constant can be considered to be made of three components;

$$K_r = K_{rs} \cdot K_{ri} \cdot K_{rb}$$

K_{rs} = recession constant for surface storage ثابت الانحسار للخزن السطحي

K_{ri} = recession constant for interflow ثابت الانحسار للجريان البيني

K_{rb} = recession constant for base-flow ثابت الانحسار للجريان القاعدي

$K_{rs} \approx 0.05 \rightarrow 0.2$, $K_{ri} = 0.5 \rightarrow 0.85$ $K_{rb} = 0.85 \rightarrow 0.99$

كلما قلت قيمة الثابت ازدادت أهمية التصريف المرتبط به ، ولنا عندما نريد

أهمال قيمة التصريف البيني نعطي للثابت (K_{ri}) قيمة واحد .

Equation (4) or even (5) can be plot as a striaght line when drawn on semi-Log paper (Q on log scale). The slope of this line represents the recession constant.

The storage S_t remaining at any time is;

$$S_t = \int_0^\infty Q_t \, dt = \int_0^\infty Q e^{-at} dt = \frac{Q_t}{a} = \frac{-1}{\ln K_r} Q_t \qquad (6)$$

نستخدم صورة المعادلة (4) الثانية (أي المعادلة ⑤) لسهولة التكامل

Example 1:

The recession limb o f a flood hydrograph is given below. The time is indicated from the arrival o f peak. Assuming the interflow component to be negligible ,estimate the base flow and surface flow recession coefficients. Also, estimate the storage at the end o f day-3.

Time from peak (day)	Discharge (m^3/s)	Time from peak (day)	Discharge (m^3/s)
0	90	4.0	3.8
0.5	66	4.5	3.0
1.0	34	5.0	2.6
1.5	20	5.5	2.2
2.0	13	6.0	1.8
2.5	9.0	6.5	1.6
3.0	6.7	7.0	1.5
3.5	5		

Solution:

The data are plotted on semi-Log paper. The flow from 4.5 to 7 days are seen to lie on straight Line AB in Fig (9). ??

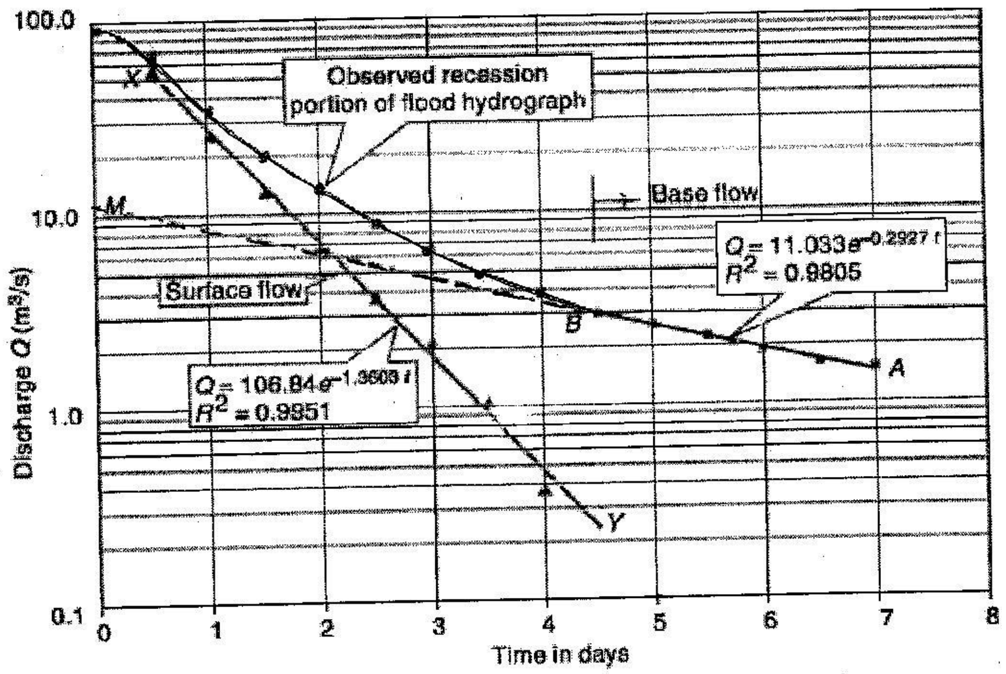


Fig. 9 Storage Recession Curve – Example 1

From eq(4): $\frac{Q_2}{Q_1} = K_r^{(t_2-t_1)}$

$\log K_{rb} = \frac{1}{t_2 - t_1} \log\left(\frac{Q_2}{Q_1}\right)$ for base flow (Line BM).

Select: at $t_1 = 0 \rightarrow Q_b = 11$, at $t_2 = 4.5 \rightarrow Q_b = 3$ $\Big\} \Rightarrow \log K_{rb} = \frac{1}{4.5-0} \log\left(\frac{3}{11}\right)$

$K_{rb} = 0.749$ $\left[Q_b = 11\,(0.749)^t\right]$ BM

Thus; the surface runoff depletion is obtained by subtracting the base flow from the given recession Limb of the hydrograph. and Apply the above procedure taking at $t_1 = 0$, $Q_s = 79$ and $t_2 = 3$ day $\rightarrow Q_s = 2.078\ m^3/s$ $\Rightarrow K_s = 0.297$

$\Rightarrow \left[Q_s = 79\,(0.297)^t\right]$ XY

From eq (6): The storage available at end of t-days is;

$$S_b + S_s)_t = \left(\frac{Q_b}{-\ln K_b} + \frac{Q_s}{-\ln K_s}\right)$$

at period t = 3 days:

$$Q_b = 11\,(0.749)^3 = 4.622\ m^3/s$$

$$Q_s = 79\,(0.297)^3 = 2.07\ m^3/s$$

$$\Rightarrow S_3 = \frac{4.622}{-\ln 0.749} + \frac{2.07}{-\ln 0.297} = 16 + 1.7 = 17.7\ \frac{m^3}{s}\cdot \text{day (cumec.day)}$$

$$= 1.52928\ Mm^3$$

هذا هو الخزين المائي المتوفر ابتداءً من نهاية اليوم الثالث.

<u>H.W</u> In a stream the base flow is observed to be 30 m^3/s on May 1st and 23 m^3/s on May 10th. If there is no rain during May, estimate the base flow on 30th May and the volume of groundwater storage on May 1st & May 30.

Effective rainfall (ER)

المطر المؤثر

Effective rainfall (المؤثر) or Excess rainfall (الزائد) (ER) is the part of rainfall that becomes direct runoff at the outlet of catchment area.

It is thus, the total rainfall from which abstractions (infiltration & initial loss) are subtracted. The DRH was correlated with so-called hyetograph of effective rainfall (ERH) shown in Fig (10).

DRH & ERH represent same quantity but in different units.

<u>φ-index</u>: represents the average rainfall intensity above which the rainfall volume is equal to the runoff volume.

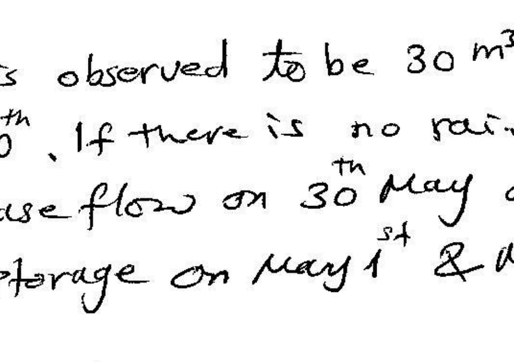


Fig. 10 Effective Rainfall Hyetograph (ERH)

<u>Example 2</u>: A storm produced a direct runoff of 5.8 cm. The data of the storm is given below. Estimate the φ-index.

Time (hr)	0	2	4	6	8	10	12	14	16
Acc. depth cm	0	0.4	1.3	2.8	5.1	6.9	8.5	9.5	10

Solution:

Time (hr)	0 - 2	2 - 4	4 - 6	6 - 8	8 - 10	10 - 12	12 - 14	14 - 16
depth (cm)	0.4	0.9	1.5	2.3	1.8	1.6	1	0.5
Intensity(cm/hr)	0.2	0.45	0.75	1.15	0.9	0.8	0.5	0.25

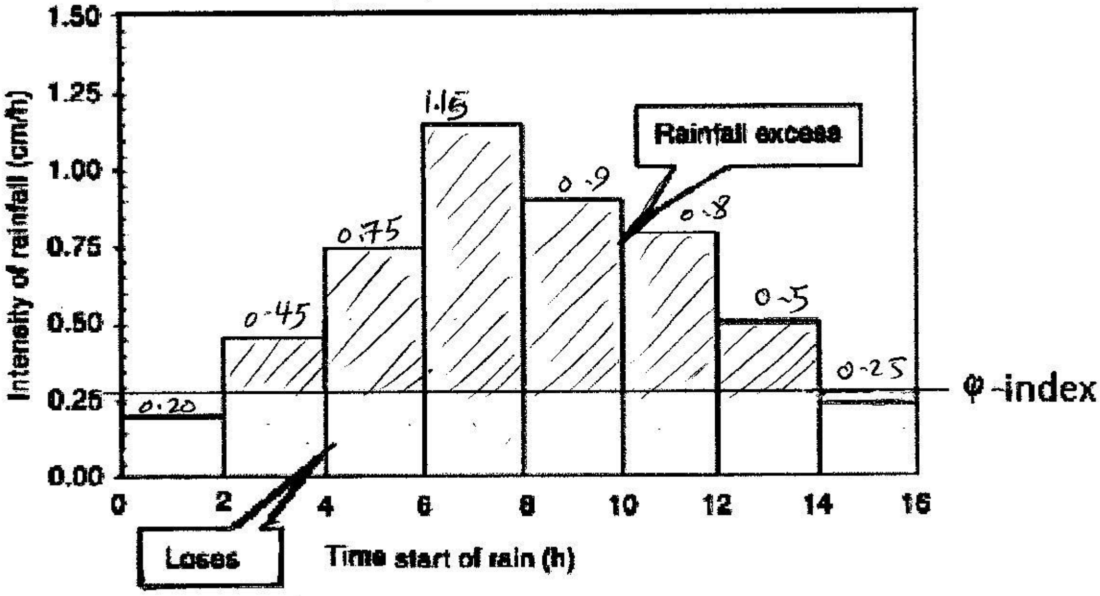


Fig. 11 Hyetograph and Rainfall Excess of the Storm – Example 2

① assume $0.45 < \phi < 0.5$ $(M=5)$

$\sum (I_i - \phi)\Delta t = R_d$; R_d: direct Runoff

$\sum (I_i \Delta t - \phi \Delta t) = \sum_{i=1}^{5} I_i \Delta t - 5\phi\Delta t = 5.8$

$= 0.75(2) + 1.15(2) + 0.9(2) + 0.8(2) + 0.5(2) - 5\phi(2) = 5.8$

$\Rightarrow \phi = 2.4$ cm/hr (Assuming is not correct)

② assume $0.2 < \phi < 0.25$ $(M=7)$

$\Rightarrow 5.8 = 0.45(2) + 0.75(2) + 1.15(2) + 0.9(2) + 0.8(2) + 0.5(2) + 0.25(2) - 7\phi(2)$

$\Rightarrow \phi = 0.271 > 0.25$ (Not o.k

③ assume $0.25 < \phi < 0.45$ $(M=6)$

$\Rightarrow 5.8 = 0.45(2) + 0.75(2) + 1.15(2) + 0.9(2) + 0.8(2) + 0.5(2) - 6\phi(2)$

$\Rightarrow \phi = 0.275$ (OK. $0.25 < \phi < 0.45$

لاحظ أن الخوارزمية قائمة على فرضية قيمة أولية لمؤشر فاي ϕ
ثم التحقق من القيمة المفروضة عبر تطبيق مفهوم المطر المؤثر
هو مكافئاً لعمق السيح المباشر.

Example 3

Rainfall of magnitude 3.8 cm and 2.8 cm occurring on two consecutive 4-h durations on a catchment of area 27 km^2 produced the following hydrograph of flow at outlet of the catchment. Estimate the rainfall excess and ϕ index.

Time from start of rainfall (h)	−6	0	6	12	18	24	30	36	42	48	54	60	66
Observed flow (m^3/s)	6	5	13	26	21	16	12	9	7	5	5	4.5	4.5

Solution:

The hydrograph is plotted as in Fig (12). The separation of the base flow of the storm Hydrograph was considered by using simple straight line.

However, DRH starts at t=0, having peak at t=12h and ends at t=48h, i.e., 36 h from peak while this period calculated from eq (3) is;

$N = 0.83(27)^{0.2} = 1.6 \text{ days} = 38.5 \text{ h}$

(which one is recommended to use?)

It abvious that the base flow has a constant value of 5 m^3/sec.

The Area under DRH curve is calculated by Trapeziodal scheme

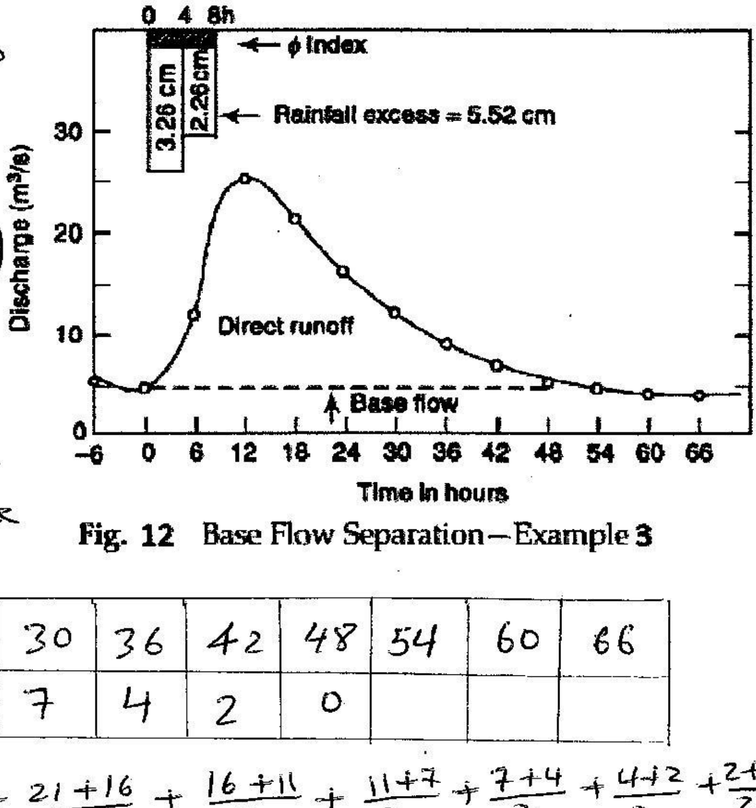


Fig. 12 Base Flow Separation—Example 3

Time (hr)	0	6	12	18	24	30	36	42	48	54	60	66
DRH m^3/sec	0	8	21	16	11	7	4	2	0			

$$\text{Area of DRH} = \Delta t\left[\frac{0+8}{2}+\frac{8+21}{2}+\frac{21+16}{2}+\frac{16+11}{2}+\frac{11+7}{2}+\frac{7+4}{2}+\frac{4+2}{2}+\frac{2+0}{2}\right]$$

$$= 6\times3600\left[8+21+16+11+7+4+2\right] = 1.4904\times10^6 \text{ m}^3$$

لاحظ أن الحاصل هو مجموع عناصر DRH مضروباً في الفترة الزمنية Δt مع التحويل.

$$\text{Runoff depth } (R_d) = \frac{\text{Volume of Runoff}}{\text{Catchment Area}} = \frac{1.4904\times10^6}{27\times10^6} = 0.0552 \text{ m}$$

$= 5.52$ cm excess rainfall

Total rainfall $= 3.8 + 2.8 = 6.6$ cm

$$\phi = \frac{6.6-5.52}{8} = 0.135 \text{ cm/hr}$$

$d_1 = \left[\frac{3.8}{4} - \phi\right] * 4 = 3.26$ cm ; $d_2 = \left[\frac{2.8}{4} - \phi\right] * 4 = 2.26$ cm ; $d_1 + d_2 = R_d$

H.W: A storm of rainfall over catchment area 5 km^2 with duration of 12 hrs. The accumulated rainfall (mass curve) is given as;

Time (hr)	0	2	4	6	8	10	12
Acc. depth (cm)	0	0.5	2.5	5.0	6.5	7.5	9.3

The ϕ-index is equal to 0.4 cm/hr. Plot the hyetograph of effective rainfall (ER) and calculate the volume of direct runoff.

Unit Hydrograph الهيدروغراف القياسي

A unit hydrograph method was first suggested by Sherman in 1932 to predicting the flood hydrograph resulting from known storm.

ان مسألة التنبؤ بالهيدروغراف الفيضاني الناتج عن عاصفة مطرية معروفة كل الابعاد قد حظيت باهتمام كبير واقترحت عدة طرق لحل هذه المسألة ولكن الأكثر شيوعاً هي طريقة الهيدروغراف القياسي التي اقترحها شيرمان عام ١٩٣٢ وحظيت بعدة تحسينات

It has undergone many refinements since then.

Definition

It is the hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the basin and at uniform rate for a specified duration D.

يعرف بأنه هيدروغراف السيح المباشر والناتج عن وحدة عمق (١ سم) للمطر الزائد تحدث بشكل منتظم وبشدة ثابتة خلال D فوق الحوض.

The definition of U-H implies the following:

- the hydrograph represents the lumped response of the catchment to a unit rainfall excess of D-duration
  الهيدروغراف القياسي يمثل رد فعل الحوض للامطار الزائدة ذات الاستمرارية D.
- The rainfall considered to have intensity of ER of (1/D) cm/hr for duration D-h.
- The distribution of the storm is considered to be uniform over catchment

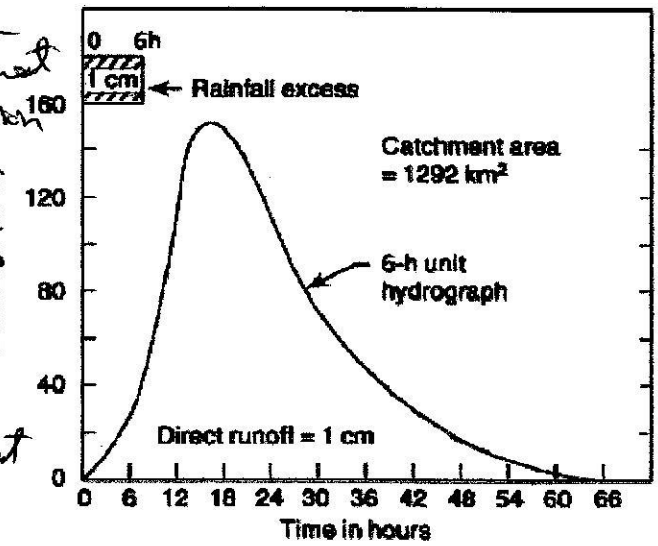


Fig. 13 Typical 6-h Unit Hydrograph

Two basic assumptions were considered for unit-hydrograph theory:

1. time invariance ثبات الوقت
2. Linear response العلاقة الخطية

Note: Catchment area = 1292 km^2
Area under U-H = 12.92×10^6 m^3
what is the relation?

Example 4

Given below the ordinates of 6-h UH for a catchment. Calculate the ordinate of the DRH due to rainfall excess of 3.5 cm occurred in 6h.

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
UH ordinate (m^3/s)	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

Solution

The ordinates of DRH are obtained by multiplying the ordinates of UH by (3.5) as in table below. The interval of the table (col. 1) are not in any way related to rainfall excess duration and can be any convenient value.

ان فترات الاحداثيات لخطط الاشكال البياني (العمود-١) ليس لها علاقة بفترة الامطار الزائدة ومن الممكن ان تكون بأية قيمة مناسبة

Time (h)	Ordinate of 6-h unit hydrograph (m^3/s)	Ordinate of 3.5 cm DRH (m^3/s)
1	2	3
0	0	0
3	25	87.5
6	50	175.0
9	85	297.5
12	125	437.5
15	160	560.0
18	185	647.5
24	160	560.0
30	110	385.0
36	60	210.0
42	36	126.0
48	25	87.5
54	16	56.0
60	8	28.0
69	0	0

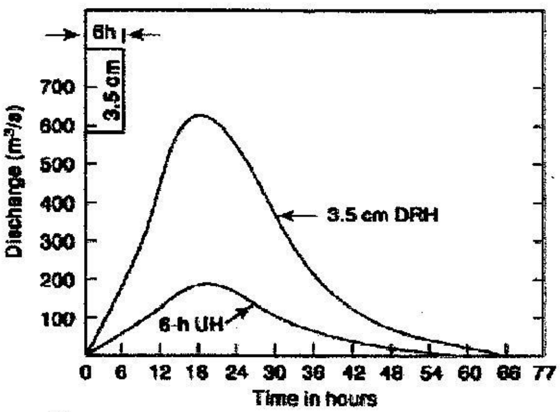


Fig. 14 — 3.5 cm DRH derived from 6-h Unit Hydrograph — Example 4

Example 5

Two storms of 6-h duration having excess values of 3.0 & 2.0 cm, respectively. The 2 cm ER follows the 3 cm rain. Use the UH of example 4 to calculate the DHR of the two storms.

Time (h)	Ordinate of 6-h UH (m^3/s)	Ordinate of 3-cm DRH (col. 2) × 3	Ordinate of 2-cm DRH (col. 2 lagged)	Ordinate of 5-cm DRH (col. 3 + 4)	Remarks
1	2	3	4	5	6
0	0	0	0	0	
3	25	75	0	75	
6	50	150	0	150	
9	85	255	50	305	
12	125	375	100	475	
15	160	480	170	650	
18	185	555	250	805	
(21)	(172.5)	(517.5)	(320)	(837.5)	Interpolated value
24	160	480	370	850	
30	110	330	320	650	
36	60	180	220	400	
42	36	108	120	228	
48	25	75	72	147	
54	16	48	50	98	
60	8	24	32	56	
(66)	(2.7)	(8.1)	(16)	(24.1)	Interpolated value
69	0	0	(10.6)	(10.6)	Interpolated value
75	0	0	0	0	

Note: 1. The entries in col. 4 are shifted by 6 h in time relative to col. 2.
2. Due to unequal time interval of ordinates a few entries have to be interpolated.

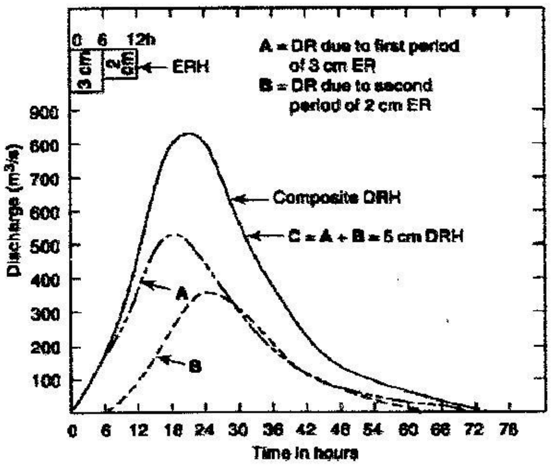


Fig. 15 — Principle of Superposition — Example 5

Application of UH تطبيق الهيدروغراف القياسي

As followed in Example 5, if a sequence of M rainfall excess value $R_1, R_2, R_3, \ldots, R_M$ all of same duration D-hr, the resulting DRH components can be written at t from the begining as; ($u(t)$: coordinates of UH)

$Q_1 = R_1\, u(t)$ [DR due to R_1 at time (t)]

$Q_2 = R_2\, u(t-D)$ [DR due to R_2 at time $(t-D)$]

$Q_i = R_i\, u(t-(i-1)D)$

$Q_m = R_m\, u(t-(m-1)D)$

and thus; at any time(t), the total components of DR is:-

$$Q_t = \sum_{i=1}^{M} Q_i = \sum_{i=1}^{M} R_i\, u(t-(i-1)D)$$

thus,

$$\left.\begin{aligned} Q_1 &= R_1 u_1 \\ Q_2 &= R_2 u_1 + R_1 u_2 \\ Q_3 &= R_3 u_1 + R_2 u_2 + R_1 u_3 \end{aligned}\right\} DRH = Q_t$$

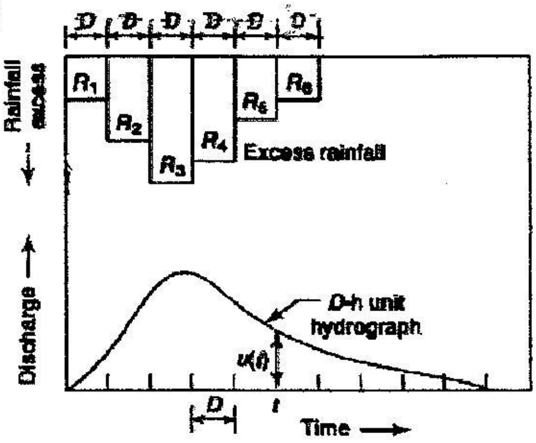


Fig. 16 DRH due to an ERH

Example 6

The ordinates of 6-h UH is given below:-

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
Ordinate of 6-h UH	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

Derive the flood hydrograph in the catchment due to the storm as;

Time from start of storm (h)	0	6	12	18
Accumulated rainfall (cm)	0	3.5	11.0	16.5

and the storm loss of rate (ϕ-index) for the catchment is estimated as 0.25 cm/hr. The base flow was assumed to be 15 m^3/s at the begining and increasing by 2 m^3/s for every 12 hrs till the end of hydrograph.

Solution;

Interval	First 6-hrs.	Second 6-hrs.	Third 6-hrs.
Rainfall depth (cm)	3.5	11-3.5 = 7.5	16.5 - 11 = 5.5
loss @ 2.5 cm/hr for each 6 hrs.	1.5	1.5	1.5
Effective rainfall (cm)	2	6	4

Calculation of Flood Hydrograph due to a known *ERH* of example 6.

Time	Ordinates of UH	DRH due to 2 cm ER Col. 2 × 2.0	DRH due to 2 cm ER Col. 2 × 6.0 (Advanced by 6 h)	DRH due to 4 cm ER Col. 2 × 4.0 (Advanced by 12 h)	Ordinates of final DRH (Col. 3 + 4 + 5)	Base flow (m^3/s)	Ordinates of flood hydrograph (m^3/s) (Col. 6 + 7)
1	2	3	4	5	6	7	8
0	0	0	0	0	0	15	15
3	25	50	0	0	50	15	65
6	50	100	0	0	100	15	115
9	85	170	150	0	320	15	335
12	125	250	300	0	550	17	567
15	160	320	510	100	930	17	947
18	185	370	750	200	1320	17	1337
(21)	(172.5)	(345)	960	340	1645	(17)	1662
24	160	320	1110	500	1930	19	1949
(27)	(135)	(270)	(1035)	640	1945	19	1964
30	110	220	960	740	1920	19	1939
36	60	120	660	640	1420	21	1441
42	36	72	360	440	872	21	893
48	25	50	216	240	506	23	529
54	16	32	150	144	326	23	349
60	8	16	96	100	212	25	237
66	(2.7)	(5.4)	48	64	117	25	142
69	0	0	—	—	—	—	—
72		0	16	32	48	27	75
75		0	0	—	—	—	—
78		0	0	(10.8)	(11)	27	49
81				0	0	27	27
84						27	27

Note: Due to the unequal time intervals of unit hydrograph ordinates, a few entries, indicated in parentheses have to be interpolated to complete the table.

Derivation of Unit Hydrograph اشتقاق الهيدروغراف القياسي

The flood hydrograph used in the analysis should be selected to meet the following

- The storm must be isolated storm occurring individually.
- The rainfall should be fairly uniform through the duration over the entire catchment.
- The duration of rainfall ranged from ($\frac{1}{5}$ – $\frac{1}{3}$) of the basin Lag.
- The rainfall excess of the selected storm should be high (1–4 cm).

ملاحظة: للكابات الأكبر من 250 كم² تأخذ فترة 6 - 12 ساعة
تعد مقبولة.

Eample 7

The following are the ordinates of storm hydrograph of a catchment area 423 km² due to 6-hr isolated storm. Derive the 6-hr unit hydrograph for this catchment.

Time from start of storm (h)	–6	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102
Discharge (m^3/s)	10	10	30	87.5	115.5	102.5	85.0	71.0	59.0	47.5	39.0	31.5	26.0	21.5	17.5	15.0	12.5	12.0	12.0

Solution

From Fig(17) which the flood hydrograph was plotted on ;-

A = begining of DRH → t=0
B = end of DRH → t=90h
P = Peak of DRH → t=20h

assuming base flow varied linearly from 10 m^3/s at t=6 to 12.5 m^3/s at t=90h

$\frac{12.5-10}{96} = 0.026$ (≈0.5 each 18 hrs.)

Checking of position B :

$N = 0.83(423)^{0.2} = 2.78$ day

from observation = 90−20 = 70h = 2.91 day

However N=2.91 days is adopted here.

From table below (col.4) volume of DRH is equal to $= 587 \times 6 \times 60 \times 60 = 12.68 \times 10^6\ m^3$

depth $= \frac{12.68 \times 10^6}{423 \times 10^6} \times 100 = 3$ cm

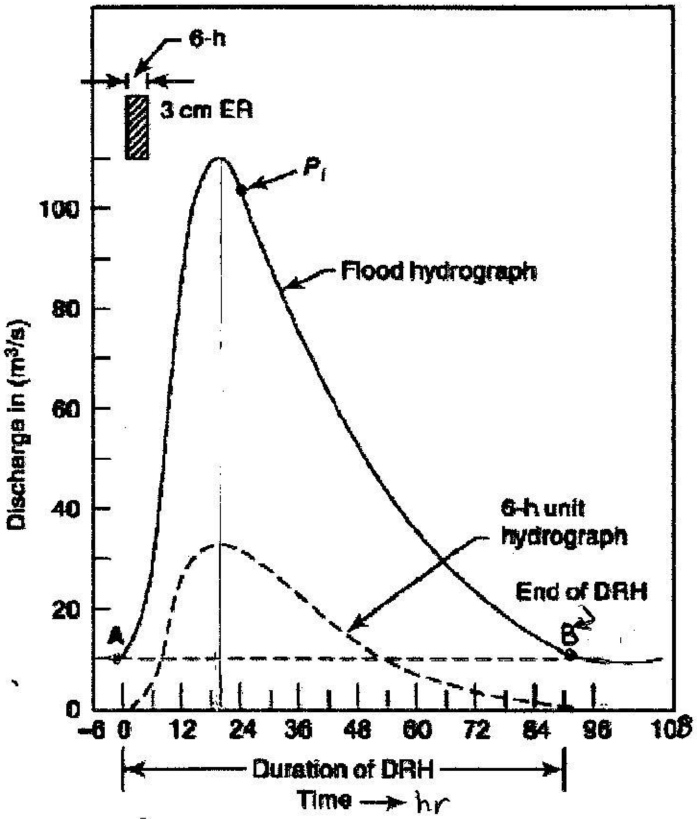


Fig.17 Drivation of UH from a flood Hydrograp

Time from beginning of storm (h)	Ordinate of flood hydro-graph (m^3/s)	Base Flow (m^3/s)	Ordinate of DRH (m^3/s)	Ordinate of 6-h unit hydro-graph (Col. 4)/3
1	2	3	4	5
–6	10.0	10.0	0	0
0	10.0	10.0	0	0
6	30.0	10.0	20.0	6.7
12	87.5	10.5	77.0	25.7
18	111.5	10.5	101.0	33.7
24	102.5	10.5	92.0	30.7
30	85.0	11.0	74.0	24.7
36	71.0	11.0	60.0	20.0
42	59.0	11.0	48.0	16.0
48	47.5	11.5	36.0	12.0
54	39.0	11.5	27.5	9.2
60	31.5	11.5	20.0	6.6
66	26.0	12.0	14.0	4.6
72	21.5	12.0	9.5	3.2
78	17.5	12.0	5.5	1.8
84	15.0	12.5	2.5	0.8
90	12.5	12.5	0	0
96	12.0	12.0	0	0
102	12.0	12.0	0	0
		sum=	587	195.7

HW

(a) *The peak of flood hydrograph due to a 3-h duration isolated storm in a catchment is 270 m3/s. The total depth o f rainfall is 5.9 cm. Assuming an average infiltration loss of 0.3 cm/h and a constant base flow of 20 m^3/s, estimate the peak of the 3-h unit hydrograph (UH) of this catchment.*

(b) *If the area of the catchment is 567 km² determine the base width of the 3-h unit hydrograph by assuming it to be triangular in shape.*

Unit Hydrograph for Different Durations

الهيدروغراف لاستدامات مختلفة

Two methods are available for developing a unit Hydrograph for different durations:

1. Superposition method
2. S-curve method

Superposition method طريقة الانطباق

If a D-h hydrograph (UH) is available, and it is desired to develop a unit hydrograph of nD-h where n is an integer, one can use this method

تشترط الطريقة أن يكون الهيدروغراف القياسي المرغوب في استخدامه هو لاستدامة مقدارها (n*D) حيث n عدد صحيح موجب و D استدامة الهيدروغراف الذي نستعمل في الاشتقاق. وعليه فإن هذه الطريقة لا تصلح في الحالات التي يكون فيها الهيدروغراف القياسي ذو استدامة أقل من الشرط. أي $n>1$

Example 8: Given UH-4hrs, Derive UH-12hr.

Time (h)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinate of 4-h UH	0	20	80	130	150	130	90	52	27	15	5	0

Solution:

Time (h)	Ordinates of 4-h UH (m^3/s)			DRH of 3 cm in 12-h (m^3/s) (Col. 2+3+4)	Ordinate of 12-h UH (m^3/s) (Col. 5)/3
	A	*B* Lagged by 4-h	*C* Lagged by 8-h		
1	2	3	4	5	6
0	0	—	—	0	0
4	20	0	—	20	6.7
8	80	20	0	100	33.3
12	130	80	20	230	76.7
16	150	130	80	360	120.0
20	130	150	130	410	136.7
24	90	130	150	370	123.3
28	52	90	130	272	90.7
32	27	52	90	169	56.3
36	15	27	52	94	31.3
40	5	15	27	47	15.7
44	0	5	15	20	6.7
48		0	5	5	1.7
52			0	0	0

From table of example -8- the procedure is:

1. Col.1 and col.2 are given.
2. Col.3 is generated by lagged col.2 D-hr (4hr)
3. Col.4 is generated by lagged col.2 2D-hr (8hr)
4. Col.5 is obtained by Adding col.2, col 3 & col.4.
5. Divide col.5 by 3cm to get UH-12hrs.

ملاحظة:

عدد مرات الترحيل للأعمدة = استدامة المطلوب / استدامة المعطى − ١

$\frac{12}{4} - 1 = 2$ هو 2 أي أن عدد مرات الترحيل كما هو في الجدول المثال

(عدد مرات توليد أعمدة مزحفة = 2 أضافة 1) العمود الأصلي أن Col.2)

كما موضح في الشكل رقم (18).

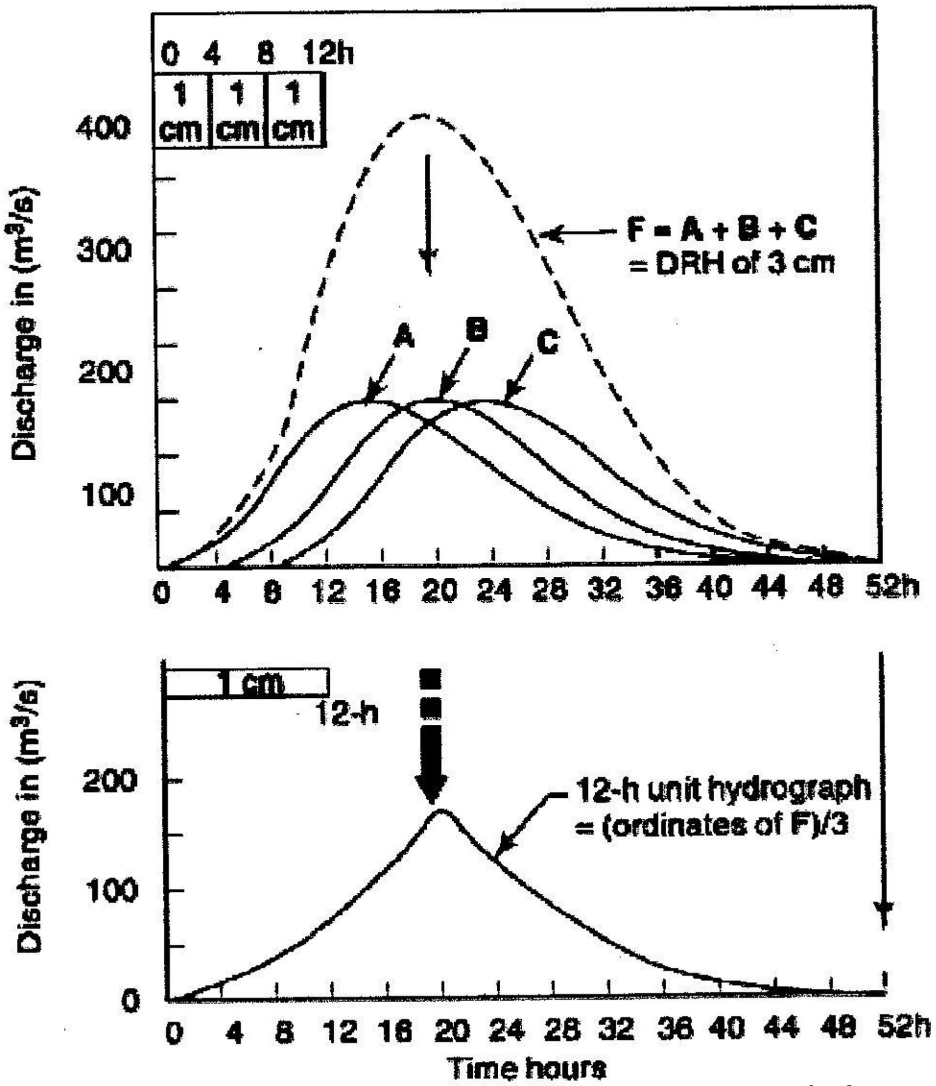


Fig. 18 Construction of a 12-h Unit Hydrograph from a 4-h Unit Hydrograph – Example 8

S-curve method — طريقة المنحني S

If it is desired to develop a unit hydrograph of duration nD where n is a fraction, the method of superposition can not be used. A technique known as S-curve is adopted.

The S-curve (some time called S-hydrograph) is produced by continuous effective rainfall (ER) at constant rate for infinite period, and obtained by summation of infinite series of D-h unit hydrograph arranged with their starting point D-h apart as shown in Fig (19).

المنحني S (الهيدروغراف S) هو هيدروغراف ناتج عن امطار مؤثرة (ER) مستمرة
بمعدل ثابت لزمن غير محدد ويتم الحصول على هذا المنحني المبين في الشكل (19)
من جمع سلاسل غير منتهية من هيدروغرافات تبعد عن بعضها البعض بفارق D-h .

ملاحظة: في البناء الحقيقي للمنحني S نلاحظ تذبذب في الجزء العلوي من المنحني وهو قمة التصريف المتوازن بسبب تجمع الامطار الصغيرة ففي هذه الحالة يصل المنحني حيث يصل Q_s عند وقت القاعدة للهيدروغراف القياسي أي (TB).

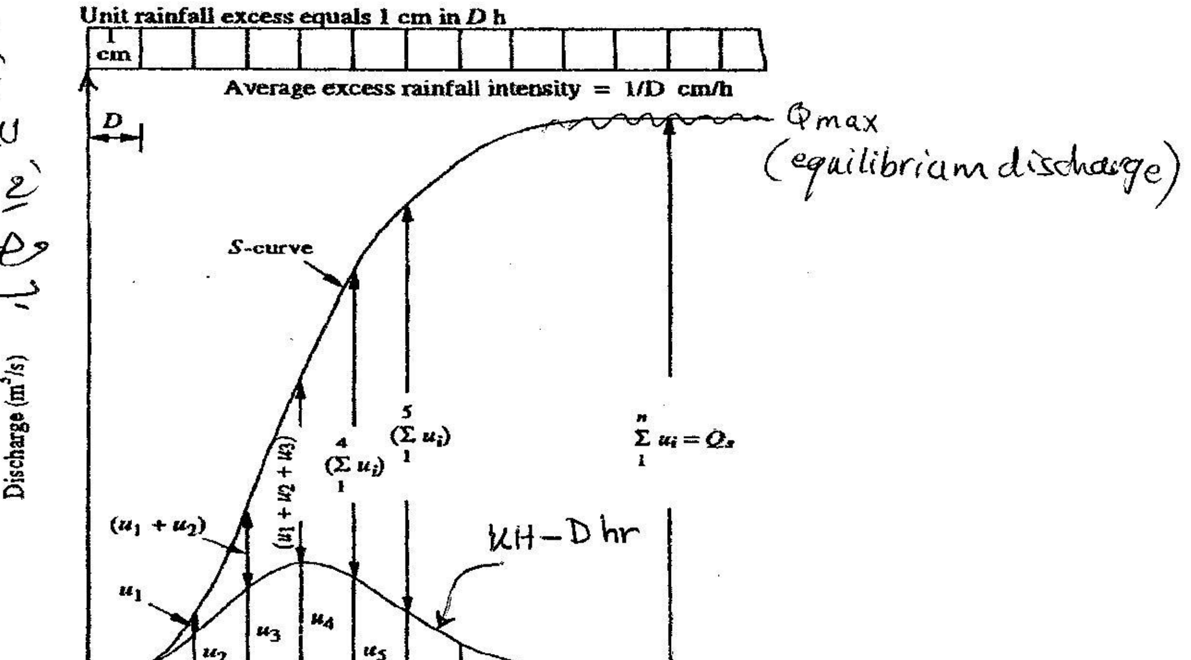


Fig. 19 S-curve

$$Q_{max} = Q_{equilibrium} = \left(\frac{A}{D} \times 10^4\right) \; m^3/hr$$

لان الشدة المطرية $= \frac{1\,cm}{D}$ واذا ما ضربت في المساحة انتجت حجماً/زمن وهو التصريف

$$\Rightarrow \frac{\frac{1/100}{D\,hr} * A\,km^2 * 10^6}{3600} = 2.778 \frac{A\,km^2}{D\,hr} = Q_{equil.}\; m^3/sec$$

Application the method to find T-hr UH

Consider D-h S-curves A & B displaced by T-h as shown in Fig (20). If the ordinates of B are subtracted from that of A. The resulting curve is DRH produced by rainfall excess of duration T and depth $= I * T = \frac{1}{D} * T = T/D$ cm. Hence the ordinates of $(S_A - S_B)$ are divided by (T/D) to get UH of T-hr.

أي أن منحنى A و B لهما شكل S والإزاحة بينهما هو T. وإذا طرحت S_B من S_A بعد الإزاحة المذكورة فإن الناتج سيكون DRH لاستدامة مطر قدرها T وعمق = شدة المطر × الزمن = $\frac{1}{D} * T = T/D$ سم ولذا وجب قسمة إحداثيات $(S_A - S_B)$ على T/D لنحصل على UH-T hr

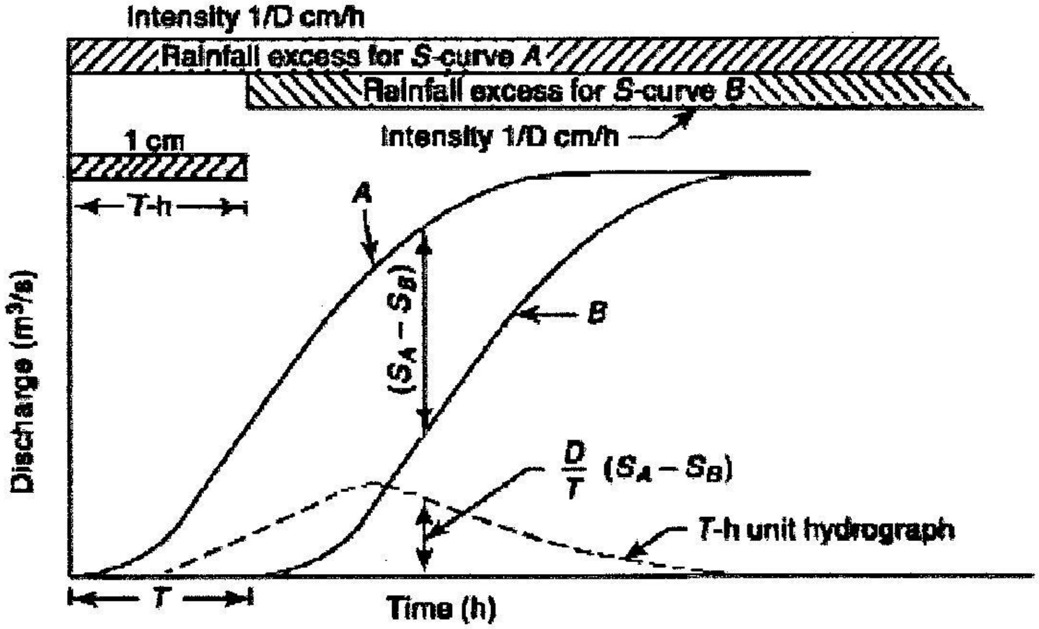


Fig. 20 Derivation of a T-h Unit Hydrograph by S-curve Lagging Method

Example 9: solve example 8 by using S-curve

Col. 2 → ordinates of 4h-UH
Col. 3 → S-curve addition
Col. 4 → S_A ordinates
Col. 5 → S_B (S_A displaced by T)
Col. 6 → $S_A - S_B$
Col. 7 → $UH = \frac{S_A - S_B}{T/D}$

ملاحظة: الإزاحات عدد اثنان
الأول: ترحيل عمود الإضافة بمقدار D
الثاني: ترحيل S_B بمقدار (T/D)
وبدون تراجع ١١

Time (h)	Ordinate of 4-h UH (m^3/s)	S-curve addition (m^3/s)	S-curve ordinate (m^3/s) (Col. 2 + Col. 3)	S-curve lagged by 12 h (m^3/s)	(Col. 4 − Col. 5)	Col. 6 / (12/4) = 12-h UH ordinates (m^3/s)
1	2	3	4	5	6	7
0	0	—	0	—	0	0
4	20	0	20	—	20	6.7
8	80	20	100	—	100	33.3
12	130	100	230	0	230	76.7
16	150	230	380	20	360	120.0
20	130	380	510	100	410	136.7
24	90	510	600	230	370	123.3
28	52	600	652	380	272	90.7
32	27	652	679	510	169	56.3
36	15	679	694	600	94	31.3
40	5	694	699	652	47	15.7
44	0	699	699	679	20	6.7
48	—	699	699	694	5	1.7
52	—	699	699	699	0	0
56 = 44+3(4)	Σ1460		699	699	0	0 Σ=699

Example 10:

Ordinates of a 4-h unit hydrograph are given. Using this derive the ordinates of a 2-h unit hydrograph for the same catchment.

Time (h)	0	4	8	12	16	20	24	28	32	36	40	44
4-h UH Ordinate (m^3/s)	0	20	80	130	150	130	90	52	27	15	5	0

Solution: In this problem ,the time interval of a given unit hydrograph should be at least of **T** ,i.e.,2hrs . Some interpolated values of 4hr-UH are required ,thus a plot or linear interpolation are accepted.

Time (h)	Ordinate of 4-h UH (m^3/s)	S-curve addition (m^3/s)	S-curve ordinate (Col. (2) + (3)) (m^3/s)	S-curve lagged by 2 h	(Col. (4) – Col. (5)) DRH of $\left(\frac{2}{4}\right)$ = 0.5 cm	2-h UH ordinates $\frac{\text{Col. (6)}}{(2/4)}$ (m^3/s)
1	2	3	4	5	6	7
0	0	—	0	—	0	0
2	8	—	8	0	8	16
4	20	0	20	8	12	24
6	43	8	51	20	31	62
8	80	20	100	51	49	98
10	110	51	161	100	61	122
12	130	100	230	161	69	138
14	146	161	307	230	77	154
16	150	230	380	307	73	146
18	142	307	449	380	69	138
20	130	380	510	449	61	122
22	112	449	561	510	51	102
24	90	510	600	561	39	78
26	70	561	631	600	31	62
28	52	600	652	631	21	42
30	38	631	669	652	17	34
32	27	652	679	669	10	20
34	20	669	689	679	10	(20)15 → 16
36	15	679	694	689	5	(10)10 → 12
38	10	689	699	694	5	(10)6 → 8
40	5	694	699	699	(0)	(0)3 → 4
42	2	699	701	699	(2)	(4)0 → 0
44	0	699	699	701	(–2)	(–4)0 → 0
	∑=1400					∑= (1398) 1392 → 1400

–Final adjusted values are given in col. 7.

–Unadjusted values are given in parentheses.

((تحويل UH من فترة كبيرة إلى صغيرة باستخدام طريقة S-curve))

ملحق - 22

Example: Derive UH-2hrs. from UH-4hrs. as given below, Using S-curve method (mandatory).

time (hr):	0	4	8	12	16	20	24	28	32	36	40	44
Q (m^3/s)	0	20	80	130	150	130	90	52	27	15	5	0

ملاحظات مهمة:

١. طريقة الانطباق (S.P.) لا تصلح لهذا المثال لأن التحويل من D=4hr إلى T=2hr والسبب أن (T/D=1/2) أي(المطلوب /الموجود) سيصبح كسرا ، والطريقة هذه تعتمد فقط الأرقام الصحيحة (Integer) ، لذا ستعتمد الطريقة العامة وهي الـ (S-curve).

٢. نحتاج إلى قيم وسطية عند كل ساعتين (المطلوب T=2hr) لذا سيتم استكمال القيم تقريبيا لتأسيس العمود الأول والثاني لجدول الحل في أدناه.

٣. العمود الثالث (عمود الإضافة) مهم جدا وهو مفتاح الحل ، نبدأ بتزحيف العمود بمقدار D بحيث يكون صفرا عند بداية الفترة الثانية ولا يُلتفت إلى فترة الأرقام الوسطية حيث لا تعتبر فترتها أصلية بل أن فترتها(T=2hr) تعد مستحدثة.

٤. ضع شارحة(-) في مربع التزحيف لتمييزها عن البداية الصفرية للهيدروغراف بالرغم من أنها تحسب صفرا عند الجمع .

٥. بعده يتم تاسيس عمود الإضافة بالجمع المتراكم للأرقام الأصلية وإكمالها إلى آخر الجدول ، ثم الشروع بجمع الأرقام التي تم استكمالها جمعا تراكميا بصورة منفصلة ولكل القيم ، كل ذلك لتجنب الالتباس أو الخطأ.

٦. أجمع العمود الثاني مع عمود الإضافة للحصول على العمود الرابع (S-curve ordinates: SA)، ثم زحف هذا العمود الجديد بمقدار T=2hr للحصول على(S-curve ordinates: SB).

٧. أطرح SB من SA للحصول على العمود السادس، ثم أضرب قيم هذا العمود× (D/T) للحصول على قيم العمود السابع الذي يمثل (UH -2 hr) ولاحظ أن T=2hr. ويمكن التحقق من القيم بإيجاد مجموع قيم العمود السابع ومقارنته بمجموع قيم العمود الثاني، ويجب أن يكونا متساويين.

٨. تعدل القيم الأخيرة للعمود السابع ، إذا تطلب الأمر و حسب السياق الطبيعي لمنحنى الهيدروغراف القياسي الذي يجب أن ينتهي عند الصفر . تصحح هذه القيم حال ملاحظة زيادة في القيم أو تذبذبا فيها، في حين يجب أن تأخذ مسار تنازلي،ويحدث ذلك جرّاء عدم دقة القيم التي تم استكمالها لإنتاج الهيدروغراف المطلوب.

Time	UH-4hr	S-curve addition	S-curve ordinates (SA)	S-curve ordinates (SB)	SA-SB	UH-2hr	
0	**0**	(−)	0	(−)	(−)	0	
2	8	(−)	8	0	8	16	
4	**20**	**0**	20	8	12	24	
6	43	8	51	20	31	62	
8	**80**	**20**	100	51	49	98	
10	110	51	161	100	61	122	
12	**130**	**100**	230	161	69	138	
14	146	161	307	230	77	154	
16	**150**	**230**	380	307	73	146	
18	142	307	449	380	69	138	
20	**130**	**380**	510	449	61	122	
22	112	449	561	510	51	102	
24	**90**	**510**	600	561	39	78	
26	70	561	631	600	31	62	
28	**52**	**600**	652	631	21	42	
30	38	631	669	652	17	34	
32	**27**	**652**	679	669	10	20	
34	20	669	689	679	10 ?	20 →	16 / 17
36	**15**	**679**	694	689	5 ?	10 →	12 / 13
38	10	689	699	694	5 ?	10 →	8 / 9
40	**5**	**694**	699	699	0 ?	0 →	4 / 3
42	2	699	701 ?	699	2 ?	4 →	2 / 0
44	**0**	**699**	699	701 ?	-2 ?	-4	0
Σ=	1400					Σ=	1400

← مرحلة أولى

- - - - مرحلة لاحقة

Solving of Example-10 by shortened method.

DR. Rasul M. Khelif

Time	4h-UH	S-hydrograph S_A	S_B	DRH=(S_A-S_B)	2h-UH	
0	0	0	--	0	0	
2	8	8	0	8	16	
4	20	20	8	12	24	
6	43	51	20	31	62	
8	80	100	51	49	98	
10	110	161	100	61	122	
12	130	230	161	69	138	
14	146	307	230	77	154	
16	150	380	307	73	146	
18	142	449	380	69	138	
20	130	510	449	61	122	
22	112	561	510	51	102	
24	90	600	561	39	78	
26	70	631	600	31	62	
28	52	652	631	21	42	
30	38	669	652	17	34	
32	27	679	669	10	20	
34	20	689	679	10	20 →	~~16~~ 17
36	15	694	689	5	10 →	~~12~~ 13
38	10	699	694	5	10 →	~~8~~ 9
40	5	699	699	0	0 →	~~4~~ 3
42	2	701	699	2	4 →	0
44	0	699	701	-2	- 4 →	0
	1400				1398	1400

Additional Example (shortened method)

*Ordinates of a 4-h unit hydrograph are given. Using this derive the ordinates of a **3**-h unit hydrograph for the same catchment.*

Time	4h-UH	S-hydrograph SA	SB	DRH=(SA-SB)	3h-UH = DRH * 4/3	
0	0	0	--	0	0	
1	6	6	--	6	8.0	
2	36	36	--	36	48.0	
3	66	66	0	66	88.0	
4	91	91	6	85	113.3	
5	106	112	36	76	101.3	
6	93	129	66	63	84.0	
7	79	145	91	54	72.0	
8	68	159	112	47	62.7	
9	58	170	129	41	54.7	
10	49	178	145	33	44.0	
11	41	186	159	27	36.0	
12	34	193	170	23	30.7	
13	27	197	178	19	25.3	
14	23	201	186	15	20.0	
15	17	203	193	10	13.3	
16	13	206	197	9	12.0	
17	9	206	201	5	6.7	
18	6	207	203	4	5.3	
19	3	206	206	0	0.0 →	1.2
20	1.5	207.5	206	1.5	2.0 →	0
21	0	206	207	-1	-1.3 →	0
	826.5				826	826.5

Synthetic Unit Hydrograph الهيدروغراف القياسي المصطنع

The most of Catchments especially those which are at remote locations, have not adequate information about rainfall and the resulting flood hydrograph, or normally scanty. Therefore to construct the UH for such area, empirical equations or curves were used to derive it but of regional validity.

The unit hydrograph derived from empirical correlations is known as synthetic hydrograph. Many methods are availables, but two of well-known of these are currently used in the world. The first is the Natural Resources Conservation service (NRCS) which previously called US-SCS (Soil Conservations service), the other method is Snyder's. The Snyder's method is considered herein.

Snyder Method

Snyder in 1938, developed a set of empirical equations for synthetic hydrograph which recieved some modifications in many countries. The most important characteristic affecting the hydrograph is basin Lag (Time Lag T_L) measured from centroid of excess rainfall (ER), and the centriod of DRH. For practical purposes, the Lag time is measured from centriod of ER to peak of DRH and it is defined as the mean time of travel of water from all parts of the watershed to the outlet during a given storm يعرف T_L بأنه المعدل الزمني الذي تستغرقه كل

الماء من جميع اجزاء الساحة الى المخرج خلال عاصفة مطرية.

Synder defined the basin Lag as the time interval from mid-point of rainfall Excess to the peak of unit hydrograph, and formulated in equation as;

$$t_p = C_1 C_t (L L_c)^{0.3} \quad \text{------------} (7)$$

t_p = basin Lag (hr)

L = basin length measured from basin divide to the gauging station (Km, mile)

L_c = distance from centroid of watershed to the gauging station (km, mile)

C_t = regional constant including storage effects and slope (C_t is ranged from $1.8 \rightarrow 2.2$)

C_1 = conversion constant of units ($C_1 = \frac{3}{4}$ for metric system, $C_1 = 1$ for customary units)

i.e,

$$t_{p_{hr}} = \frac{3}{4} C_t (L_{km} L_{c_{km}})^{0.3}$$

$$t_{p_{hr}} = C_t (L_{mile} L_{c_{mile}})^{0.3}$$

Snyder adopted Standard duration t_r (hr) as;

$$t_{r_{(hr)}} = \frac{t_p}{5.5} \quad \text{------------} (8)$$

The peak discharge Q_p for a unit hydrograph of standard duration t_r is;

$$Q_p = \frac{C_2 \, C_p \, A_{km^2}}{t_{p\,(hr)}} \quad \text{------------} (9)$$

C_p = peak discharge coefficient ranged from $0.56 \rightarrow 0.69$

C_2 = Conversion constant of units :-

($C_2 = 2.78$ for 1cm depth, A (km^2), Q m^3/sec)

($C_2 = 645$ for 1inch depth, A $mile^2$, Q ft^3/sec)

i.e

$$Q_{p_{m^3/sec}} = \frac{2.78 \, C_p . A}{t_p}$$

for metric system

If non-standard duration of rainfall, t_R is adopted (instead of t_r), thus, the modified basin Lag, t_p' is given by;

$$t_p' = t_p + \frac{t_R - t_r}{4}$$

$$\text{or; } t_p' = \frac{21}{22} t_p + \frac{t_R}{4} \qquad (10)$$

t_p' = basin Lag (hr) for duration of excess rainfall of t_R (hr).

Note:
eq(9) for t_p' is; $Q_p' = \frac{C_2 C_p A}{t_p'}$, and when $t_R = t_r \Rightarrow t_p' = t_p \Rightarrow Q_p' = Q_p$.

The time base T_B is given by Snyder as;

$$T_B = 72 + 3 t_p' \qquad (11)$$

(hr)

It is suitable for large catchment or moderate say $> 500 \, km^2$

$$T_B = 5\left(t_p' + \frac{t_R}{2}\right) \qquad (12)$$ حالة عامة

Suitable for small catchments.

For standard duration ($t_R = t_r$) $T_B = \frac{60}{11} t_p$ — (13) حالة خاصة

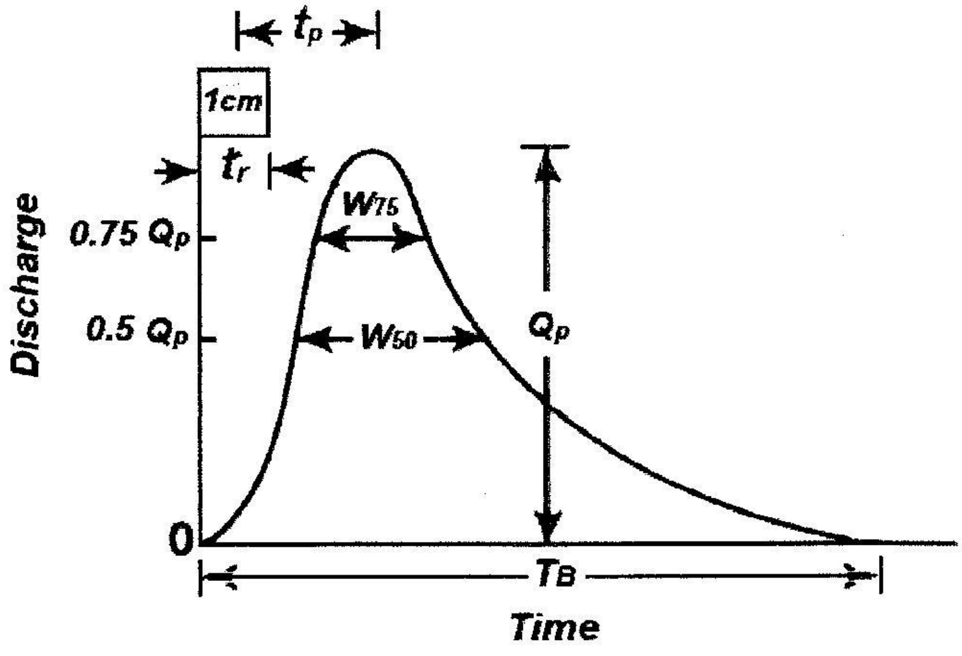


Fig. 21—Elements of a Synthetic Unit Hydrograph

To assist the sketching of unit hydrograph, the width of units (of course time) at 50% and 75% of the peak discharge have been found by US Army Corps of Engineers as; see Fig (21).

$$W_{50} = \frac{2.144}{q^{1.08}}, \quad W_{75} = \frac{4}{7} W_{50} \qquad (14)$$

In which $q = Q_P/A$ = peak discharge per unit Area $(m^3/s/Km^2)$

Alternatively, the more reliable value of T_B is derived from the fact that the area under UH is equivalent to direct runoff of 1 cm assuming triangular shape yields;

$$T_B = \frac{\left(\frac{50}{9}\right)}{q} = \frac{5.56}{q} \qquad (15)$$

If the area under curve of UH approximated by trapezoidal segment, it yields (as shown in Fig 22)

$$1\,cm = \frac{1}{A}\left[\frac{W_{50}+T_B}{2} * 0.5\,Q_p + \frac{W_{50}+W_{75}}{2} * 0.25\,Q_p + \frac{W_{75}}{2} * 0.25\,Q_p\right]\left(\frac{hr}{Km^2}\cdot\frac{m^3}{Sec}\right) * 0.36$$

Subs. W_{50} & W_{75} from eq (14) and approximate $q^{1.08} \approx q$; yields

$$T_B = \frac{6.67}{q} \qquad (16)$$

~~i.e.: $T_B = \left(\frac{60}{9}\right)/q$~~

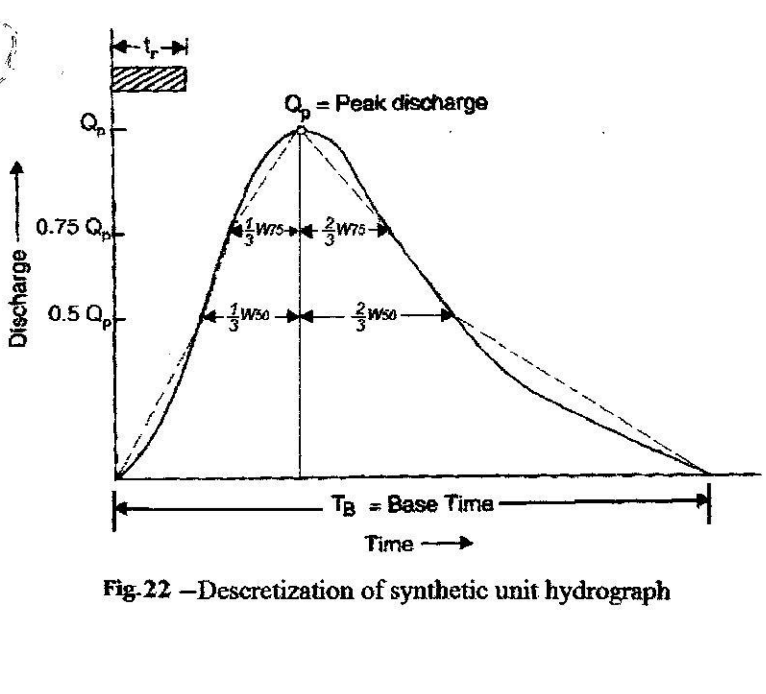


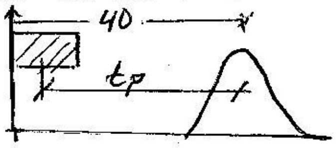
Fig.22 –Descretization of synthetic unit hydrograph

Example 11:

From the topographical map of drainage basin, the following quantities are measured: $A = 3480\ km^2$, $L = 235\ km$, $L_c = 120\ km$. The 12hr UH derived for the basin has a peak discharge of $155\ m^3/s$ occurring at 40 hrs. Determine the coefficients C_t & C_p for the synthetic Hydrograph.

Solution:

Note: If duration is given, it is mostly $t_R \neq t_r$ and must be checked.



$t_R = 12hr$, $t_p' = 40 - \frac{12}{2} = 34\ hr$

$t_p' = t_p + \frac{t_R - t_r}{4} \Rightarrow t_p' = t_p + \frac{t_R}{4} - \frac{t_p}{4(5.5)}$

$t_p = \left(34 - \frac{12}{4}\right)\frac{22}{12} = 32.48\ h \Rightarrow t_r = \frac{t_p}{5.5} = 5.90\ hr.$

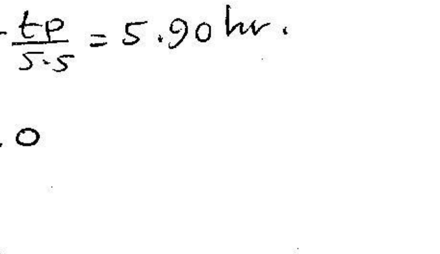
$t_p = \frac{3}{4} C_t (235 \times 120)^{0.3} = 32.48 \Rightarrow C_t = 2.0$

$Q_p' = \frac{2.78\, C_p\, A}{t_p'} \Rightarrow 155 = \frac{2.78\, C_p\, (3480)}{34}$

thus; $C_p = 0.545$

Example 12:

Derive a 3-hr synthetic unit hydrograph of a basin with Area = $3000\ km^2$, Length of main stream = 120 km, distance from centroid of the basin to the outlet = 63 km, $C_t = 2.10$, $C_p = 0.64$



$t_p = \frac{3}{4}(2.1)(120 \times 64)^{0.3} = 23.06\ hr$

$t_r = \frac{t_p}{5.5} = \frac{23.06}{5.5} = 4.19\ hr$

$t_R = 3\ hr$ (given)

$t_p' = t_p + \frac{t_R - t_r}{4} = 23.06 + \frac{3 - 4.19}{4} = 22.76\ hr$

$Q_p' = \frac{2.78(0.64)(3000)}{22.76} = 234.52\ m^3/sec$

$T_B = \frac{6.67}{Q/A} = \frac{6.67(3000)}{234.52} = 85.3\ hr$

$W_{50} = \frac{2.144}{Q/A} = 27\ hr$

$W_{75} = \frac{4}{7}(27) = 15.67\ hr$

(ملاحظات مهمة)

1. إذا كان لديك على مقطع عرضي لنهر فيه (n) من محطات القياس فيتوجب حساب التصريف في (n-2) من المقاطع الصغيرة ، لأن حسابها في أكثر من ذلك يعني قياس السرع عند الضفاف وهذا غير مقبول مطلقا.

2. لاحظ أن التصريف الكلي يجب إيجاده بجمع التصاريف الجزئية وليس الاكتفاء بإيجاد هذه التصاريف دون تدوين نتيجة التصريف.

3. السرع والتصاريف تعامل لثلاث مراتب بعد الفارزة. لأن دقة كبيرة أي (م³/ثا) .

4. الهيدروغراف يجب أن يبدأ بصفر وينتهي بصفر ، أليس كذلك ؟ فلماذا نهمل الصفر الأخير !!! كما أن على الطالب التحقق (Checking) من النتائج عند إجراء حسابات الهيدروغراف.

5. عند إجراء عملية التزحيف (shifting) عند حساب الهيدروغراف في أي من الطرق المعروفة ، يجب تمديد عمود الزمن ليتناسب مع التزحيف وقيمه المقابلة.

Derivations:

$$Q_p = C_p \frac{\text{Volume}}{\text{time}}$$

If Area is in *mil*^{2} and depth in *inch* (unit depth), Q_p in *ft*^{3}*/sec*, and time in *hour*, thus;

$$Q_{p\,(ft^3/sec)} = C_p \frac{A \times (5280)^2\,ft^2 \times \frac{\text{depth(1 inch)}}{12}}{t_p \times (3600)}$$

$$Q_{p\,(ft^3/sec)} = 645\,C_p \frac{A_{(mil^2)}}{t_{p\,(hr)}} \quad \text{for unit depth 1 – inch.}$$

So as for Area is in *km*^{2} and depth in *cm* (unit depth), Q_p in *m*^{3}*/s*, and time in *hour*, thus;

$$Q_{p\,(m^3/s)} = C_p \frac{A \times (1000)^2\,m^2 \times \frac{\text{depth(1cm)}}{100}}{t_p \times (3600)}$$

$$Q_{p\,(m^3/s)} = 2.78\,C_p \frac{A_{(Km^2)}}{t_{p\,(hr)}} \quad \text{for unit depth 1 – cm.}$$

$$w_{50(hr)} = \frac{770}{q^{1.08}} \qquad q \text{ is } \frac{Q_p}{A} \text{ measured in } \frac{ft^3/s}{mil^2} \quad \text{for 1 – inch depth.}$$

Hence, the dimension of the factor (770) is: $hr \times \left[\frac{ft^3/s}{mil^2 \times inch}\right]^{1.08}$

The factor (770) can be reduced im metric system as:

$$= 770 \times hr \times \left[\frac{ft^3}{s} \times \frac{m^3}{(3.281)^3 \times ft^3} \times \frac{1}{mil^2} \times \frac{mil^2}{(1.609)^2 \times km^2} \times \frac{1}{inch} \times \frac{1 \times inch}{2.54 \times cm}\right]^{1.08}$$

$$= 770 \times \left[\frac{1}{(3.281)^3} \times \frac{1}{(1.609)^2} \times \frac{1}{2.54}\right]^{1.08} hr \times \left[\frac{m^3/s}{km^2 \times cm}\right]^{1.08}$$

$$= \left[\frac{770}{(232.2547)^{1.08}}\right] hr \times \left[\frac{m^3/s}{km^2 \times cm}\right]^{1.08} = 2.144 \text{ of units} : hr \times \left[\frac{m^3/s}{km^2 \times cm}\right]^{1.08}$$

And thus;

$$w_{50(hr)} = \frac{2.144}{q^{1.08}} \qquad q \text{ is } \frac{Q_p}{A} \text{ measured in } \frac{m^3/s}{km^2} \quad \text{for 1 – cm depth.}$$

The factor (5.87) is followed wrongly in the text, through replacing the right factor 2.144, since it was derived for metric system but with 1-inch not 1-cm.

↑ ٢٠٢ ,5.87

Snyder conversions

Basic formulae:

$$Q_{p\ (m^3/s)} = 2.78 C_p \frac{A_{(Km^2)}}{t_{p\ (hr)}}$$ for unit depth (1- cm).

$$Q_{p\ (ft^3/sec)} = 645\, C_p \frac{A_{(mil^2)}}{t_{p\ (hr)}}$$ for unit depth (1- inch).

C_p is ranged from 0.56 to 0.69 for both systems of units .

$$t_{p\ (hr)} = \frac{3}{4} C_t \left[L_{(km)} L_{c\ (km)}\right]^{0.3}$$

$$t_{p\ (hr)} = C_t \left[L_{(mil)} L_{c\ (mil)}\right]^{0.3}$$

C_t is ranged from 1.8 to 2.2 for both systems of units .

$$w_{50(hr)} = \frac{770}{q^{1.08}}$$ q is in $\frac{ft^3/s}{mil^2}$ for 1 − inch depth.

$$w_{50(hr)} = \frac{2.144}{q^{1.08}}$$ q is in $\frac{m^3/s}{km^2}$ for 1 − cm depth.

$$w_{75(hr)} = \frac{w_{50}}{1.75}$$ for both above equations.
