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On Secular Change in Inflows to Lake Biwa

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Synopsis

The purpose of this paper is to study the secular change and a possibility of the prediction of inflows into Lake Biwa and to disclose the climatic factors affecting on the annual loss of water, which is one of the causes of the secular change of inflows.

The results obtained are the followings:

(1) On the secular change in annual and summer inflows, the periodicity of about 60 years is discerned by the correlogram analysis.

(2) The prediction of annual inflow, based upon a linear combination of the past data, is little significant in practice from the view-point of the predictive error.

(3) Sun-shine is one of the dominant climatic factors affecting on the total loss of water resulting from the evaporation, the transpiration and so on.

1. Introduction

Recently, in Kinki District, Japan, the whole-scale development of water resources has become one of the most urgent problems with the rapid progress of industry. For this demand, a serious consideration has been given to the effective use of Lake Biwa. In this sense, it is very important to study the characters about the secular change in the inflow to Lake Biwa as the essence of water resources.

The studies of the river flow over a long-term period will be classified into the following two approaches: One is the statistical study of the state of the variation of flow and the other is the physical study of the climatic causes of variation. Furthermore, in the former, there are many studies about the periodicity of the variation, for example, the stage variation of the Yangtze river by Hayami[1] and the variations of annual flood discharges in the Tone river and the Yodo river by Ueyama[2], and about the stationary probability process under the assumption of a random variation, for example, the long range forecasting of flood discharge by Ishihara and Ueyama[3], and the characters of the hydrological quantities in Japan by Takase[4]. However, since the prescribed difference of the statistical approaches is derived from the magnitude of the time-scale of variation, they should be treated by the unified analysis based upon the theory of time series.

This paper concerns with the secular changes in the inflow into Lake Biwa and the physical causes of its changes from the point of view of the prescribed basis. That is to say, after the inflow into the Lake Biwa is calculated from the observed outflow and the fluctuation in water levels, the periodicity of annual inflow is obtained through the investigation of the auto-correlation of inflows, and the practicability of prediction is examined from the data subtracted by the periodicity.

Since this variation of annual inflow is considered as the variation of the annual loss of water as well as the precipitation, the relation between the annual loss of water and the climatic causes is also examined.

2. Inflow into Lake Biwa

First of all, the method of calculation of the inflow into Lake Biwa will be explained.

Lake Biwa is supplied by many rivers of various scales, and furthermore the volumes of inflow due to the ground-water cannot be ignored. Hence, it is almost impossible to observe directly the total inflows into the lake, and it cannot help estimating through the rate of outflow of the Seta river, etc. and the time fluctuation of the water-level at Toriigawa station, indirectly. That is assuming that h_1 and h_2 (cm) are the water levels at times t_1 and t_2, respectively, and $\sum q$ (cm) is the total volume of outflow, in expressed as the depth of the lake during this time interval, the total volume of inflow is given by the following equation :

$$Q = h_2 - h_1 + \sum q \tag{1}$$

The inflow calculated by the use of eq. (1) means the effective inflow, which equals the total inflow subtracted by the total loss of water. Here, the total inflow consists of the stream flow, the precipitation falling directly on the surface of the lake, and the ground water flow, and the total loss of water consists of the interception, the evaporation from the ground and the water surface, watershed leakage from the bottom of the lake and the water used for various purposes like irrigation and others.

Data used in the calculation are provided by Kinki Regional Construction Bureau for the period from 1875 to 1961[5]. Of course, it is likely that some of the data will contain several doubts, but there is nothing beyond it in reliability of the data, the magnitude of the observed period, and so on.

Prior to the discussion of the secular change in inflows, the seasonal characters upon which the secular change mainly depends should be disclosed. The variation of monthly inflows into Lake Biwa is shown in Fig. 1. In the figure, it is known that in winter and spring, November to May, the ratio of the standard deviation σ to the mean m for the monthly inflows nearly constant of about 30%, while, in summer and autumn, June to October, the ratio varies the range of 60 ~80% and shows an extreme unstability of the inflow. Of course, in the latter unstable period corresponds to the rainy and the

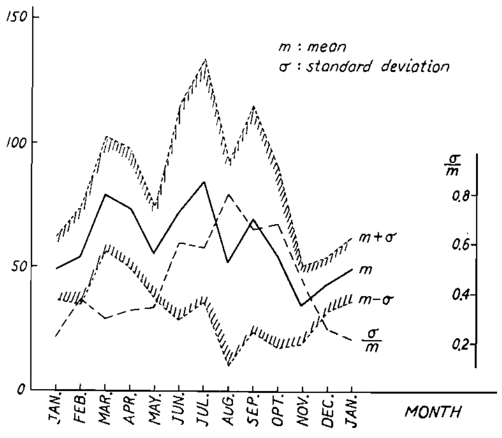

Fig. 1. Variation of monthly inflow, 1940 to 1961.

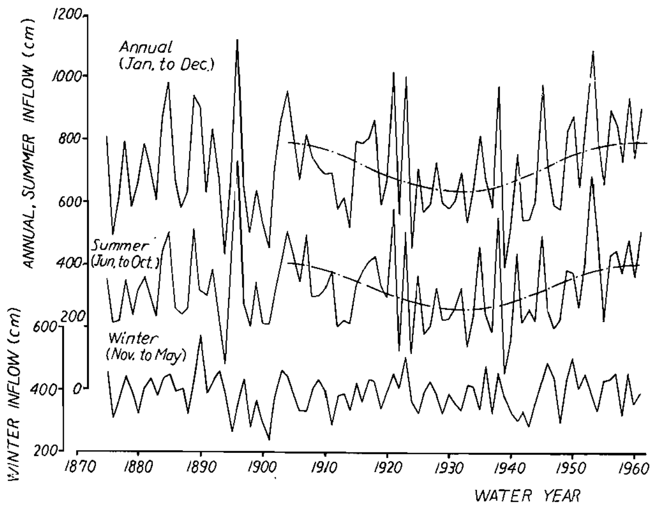

Fig. 2. Secular change of annual, summer and winter inflows.

typhonic seasons. Hence, the secular change in annual, summer (Jun. to Oct.) and winter (Nov. to May) inflows are shown in Fig. 2. From this figure, it becomes clear that the variation of the annual inflow is chiefly controlled by the summer one but little by the winter one. It is also found that the correlation between the summer and the winter inflow is not disclosed. Therefore, for the discussion of the secular change in the annual inflow, it may suffice that the summer inflow is only concerned.

3. Classification of secular change in annual inflow

For the sake of convenience of the following explanation, a brief description for the treatment by the time series will be made. Denoting the time series of the inflow sequence by $Q(t)$, $Q(t)$ consists generally of the regular variation of $p(t)$ and $q(t)$, the random variation $m(t)$ and the random error $n(t)$, and therefore, the following relation is obtained:

$$Q(t) = p(t) + q(t) + m(t) + n(t) \tag{2}$$

In eq. (2), let assume that $p(t)$ and $q(t)$ are the periodic and the tendencious variations, and $p(t)$ is expressed by the form of a Fourier series and $q(t)$ by a polynomial with respect to the time t, and neglect the random error $n(t)$. Then above equation is rewritten as

$$Q(t) = \sum_{i=1}^{n} a_i \sin\frac{2\pi}{T_i}(t+\varepsilon_i) + \sum_{i=0}^{n} b_i t^i + m(t) \tag{3}$$

In other words, to know the variation in the inflow $Q(t)$ equals to estimate the coefficients a_i and b_i, the numbers m and n in the terms concerning the regular variations and the random variation $m(t)$. Furthermore, a key to the definite prediction of the inflow in the future will be given by making the characters of these quantities evident. Indeed, for the extrapolation of the time series into the future, many studies have been carried out[6][7][8] but it takes too much troubles in calculation to treat with a problem in the form of eq. (3)[9]. Consequently, the present problem will be concerned in a more simplified form. The periodic variation is first examined and removed from the total variation. The tendencious variation is also made by the same treatment. Next, for the time series of the residual variation eliminated by the regular trend $p(t)$ and the drift $q(t)$ from $Q(t)$, the method of prediction and its practicability are concretely discussed.

4. Detection and removal of regular variation

Among the regular changes in inflows into Lake Biwa, the periodic variation is examined here. Since the periodicity of an inflow series is approximately expressed as a series of a sinuous function $\sum a_t \sin\frac{2\pi}{T_t}(t+\varepsilon_t)$ in eq. (3), the problem is to estimate the amplitude a_t, the period T_t and its phase ε_t. To estimate the period, a periodogram or a correlogram is usually used. Since the periodogram analysis makes more troubles in computation and the correlogram analysis will satisfy the present subject, the period is treated by the correlogram hereafter.

Generally, the serial correlation coefficient of the inflow series is given by

$$\left.\begin{aligned} r_k &= \frac{1}{N-k}\sum_{t=1}^{N-k}\{Q(t)-\bar{Q}_1\}\{Q(t+k)-\bar{Q}_2\}/s_1\cdot s_2 \\ \text{where}\quad & \\ s_1 &= \frac{1}{N-k}\sum_{t=1}^{N-k}Q(t)^2-\bar{Q}_1^2, \quad s_2=\frac{1}{N-k}\sum_{t=k+1}^{N}Q(t)^2-\bar{Q}_2^2 \\ \bar{Q}_1 &= \frac{1}{N-k}\sum_{t=1}^{N-k}Q(t), \quad \bar{Q}_2=\frac{1}{N-k}\sum_{t=k+1}^{N}Q(t) \end{aligned}\right\} \tag{4}$$

In the correlogram where r_k is calculated by above relations, because a positive maximum point shows a closer auto-correlation between the inflow series than neighouring points, the possibility of periodicity will be obtained at the maximum point. For this judgement, the significant level of correlation coefficient may by used, but a complete table for the significant level of serial correlation coefficient has not been made yet[10]. For this reason, an ordinary significant level of correlation coefficient is used. That is, by making the hypothesis that the correlation coefficient in population is equal to zero, the basis of judgement will be given by the probability that the sample point will not fall in the critical region when the hypothesis is not valid.

Here, let assume that the significance of the periodicity will be recognized when the probability is smaller than 1%. The significant parts of correlogram as to the summer inflow and the average precipitation over the basin are shown in Fig. 3. In this figure, as to the summer inflow and the precipitation, the significance in the periodicity is recognized at about $k=57$ years and there the maximum values are shown in its neighbourhood.

This fact means that a trend with the periodicity of about 57 years exists in the summer inflow to Lake Biwa. On the other hand, from the data of old floods during 1780 to 1870 collected by Heigo Tsuji for the average depth of innundation at Katata village[11], the periodicity of about 30 years was obviously seen. However, since the autocorrelation coefficients give the negative values in succession in the neighbourhood of 30 years corresponding to about a half of 57 years, the periodicity of 57 years may be regarded as a fundamental periodicity.

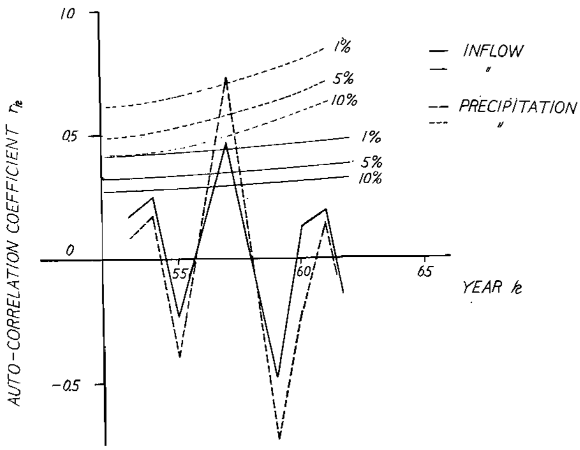

Fig. 3. Correlogram of summer inflow and precipitation for $k=53\sim62$ years.

Next, the phase and the amplitude of the periodic variation should be examined, because the periodicity T is already known. Rewritting $\Sigma a_t \sin\left(\frac{2\pi}{T_t}t+\varepsilon_t\right)+b_0$ in eq. (3) into $a\sin\frac{2\pi}{T}t+b\cos\frac{2\pi}{T}+c$, the constants a, b and c can be so determined as to minimize the variance;

$$\Sigma\left\{Q(t)-\left(a\sin\frac{2\pi}{T}t+b\cos\frac{2\pi}{T}t+c\right)\right\}^2$$

under the restraint;

$$\Sigma\left\{Q(t)-\left(a\sin\frac{2\pi}{T}t+b\cos\frac{2\pi}{T}t+c\right)\right\}=0$$

For the convenience of computation, the origin of time in the middle of duration N will be taken, and then the maximum likelyhood estimators $\hat{a}$, $\hat{b}$ and $\hat{c}$ are given by the next expression:

$$\left.\begin{aligned}
&\hat{a}=\frac{\sum\limits_{t=-n}^{n} Q\sin\frac{2\pi}{T}t}{2\sum\limits_{t=1}^{n}\sin^2\frac{2\pi}{T}t},\quad \hat{b}=\frac{N\sum\limits_{t=-1}^{n} Q\cos\frac{2\pi}{T}t-\left(2\sum\limits_{t=1}^{n}\cos\frac{2\pi}{T}t+1\right)}{N^2-2N\sum\limits_{t=1}^{n}\sin^2\frac{2\pi}{T}t-\left(2\sum\limits_{t=1}^{n}\cos\frac{2\pi}{T}t+1\right)}\\
&\hat{c}=\frac{\sum\limits_{t=-n}^{n} Q}{N}-\frac{\hat{b}\left(2\sum\limits_{t=1}^{n}\cos\frac{2\pi}{T}t\right)}{N}
\end{aligned}\right\} \qquad (5)$$

where $n=(N-1)/2$.

These constants are determined by using $T=57$ for the above relations. This curve fitting and the following computation are done by using the data during 1904 to 1961 as the basic data, for the reason that the data concerning the outflow will not be trustworthy, before the completion of the Nangô weir. The result obtained is as followings:

$$p(t)=14.2\sin\frac{2\pi}{57}t-72.1\cos\frac{2\pi}{57}t+334.2 \qquad (6)$$

in which the origin of time is taken at 1933 and units are cm and year for

$p(t)$ and t, respectively.

This curve is also shown in Fig. 2 by a chain line. That is, it varies between the peaks at 1904, 1961 and the trough at 1932 and the range of variance is 73.5 cm in the water-depth of the lake.

If the residual trend $q(t)$ is estimated and removed from the inflow series $Q(t)-p(t)$, there still remains the random variation. In this case, the special residual trend is not disclosed.

5. Analysis of random variation

Before taking up a concrete prediction of inflow, the staionary series in inflow should be confirmed for the residual inflow variation. It is approximately made by the approach that the inflow series $Q(t)-p(t)$ from 1904 to 1961 are diveded into 6 parts of duration with about 10 years, and among their averages or variances any significant difference is not noticed.

For the stationary inflow series obtained, the prediction to the future and its practicability are discussed by the application of Wiener's theory. Before the discussion, for conveience, $Q(t)-p(t)$ is transformed into the variate $f(t)$ of which standard deviation is unity.

In general, when the values of time series $f(t)$ were known before a time-point t, the prediction means the estimation of the future value $f(t+p)\,(p>0)$ at a time $(t+p)$, in which p is a period.

Let assume that the data at a past time $t-\tau$ gives a linear effect to the future data. Then, to approximate the future value $f(t+p)$ by its sum $\int_0^\infty f(t-\tau)dK(\tau)$ as well as well as possible, the form of kernel $K(\tau)$ in the integral equation should be determined.

Therefore, the prediction will mean what minimize the difference between the actual future of a time series and its predicted future in the sense of least square of error. That is to say, the kernel K should be so determined as to give the solution to the calculus of variations in which the function of K

$$\sigma^2(K)\equiv\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}\left\{f(t+p)-\int_0^\infty f(t-\tau)dK(\tau)\right\}^2dt \qquad (7)$$

takes the minimum value. This solution becomes in a form of the Fredholm integral equation of the second kind,

$$\varphi(\tau+p)=\int_0^\infty\varphi(\tau-\sigma)dK(\sigma),\quad \tau>0 \qquad (8)$$

where $\varphi(t)$ is the auto-correlation function of time series and it is already known here as the auto-correlation coefficient of $f(t)$.

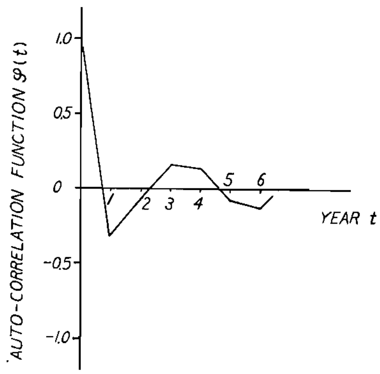

Fig. 4. Correlogram of residual summer inflow, removed periodic change from total inflow.

Furthermore, the technique of Fourier transform and its factorization are used to get the solution of eq. (8), that is, predictor $f(t+p)$ and average quadratic error $\sigma^2(K)$.

The correlogram of the residual summer inflow is shown in Fig. 4 and it seems to show a cyclic periodicity. Then, putting the general form of correlation function by

$$\varphi(t)=e^{-\alpha t}\cos\beta t, \tag{9}$$

the optimum predictor and its average quadratic error are given by

$$f(t+p)=A\cdot f(t)-B\int_0^\infty f(t-\tau)\cdot e^{\sqrt{\alpha^2+\beta^2}\cdot\tau}\cdot d\tau \tag{10}$$

where

$$A=e^{-\alpha p}[\{\sqrt{(\alpha/\beta)^2+1}-(\alpha/\beta)\}\sin\beta p+\cos\beta p] \tag{11}$$

$$B=2e^{-\alpha p}(\alpha^2+\beta^2-\alpha\sqrt{\alpha^2+\beta^2})\sin\beta p/\beta \tag{12}$$

and

$$\sigma^2=1-\{\sqrt{(\alpha/\beta)^2+1}-(\alpha/\beta)\}e^{-2\alpha p}\{\sqrt{(\alpha/\beta)^2+1}(\alpha/\beta)\cos 2\beta p\} \tag{13}$$

Here, the meaning of the above relations is in the following: First, in the case of a fixed interval p of prediction, the optimum predictor of $f(t+p)$ is $A\cdot f(t)$ on the basis of the only information at the time t, and the correction to $A\cdot f(t)$ is done by the second term in eq. (10), which results from the past information before t. In this case, comparison with the information $f(t-\tau)$ at any past time $t-\tau$, the information $f(t-\tau-1)$ at one unit before the time $t-\tau$ is $1/e^{\sqrt{\alpha^2+\beta^2}}$ times in the weight. Next, in the case of a varied interval p, the optimum predictor $f(t+p)$ and its error σ necessarily tend to 0 and 1 as p increases. At the same time, since the tending is mainly influenced by the power term $e^{-\alpha p}$, the prediction rapidly becomes vain.

The result predicted is significant, when the predictive error σ is in an allowable limit. Of course, the significant predictive interval p is affected by constants α as well as β, but the effect by α is more important as described in the foregoing. Let consider the significant limit p_m of predictive interval p independent of β. Putting the allowable error of prediction by σ_a, and substitutung $\sigma\leq\sigma_a$ and $\cos 2\beta p\leq 1$ into eq. (13), the allowable limit of predictive interval should at least satisfy the relation,

$$p\leq-\frac{1}{2\alpha}\log_e(1-\sigma_a{}^2)\equiv p_m \tag{14}$$

Especially, in the case of discrete time series, the prediction at the unit time later should be at least significant, so that inserting $p_m\geq 1$ into eq. (14), the resulting equation becomes

$$\alpha\leq-\frac{1}{2}\log_e(1-\sigma_a{}^2)\equiv\alpha_m \tag{15}$$

The relationship between σ_a and α_m in eq. (15) is shown in Table 1. In conclusion, if α_m corresponding to the allowable error σ_a is smaller than the depression coefficient α in an actual correlogram derived from stationary

TABLE 1.
Relation between allowable error σ_a for prediction and critical coefficient α_m of significance.

σ_a	0.99	0.95	0.90	0.75	0.50
α_m	1.956	1.168	0.831	0.414	0.144

time series $f(t)$, the practical prediction is impossible.

The computation of theoretical constants α, β in eq. (9) can be calculated in the following approximate method. α can be determined by the least square method, by putting $\beta=2\pi/\Omega$ in which the period Ω is approximately taken as the interval at the maximum value in the first cycle of correlogram. Namely, by using appropriate h terms, α is determined by

$$\alpha=-\log_e x, \tag{16}$$

in which x is the solution of the equation of

$$r_1 \cos\beta + r_2 \cos 2\beta\cdot x + \cdots\cdots + r_h \cos h\beta\cdot x^{h-1} = \cos^2\beta\cdot x + \cos^2 2\beta\cdot x^3 + \cdots\cdots + \cos^2 h\beta\cdot x^{2h+1} \tag{17}$$

In order to know whether the h-th term is appropiate or not, the following method is used. That is, the judgement is done by whether the correlation functions of higher terms than h-th one in eq. (9) are in the confidence limit which is calcualated from sample correlation coefficients or not.

In the case of the summer inflow to Lake Biwa, the results computed are $h=3$, $\alpha=1.02$ and $\beta=1.80$ for the correlogram of Fig. 4. If the allowable error is taken as $\sigma_a=0.9$, the critical coefficeint of α is given by $\alpha_m=0.83$ in Table 1. As α_m is smaller than α, so the series of the annual summer inflows removed by the periodicity will be at random occurrence. It can be concluded that the prediction of the annual summer inflows, made by a linear combination of past residual inflows, is of no value in practice. And also, this fact means that the mathematical treatment by means of the probability theory as random process may be used to the residual inflow removed by the periodicity. Indeed, this probabitity distribution is shown by the small circles in Fig. 5 and it can be easily expressed as the normal distribution by the use of a proper transformation.

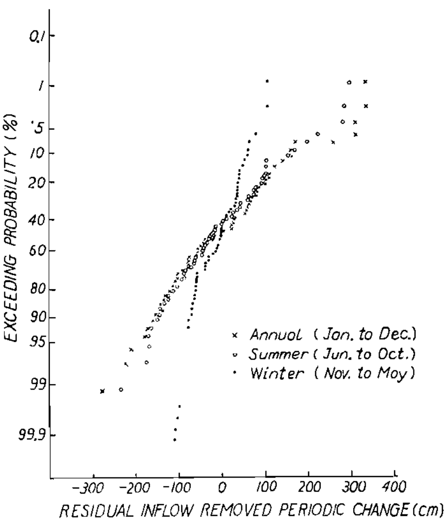

Fig. 5. Probability distribution of residual annual, summer and winter inflow removed periodic change.

The above description has made for the summer inflow, whereas for the winter inflow the significant secular change cannot be noticed. For the annual inflow the same secular change as the summer one can be discerned and is also shown in Fig. 2. The probability distribution of annual and winter inflows removed by the periodic change are shown in Fig. 5.

6. Relationship between precipitation and inflow

In this section, let consider the climatic causes of the secular change in inflows. The inflow is the difference between the precipitation as the source of water supply and the total loss of water during runoff, so that it is necessary to know both causes of variation. However, they are very complex phenomena and especially for the precipitation the meteorogical condition at higher altitudes may be a primary factor. Therefore, the total loss of water, which will be possibly estimated only by the usual observation near the ground surface, will condidered.

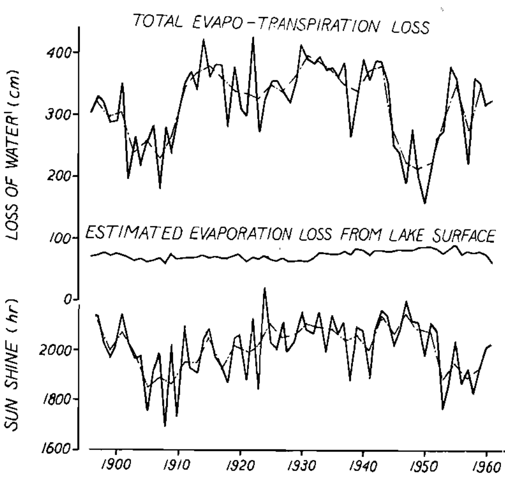

Fig. 6. Secular changes of total evapo-transpiration, estimated evaporation lake surface, and sun-shine at Hikone.

The upper curve of Fig. 6 is the secular change of the total loss of water calculated by subtracting the obtained inflow from the average precipitation over the basin. Since, as already mentioned, the whole trend in the secular change is important, and by the correlogram analysis the periodicity over 1% significant level cannot be discerned, the grasp of the outline in the secular change is carried out by a proper moving average method. In this case, the moving average for 4 years is appropriate for it, and it is shown by a chain line in Fig. 6. In this figure, the total loss of water seems to be troughs for about ten years in the neighbourhood of 1905 and 1950, and the outline of this change is likely to have a reverse inclination in comparison with that of inflow.

If a consideration is limited to the annual balance of water, the total loss of water may be considered as the total evaporation and transpiration from the lake and the ground. Assuming that a proportional relationship between monthly amount of surface evaporation from the lake and that from pan evaporation, the proportional coefficients are obtained as seen in Table 2. The curve in the middle of Fig. 6 is the estimated evaporation from the lake which is computed by annualy summing monthly lake evaporations obtained from those pan coefficeints. The obtained result shows that the secular change of the total evapotranspiration chiefly depends upon the evapotranspiration from the ground except from the lake, because the evaporation from the lake surface seems nearly constant.

TABLE 2.
Proportional coefficient between monthly amounts of surface evaporation from Lake Biwa and pan evaporation at Hikone, 1954 to 1960.

Evaporation \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
from Water Surface (at Seta)	cm 28	45	53	84	87	72	109	115	72	53	45	37
from Pan (at Hikone)	47	54	74	102	114	123	157	173	117	78	63	48
Pan Coefficient	0.59	0.83	0.71	0.83	0.76	0.58	0.69	0.66	0.62	0.67	0.71	0.77

From the view-point of the heat-balance theory, the main physical phenomenon affecting on the total evapo-transpiration is considered to be the supply of heat into the basin and its outward divergence. However, the climatic elements at Hikone meteorological observatory, the insolation as a supply source of heat seems to be the most dominating element affecting on the secular change of the total evapo-transpiration in comparison with vapor-pressure difference, the wind velocity, and so on.

The observation of insolations involves discontinuous records of the direct solar radiation by the silver disk pyrheliometer until 1951 and of the radiation on the horizontal surface by the Robitszch meter after 1954, and a continuous record of sun-shines by the Jardan meter. Among them, the monthly amount of direct solar radiation in each year varies in the range of 1.1~1.3 cal/cm^2·min during sun-shine and does not make a great seasonal change. By considering the linear relation between the monthly radiation on the horizontal surface and the monthly sunshine in Fig. 7, it can be said that the intensity of insolation does not vary widely during sun-shine. Hence, the amount of insolation can by annually estimated by the use of cumulative sun-shines.

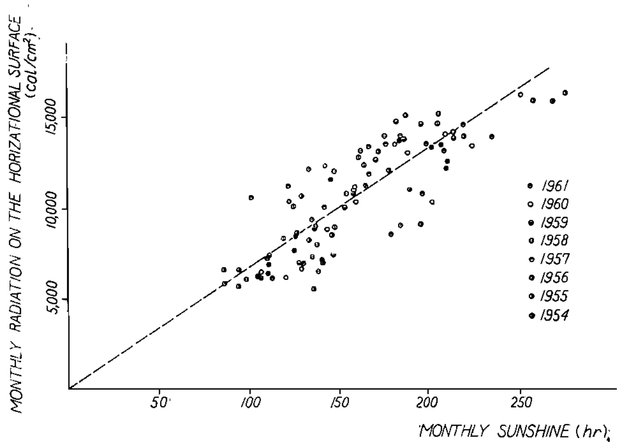

Fig. 7. Relation between monthly rediation on the horizontal surface and monthly sun-shine at Hikone.

The secular change in cumulative sun-shines and its moving average for 4 years are shown by a full line and a chain line in the lower sheet of Fig. 6. The secular changes in the cumulative sun-shines and the total loss of water seem to resemble each other except for a few years in the neighbourhood of 1950. On the other hand, the expression of the total evapo-transpiration made by vapor-pressure differences and wind velocity, etc. as of

Dalton's law, was made by various trials, but it was in vain because of inconsistency of their trends. This fact will mean that, for the total evapo-transpiration in so large area as Lake Biwa basin (about 3,800 km^2), a climatic factor prevailing over the basin like the heat supply has a more dominant effect than that of strong localities such as vapor-pressure differences, wind velocity etc., that is, the divergent factor as explained by Cummings and others[12].

For a few years nears 1950, an inconsistency of trends between the total evapo-transpiration and the cumulative sun-shines will be considered to result from the change of hydrologic condition due to the rapid removal of forest and the cultivation of land[13], while the details will not be known.

7. Summary

This paper described the characters of the secular change in the inflow into Lake Biwa by the use of the time series analysis, especially its periodity and randomness, the possibility of the prediction of the future inflow and the climatic factors affecting on the annual loss of water, which is the difference between the inflow into the lake and the precipitation over the basin, are concerned.

The summary obtained are in the followings:

(1) Since the secular change in the winter inflow (Nov. to May) is nearly stationary, that in the annual inflow is mainly due to the summer inflow (Jun. to Oct.).

(2) The periodicity of about 60 years in the secular trend of annual and summer inflows is discerned by correlogram analysis. By fitting a sinuous function to this periodic change, peaks of the annual inflow occur in 1903 and 1960, its trough in 1931, and its amplitude becomes 94 cm in water depth of the lake. No special trend can be found out about the residual inflow which is removed by such a periodicity from the total inflow.

(3) The prediction by the use of the Wiener's theory, based upon a linear combination of the residual inflows, is of little significance in practice from the view-point of predictive error.

(4) Since, owing to the field observation, the secular change in the annual amount of evaporation from the lake surface is not so large, the secular change of the total loss of water will result mainly from the evaporation and the transpiration from the ground and the vegetation in the drainage area surrounding the lake.

(5) One of the dominant factors affecting on the secular change in the total loss of water is the insolation, and especially cumulative sun-shines because both secular changes resemble each other.

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