علم المياه (الهيدرولوجي) - المرحلة الرابعة

مراجع المقرر :

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او الهيدرولوجيا الهندسية، ترجمة جامعة الموصل

2. ***Environmental Hydrology by Ward and Trimble, 2004***
3. ***Engineering Hydrology by Linsley, 1988***

المحاضرة الاولى

الدورة المائية (الهيدرولوجية) ومعادلة الموازنة المائية وتوزيع المياه في العالم

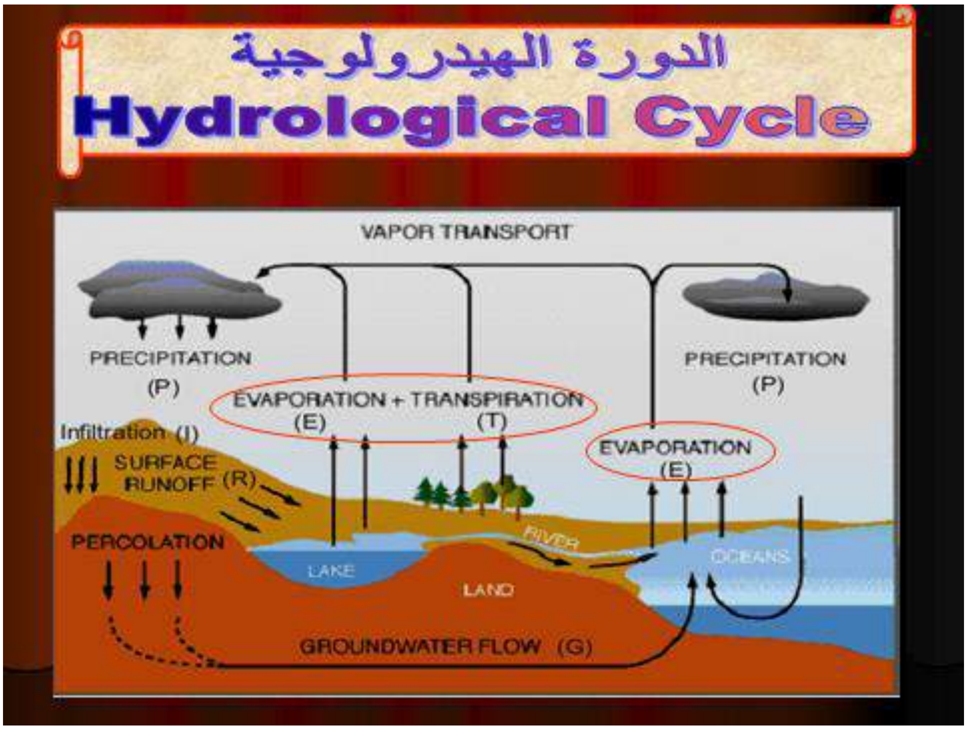
1 .1. علم المياه (الهيدرولوجي Hydrology) : هو علم الماء الذي يتعامل مع المياه من حيث تكوينها و دورتها و توزيعها فوق سطح الارض وفي الغلاف الجوي ولكونه أحد فروع علم الارض فهو يتناول بصورة اساسية مياه المحيطات و البحار و الانهار و السقيط بكافة أنواعه (المطر و الثلج و الحالوب) بالاضافة الى المياه الجوفية.

و لكون هذا العلم واسع و متشعب فإنه يتعامل مع علوم أخرى لها علاقة مباشرة بهذا العلم منها علم الانواء الجوية و الجيولوجيا و الاحصاء و الكيمياء و الفيزياء و ميكانيك الموائع ، ويقسم هذا العلم إلى قسمين:

1. **الهيدرولوجيا العلمية :** الدراسة التي تتعامل تعاملاً رئيسياً مع المواضيع النظرية.
2. **الهيدرولوجيا الهندسية (التطبيقية) :** الدراسة التي تتعامل مع المواضيع الهندسية مثل :
   - تقدير الموارد المائية.
   - دراسة العمليات مثل السقيط و السيح و التبخر الكلي و تداخلاتها.
   - دراسة المشكلات مثل الفيضان و الجفاف واستراتيجية درئها.

1 .2. الدورة الهيدرولوجية Hydrological Cycle:

حركة الماء بكافة أشكاله (أمطار وثلوج و حالوب) بين سطح الارض إلى الغلاف الجوي و بالعكس نتيجة لتأثيرات مناخية أو لحالة الجو اليومية أو الاعتيادية ، حيث أن الماء يتبخر بفعل حرارة الشمس ثم ينتقل إلى الغلاف الجوي و يتكاثف ليتزل مرة أخرى إلى المحيطات و البحار على شكل أمطار أو قد تحمل الرياح الغيوم إلى اليابسة ليسقط على سطح الارض مكوناً المجاري المائية كالانهار و الجداول أو يسقط على شكل ثلوج أو برد (حالوب) وقد يتسرب قسم كبير منه إلى جوف الارض مكوناً ما يسمى بالمياه الجوفية.



1 .3 . مسارات الدورة الهيدرولوجية Hydrological cycle Paths:

بصورة عامة و مبسطة فإن مسارات الدورة الهيدرولوجية هي :

1. السقيط precipitation 2. التبخر evaporation+ النتح transpiration 3. المياه الجوفية groundwater 4. السيح السطحي surface runoff 5. الغيض infiltration

وإن كل مسار من هذه المسارات يتضمن واحد أو أكثر من المظاهر الآتية:

أ. نقل الماء ب. خزن وقتي للماء

1 .4. معادلة الموازنة المائية Water Budget Equation:

إن مياه الجابية لمساحة معلومة خلال فترة من الزمن (Δt) تكون :

التغاير في الخزين = كتلة الخزين الداخل – كتلة الخزين الخارج

$$\Delta S = V_i - V_o$$

مثال / جابية مساحتها 15 كم^2 ، إحسب :

1. التغير في حجم الخزين (لفترة سنة) فوق الارض و تحتها لهذه الجابية إذا كان حجم الماء للجريان الداخل 8*10^4 م^3 و للجريان الخارج 6.5*10^4 م^3 ؟

2. إذا كان المعدل السنوي لجريان المجرى المائي هو 10^7 م^3 ، إحسب العمق المكافيء؟

الحل:

1. $\Delta S = V_i -$

$\Delta S = 8 * 10^4 - 6.5 * 10^4 = 1.5 * 10^4 \ m^3$

2. Average Depth = $10^7 / 1.5*10^6 = 0.667$ m. = 66.7 cm.

WATER BUDGET EQUATION

For a given problem area, say a catchment, in an interval of time Δt, the continuity equation for water in its various phases is written as

Mass inflow – mass outflow = change in mass storage

If the density of the inflow, outflow and storage volumes are the same

$$V_i - V_0 = \Delta S \qquad (1.1)$$

where V_i = inflow volume of water into the problem area during the time period, V_0 = outflow volume of water from the problem area during the time period, and ΔS = change in the storage of the water volume over and under the given area during the given period. In applying this continuity equation [Eq. (1.1)] to the paths of the hydrologic cycle involving change of state, the volumes considered are the equivalent volumes of water at a reference temperature. In hydrologic calculations, the volumes are often expressed as average depths over the catchment area. Thus, for example, if the annual stream flow from a 10 km^2 catchment is 10^7 m^3, it corresponds to a depth of $\left(\frac{10^7}{10 \times 10^6}\right)$ = 1 m = 100 cm. Rainfall, evaporation and often runoff volumes are expressed in units of depth over the catchment.

While realizing that all the terms in a hydrological water budget may not be known to the same degree of accuracy, an expression for the water budget of a catchment for a time interval Δt is written as

$$P - R - G - E - T = \Delta S \qquad (1.2\text{-a})$$

In this P = precipitation, R = surface runoff, G = net groundwater flow out of the catchment, E = evaporation, T = transpiration and ΔS = change in storage.

The storage S consists of three components as

$$S = S_s + S_{sm} + S_g$$

where S_s = surface water storage

S_{sm} = water in storage as soil moisture and

S_g = water in storage as groundwater.

Thus in Eq. (1.2-a) $\Delta S = \Delta S_s + \Delta S_{sm} + \Delta S_g$

All terms in Eq. (1.2-a) have the dimensions of volume. Note that all these terms can be expressed as depth over the catchment area (e.g. in centimetres), and in fact this is a very common unit.

In terms of rainfall–runoff relationship, Eq. (1.2-a) can be represented as

$$R = P - L \tag{1.2-b}$$

where L = Losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage. Details of various components of the water budget equation are discussed in subsequent chapters. Note that in Eqs (1.2-a and b) the net import of water into the catchment, from sources outside the catchment, by action of man is assumed to be zero.

EXAMPLE 1.1 *A lake had a water surface elevation of 103.200 m above datum at the beginning of a certain month. In that month the lake received an average inflow of 6.0 m³/s from surface runoff sources. In the same period the outflow from the lake had an average value of 6.5 m³/s. Further, in that month, the lake received a rainfall of 145 mm and the evaporation from the lake surface was estimated as 6.10 cm. Write the water budget equation for the lake and calculate the water surface elevation of the lake at the end of the month. The average lake surface area can be taken as 5000 ha. Assume that there is no contribution to or from the groundwater storage.*

SOLUTION: In a time interval Δt the water budget for the lake can be written as

Input volume – output volume = change in storage of the lake

$$(\bar{I}\Delta t + PA) - (\bar{Q}\Delta t + EA) = \Delta S$$

where $\bar{I}$ = average rate of inflow of water into the lake, $\bar{Q}$ = average rate of outflow from the lake, P = precipitation, E = evaporation, A = average surface area of the lake and ΔS = change in storage volume of the lake.

Here $\Delta t = 1$ month $= 30 \times 24 \times 60 \times 60 = 2.592 \times 10^6$ s = 2.592 Ms

In one month:

$$\text{Inflow volume} = \bar{I}\Delta t = 6.0 \times 2.592 = 15.552 \text{ M m}^3$$

$$\text{Outflow volume} = \bar{Q}\Delta t = 6.5 \times 2.592 = 16.848 \text{ M m}^3$$

$$\text{Input due to precipitation} = PA = \frac{14.5 \times 5000 \times 100 \times 100}{100 \times 10^6} \text{ M m}^3 = 7.25 \text{ M m}^3$$

$$\text{Outflow due to evaporation} = EA = \frac{6.10}{100} \times \frac{5000 \times 100 \times 100}{10^6} = 3.05 \text{ M m}^3$$

Hence $\Delta S = 15.552 + 7.25 - 16.848 - 3.05 = 2.904$ M m³

Change in elevation $\Delta z = \dfrac{\Delta S}{A} = \dfrac{2.904 \times 10^6}{5000 \times 100 \times 100} = 0.058$ m

New water surface elevation at the end of the month = 103.200 + 0.058

= 103.258 m above the datum.

EXAMPLE 1.2 *A small catchment of area 150 ha received a rainfall of 10.5 cm in 90 minutes due to a storm. At the outlet of the catchment, the stream draining the catchment was dry before the storm and experienced a runoff lasting for 10 hours with an average discharge of 1.5 m³/s. The stream was again dry after the runoff event. (a) What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation and transpiration? What is the ratio of runoff to precipitation?*

SOLUTION: The water budget equation for the catchment in a time Δt is

$$R = P - L \qquad (1.2\text{-b})$$

where L = Losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage. In the present case Δt = duration of the runoff = 10 hours.

Note that the rainfall occurred in the first 90 minutes and the rest 8.5 hours the precipitation was zero.

(a) P = Input due to precipitation in 10 hours
$= 150 \times 100 \times 100 \times (10.5/100) = 157{,}500 \text{ m}^3$
R = runoff volume = outflow volume at the catchment outlet in 10 hours
$= 1.5 \times 10 \times 60 \times 60 = 54{,}000 \text{ m}^3$
Hence losses $L = 157{,}500 - 54{,}000 = 103{,}500 \text{ m}^3$

(b) Runoff/rainfall = 54,000/157,500 = 0.343
(This ratio is known as *runoff coefficient* and is discussed in Chapter 5)

1.4 WORLD WATER BALANCE

The total quantity of water in the world is estimated to be about 1386 million cubic kilometres (M km^3). About 96.5% of this water is contained in the oceans as saline water. Some of the water on the land amounting to about 1% of the total water is also saline. Thus only about 35.0 M km^3 of fresh water is available. Out of this about 10.6 M km^3 is both liquid and fresh and the remaining 24.4 M km^3 is contained in frozen state as ice in the polar regions and on mountain tops and glaciers. An estimated distribution of water on the earth is given in Table 1.1.

Table 1.1 Estimated World Water Quantities

Item	Area (M km^2)	Volume (M km^3)	Percent total water	Percent fresh water
1. Oceans	361.3	1338.0	96.5	—
2. Groundwater				
(a) fresh	134.8	10.530	0.76	30.1
(b) saline	134.8	12.870	0.93	—
3. Soil moisture	82.0	0.0165	0.0012	0.05
4. Polar ice	16.0	24.0235	1.7	68.6
5. Other ice and snow	0.3	0.3406	0.025	1.0
6. Lakes				
(a) fresh	1.2	0.0910	0.007	0.26
(b) saline	0.8	0.0854	0.006	—
7. Marshes	2.7	0.01147	0.0008	0.03
8. Rivers	148.8	0.00212	0.0002	0.006
9. Biological water	510.0	0.00112	0.0001	0.003
10. Atmospheric water	510.0	0.01290	0.001	0.04
Total: (a) All kinds of water	510.0	1386.0	100.0	
(b) Fresh water	148.8	35.0	2.5	100.0

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The global annual water balance is shown in Table 1.2.

Table 1.2 Global Annual Water Balance

Item	Ocean	Land
1. Area (M km^2)	361.30	148.8
2. Precipitation (km^3/year)	458,000	119,000
(mm/year)	1270	800
3. Evaporation (km^3/year)	505,000	72,000
(mm/year)	1400	484
4. Runoff to ocean		
(i) Rivers (km^3/year)		44,700
(ii) Groundwater (km^3/year)		2,200
Total Runoff (km^3/year)		47,000
(mm/year)		316

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It is seen from Table 1.2 that the annual evaporation from the world's oceans and inland areas are 0.505 and 0.072 M km^3 respectively. Thus, over the oceans about 9% more water evaporates than that falls back as precipitation. Correspondingly, there will be excess precipitation over evaporation on the land mass. The differential, which is estimated to be about 0.047 M km^3 is the runoff from land mass to oceans and groundwater outflow to oceans. It is interesting to know that less than 4% of this total river flow is used for irrigation and the rest flows down to sea.

These estimates are only approximate and the results from different studies vary; the chief cause being the difficulty in obtaining adequate and reliable data on a global scale.

The volume in various phases of the hydrologic cycle (Table 1.1) as also the rate of flow in that phase (Table 1.2) do vary considerably. The average duration of a particle of water to pass through a phase of the hydrologic cycle is known as the *residence time* of that phase. It could be calculated by dividing the volume of water in the phase by the average flow rate in that phase. For example, by assuming that all the surface runoff to the oceans comes from the rivers,

From Table 1.1, the volume of water in the rivers of the world = 0.00212 M km^3

From Table 1.2, the average flow rate of water in global rivers = 44700 km^3/year

Hence residence time of global rivers, T_r = 2120/44700 = 0.0474 year = 17.3 days.

Similarly, the residence time for other phases of the hydrological cycle can be calculated (Prob. 1.6). It will be found that the value of T_r varies from phase to phase. In a general sense the shorter the residence time the greater is the difficulty in predicting the behaviour of that phase of the hydrologic cycle.

Annual water balance studies of the sub-areas of the world indicate interesting facts. The water balance of the continental land mass is shown in Table 1.3(a). It is interesting to see from this table that Africa, in spite of its equatorial forest zones, is the driest continent in the world with only 20% of the precipitation going as runoff. On the other hand, North America and Europe emerge as continents with highest runoff. Extending this type of analysis to a smaller land mass, viz. the Indian subcontinent, the long term average runoff for India is found to be 46%.

Table 1.3(a) Water Balance of Continents[2] mm/year

Continent	Area (M km^2)	Precipitation	Total runoff	Runoff as % of precipitation	Evaporation
Africa	30.3	686	139	20	547
Asia	45.0	726	293	40	433
Australia	8.7	736	226	30	510
Europe	9.8	734	319	43	415
N. America	20.7	670	287	43	383
S. America	17.8	1648	583	35	1065

Water balance studies on the oceans indicate that there is considerable transfer of water between the oceans and the evaporation and precipitation values vary from one ocean to another (Table 1.3(b)).

Table 1.3(b) Water Balance of Oceans[2] mm/year

Ocean	Area (M km^2)	Precipitation	Inflow from adjacent continents	Evaporation	Water exchange with other oceans
Atlantic	107	780	200	1040	–60
Arctic	12	240	230	120	350
Indian	75	1010	70	1380	–300
Pacific	167	1210	60	1140	130

Each year the rivers of the world discharge about 44,700 km^3 of water into the oceans. This amounts to an annual average flow of 1.417 Mm^3/s. The world's largest river, the Amazon, has an annual average discharge of 200,000 m^3/s, i.e. one-seventh of the world's annual average value. India's largest river, the Brahmaputra, and the second largest, the Ganga, flow into the Bay of Bengal with a mean annual average discharges of 16,200 m^3/s and 15,600 m^3/s respectively.

1 .5. التطبيقات الهندسية للهيدرولوجيا Engineering Aplications of Hydrology:

إن اكبر تطبيق لعلم الهيدرولوجي هو في تصميم مشاريع الموارد المائية و تشغيلها مثل :

1. الري 2. تجهيز الماء 3. السيطرة على الفيضان 4. الطاقة المائية 5. الملاحة

وتحتاج التحريات الهيدرولوجية لتقديرات وافية لجميع هذه المشاريع إلى العوامل الضرورية الآتية:

- سعة الخزين في منشآت الخزن مثل الخزانات و السدود (ضرورة معرفة التصاريف القصوى لتصميم أي سد أو حاجز مائي).
- كميات و حجوم الجريان في الفيضان لجعله قادراً على التصريف الامين للزيادات في الجريان (تصميم المسيل المائي Spillway).
- أقل جريان و كمية الجريان المتوافرة من مصادر مختلفة (لأخذها بنظر الاعتبار و تحديد الاحتياجات المائية في مواسم الجفاف)
- التداخلات في موجات الفيضان و المنشآت الهيدروليكية مثل السداد و الجسور و الخزانات و السدود.

1. 6 . عوامل الفشل النموذجية للمنشآت الهيدروليكية :

إن فشل أو نجاح أي مشروع مائي يعتمد على مدى دقة التقديرات الهيدرولوجية و من عوامل الفشل:

1. إنهيار سدود ترابية نتيجة لارتفاع منسوب الماء و عجز في سعة مخارج تصريف المياه الفائضة (المسيل المائي Spillway).
2. سقوط قناطر و جسور نتيجة الزيادة في جريان الفيضان.
3. قصور في إمكانية إمتلاء خزانات الماء الكبيرة نتيجة تضخيم الجريان في المجرى المائي (تصميم مقطع جريان اكبر من كمية الماء المتاحة مما يسبب قلة التصاريف و سرعة الجريان و عدم تأمين الاحتياج المائي المطلوب).

1. 7. مصادر المعلومات Sources of Data:

1. سجلات الطقس : درجة الحرارة و الرطوبة و سرعة الرياح.
2. معلومات السقيط.
3. سجلات الجريان في المجاري المائية.
4. معلومات التبخر.
5. خصائص الغيض في التربة للمساحة المخصصة للدراسة.
6. خصائص المياه الجوفية.
7. الخصائص الفيزياوية و الجيولوجية للتربة في المساحة المطلوب دراستها.