CHINESE GEOGRAPHICAL SCIENCE
Volume 11, Number 4, pp. 321 - 325, 2001
Science Press, Beijing, China

CALCULATION AND ANALYSIS ON CHANGE OF AGRICULTURAL WATER CONSUMPTION IN THE CHANGJIANG DELTA

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ABSTRACT: The potential evapotranspiration of specific crops in the Changjiang Delta is calculated by using Penman-Monteith method, and an agricultural water consumption model in the area is developed on the basis of agricultural production situation. This model has higher precision compared with actual data and can reflect the actual status of agriculture water need. Considering the meteorological, hydrological, economical development situation of the Changjiang Delta, this paper calculates and analyzes the volumes of agricultural water consumption in 2000, 2010, 2030 and 2050 under different climate change conditions and different development speeds of urbanization in future. The result shows agriculture water demand increases with temperature rising and decreases obviously with cultivated area reducing. For the Changjiang Delta, the volume of agricultural water consumption in the future will less than that of present.

KEY WORD: agricultural water consumption; Changjiang Delta; climate change impact

CLC number: S271 Ducument code: A Article ID: 1002-0063(2001)04-0321-05

Climate change has profound impacts on humanity. Climate change and a series of consequences caused by it have been paid more and more attention in every research field. Climatic warming in the future will have great influence on the China's agriculture. As the report points out, with climatic warming some regions of China maybe have an increasing tendency of the amount of precipitation and evaporation, while the water amount retained in soil will decrease about 11% in the end. Climate change also has great impacts on regional economy, the volume of total water resources and the supply-demand balance of regional water resources (ZHANG *et al.*, 1999a, b; 2001a, b). Climatic warming makes soil water evaporation and plant evapotranspiration intense, and is unfavorable to crop's growth, thus leads to reduction of crop yields. The Changjiang Delta is one of the most important grain-producing area of China. Though the Changjiang Delta provides large amount of water supplement (SHE, 1997), shortage of water resources caused by future climate change will definitely influence the agricultural production and crop yields because of dense population, shortage of cultivated land area, unevenly-distributed water resources and great water consumption. So, setting up a model to calculate and evaluate agricultural water consumption, and analyzing the present status and future tendency of agricultural water consumption of each region in Changjiang Delta will be of great importance for rea-

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Received date: 2001-03-09
Foundation item: Under the auspices of the Doctorate Foundation Projects of China Education Committee (No. 98028432).
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sonable use and exploitation of water resources, assuaging contradiction in the water supply and demand, and fully developing the potential of agricultural production of this region.

1 MODEL FOR CALCULATING AGRICULTURAL WATER CONSUMPTION

1.1 Calculation Equations

Here the agricultural water consumption refers to the water consumption in keeping crops with exclusion of the water use in dwellers' daily life and raising cattle. The water consumption for crops includes: 1) water consumed by plant assimilation and retained inside crop body; 2) transpiration from vegetation for physioloial r equirements; 3) soil evaporation; 4) evaporation from the outside of plants.

Of the above factors, 2) and 3) are dominant for water consumption. As such, we can approximately denote the water volume needed by crops by virtue of field evapotranspiration consisting of crop transpiration and soil evaporation. Generally, it is hard to make observation of potential evapotranspiration from cropped plots. Instead, it is a commonest practice to make use of a climatological formulas for the purpose, in which the Penman-Montieth's expression will yield the evaporative capacity (ET_0), then it multiplied by the coefficient(f) (WENG, 1996) to calculate potential evapotranpiration(ET_m).

The potential evapotranspiration of a specific cropped field(ET_c) is found by multiplying the potential evapotranspiration by the crop coefficient K_c (OUYANG, 1990). Then we have

$$ET_m = f \times ET_0 \tag{1}$$

$$ET_c = K_c \times ET_m = K_c \times f \times ET_0 \tag{2}$$

$$ET_0 = C[\frac{\Delta}{\Delta + \gamma}R_n + \frac{\gamma}{\Delta + \gamma}f(u)(e_a - e_d)] \tag{3}$$

where R_n is the equivalent of surface net radiation (mm/day), Δ the slope of a curve for temperature-dependent saturation vapor, γ the psychrometric constant; E_a the dryness index in the form $E_a = f(u)(e_a - e_d)$ with $f(u)$ being a function of wind and $(e_a - e_d)$ the difference between saturated and measured vapor, and C the function of relative humidity, net radiation and wind as an adjusting factor given by the World Food Organization.

1.2 Explanation for the Variables and Their Parameterization

(1) $f(u)$: function of wind

$$f(u) = C_1(1 + U/100)$$

where C_1 is coefficient, U is the wind velocity above 2 meters high(m/s), if it cannot be obtained by observation, it can be transferred from the velocity of U_a at the height according to the below formula:

$$U_2 = U_a(2/a)^{0.2}$$

(2) $(e_a - e_d)$: the difference of mean saturated and measured vapor (hpa)

(3) Δ: the slope of a curve for temperature-dependent saturation vapor(hpa/℃)

(4) R_n: radiation balance(mm/d)

$$R_n = R_{ns} - R_{nl}$$

where R_{ns} is net short wave radiation; R_{nl} is net long wave radiation.

$$R_{ns} = (1 - \alpha) R_a f(S_1)$$

$$f(S_1) = (0.25 + 0.5 S_1)$$

where R_a is astronomical radiation (mm/d); α is reflective index, S_1 is percentage of sunshine.

$$R_{nl} = \delta\sigma[(T_0^4 - T^4(1.035 - 0.295e^{-0.166w_\infty})]$$

$$(1 - 0.54e^{0.02z^2}n) \times 0.965e^{0.18z}$$

$$w_\infty = (0.1054 + 0.1513e_d)\exp(0.06z)$$

where Z: sea level elevation; n: total cloud cover in the form of decimal fraction; σ: index in the radiation law; T: air temperature; T_0: land surface temperature; e_d: air vapor pressure(hpa).

(5) C: adjustable index

$$C = a_0 + a_1 RH_{max} + a_2 \frac{R_{ns}}{1 - \alpha} + a_3 U$$

where RH_{max} is the maximum relative humidity; R_{ns}, net radiation; U, wind velocity at 2-meter hight; a_i, index (i, 0 - 3) respectively: $a_0 = 0.6817006$; $a_1 = 0.0027864$; $a_2 = 0.0186768$; $a_3 = -5.89680864$.

1.3 Calculation for Agricultural Water Consumption

For a particular kind of crop j, the water volume in its growth-development interval as a whole (W_j) is the sum of products of the crop coefficient at each of the sub-intervals multiplied by the potential evapotranspiration of a reference crop for the same period, that is:

$$W_j = \sum (K_c)(ET_m)_i \quad (4)$$

The total agricultural water consumption W_s takes the form

$$W_s = \sum \beta W_j S_j \quad (5)$$

where S_j denotes the sowing area for crop j, and β = 1.1 – 1.3 for rice and 1.0 for other crops.

Thus, we have a model for agricultural water consumption based on (3), (4), (5). This region's rice growth is by the means of irrigation, so the water consumption for rice should multiply a index of more than 1.0, 1.1 – 1.3 according to different soil types. In this research, three kinds of main crops are considered, wheat, rice and rape. And the coefficient for them is 0.4, 0.5, 0.3 respectively according to the agricultural meteorologist's advice. A double cropping system on an annual basis is practiced over the region, the staple crops being wheat, rape, rice and cotton, which are sown in winter or summer. As a result, our model-yielded volume of agricultural water consumption is lower by 5.3% – 10.6% compared to the practical hydrological records of 1994 and 1995 (Hydrological Bulletin of Jiangsu Province, 1995), and the findings are consequent on the fact that we did not allow for the growth of vegetables and other crops in a limited number. The resulting errors are rational, showing that the presented model has higher accuracy in giving actual water consumption in an agricultural context.

Fig. 1 portrays the calculation results of the distribution of the volumes of the agricultural consumption based on the model across the region, indicating that the volume is the most in the areas of Yangzhou, Nantong, Suzhou and Shanghai, next being Hangzhou and Jiaxing. The volume is related to cultivated area, crop type and cultivation techniques for different crops. However, for the consumption on a unit area, it is more in the east than in the west.

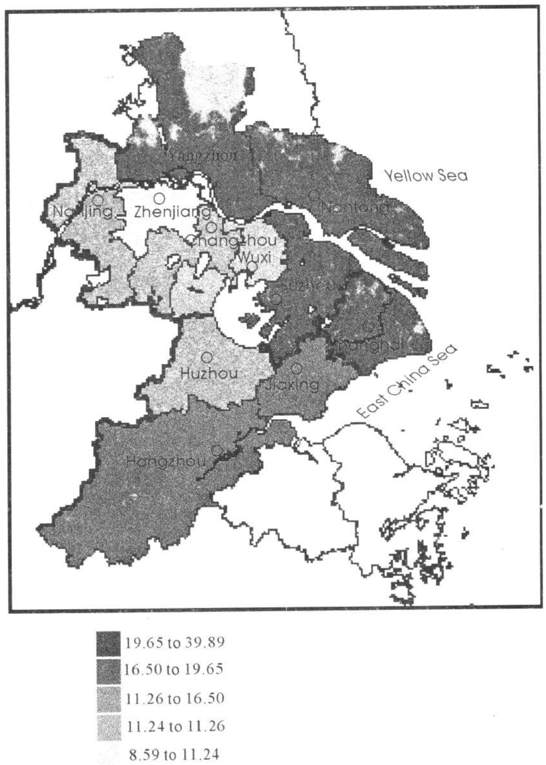

Fig. 1 Distribution of agricultural water consumption in Changjiang Delta. (Unit: a hundred billion m³)

2 AGRICULTRURAL WATER CONSUMPTION IN FUTURE CLIMATE CONDITIONS

From the above mentioned model, agricultural water comsumption is principally under the impact of climate states, to far less extent, of agricultural technique improvement and water consumption per hectare differs from crop to crop in a range of future temperature rises, as given in Table 1.

From Table 1 it can be seen that with rainfall unchanged precipitation and 0.5℃ rise in temperature, the water consumption increment per hectare is 30.0 – 75.0, 25.5 – 33.0 and 60.0 – 67.5m³ for wheat, rape and rice, respectively.

The total volume used in future agriculture depends not only on climatic effect but also on the Change of cropped area. The cropped area has been reduced considerably in recent years in view of swift growth of town-and township-run enterprises, housing structures, the development of additional towns and small cities,

Table 1 Water consumption per hectare for various crops with the change in precipitation (ΔP) and temperature(ΔT)

	ΔT(℃)	Water consumption (m^3) ΔP -20%	-10%	0	10%	20%
Wheat	0.0	171.0	85.5	0.0	-85.5	-171.0
	0.5	201.0	115.5	30.0	-55.5	-142.5
	1.0	238.5	153.0	67.5	-19.5	-103.5
	1.5	273.0	187.5	102.0	16.5	-69.0
	2.0	309.0	223.5	138.0	52.5	-33.0
	2.5	346.5	261.0	175.5	88.5	4.5
Rape	0.0	123.0	61.5	0.0	-61.5	-123.0
	0.5	148.5	87.0	25.5	-34.5	-97.5
	1.0	178.5	117.0	49.5	-10.5	-73.5
	1.5	205.5	142.5	82.5	21.0	-40.5
	2.0	232.5	171.0	109.5	49.5	-13.5
	2.5	262.5	201.0	139.5	79.5	16.5
Rice	0.0	0.0	0.0	0.0	-792.0	-1584.0
	0.5	60.0	60.0	60.0	-732.0	-1524.0
	1.0	121.5	121.5	121.5	-670.5	-1462.5
	1.5	184.5	184.5	184.5	-607.5	-1399.5
	2.0	247.5	247.5	247.5	-544.5	-1336.5
	2.5	313.5	313.5	313.5	-478.5	-1270.5

and the expansion of large and medium-sized cities. In the future, for the volume of agricultural water consumption, the reduction of cultivated land and future climatic conditions will be considered together. At present, such area is dropping quickly and in the future, yearly decrease in the area should be smaller than 0.1% compared with the size in the previous year. Table 2 indicates that in the years to follow, regardless of the precipitation regime, temperature rise will lead to the increase of agricultural water volume, and, however, such a volume decreases noticeably on the strength of the reduction of cropped area.

Table 2 Annual possible water consumption in agriculture in future climatic conditions

ΔT(℃)	Water consumption (10^8t) 2000	2010	2030	2050
0.0	196.7	191.9	182.3	173.1
0.5	198.8	193.9	184.4	175.0
1.0	200.8	196.5	186.4	177.0
1.5	203.1	198.2	188.5	179.0
2.0	205.4	200.4	190.7	181.1
2.5	207.6	202.6	192.8	187.2

In the future, agricultural water consumption will less than that of present because of temperature rising and cultivated land area decreasing. Compared with the percentage of total water consumption including industry, agriculture and dwellers' daily life water consumption (XIANG, 1999), it will decrease from 40% at present to 17% in 2050 (Table 3).

Tsble 3 The proportion of agriculture water need in total water use

Proportion(%) 1995	2000	2010	2030	2050
47	44	39	27	17

3 CONCLUSIONS

1) This paper sets up a physical model for the agricultural water consumption in the Changjiang Delta. According to future possible climate conditions, combing with this region's agriculture and economic development situation and the IPCC's (Intergovernmental

Panel on Climate Change) requirement, this paper evaluaties agricultural water consumption amount in 2000, 2010, 2030, 2050.

2) Based on the model, we calculate the volume of water agricultural consumption of this region. The result is $173 \times 10^8 - 208 \times 10^8 m^3$, which is 5.3% - 10.6% less than the actual amount. The resulting errors are pormissible as we only include three principal crops (rice, wheat and rape) in the calculation process, showing that the presented model has higher accuracy in giving actual water consumption in an agricultural context.

3) Agricultural water consumption is mainly influenced by temperature rising and cultivated land area. The calculation result shows agricultural water consumption in the future will less than that at present in the Changjiang Delta.

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