An Approach to the Hydrologic Seasons in the Central Region of Japan.

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Contents

Abstract

In the field of forest hydrology, it is important to know the approximate amount of water stored in a drainage area at any one time. This paper deals with methods for estimating from daily records of runoff and precipitation the monthly changes in retention storage and detention storage and other components of the water cycle. The monthly water losses to runoff expressed as precipitation minus runoff are adjusted first for evaporation and transpiration, then for groundwater storage on the basis of the storage curve derived from the ground water depletion curve. The residual may then logically by considered to be the amount or retention storage on the watershed at the end of each month for the average year employed in this study. Sample data for an experimental watershed are given.

Acknowledgment

Many thanks are due to Dr. S. Ogihara, Professor of Tokyo University and also to Dr. C. R. Hursh, American Fulbringht Research Scholar now staying in Japan, for their guidance and suggestions during the study. The writer is also indebted to both Instructors S. Nakashima and I. Yamaguchi for their assistance in the compilation of basic stream gauging data.

Introduction

With ever increasing needs for more intensive land use simultaneously with expanding needs for water, a knowledge of the hydrologic cycle on individual watersheds becomes increasingly urgent. In other words, it is important to find out the volume of water stored in a drainage area for a time interval shorter than the 12 months period that has been used heretofore. Much progress has been made in establishing a practical accounting method. (*3*), (*4*), (*5*).

The present paper discusses the problem of keeping monthly accounts of the essential water-cycle components for an experimental drainage area. The monthly interval makes it possible to better understand the significance of hydrologic seasons and hydrologic year in Aichi Prfecture, for which a preliminary studyhas recently been reported. (*7*).

This present study employs data from watershed A, Tokyo University Forest in Aichi. Watershed A is the best protected area for basic hydrological research among several experimental drainage areas in the Tokyo University Forests in Aichi. This watershed supports a good forest cover mostly of pine with a mixture of some broad-leaved trees. It is a typical so-calld ''small watershed'' of 106.7 ha in area having an average elevation of 446 m. The basic geology is granite, the most characteristic geology in Tookai District, wich is one of the questionable areas from the view point of watershed mangement. Ten years (1934—1943) of records have been chosen from the 25 years of stream gauging data taken since 1930. Employing these ten years of data, the average annual cycle of water storage is described.

Monthly replenishment and extraction

Ninety percent of observed precipitation (p) is assumed as net precipitation to the forest floor ; that is, total rainfall corrected by 10 percent for canopy interception and stemflow. Also two percent of observed rainfall is assumed to be channel precipitation and this amount is subtracted from the measured runoff (ro) to obtain the net runoff from the land surface of the drainage area. Values net p and net ro are shown by months in Columns 1 and 2, respectively, of Table 1. The value of net p minus net ro, net (p~ro), is temporarily named replenishment here, because this value is considered as a mothly increase to the amount of water in storage on the drainage area during the month.

The monthly value of evaporation and transpiration are estimated in two different ways. One is to distribute the average annual losses (total net p minus total net

Table 1. Computation table for retention storage estimation for an average year on watershed A in Aichi.

Month	Net precipitation	Net runoff	Composite replenishment	By Meyer's Method			Changes of water in storage	Relative variation of composite base of 50 mm	Composite storage having arbitrary base of 50 mm	Detention storage from the storage curve	Retention storage	Change of detention storage	Change of retention storage	Extraction by distribution method	Monthly average of daily maximum temperature
				Evaporation	Transpiration	Composite extraction									
	net p (1)	net ro (2)	net $(p-ro)$ (3) (1)−(2)	e (4)	t (5)	$e+t$ (6) (4)+(5)	Δs (7) (3)−(6)	$\Sigma\Delta s$ (8)	$D+R$ (9) (8)+50	D (10)	R (11) (9)−(10)	ΔD (12)	ΔR (13)	(14)	t°C (15)
Jan.	47	31	16	9		9	7	7	57	17	40	−1	+8	19	5.3
Feb.	73	34	39	13		13	26	33	83	17	66	0	+26	21	5.9
Mar.	114	62	52	22	10	32	20	53	103	32	71	+15	+5	37	10.2
Apr.	145	70	75	30	28	58	17	70	120	33	87	+1	+16	60	16.5
May.	126	68	58	33+3	40	76	−18	52	102	29	73	−4	−14	76	**21.1**
June.	230	94	136	55−6	55	104	32	84	134	39	95	+10	+22	87	24.2
July.	204	157	47	54	70	124	−77	7	57	23	34	−16	−61	102	28.3
Aug.	165	68	97	45+3	75	123	−26	−19	31	15	16	−8	−18	106	29.5
Sep.	205	95	110	52−4	45	93	17	−2	48	27	21	+12	+5	91	25.1
Oct.	174	95	79	38+2	30	70	9	7	57	29	28	+2	+7	70	19.4
Nov.	78	55	23	16+2	16	34	−11	−4	46	27	19	−2	−9	51	13.8
Dec.	49	35	14	10		10	4	0	50	18	32	−9	+13	26	7.3
Total	1610	864	746	377+0	369	746	0	These are the values at the ending moment of the month				0	0	746	

Note. All values except the last column are in mm depth.

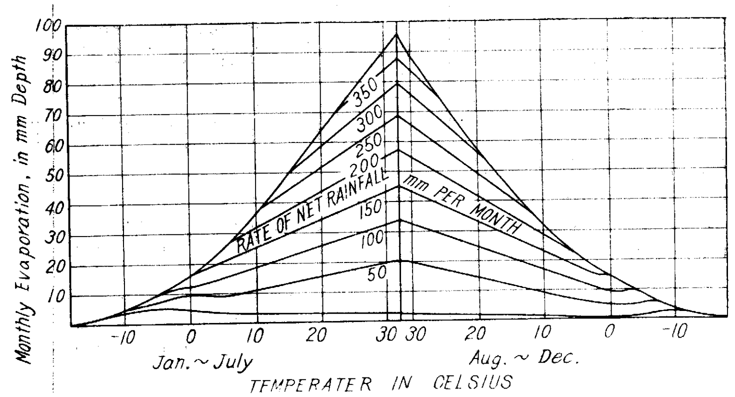

Fig. 1. Evaporation from land areas for various temperatures and rates of rainfall per month for Aici Prefecture.
(Meyer's origin, modified by Noguchi)

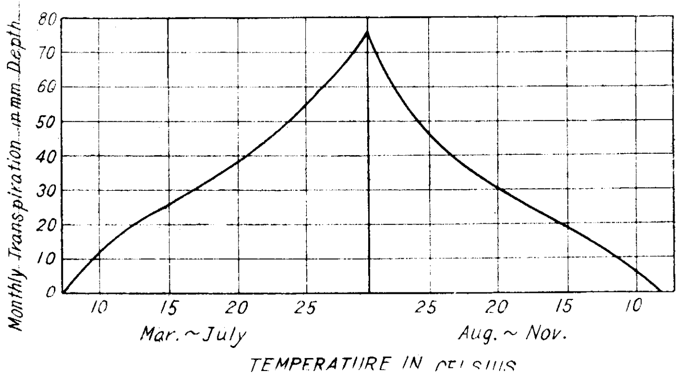

Fig. 2. Transpiration for various temperatures by month for Aichi Prefecture.
(Meyer's origin, modified by Noguchi)

RO)* on the basis of the monthly average of the daily maximum air temperature. The temperature for each month is first computed as a percentage of the total temperatures for all months. Then this percetage is used to determine the proportional amount of the total annual evapotranspiration that might take place during the month on this basis of temperature alone. The results are shown in Column 14 of Table 1. The second method of estimating monthly evapo-transpiration is to use the graphs as shown in Figure 1 and Figure 2 which are modifications of Adolph Meyer's method. (*1*). In the modification of the original Meyer's graphs, only the reading scale is altered to take into consideration the total annual average losses. The results of applying these graphs are inserted in Columns 4 and 5, respectively, and evaporation is slightly corrected reflecting the monthly duration of sunshine at Aichi. The summation of these two columns appears in Column 6. The evapo-transpiration estimated in this manner actually

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* Foot note : *P*—*RO* refers to the annual totals, small *P*—*ro* is used to indicate monthly totals.

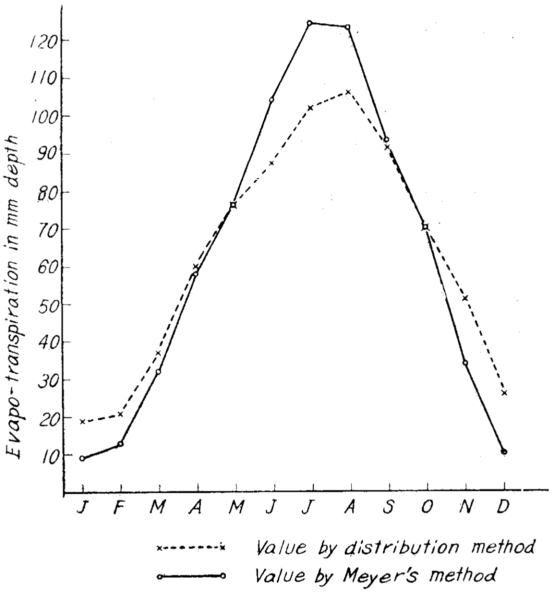

Fig. 3, Annual variation of monthly evapo-transpiration in Watershed A, through two methods.

has some slight difference from the value brought through the first method in Column 14. In months of moderate rainfall, i. e., in spring and in autumn, however, it may be said that the results of two different ways are approximately equal. (See Figure 3.) This fact appears to justify the appropriateness of the trial scaling in the writer's modification of Meyer's original graphs. Because more factors have been taken into consideration in the second method than in the first method, it is logical to assume that the values in Column 6 are somewhat more acceptable.

Application of basal formula of storage

The relationship between rainfall, runoff, collective losses, and storage is usually expressed by the equation

$$(p-ro)-L=\pm\Delta s$$

in which p is the total precipitation for the period, ro the total runoff for the period, L the total losses for the period, and Δs the increment in surface and subsurface storage during the period, the sign being plus for an increase in storage and minus for a decrease. The quantity Δs is made up of three separate factors, viz. :

(1) Increment or decrement in surface storage in streams, land depression, and tree canopy,

(2) the change in the amount of ground water in storage, and

(3) the change in field moisture.

Considering the amount of extraction by evaporation and transpiration to be the total losses here, the residual of the extraction amount from the replenishment (net *p*—net *ro*—*L*) equals logically the change of subsurface storage (Δs) from the beginning to the end of the month. (Column 7.)

In this paper, the surface part of storage is automatically eliminated by dealing only with the net values of precipitation and runoff. By summing up the monthly changes of Δs from January to December, the relative annual variation of subsurface storage is derived. Column 8 gives the results of such a summation on a trial base of a calendar year, and indicates the comparative amount of storage at the end of each month. In some months of the fall season these figures take a minus sign. Since, however, it is more convenient for us to illustrate the variation of subsurface storage by employing all the value as having plus signs, an arbitrary constant is added as being the unknown base on which the watershed operates from year to year. Supposing this to be 50 mm, then we can obtain the figures for the storage amount as shown in Column 9.

Variation of detention storage alone

The values shown in Column 9 are for total storage or for composite storage of detention and retention. On the other hand, the detention (ground water) storage at the ending moment of a certain month can be estimated separately by means of the normal ground water depletion curve and the storage curve. When there has been no rain for several days previously, the runoff data of the last day of the month becomes a good index of the ground water in storage at that time. If the runoff data during the ending several days have no smooth recession because of rainfall, then hydrograph analysis must be resorted to in order to get the amount of ground water runoff. Approximately, however, we can interpolate the value of ground water runoff between a sequence of dry days before and after the last day of the month. The principle of the interpolation employed by the writer is illustrated in Figure 4. Especially in the study of ten years' average value, this approximation may be said to be feasible.

The storage value derived from the storage curve as shown in Figure 5 does not

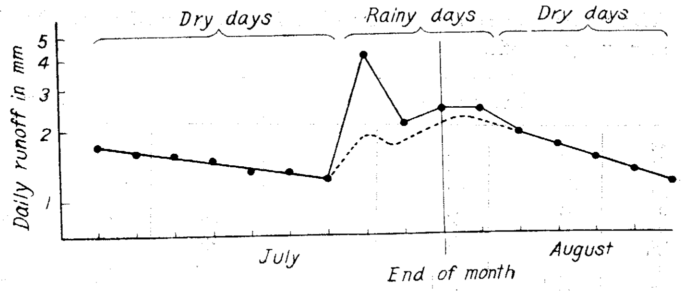

Fig. 4. Principle of interpolating the rainy day's ground water runoff between two groups of dry days. (Ground water runoff is inserted by broken line)

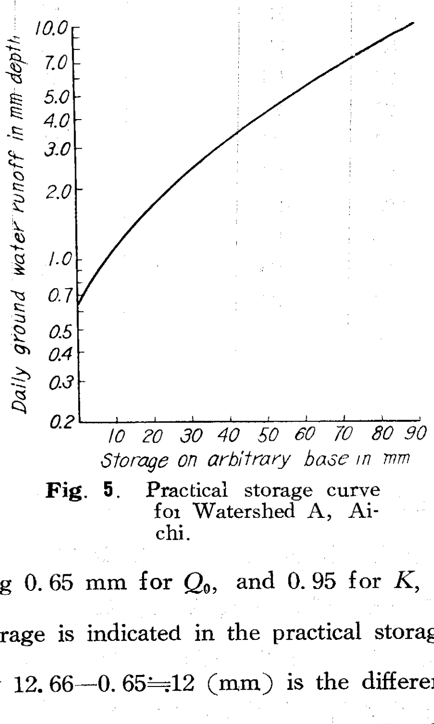

Fig. 5. Practical storage curve for Watershed A, Aichi.

contain the amount of ground water in storage below an arbitrary minimum base. This can be nearly estimated by the storage formula,

$$s=\int Qdt=\int_0^\infty Q_oK^tdt=\frac{-Q_o}{\log_e K}(K<1)$$

Here, S : Storage at the time of minimum runoff which is actually measured, Q : Runoff per day, K : depletion constant, t : number of day, Q_o : Q when $t=0$.

Putting 0.65 mm for Q_0, and 0.95 for K, we get $S=12.66$ mm. At that time 0.65mm of storage is indicated in the practical storage curve having an arbitrary base. Accordingly 12.66—0.65≒12 (mm) is the difference between actual storage and the value indicated in the storage curve graph. Employing 12.66 mm of storage as the base at the minimum runoff 0.65 mm per day, the detention storage (D) values at the end moment of the month are derived as shown in Column 10 of Table 1.

Variation of retention storage alone

Retention storage can be defined as the residual of detention storage from the composite storage ($D+R$) at the end of a certain month. The values shown in Column 11 are established on the temporary base similarly to the composite storage in Column 9. The actual water volume of the retention storage cannot be known.

Table 2. Water economy as a total of replenishment, extraction and the change of storage by month.

Month	Income				Outgo			
	Composite replenishment	Supplying amount from $D=\Delta D$ $(-)$	Supplying amount from $R=\Delta R$ $(-)$	Total	Extraction $(e+t)$	Increased amount of D $=\Delta D$ $(+)$	Increased amount of R $=\Delta R$ $(+)$	Total
Jan.	16	1		17	9		8	17
Feb.	39			39	13		26	39
Mar.	52			52	32	15	5	52
Apr.	75			75	58	1	16	75
May.	58	4	14	76	76			76
June.	136			136	104	10	22	136
July.	47	16	61	124	124			124
Aug.	97	8	18	123	123			123
Sep.	110			110	93	12	5	110
Oct.	79			79	70	2	7	79
Nov.	23	2	2	34	34			34
Dec.	14	9	9	23	10		13	23

Note : Unit in mm depth.

Income and outgo amount by month

The changes of detention storage and retention storage from the beginning to the end of a certain month can be easily computed. Columns 12 and 13 in Table 1 show these changes. The plus sign shows the increase of storage, i. e., the deposition as the excess of replenishment net $(p-ro)$ over the extraction of evapo-transpiration. The minus sign shows the decrease of storage ; that is, withdrawal from the supply amount by e and t. Consequently the following equation is derived :

$$\text{net } (p-ro)+\textit{Supply amount from } (D+R) \textit{ at the beginning of the month}=(e+t)+\textit{Deposition into } (D+R) \textit{ at the ending time of the month}=(e+\textit{Deposition } D)+(t+\textit{Deposition into } R).$$

Separation of infiltrated amount of water into supplies for field moisture and ground water.

The replenishment amount net $(p-ro)$ can be put as follows : net $(p-ro)=$net $(p-$surface runoff$)-$groundwater runoff.

Accordingly, net (p- surface runoff)=net($p-ro$)+groundwater runoff.

Table 3. Computation table of supply amount for ground water S_g.

month	(1) t	(2) ΔR	(3) Fr	(4) net ($p-ro$)	(5) gro	(6) (4)+(5)	(7) (6)−(3)	(8) e	(9) (7)−(8) S_g	(10) ΔD
Jan.		+ 8	8	16	17.5	33.5	25.5	9	16.5	− 1
Fed.		+26	26	39	17	56	30	13	17	0
Mar.	10	+ 5	15	52	24.5	76.5	61.5	22	39	+15
Apr.	28	+16	44	75	32.5	107.5	63.5	30	33.5	+ 1
May.	40	−14	26	58	31	89	63	36	27	− 4
June.	55	+22	77	136	34	170	93	49	44	+10
July.	70	−61	9	47	31	78	69	54	15	−16
Aug.	75	−18	57	97	19	116	59	48	11	− 8
Sep.	45	+ 5	50	110	21	131	81	48	33	+12
Oct.	30	+ 7	37	79	28	107	70	40	30	+ 2
Nov.	16	− 9	7	23	28	51	44	18	26	− 2
Dec.		+13	13	14	22.5	36.5	23.5	10	13.5	− 9

Note : Unit in mm depth.

This means the volume of water infiltrated through the land surface of the drainage area. Ground water runoff (gro) for a month can be approximated by the mean of detention storages at the beginning and the end of the month. The results of the computation of the infiltrated amount (F) are inserted in Column 3 in Table 3. On the other hand, supposing that the part of supply for transpiration comes out from the retained water, the temporarily retained part of infiltrated water in a period of a month (F_r) can be obtained by

$$F_r=(t-\Delta R).$$

Then, the residual part of it from the total infiltration goes into the supply for groud water (S_g) and into evaporation, so that

$$F-F_r=S_g+e.$$

Naturally ΔD can be defined also by means of

$$\Delta D=S_g-gro.$$

The data are shown in Table 3.

The period from replenishment to extraction

The retention storage shows its minimum to be at the end of August. Suppose that total transpiration until this time must be equal to the total supply into retention storage (F_r) until this time, and the total transpiration during the period from March to August is found to be equal to the total retention part of infiltration since the middle of November before. (See Table 4.) Consequently, it is possible that the main part of the period for storage lies between November and March.

Table 4. Comparison of transpiration total and the sum of retention part of replenishment until the end of August.

Moth		Sum of retention part of replenishment		Sum of transpiration
	Aug.	57 mm	<	75 mm
since	July.	66	<	145
″	June.	143	<	200
″	May.	169	<	240
″	Apr.	213	<	268
″	Mar.	228	<	278
″	Fed.	254		
″	Jan.	262		
″	Dec.	275		
″	Nov.	282	>	

Hydrologic season

An example of hydrologic season is described by Parker on the condition of the northern United States as follows :

Storage period (roughly December to May)

Period of vegetation growth (roughly June to August)

Replenishing period (roughly september to November).

According to the writer's opinion, the hydrologic season for Japan at Aichi must be determined not only by the inner year variation of subsurface storage but the other components and aspects of the water cycle. In our drainage area the inner year variation of storage can be illustrated as in Figure 6. In this Figure we can see apparently the maxima of retention and detention storage at the end of June, with a second peak at the end of April. Now let us consider the meaning of these two peaks. Whereas the maximum at the end of June is affected by the heaviness of rain which is characteristic of this rainy season, the second peak at the end of April can be recognized as the point of the accumulative trend of storage in the period of the dormant season that is terminated by the beginning of a period of active extraction. In other words, the end of April may be a more adequate expression of the beginning of a definite period in the hydrologic year than is the end of June, so far as expressing a period of active evapotranspiration is concerned. For this reason, it may be acceptable to begin the time of extraction from storage at the end of April, which also has been shown to be the beginning of the hydrologic year, as reported previously (*7*). Incidentally, it is stated by Brater (*6*, page 171) that "the grouud water level in the United States usually reaches

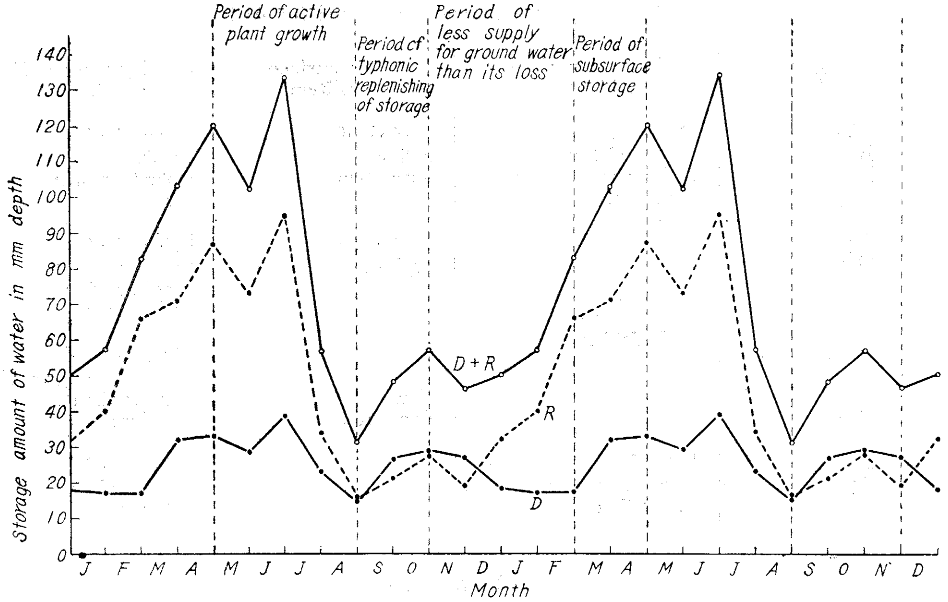

Fig. 6. Annual average variation of retention storage and detention storage by month in Watershed A, Aici.

its maximum stage about the first of May''.

Both field moisture (retention) storage and ground water (detention) storage at Aichi are subject to depletion from May to August, except in the rainy season which is especially concentrated in June. At the end of August, they reach their annual minima. The period until this time may appropriately be called the period of vegetation growth. Then storage is replenished by the rainfall during the typhoon season, producing a small secondary storage peak at the end of October. In general, accumulation of field moisture goes on until the next April after a slight depletion in November. The depletion of the ground water, however, tends to continue until the next February. Accretion of ground water occurs in March and April. Hence, the end of October and the end of February also help delineate hydrologic seasons. In the period from November to February, the ground water storage decreases though the field moisture increases gradually. This can be considered logical on the ground that field moisture deficiencies must be satisfied first. It also suggests that the supply for detention storage is less than its loss in the range of this period. This is demonstrated by comparing figures in Column 9 and in Column 3 of Table 3.

The hydrologic season may be set from several points of view, but here a few results of the trial for it will be shown in Table 5.

Table 5. Suggested hydrologic seasons for Aichi.

month	By sub-surface condition	By surface condition	By the combined condition
May. June. July. Aug.	Period of field moisture and ground water depletion	Period of active extraction	Period of active plant growth
Sep. Oct.	Period of field moisture replenishing	Period of typhonic rain	Period of typhonic replenishing of storage
Nov. Dec. Jan. Feb.		Period of dormancy	Period of less supply for ground water than its loss
Mar. Apr.	Peiod of ground water accretion		Period of sub-surface storage

Conclusion

We must take many factors into consideration for determining the hydrologic season. In our Aichi watershed under consideration, the two rainy seasons are concentrated in the opening of summer and in the beginning of fall, as in most regions of Japan. Although the rainfall at these times of course affects the subsurface storage condition, actually the indices for defining hydrologic seasons is not rainfall directly but rather the storage end extraction of moisture by evaporation and transpiration. The overlapping of the accretion period and depletion period for two storage components, howeve , makes it somewhat more difficult to sharply define hydrologic seasons at Aichi than for some other sections of the world. The writer believes that it is not now advisable to attempt to define definite hydrologic season for Aichi. The trial as shown in Table 5 is suggested as only a tentative solution until further researches have been carried out for Japan.

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日本中部地方の Hydrologic Season について（和文摘要）

助教授　野口陽一

地表下の水分貯留量を土壌水分と地下水とに分け，それらの一年間の変化を月単位に追求した。長期間の蒸発・蒸散総量を同期間内の降水総量と流出総量との差から推定し，その一ケ年相当量を気温および日照時間を考えて各月に配分し，これと各月の降水量，流出量とを比較する。地表面を境界とする降水量の参透量，空中への蒸発・蒸散量を月毎に求めれば，地表下に蓄積される水分量が推定される。一方重力水（地下水）に関しては各月の終りに無降雨が続いたときの流出量を指標とし，正常地下水減少曲線から重力水貯留水分が得られる。以上の操作の結果得られる年間の地表下水分変化曲線から **Hydrologic season** の特徴を把握するため，地上における降雨の集中期，樹木蒸散の活動期をも併せ考えて試みに各季節の名称を附した。梅雨期と颱風期が地下水貯留状態の変化を複雑にしている。4月の終りにある水分貯留量のピークは6月のそれに次ぐものであるが季節区分としては6月よりも4月の終りがよい。これらのことはわが国全体としても特徴的なことと一応考えられる。しかしこれらの結果を流域管理に応用するためには，さらに他の地方においても同様の研究を行いそれぞれの地方の地域的な水文学的特性を摑む必要があると考えられる