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Investigating the conversion coefficients for free water surface evaporation of different evaporation pans

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Abstract:

The conversion coefficients of free water surface evaporation were investigated. Comparisons were made between numerous evaporation tanks (pans) and a 20 m^2 evaporation tank. Based on 6 years of evaporation data collected at Nansihu Lake Evaporation Station in Shandong Province, China, the following results have been obtained. First, conversion coefficients varied according to the evaporator type. The average yearly conversion coefficient was only 0·60 for ϕ20 evaporator (an evaporation pan with a diameter of 20 cm), whereas it was about 1·07 for the E601's pan, whose rim was about 7·5 cm above ground. Second, the conversion coefficient changes within a year had the same pattern among the evaporators evaluated. The monthly conversion coefficients had the minimum values in March or April, then increased with time, and reached their maximum values in August or September. After September, the conversion coefficients varied in different directions with time. Third, the conversion coefficients changed from year to year, but their variations between maximum and minimum values were between 0·06 and 0·16. Fourth, the installation modes, structures, and composition of the evaporators affected the evaporation amount. Fifth, the conversion coefficients at Nansihu and Yucheng stations for the same evaporator did not show a distinct difference. The E601 evaporator has almost the same conversion coefficients at six of seven stations spanning almost 20° in latitude from northern to southern China. Sixth, the yearly evaporation from a 100 m^2 evaporation tank was almost the same as that from the 20 m^2 evaporation tanks; however, the differences still existed in any given month. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS Nansihu Lake Experimental Station; free water surface evaporation; conversion coefficients; evaporators

INTRODUCTION

Free water surface evaporation is one of the most important processes of the natural hydrological cycle and a part of water loss of water bodies, such as rivers, lakes, and reservoirs. Hydrological and hydraulic engineering projects, regional water-balance studies, and regional water resources planning all need the free surface evaporation data (Hong, 1991). The free surface evaporation is also an important weather variable that has numerous applications related to decision making in agriculture, forestry, ecology, hydrology, and other fields (Bruton *et al*., 2000b).

In general, there are two ways to estimate the free water surface evaporation amount: one is to calculate the amount according to meteorological parameters and the other is to measure it directly in the experimental field. Since the late 1800s, when the first empirical investigation was published after Dalton's work, there have been a number of formulas used to calculate the amount of free water surface evaporation (Dalton, 1802; Budiko, 1958; Sartori, 2000). Singh and Xu (1997) gave an evaluation of 13 mass-transfer equations for determining free water evaporation. In recent years, some new techniques have also been employed in estimating evaporation, including artificial neural networks (Bruton *et al*., 2000a) and satellite automatic

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picture transmission (APT) thermal infrared data (Xin and Shi, 1991). The countless number of papers and equations on evaporation mean that none of them is universally acceptable and that each equation is valid for only particular circumstances and climates similar to those where the measurements were made (Sartori, 2000). Sartori (2000) gave a critical review on the equations employed for the calculation of the evaporation rate from free water surfaces and concluded that, up until now, there has been no consensus on which equations were better to employ, since a large scatter in evaporation rates had been found.

Another popular method is to measure evaporation in the field with evaporation instruments, such as evaporation pans. The World Meteorological Organization (WMO, 1966) suggests the following as standard equipment for measuring free water surface evaporation: a 20 m^2 evaporation tank, a Russian GGI-3000, and a Class A evaporator from the USA. Chin and Zhao (1995) developed a methodology to assess the relative merits of using evaporation-pan networks. Lawrimore and Peterson (2000) analysed the pan evaporation trends in dry and humid regions of the USA. However, this equipment cannot be found in most hydrological and meteorological stations in China, where E601 and $\phi 20$ evaporation pans (i.e. pan diameter of 20 cm) are used instead. Therefore, a conversion coefficient for free water surface evaporation on different evaporators is necessary. Here, we report on the study of conversion coefficients based on 6 years of evaporation data for various evaporators from field experiments. The results can be used to estimate regional free water surface based on the available data from E601 and $\phi 20$ evaporation pans. The North China region, consisting of Beijing and Tianjin, is a densely populated area acting as the centre of politics, economy, culture and transportation in China. However, the average amounts of water resources in this region per capita and per hectare are one-fourth and one-fifth of the country's averages respectively (Table I). In order to cope with the water shortage problem in this region, many water resources engineering plans have been proposed. All these projects need free water surface evaporation information. In fact, the main purpose of building the Nansihu Lake evaporation experimental station is to supply basic data for the Water Transfer from South to North Project.

The time scale is critical to the conversion coefficients, as well as the evaporation estimation (Xu and Singh 1998). The conversion coefficients presented in this paper are all monthly based thorough accumulations of daily evaporation. These results could not be used as daily coefficients, because daily pan evaporation is very difficult to measure accurately and consistently over longer time periods (Bruton *et al*., 2000a).

The overall objective of this research is to study the conversion coefficients of various evaporators and a 20 m^2 evaporation tank based on experimental data at Nansihu Lake Experimental Station. The results can directly supply water surface evaporation information for water resources engineering in the North China region. The results can also be used to estimate regional free water surface in areas with similar climate conditions. In addition, pan evaporation data could be very useful as a practical tool for estimating potential evapotranspiration (Jones, 1992).

Table I. Population, agriculture, industry, and water resources in the five regions of China

Region	Population (million)	Territory share (%)	Grain yield share (%)	Industry output share (%)	Water resource share (%)	Water yield (10 000 m^3 km^{-2})	Water resource	
							m^3/capita	m^3 per hectare cultivated land
Northeast	105·2	8·44	12·60	9·49	5·57	19·09	1453·84	9358·50
North	322·1	19·46	26·83	26·26	6·14	9·13	523·14	5620·80
Northwest	88·1	31·88	6·12	3·01	8·14	7·39	2537·58	19 603·95
Southeast	467·3	13·18	37·17	53·35	33·72	74·08	1981·38	39 377·70
Southwest	240·5	27·05	17·28	7·88	46·44	49·07	5301·54	92 831·55

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MATERIALS AND METHODS

Location of the experimental station

The Nansihu Lake Experimental Station is located at the eastern part of the No. 2 dam on Nansihu Lake, the largest freshwater lake in the Shandong Province, China, with a catchment area of 31 422 km^2 (Figure 1). The field is situated at 117°00′E, 34°53′N, and at 38 m above sea level. The area of the station is about 9900 m^2, of which 3960 m^2 is used for installing observation instruments and the remaining 5940 m^2 is used for office and infrastructure. The site is flat and open and is totally surrounded by the lake. The field, one of the largest free water surface evaporation sites in China, was constructed in 1980 and began operations in 1985.

The Nansihu Lake region has a typical monsoon climate, and air mass movement direction and intensity vary from month to month. The air temperature, humidity, wind direction, wind speed, and precipitation in this region thus vary from season to season. The wind directions are easterly or southeasterly in spring, westerly or southwesterly in fall, and northerly or northwesterly in winter.

Instrument installation

A national, standard meteorological observation station was set up on the northeastern portion of the site and 15 different evaporators were installed in the western and southern portion (Figure 2). Detailed information about the different types of evaporator installed is given in Table II. They fall into four categories:

1. Evaporation tanks (pans) with different surface areas of 100 m^2, 20 m^2, 5 m^2, 3 m^2, and 1 m^2.
2. Class-A evaporators (USA), GGI-3000 evaporation pan (Russia, former USSR), E601 evaporation pan (China), ϕ20 evaporation pan (China), and tube evaporation pan with a bore of 80 cm (ϕ80).
3. Tube GGI-3000 (GGI3000-2), GGI-3000 half buried in soil (GGI3000-3), exposed GGI-3000 (GGI3000-4), and the E601's pan without grade (E601-2).
4. Fibreglass E601 (E601-3).

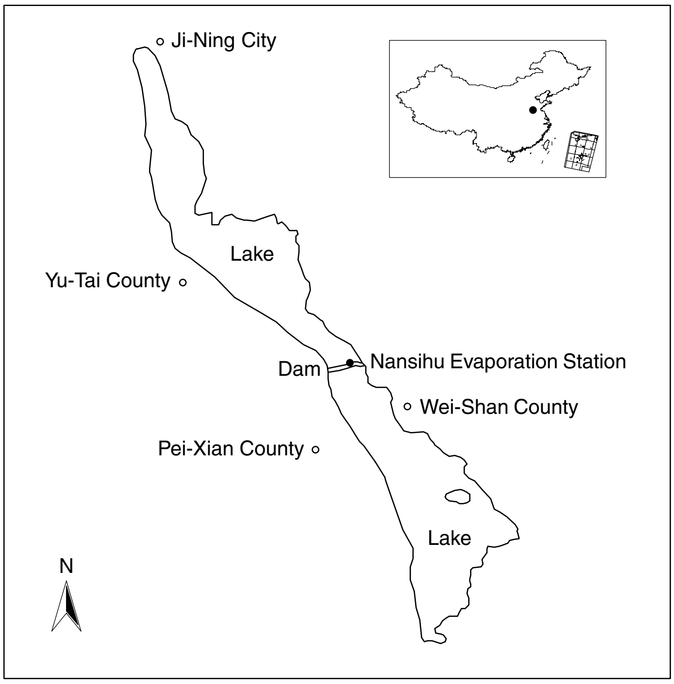

Figure 1. The location of Nansihu Evaporation Experimential Station

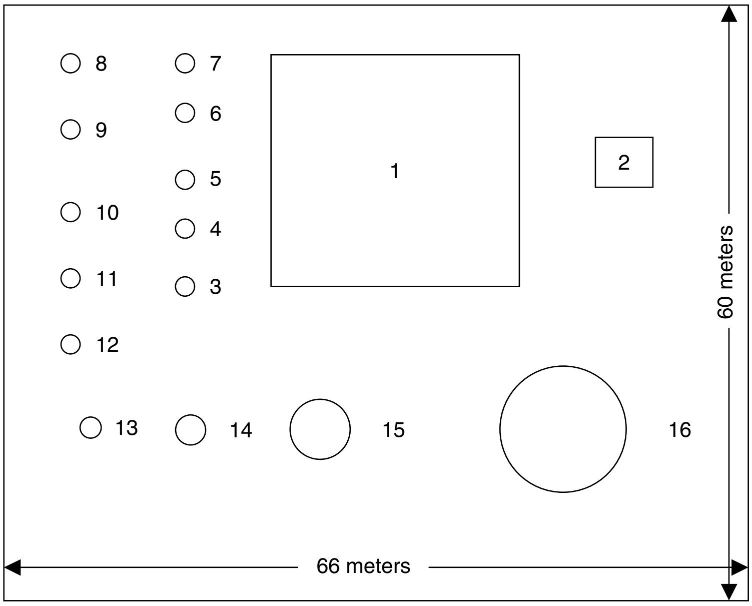

Figure 2. Evaporators at Nansihu Evaporation Experimental Station: (1) standard meteorological observation station; (2) solar radiation; (3) standard E601; (4) the E601's pan without grade; (5) standard GGI-3000; (6) GGI-3000 half buried in soil; (7) exposed GGI-3000; (8) tube evaporation pan with a bore of 80 cm; (9) Class-A evaporator; (10) tube GGI-3000; (11) 1 m^2 evaporation pan; (12) fibreglass E601; (13) 3 m^2 evaporation pan; (14) 5 m^2 evaporation pan; (15) 20 m^2 evaporation pan; (16) 100 m^2 evaporation pan. $\phi 20$ evaporation pan is located inside the meteorological station

Water surface temperature, water temperature at 0·4 m below the water surface, and wind speeds at 0·2 m and 1·5 m above the ground were also measured to build a quantitative relationship between free water surface evaporation and meteorological factors. These results will be discussed in another paper.

Observations

Evaporation was determined by the water levels, which were measured by the point gauge method. The electric ZHD point gauge for evaporation pans was used, and had an accuracy of 0·1 mm. The water-level measurement was taken twice a day, at 8 : 00 a.m. and 8 : 00 p.m., to see the difference between day evaporation and night evaporation. The daily evaporation was computed based only on the value at 8 : 00 a.m., which was consistent with the observation of most meteorological factors, using the following equation:

$$E = P + (n_1 - n_2) \tag{1}$$

where E denotes daily evaporation, P is daily precipitation (measured at the same site and the same time), and n_1 and n_2 are water surface heights measured in the evaporation pans for the previous and present measurements respectively.

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Table II. The evaporators installed at Nansihu Lake Experimental Station

Evaporator	Description	Size	Installation	Remarks
E601-1	Standard E601	Area: 3000 cm^2 Depth: 60 cm (cylinder) + 8·7 cm (circular cone)	There is a 22·5 cm high grade on the bottom and the rim of the evaporator is 30 cm above ground level	Modified evaporator from GGI-3000. Standard GGI-3000 plus 4 arc water trough of 20 cm in width
E601-2	E601 without grade	Same as standard E601	There is no grade and the rim is 7·5 cm above ground	Different installation method from standard E601
E601-3	Standard E601	Same as standard E601	Same as standard E601	Different material (fibreglass) from standard E601
GGI3000-1	Standard GGI-3000	Same as standard E601	Buried in the ground with rim about 7·5 cm above the ground level	Popular in former USSR
GGI3000-2	Tube GGI-3000	Same as standard GGI-3000	Same as standard GGI-3000	Standard GGI-3000 plus a tube with 113 cm in diameter and 150 cm in height
GGI3000-3	GGI-3000 half-buried in soil	Same as standard GGI-3000	Half of evaporator is buried and the rim is 30 cm above ground	Different installation method from standard GGI-3000
GGI3000-4	Exposed GGI-3000	Same as standard GGI-3000	Exposed to air	Not buried in soil
Class-A	Class-A	Area: 12·56 ft^2 (diameter: 4 ft) Depth: 10 in	Supported by a wood frame and the bottom is 5 cm higher than ground	Popular in USA
ϕ80	Tube pan with a bore of 80 cm	Bore: diameter, 80 cm; depth, 40 cm Tube: diameter, 100 cm; depth, 45 cm	Supported by a brick foundation with diameter of 110 cm and height of 25 cm. The rim is 70 cm from the ground	The bore is used to measure evaporation. The space between bore and tube is filled water. A 5 cm deep wooden frame is used to hold the bore at the bottom of tube
1 m^2	1 m^2 evaporation tank	Area: 1 m^2; depth: 2 m	Rim is 10 cm from the ground	
3 m^2	3 m^2 evaporation tank	Area: 3 m^2; depth: 2 m	Rim is 10 cm from the ground	
5 m^2	5 m^2 evaporation tank	Area: 5 m^2; depth: 2 m	Rim is 10 cm from the ground	
20 m^2	20 m^2 evaporation tank	Area: 20 m^2; depth: 2 m	Rim is 10 cm from the ground	Standard tank recommended by WMO
100 m^2	100 m^2 evaporation tank	Area: 100 m^2; depth: 2 m	Rim is 10 cm from the ground	
ϕ20	ϕ20 evaporator	Area: 314 cm^2 (diameter: 20 cm) Depth: 10 cm	Rim is 70 cm from the ground	Installed at every meteorological station in China

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Calculation of the conversion coefficients

The WMO suggests a 20 m^2 evaporation tank as the standard equipment for free water surface evaporation; therefore, we calculate all the conversion coefficients R in comparison with the evaporation from a 20 m^2 evaporation tank, i.e.

$$R = E_{20}/E_s \tag{2}$$

where E_{20} and E_s are the evaporation amounts from a 20 m^3 evaporation tank and the specific evaporator respectively.

Statistical testing

In this study, a lot of comparisons have been made. The two-tailed t-test was used to check whether these differences are statistically significant or not. We assume that the evaporation amount is normally distributed, because if the mean of a random variable is three or four times greater than its standard deviation, then the probability of a normal random variable being less than zero is very small and can, in many cases, be neglected (Hann, 1977).

Three formulas are used to calculate the test statistics, depending on whether the variances are known and whether the variances are the same for the two variables (Montgomery *et al.*, 2001). In the first case, both the population standard deviations σ are known; in the second case, the σ values are not known, but they are equal; in the third case, both σ values are not known and they are not equal. As our sample is limited, we could not know the value of σ *a priori* and so our testing falls into the second and third categories. An F-test was used to check whether the two σ values were equal or not before a t-test was applied. If the two σ values were equal, then the statistic t_0 was calculated by using the formula for the second case, otherwise the test statistic and degrees of freedom were calculated by using the formula for third case.

RESULTS AND DISCUSSION

Results of the conversion coefficients

The monthly conversion coefficients for various evaporators are shown in Table III. The data for all evaporators were obtained for the time period of 1985 to 1990, with the exception of E601-3, for which the data were collected from 1986 to 1990.

Three types of E601, three of four types of GGI-3000, and all evaporation tanks, have conversion coefficients exceeding 0·93. The discrepancy of the evaporation pan with a diameter of 20 cm is the greatest, with an average conversion coefficient of only 0·60. This is because the $\phi 20$ evaporation pan has the smallest volume (Table II) and its reaction to changes of climatic and meteorological conditions are most prominent. The largest evaporation amount resulted in the smallest conversion coefficients. The Class-A, GGI3000-4 and $\phi 80$ evaporators stand in the middle, with values between 0·82 and 0·88.

A coefficient value close to unity means that the evaporation amount from the evaporator is numerically close to that measured over a 20 m^2 tank. The yearly water surface evaporation amount can be estimated from the specific evaporator if the conversion coefficient is close to unity. However, from a practical point of view, the stability of the conversion coefficient over different months is more important than the value itself. If the monthly conversion coefficient is stable over a year for a specific evaporator, then we can obtain the monthly 20 m^2 evaporation pan's free water surface evaporation amount from this evaporator, which usually cost less money to construct than a 20 m^2 evaporation tank.

For the same type of evaporator, the dimension is positively related to the conversion coefficients and negatively related the evaporation amount. The evaporation tank series with different areas is a typical example of such a relationship.

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Table III. Monthly and yearly mean conversion coefficients and their coefficients of variation

Evaporator	Conversion coefficient									Mean	Coefficient of variation
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov		
E601-1	0·93	0·89	0·92	0·94	1·00	1·04	1·08	1·05	1·08	0·99	0·066
E601-2	1·00	0·96	1·02	1·00	1·06	1·13	1·20	1·13	1·16	1·07	0·070
E601-3	0·88	0·84	0·88	0·90	0·97	1·05	1·13	1·04	1·07	0·98	0·095
GGI3000-1	0·93	0·87	0·90	0·91	1·00	1·08	1·09	1·05	1·08	0·99	0·080
GGI3000-2	0·84	0·86	0·89	0·87	0·92	1·02	1·08	0·99	1·05	0·95	0·085
GGI3000-3	0·86	0·77	0·88	0·85	0·94	1·09	1·12	1·03	1·10	0·96	0·120
GGI3000-4	0·68	0·66	0·73	0·72	0·80	0·99	1·02	0·86	0·90	0·82	0·145
Class-A	0·81	0·68	0·75	0·73	0·81	0·92	1·04	0·95	1·15	0·87	0·160
ϕ80	0·78	0·70	0·76	0·73	0·84	0·97	1·07	0·98	1·07	0·88	0·149
1 m^2	0·84	0·84	0·95	0·94	1·00	1·06	1·04	0·88	0·83	0·93	0·085
3 m^2	0·92	0·92	1·02	1·00	1·09	1·14	1·05	0·93	0·89	1·00	0·078
5 m^2	0·95	0·96	1·02	1·02	1·05	1·08	1·02	0·95	0·93	0·99	0·047
ϕ20	0·55	0·49	0·52	0·52	0·57	0·61	0·71	0·67	0·75	0·60	0·138

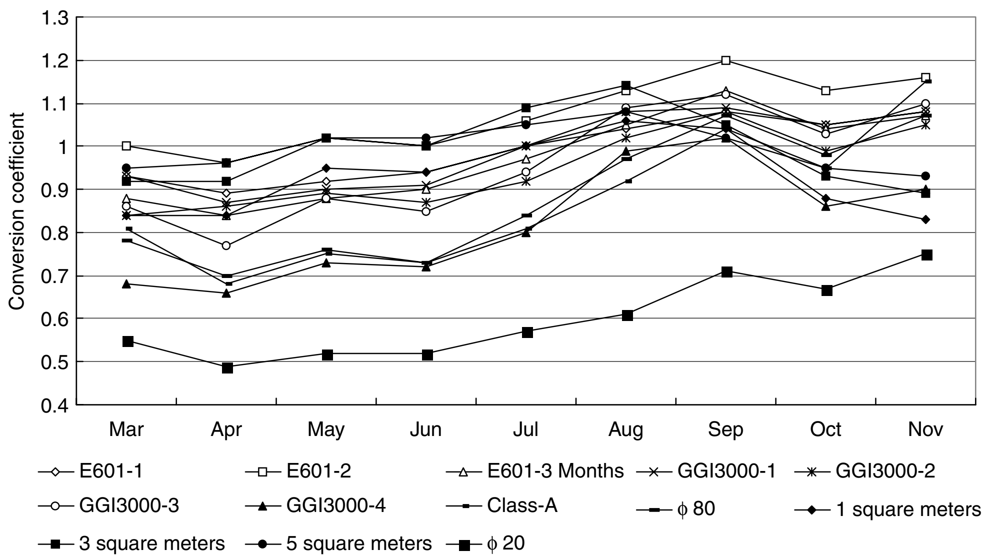

Figure 3. The conversion coefficients change in a year

Seasonality of the conversion coefficients

The conversion coefficients of an individual evaporator can vary with time, which indicates that the conversion coefficients are unstable in a temporal distribution. The conversion coefficients varied throughout the year in the same pattern for all the evaporators (Figure 3). The conversion coefficients have the lowest values in March or April, then increase with time, and reach their maximum values in August or September. After that time, the conversion coefficients of some evaporators, such as evaporation tanks, decrease with time (Figure 4), and other evaporators, such as the Class-A evaporator, the ϕ20 evaporator and the ϕ80 evaporator, continue to increase and reach their maximum values in November (Figure 5).

The coefficients of variation of conversion coefficients within a year varied among the different evaporators (Table III). Three evaporation tanks that have the same structure but different areas showed that the volume of the evaporator is negatively related to coefficients of variation.

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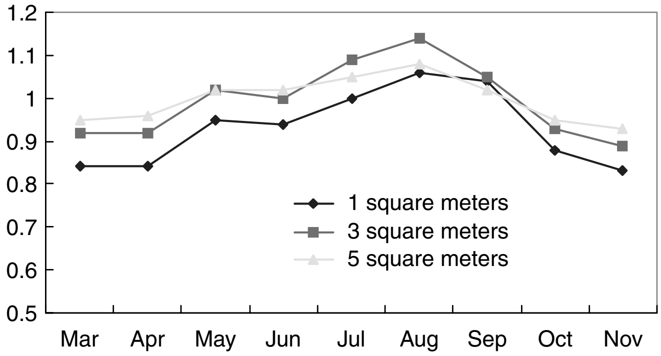

Figure 4. Changes of conversion coefficients over a year for evaporation tanks

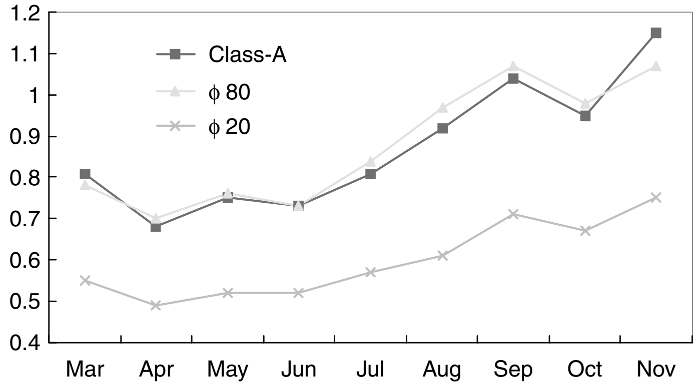

Figure 5. Changes of conversion coefficients change over a year for Class-A, $\phi 20$ evaporator, and $\phi 80$ evaporator

Table IV. The differences between minimum and maximum monthly value of conversion coefficients for various evaporators

Evaporator	Difference
E601-1	0·24
E601-2	0·24
E601-3	0·29
GGI3000-1	0·22
GGI3000-2	0·24
GGI3000-3	0·35
GGI3000-4	0·36
Class-A	0·47
$\phi 80$	0·37
1 m^2	0·23
3 m^2	0·15
5 m^2	0·17
$\phi 20$	0·26

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In spite of having the same pattern within a year, the evaporators exposed to air had notable differences in their maximum and minimum monthly values. This value was about 0·37 for ϕ80 evaporator, 0·47 for Class-A, and 0·36 for GGI3000-4. The evaporation tanks have the smallest differences in their maximum and minimum monthly values (Table IV).

Free water surface evaporation is affected by meteorological conditions such as humidity, temperature (of air and water) and wind speed. These factors determine the basic seasonal fluctuation pattern of evaporation over a year. The physical processes and mechanisms are highly complicated and require additional future investigation.

Year-to-year change in conversion coefficients

The conversion coefficients change from year to year, but their variations are not significant according to our observation data. The variation in annual conversion coefficients was 0·06 for the ϕ20 evaporator and 0·16 for the GGI3000-4 evaporator (Table V). This result indicates that the yearly conversion coefficients for a specific evaporator at the same site are relatively stable.

The average rainfall from March to November for the years 1985 to 1990 at the Nansihu Lake Experimental Station was about 631·1 mm, with considerable variation between years. The rainfall was 891·5 mm in 1985 (wet year), 625·5 mm in 1990 (roughly the same as the 6 year average value, normal year), but only 375·2 mm in 1988 (dry year). The free water surface evaporations from March to November for the E601 evaporator were 712·3 mm, 749·7 mm and 836·1 mm respectively for these 3 years. The free water evaporation was about 5·0% smaller in a wet year and about 11·5% larger in a dry year than in a normal year. However, the conversion coefficients did not show the same difference as evaporation: they were the same in the wet year and the normal year and only a 2% difference exists between a dry year and a normal year.

A meteorological station at the No. 2 dam of Nansihu Lake showed that the average annual precipitation was 699·4 mm from 1964 to 1983 (http:/cgz.myrice.com/wshhtm/zrzk.htm), and the precipitation from March to November was 660·2 mm, which is only slightly different from the 6 year average value of 631·1 mm. However, the 891·5 mm and 375·2 mm precipitation amounts could still be considered as 'wet year' and 'dry year' respectively according to this value.

The impacts of installation methods on conversion coefficients

The different installation methods for the same evaporator at the same site could result in both different evaporation and conversion coefficients. This is because the installation method changes the boundary

Table V. The differences between minimum and maximum yearly value of conversion coefficients for various evaporators

Evaporator	Difference
E601-1	0·12
E601-2	0·14
E601-3	0·08
GGI3000-1	0·09
GGI3000-2	0·09
GGI3000-3	0·07
GGI3000-4	0·16
Class-A	0·12
ϕ80	0·09
1 m^2	0·10
3 m^2	0·08
5 m^2	0·10
ϕ20	0·06

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conditions of the evaporator. For example, the evaporator exposed to air has a greater evaporation than one buried in soil, and a greater evaporation will result in a smaller conversion coefficient. Table II showed that the difference in conversion coefficients between GGI3000-1 and GGI3000-4 was about 17·2%. The water surface evaporation from exposed GGI-3000 was greater than that from the standard GGI-3000 for every month (Figure 6). The unit that was half buried in soil (GGI3000-3) generally had a value between these two extremes, with a few exceptions.

The E601's pan without grade (E601-2) had a smaller evaporation and a larger conversion coefficient than the standard E601 installation method (Table III and Figure 7).

The impacts of installation methods on conversion coefficients can be attributed to two reasons. First, the evaporator exposed to air will receive more net solar radiation than that buried in soil. The latter also uses part of its solar radiation in heat exchange with soil. The larger net solar radiation results in higher water temperature and larger differences in vapour pressure at the surface of the water and in the air. Second, the evaporator exposed to air will be subject to a stronger influence from wind than that buried in soil. These two factors are directly related to evaporation as expressed by Dalton's formula:

$$E = (e_0 - e_z)f(u) \tag{3}$$

Of the total heat loss from a free water surface, more than 50% is due solely to evaporation (Sartori, 2000). From the energy balance point of view, the evaporator exposed to air should also evaporate more than that buried in soil.

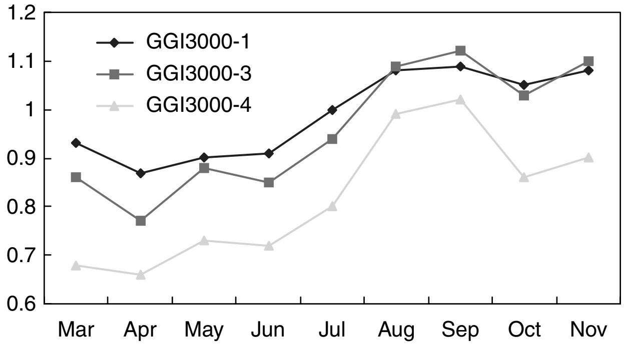

Figure 6. Effects of installation methods on conversion coefficients (GGI-3000)

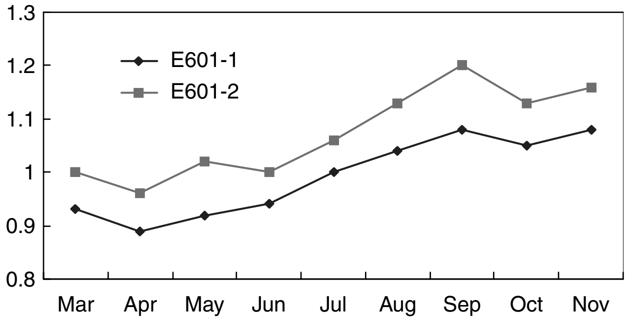

Figure 7. Effects of installation methods on conversion coefficients (E601)

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Impact of evaporator structure on conversion coefficient

The evaporator structure also affects evaporation measures and conversion coefficients. To assess the impact of evaporator structure on conversion coefficient, a cylinder with a diameter of 113 cm and a height of 150 cm was placed on the outside of a standard GGI-3000. This GGI-3000 with altered structure was referred to as tube GGI-3000 (GGI3000-2 in Table II). The results showed that a difference in conversion coefficients between the standard GGI-3000 and the structure-changed GGI-3000 did exist (Table III and Figure 8).

The tube GGI-3000 had a higher evaporation and smaller conversion coefficients than that of that standard GGI-3000. One reason may be that the partial net solar radiation, which exchanges heat with soil for a standard GGI-3000 mode, was now used to evaporate, because the space between the standard GGI-3000 and the tube is filled with water.

Impacts of materials on conversion coefficients

Traditionally, evaporators have been made of metal. In our experiment we tested an E601 made of fibreglass (E601-3) to examine the impact of evaporator composition on evaporation, as well as on conversion coefficients. The yearly conversion coefficient was not found to differ greatly, but monthly conversion coefficients did differ (Figure 9). This phenomenon can be explained by the fact that different materials have different heat-conducting characteristics. In all months except August and September, the metal evaporators had smaller evaporation and larger conversion coefficients.

Comparison of results between regions in China

At Yucheng Integrated Experimental Station, Shandong Province, China, situated at 116°38′E, 36°56′N and 20·6 m above sea level, we built another free water surface experiment station. Many evaporators are the same

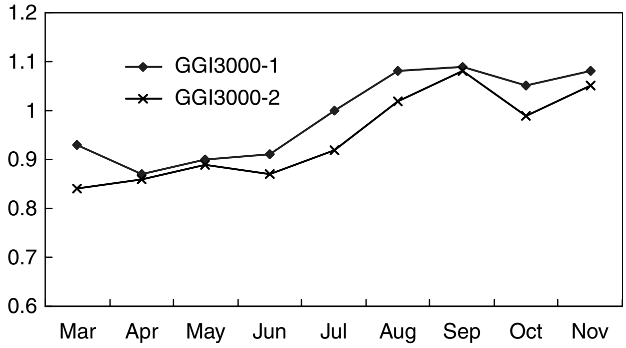

Figure 8. Effects of evaporation structure on conversion coefficients

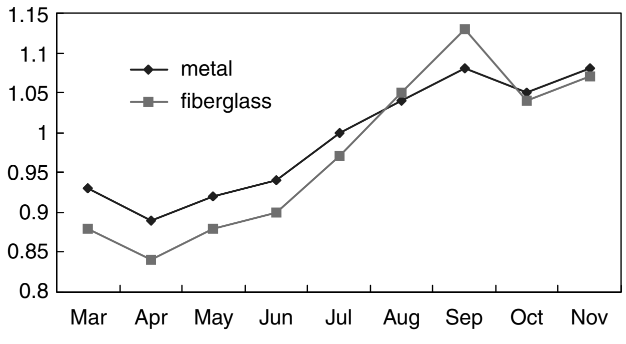

Figure 9. Effects of evaporator's material on conversion coefficients

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at the two stations (Hong, 1991), allowing for a comparison of the conversion coefficients at the two sites. The conversion coefficients at these two stations for the same evaporator did not show a distinct difference (Table VI), and they are nearly the same for the standard E601 evaporator.

Besides Yucheng Integrated Experimental Station, there are five other free water surface evaporation stations in eastern China, all of them equipped with a 20 m^2 evaporation tank and a standard E601 evaporator. The conversion coefficients for a standard E601 at these stations are shown in Table VII. The order in the table is from northern to southern China and the span is almost 20° in latitude. However, the results are almost the same, with the exception of those from the Guanting station. The physical location of the Guanting station, the regional arid climate, and the surrounding environment are perhaps the main reasons causing the difference. The consistency of conversion coefficients between the 20 m^2 evaporation tank and the E601 evaporator in eastern China suggests that the most popular evaporator, the E601, has a relatively stable conversion coefficient in eastern China if the climatic and meteorological conditions are the same. The E601 may be considered as a standard evaporator in China, as it has a stable conversion coefficient and is very popular there.

Relationships between 100 m^2 and 20 m^2 evaporation tanks

Table VIII shows the ratios of the evaporation amounts from the 100 m^2 evaporation tanks to those from the 20 m^2 evaporation tanks. The ratio represents the conversion coefficient used for the 20 m^2 evaporation tank if we use 100 m^2 evaporation tank as a standard. Figure 10 shows the monthly average daily evaporation for the 20 and 100 m^2 evaporation tanks. They have nearly the same annual evaporation and a distinct relationship (Figure 11). However, there were still differences in monthly data between the 20 and 100 m^2 evaporation tanks. The conversion coefficients distribution within a year has the same pattern as the other evaporators shown in Table III.

Table VI. The differences between conversion coefficients at Nansihu and Yucheng stations

Evaporator	Conversion coefficient difference							Mean
	Apr	May	Jun	Jul	Aug	Sep	Oct	
E601-1	−0·02	−0·01	0·00	0·02	−0·04	0	0·04	0·00
GGI3000-1	0·04	0·01	0·07	0·08	0·10	0·08	0·09	0·07
GGI3000-2	0·02	0·02	0·02	0·00	0·01	0·04	0·01	0·02
Class-A	0·07	−0·02	−0·01	0·05	0·03	0·04	−0·05	0·00
ϕ80	0·03	0·07	0·03	0·09	0·08	0·08	0·03	0·05
ϕ20	−0·02	−0·01	−0·03	−0·03	−0·07	−0·02	−0·01	−0·03

Table VII. The conversion coefficients for E601 in eastern China

Station	Longitude (E)	Latitude (N)	Conversion coefficient							Mean
			Apr	May	Jun	Jul	Aug	Sep	Oct	
Yingpan	124°15′	41°56′		0·88	0·89	0·95	1·06	1·10	1·12	1·00
Guanting	115°33′	40°16′	0·82	0·81	0·86	0·95	1·02	1·01	0·97	0·92
Yucheng	116°38′	36°56′	0·91	0·93	0·94	0·98	1·08	1·08	1·01	0·99
Nansihu	117°00′	34°53′	0·89	0·92	0·94	1·00	1·04	1·08	1·05	0·99
Yixing			0·87	0·91	0·93	0·93	0·97	1·05	1·03	0·96
Donghu	114°04′	30°38′	0·92	0·93	0·95	0·98	0·99	1·04	1·05	0·98
Guangzhou	113°17′	23°14′	0·89	0·96	0·99	1·03	1·03	1·05	1·05	1·00

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Table VIII. The relationships between 100 and 20 m^2 evaporation tanks

	March	April	May	June	July	August	September	October	November	Mean
Ratio	0·90	0·95	1·00	0·99	1·02	1·04	0·99	0·98	0·88	0·99
Minimum	0·80	0·91	0·91	0·97	0·94	0·97	0·96	0·92	0·81	
Maximum	1·00	1·02	1·08	1·04	1·08	1·05	1·02	1·00	1·00	
Max.-Min.	0·20	0·11	0·17	0·07	0·14	0·08	0·06	0·08	0·19	

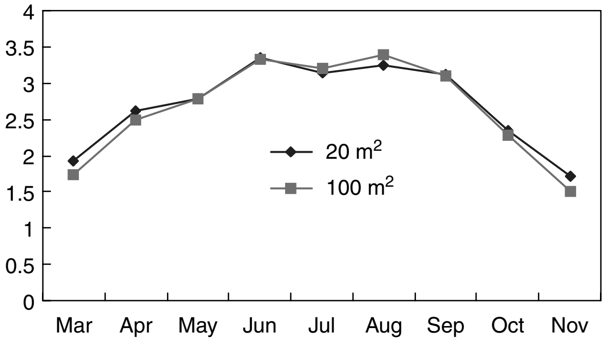

Figure 10. Monthly average daily evaporation for 20 and 100 m^2 evaporation tanks

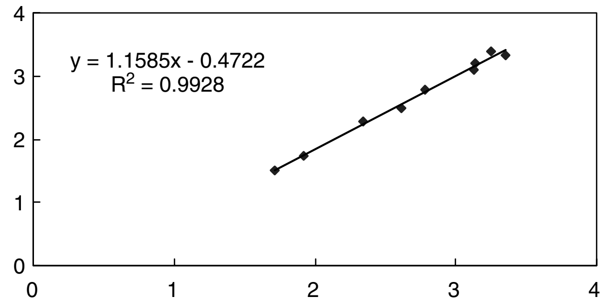

Figure 11. Relationship of monthly average daily evaporation amount between 20 and 100 m^2 evaporation tanks

Statistical results

The results of F-testing showed the consistency of the variations of water surface evaporation over a year between different evaporators. Table IX indicates that the ϕ20 evaporator has a different standard deviation from most other evaporators. This is because the ϕ20 evaporation pan has the smallest volume and its reaction to changes of climatic and meteorological conditions are most prominent. However, its standard deviation did not show significant differences from the Class-A and ϕ80 evaporators. This result may be the reason why these three evaporators had the same patterns of changes of conversion coefficients over a year and had a different pattern with other evaporators (Figures 4 and 5).

The results of the t-testing for yearly mean evaporation amount are shown in Table X. First, the yearly water surface evaporation from the ϕ20 evaporator is significantly different than all other evaporators. This is because the ϕ20 evaporation pan has the smallest volume and its reaction to changes of climatic and meteorological conditions are most prominent. Hence, the annual evaporation from the ϕ20 evaporator, which is installed in every meteorological station in China, must be converted before it is used. Second, the impacts of

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Table IX. Results of F-testing for standard deviation for various evaporators

	E601-1	E601-2	E601-3	GGI-1	GGI-2	GGI-3	GGI-4	Class-A	ϕ80	1 m^2	3 m^2	5 m^2	20 m^2	100 m^2	ϕ20
E601-1															*
E601-2															**
E601-3															*
GGI-1															*
GGI-2															*
GGI-3															
GGI-4											*				
Class-A										*	**	*			
ϕ80										*	*				
1 m^2								*	*						***
3 m^2							*	**	*						***
5 m^2								*							**
20 m^2															**
100 m^2															*
ϕ20	*	**	*	*	*					***	***	**	**	*	

* Significant at $\alpha = 0{\cdot}1$; ** Significant at $\alpha = 0{\cdot}05$; *** Significant $\alpha = 0{\cdot}01$.

Table X. Results of t-testing for mean evaporation for various evaporators

	E601-1	E601-2	E601-3	GGI-1	GGI-2	GGI-3	GGI-4	Class-A	ϕ80	1 m^2	3 m^2	5 m^2	20 m^2	100 m^2	ϕ20
E601-1							*								***
E601-2							**	*	*						***
E601-3															***
GGI-1							*								***
GGI-2															***
GGI-3															***
GGI-4	*	**		*							*	*	*	*	**
Class-A		*													**
ϕ80		*													**
1 m^2															***
3 m^2							*								***
5 m^2							*								***
20 m^2							*								***
100 m^2							*								***
ϕ20	***	***	***	***	***	***	**	**	**	***	***	***	***	***	

* Significant at $\alpha = 0{\cdot}1$; ** Significant at $\alpha = 0{\cdot}05$; *** Significant $\alpha = 0{\cdot}01$.

installation methods on evaporation amount and conversion coefficients are significant. The yearly evaporation from a standard GGI-3000 (GGI-3000-1) is significantly different from the exposed GGI-3000 (GGI-3000-4) at $\alpha = 0{\cdot}10$. We cannot reject the hypothesis that the standard GGI-3000 has the same annual evaporation as the evaporation tanks—whether small tanks (1, 3, 5 m^2) or big tanks (20 and 100 m^2)—but we can reject the hypothesis that an exposed GGI-3000 has the same evaporation as evaporation tanks with areas of 3, 5, 20 and 100 m^2. Third, the difference in evaporation between a standard E601 (E601-1) and an E601 pan without grade (E601-2) is not significant. The evaporation amount from the E601 pan without grade showed a statistical disparity with that from Class-A and ϕ80 evaporators, although a standard E601 did not. Fourth, the influences of an evaporator's structure and materials on annual evaporation and conversion coefficients are

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not significant when comparing the standard GGI-3000 (GGI-3000-1) with the tube GGI-3000 (GGI-3000-2), and standard E601 (E601-1) with fibreglass E601 (E601-3). But minor differences did exist. For example, we can reject that the standard GGI-3000 (GGI-3000-1) has the same annual evaporation amount as the exposed GGI-3000 (GGI-3000-4), but we cannot reject that the tube GGI-3000 (GGI-3000-2) has the same annual evaporation amount as the exposed GGI-3000 (GGI-3000-4). Fifth, the evaporators recommended by WMO, such as the Class-A, GGI-3000 (standard), had the same annual evaporation as evaporation tanks.

It should be noted that all the testing done were based on annual evaporation and these results cannot be used for specific months. Additionally, the short length of records (6 years) places restrictions on monthly testing.

CONCLUSIONS

Free water surface evaporation is an important hydrologic process and its amount is critical in engineering design and water resources management and planning. The experimental results in this study can directly supply free water surface evaporation to the regional water resource engineering projects and may be used to estimate water surface evaporation from a specific evaporator using the conversion coefficients given in this study. Moreover, pan evaporation data could be very useful as a practical tool for estimating potential evapotranspiration.

Variations in the conversion coefficients over a year have the same pattern regardless of the evaporator used for the measurements. The conversion coefficients may change from year to year, but their variations are not significant according to our observation data.

The installation methods, structures, and materials for the evaporators may affect the evaporation measured. However, the differences may or may not be statistically significant. The *t*-test results show that installation methods can produce significantly different evaporation.

The E601 evaporator, a modified GGI-3000 evaporator, appeared to have a relatively stable conversion coefficient when compared with the 20 m^2 evaporation tanks in eastern China, as it has almost the same conversion coefficients at six of the seven stations from northern to southern China. The E601 may be considered as a standard evaporator in China, as it has a stable conversion coefficient and is very popular there.

The yearly evaporation from the 100 m^2 evaporation tank has a distinct relation with that from 20 m^2 evaporation tanks ($R^2 = 0{\cdot}9928$), but the differences in evaporation between these evaporation tanks are still notable in any given month.

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