Simulation of Irrigation Water Loss Based on VSMB Model

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Abstract The low degree of development and utilization as well as the contradiction between supply and demand of water resources in Huangshui River basin are the main restricting factors of the local agricultural development. The study on the simulation of irrigation water loss based on the VSMB model has very important significance to strengthening regional water management and improving water resource utilization efficiency. Five groundwater wells were set up to carry out the farmland irrigation water infiltration and the experimental study on groundwater dynamic effect. Two soil moisture monitoring sites were set up in two typical plots of Daxia and Guanting irrigation area at the same time and TDR300 was used to monitor four kinds of deep soil moisture (10 cm, 30 cm, 50 cm and 70 cm). On this basis, the VSMB model was used to study the irrigation water loss in the irrigation area of Yellow River valley of Qinghai Province, including soil moisture content, the actual evapotranspiration, infiltration, runoff, groundwater buried depth and so on. The results showed that the water consumption caused by soil evaporation and crop transpiration accounted for 46.4% and 24.1% of the total precipitation plus irrigation, respectively, and the leakage accounted for 30.3% and 60.6% of the total precipitation plus irrigation, respectively, from March 1, 2013 to April 30, and from August 1 to September 30. The actual evaporation of the GT - TR1 and GT - TR2 sites in the whole year of 2013 was 632.6 mm and 646.9 mm, respectively, and the leakage accounted for 2.6% and 1.2% of the total precipitation plus irrigation, respectively. RMSE of the simulation results of the groundwater depth in Daxia irrigation area during the two periods was 92.3 mm and 27.7 mm, respectively. And RMSE of the simulation results of the water content of soil profile in the two monitoring sites of Guanting irrigation area was 2.04% and 5.81%, respectively, indicating that the simulation results were reliable.

Key words VSMB model, Irrigation water loss, Soil moisture balance, Irrigation area

1 Introduction

Qinghai Province has rich water resources, and the average annual total amount of water resources reaches 62.93 billion m^3, but the regional precipitation is rare and the spatial and temporal distribution is uneven. The valley of Huangshui River as the primary tributary of the Yellow River occupies 3.5% of the province's total amount of water resources, but has 52.3% of the province's arable land. The development and utilization level of water resources is low, and the prominent water supply and demand contradiction has become the most principal constraint on the agricultural development in Huangshui River valley[1]. VSMB (Versatile Soil Moisture Budget) model, as a conceptual model to predict soil moisture, was developed by the Canadian scholars Baier and Robertson in 1966[2], particularly suitable for simulation of soil moisture profile distribution and groundwater level in the process of irrigation and infiltration. VSMB considers the major soil and plant processes that involve water, and has been widely used in estimation of soil moisture distribution of crops in Canada. Through the constant introduction of latest soil moisture movement research results and numerous improvements, the model has been developed to a mature 4th version (VSMB 2000). VSMB model divides the soil profile containing soil root into several layers, and each layer has independent root density and field capacity characteristics. After the 3rd version, the permanent wilting coefficient and saturated water content are introduced to determine the effectiveness of soil moisture for crop growth, thus providing a basis for the adjustment of the irrigation system. According to the dynamic movement characteristics of soil moisture, VSMB 2000 is used to determine the changes of the water elements. VSMB 2000 model uses FORTRAN language for compilation, and has a modular structure. It takes the simulation and calculation of physical quantities as the submodules that are relatively independent, and the transfer of parameters or physical quantities contributes to the linking to complete the overall function of model. VSMB 2000 model uses the soil physical parameters, crop root parameters, meteorological information and potential evapotranspiration, to establish control file, output file and daily weather file. Each file name is entered into the VSMB model program's interface to simulate the dynamic moisture changes in at all levels of field soil. Output results include all levels of soil moisture, actual evapotranspiration, infiltration, runoff, groundwater depth, etc. In this study, we use VSMB model to simulate the irrigation water loss of irrigation area in Yellow River valley of Qinghai Province, which is of great importance to strengthening regional management of water resources, and improving water resource use efficiency.

2 Overview of the study area

2.1 Daxia irrigation area Daxia irrigation area is in Hetanzhai Village of Gaodian Town along the left bank of Huangshui River. It features a semi-arid plateau continental climate with annual average temperature of 4.5℃ - 7.5℃ and frost-free period of 130 - 150 d. The terrain is complex, the altitude difference is large, and the precipitation varies in different areas. The precipi-

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tation in mountainous area is generally greater than in plain area, and the annual precipitation is 320 – 340 mm in plain area; the evaporation in mountainous area is lower than in plain area, and the annual evaporation is 843 mm in plain area. The maximum frozen soil depth is 86 cm, and the soil includes sierozem and kastanozems. The soil parent materials include alluvial deposit, diluvial deposit and secondary loess, and the soil has a loose and granular structure.

2.2 Guanting irrigation area Guanting irrigation area, located in hilly and gully region, has a typical continental climate, showing a significant and vertical difference. There is a large difference in regional precipitation, and the annual precipitation is 400 – 500 mm in shallow mountainous area. The precipitation during the flood season account for 60% of annual precipitation, and the rainfall is heavy, with the maximum daily precipitation of 142 mm, forming the features of winter and spring droughts, summer floods. The maximum depth of frozen soil is 108 cm. Huangshui River runs across the northern part of the county, and Yellow River flows through the southern part. In addition to the water from Yellow River on the verge of the southern irrigation area, there are also water resources available from some primary tributaries of Yellow River such as Baojiagou, Lujiagou, Ganggou and Damajiagou, but due to small water-collecting area and seasonal features, the runoff is small and there is little water available downstream. According to survey, the groundwater is not rich in the irrigation area, and it is deeply buried, so the potential for the use of groundwater for irrigation is not high, and Huangshui River and Yellow River become the main source of water for irrigation in the county. The irrigation area has complex terrain, and there are great changes in elevation. Sierozem, kastanozems, chernozem, mountain meadow soil, gray cinnamonic soil and alpine meadow soil are distributed in valley terraces, hills, middle mountains and high mountains, respectively. Soil parent material is mainly loess, and soil texture is silt loam, with sand content of 40% to 56% and porosity of more than 50%. Soil permeability is strong, and the cross-section development is weak. The calcic horizon is high, and it is mostly mild to medium loam soil, with soil thickness of 10 – 20 m. The gravel layer is in the lower part.

3 Materials and methods

3.1 Experimental design

3.1.1 Laying of groundwater wells. In this study, five groundwater wells are dug in the typical plots of Daxia irrigation area to carry out the experimental study on irrigation water infiltration and the dynamic effect on groundwater. The location of groundwater wells is shown in Fig. 1. Two vertical water gauges are set up in the left bank of Huangshui River, and the distance (P_1) between well 1, 2, 3, 4, 5, and water gauge is 68.3 m, 68.6 m, 48.8 m, 29 m, 29.9 m, respectively. In order to make the groundwater level and river water level reflect the change in irrigation water infiltration and river water level in the same system of elevation, two bench marks (E102°13′35.8″, N36°29′11.36″; E102°13′36.0″, N36°29′7.42″) are set in the typical plots of Daxia irrigation area, with buried depth of 1.5 m and elevation of 100 m and 97.763 m, respectively. The distance between the two bench marks is about 124 m. The bench mark is calibrated monthly, and the river water gauge elevation and groundwater well elevation are also adjusted and tested. One day before irrigation, the water level of five groundwater wells is observed; during the late irrigation, it is observed at 9:00, 14:00, 19:00, and the observation is not stopped until the groundwater level is stable. The groundwater level and river water level are observed at the same time. The groundwater level is observed using PD-26 portable laser rangefinder combined with overhung electronic sensors. The measurement accuracy of laser rangefinder is ± 2 mm; the measurement range is 0.2 – 60 m; laser grade is 2 and the wavelength is 635 mm; the work temperature is – 10℃ – 50℃. In accordance with requirements of *Groundwater Monitoring Standards* (SL 183 – 2005)[13], the groundwater level is measured twice at intervals of not less than 1 min. When the difference between the two measured values is less than 0.02 m, the average water level is taken; when the difference exceeds 0.02 m, the measurement should be repeated. In actual observation, when the measurement error is within 0.005, the average is taken, higher than the standard specification. The measurement results are verified on the spot, and the water level line of each groundwater well is drawn in a timely manner; if it is abnormal, it is necessary to conduct supplementary monitoring to ensure true, accurate, complete and reliable monitoring information. During the irrigation period, it is observed at 9:00, 14:00, 19:00; after the water level is steady, it is observed at 9:00 every day. Using the product of average groundwater level change of groundwater well, distribution area, amplitude and specific yield, the water storage change is calculated as follows:

$$W_{dd} = F \cdot \mu \cdot \Delta h \quad (1)$$

where F is area (ha); μ is specific yield; $\triangle h$ is the amplitude of variation in water level (mm).

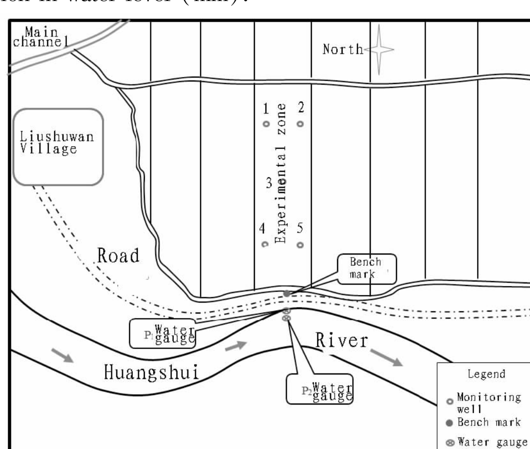

Fig. 1 Location of groundwater wells

3.1.2 Observation of soil moisture content. Daxia irrigation area has two monitoring sites of soil moisture content: one is around monitoring well 3, 40 m away from distributary, garlic is planted here, and the monitoring soil is clay; the other site is 300 m to the northeast of monitoring well, corn is planted, and the 40 cm upper part of the soil is clay layer, and the lower part is sandy clay. Guanting irrigation area has two monitoring sites of soil moisture content, located in Meiyi Village of Zhongchuan Township, and corn and rape are planted in the two sites, respectively. The monitoring sites of soil moisture content in Daxia irrigation area and Guanting irrigation area are shown in Table 1. Using TDR300 soil moisture tachometer, the moisture content of soil with the depth of 10 cm, 30 cm, 50 cm and 70 cm is measured, respectively; soil texture, crop varieties and irrigation conditions are recorded before measurement. The soil moisture content uses the mean of four points with the same depth, and a certain distance is maintained between sampling points.

Table 1 Monitoring statistics about the soil moisture content of the typical plots in irrigation area

Name of irrigation area	No.	Name	Location	Coordinates		Longitude
				Crops	Latitude	
Daxia irrigation area	1	DX - TR1	Community 1 of Liushuwan	36°29′8.2″	102°13′37.10″	Garlic
	2	DX - TR2	Community 1 of Liushuwan	36°29′1.4″	102°13′43.1″	Corn
Guanting irrigation area	1	GT - TR1	Meiyi Village of Zhongchuan Township	35°52′47.31″	102°52′22.79″	Corn
	2	GT - TR2	Meiyi Village of Zhongchuan Township	35°53′05.26″	102°52′16.85″	Rapeseed

3.1.3 Observation of meteorological factors. The "CR1000" automatic monitoring weather station, installed on the test site, is used to measure air temperature, relative humidity, barometric pressure, wind speed, wind direction, solar radiation, rainfall and sunshine hours, and it is measured once every 1 or 2 h. According to monitoring results, the daily average or cumulative value is calculated. The technical specifications of monitoring probes are shown in Table 2.

Table 2 Measuring range and accuracy of meteorological factors

Measuring indicators	Air humidity ℃	Relative humidity//%	Barometric pressure//hPa	Wind speed m/s	Wind direction//°	Solar radiation W/m^2	Rainfall mm/h
Measuring range	-20 ~ 60	0 ~ 100	800 ~ 1000	0 ~ 40	0 ~ 360	0 ~ 2000	0 ~ 508
Accuracy	±0.1	±2	< ±1	±2	< ±0.5	±0.5	±2 ~ ±4

3.2 VSMB model

3.2.1 Conceptual basis. According to the difference in root density and field capacity, VSMB divides the soil profile containing roots into several soil layers. The initial definition of Dyer and Robertson about layer is the soil thickness containing roots[2]. To distinguish between the soil mass and the true soil, the subsequent versions of VSMB model divide the soil into a number of soil layers which can go through water injection and drainage at the same rate on the same day. The two-tier system model of VSMB3, adapted from the simple dual soil layer model, is used for field mobility study[3], and compatible with a variety of soil moisture computing model[4]. It is also successfully applied to simulating the transport processes of soluble contaminants between surface and groundwater[5]. The first layer is the depth that the wetting front can achieve in a day during movement down from the surface, and there is a diffusion parameter to describe this movement. Whether there are shallow water level conditions or not, the continuous process is the basis of simulating soil surface moisture maintenance and soil moisture infiltration. The concept of drainage in the order and the drainage delayed a day is the basis of two-tier system model of VSMB3, and also the basis of three-tier system model of VSMB2000. The flow chart is shown in Fig. 2. VSMB adds a new bottom layer (layer III), designed to simulate groundwater table. The third drainage layer is mainly about groundwater table management, limited by the maximum groundwater depth. Broughton and Foroud think the main difference between the sub-model and groundwater level model is that the sub-model in VSMB2000 can be connected to other functions in VSMB2 and VSMB3, including the plant root biological process prediction based on soil layer and shallow soil moisture prediction based on two-layer theory[6]. Only when there is water level function can there be the third layer, and each soil layer is one of the above two drainage layers at least. The third drainage layer is also referred to as "storage reservoir". According to the dynamic movement of water, VSMB2000 manages water within the soil, evapotranspiration, percolation, infiltration, runoff, drainage water, lateral drainage and capillary elevation. Some movements in soil profile, such as infiltration, groundwater table change and capillary elevation, need to be computed in each soil layer of drainage layers.

3.2.2 Calculation of soil moisture evapotranspiration loss (i) Calculation of soil moisture evaporation. Evapotranspiration, the daily actual evapotranspiration (*AET*) of various soil layers ($AETZ_i$), is the sum of soil evaporation and plant transpiration. VSMB is expressed by the following equation.

$$AETZ_i = PET \cdot Zsol_i \cdot Cofkz_{ip} \qquad (2)$$

where $AETZ_i$ is the actual evapotranspiration of the ith layer soil, mm/d; *PET* is the potential evapotranspiration, mm/d, calculated by Penman - Monteith formula; $Zsol_i$ is the moisture holding capacity of the ith layer soil, mm.

$$Zsol_i = Zval_i \cdot Contz_i / Capacz_i \qquad (3)$$

where $Zval_i$ is the correction coefficient of the ith layer soil drying curve; $Contz_i$ is the effective moisture content of the i th layer soil; $Capacz_i$ is the maximum effective moisture content of the i th layer soil (difference between field capacity and permanent wilting

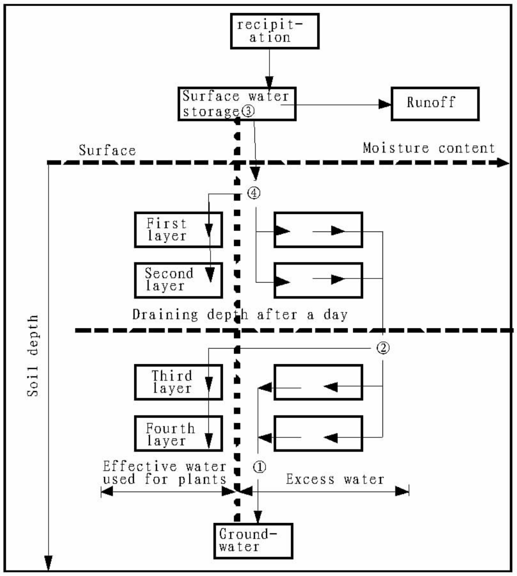

Fig. 2 The path of water infiltration through the root soil

coefficient); *Cofkzip* is the crop water absorption parameter which determines the absorption characteristics of crop roots; the subscript *i* denotes the ith layer soil; *p* represents the *p* th development period of crops (determining root distribution).

As two important parameters, $Zsol_i$ and *Cofkzip* indicate that VSMB model is better than other soil moisture balance models.

The daily *AET* is the sum of actual evapotranspiration of various layers of soil; *m* is the total number of soil layers.

$$AET = \sum_{i=1}^{m} AETZ_i \quad (4)$$

When the soil is dry, *Zsol* coefficient is often dominant; when the soil moisture content is high, *Cofkz* coefficient is dominant. This is what Belmans *et al*. emphasize[7], and under adequate water conditions, the transpiration rate may exceed ETP[8]. At the end of growth period, when the leaf area index is high, the integrated value of *Cofkz* of all soil layers may exceed 1, which can precisely reflect this situation.

The simulation uses RMSE as an indicator to evaluate simulation effect, which is expressed as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{n}} \quad (5)$$

where x_i is the measured average profile soil moisture content or average groundwater depth; y_i is the soil moisture content or groundwater depth simulated using VSMB model on the same day; *n* is the number of the observed values.

(ii) Calculation of soil surface evaporation. After infiltration, there is also excess water in the soil surface or the position close to the soil surface, or the groundwater table is on the soil surface, and some free water will evaporate from the soil surface. Based on the lysimeter data[9] under high PET conditions and a series of data used by Boisvert *et al*. [10], an empirical relationship has been found in the further experimental study. They all take surface evaporation as the function of soil surface moisture, potential and actual evapotranspiration, and excess moisture of the first soil layer for calculation.

$$Evap = PET - AET, \quad if\ SW > PET - AET$$
$$Evap = SW + Xcesz_i\left[\frac{Xcesz_i}{Xcapz_i}\right]^E \quad if\ SW < PET - AET \quad (6)$$

where *Evap* is the water evaporation, mm, varying between 0 and $PET - AET$; *SW* is the surface water; $Xcesz_i$ is the excess moisture within the *i*th layer soil, mm; $Xcapz_i$ is the maximum excess moisture within the *i*th layer soil, mm; *E* is the coefficient set in the control file, with the default value of 1, the equation was originally proposed by Dyer[9], and the optimum value of *E* is one third of the cube root.

3.2.3 Modeling. The programme has several options, and they are selected according to the parameters in the control file, including (i) inserting coefficient *Cfkz* (*k*-coefficients earlier) and root depth within the soil layer, and between two soil layers; (ii) using groundwater table function; (iii) allowing users to use Baier and Robertson formula or given value to calculate soil evapotranspiration; (iv) applying winter computing function; (v) allowing users to specify the variable format of meteorological input data file; (vi) producing graphics output of moisture over time for various layers of soil; (vii) printing production variable format; (viii) creating complementary output file for users' choice and further analysis.

3.3 Data processing EXCEL is used for data collation and analysis, and EXCEL and CAD are used for drawing.

4 Results and analysis

4.1 Simulation of irrigation water loss in typical plots of Daxia irrigation area We conducted simulation in the typical plots of Daxia irrigation area in two periods (2013. 3. 1 –2013. 4. 30; 2013. 8. 1 –2013. 9. 30). After the model parameter calibration, the simulation results about moisture content, actual evapotranspiration, infiltration, runoff and groundwater depth in various layers of soil in the typical plots of Daxia irrigation area during 2013. 3. 1 –2013. 4. 30 can be shown in Table 3 and Fig. 3a. From Table 3 and Fig. 3a, it can be found that during 2013. 3 –4, there was no precipitation; the irrigation water amount was 193. 6 mm; the potential evapotranspiration was 231. 5 mm. Through simulation, during 2013. 3. 1 – 2013. 4. 30, the actual evapotranspiration was 89. 9 mm, and leakage was 58. 7 mm, that is, the water consumption due to soil evaporation and crop transpiration accounted for 46. 4% of total irrigation water and precipitation, while leakage accounted for 30. 3%. It should be noted that in the simulation results, the sum of evapotranspiration and leakage is not equal to the sum of precipitation and irrigation water, which was due to consumption or increase of part of soil moisture storage. The simulation results during 2013. 8. 1 –2013. 9. 30 can be shown in Table 4 and Fig. 3b. During 2013. 8. 1 –2013. 9. 30, the precipitation was 98. 2. 6 mm; irrigation water amount was 27. 3 mm; the potential evapotranspiration was 226. 5mm.

Through simulation, during 2013.8.1 – 2013.9.30, the actual evapotranspiration was 30.3 mm, and leakage was 76 mm, that is, the actual evapotranspiration accounted for 24.1% of total irrigation water and precipitation, while leakage accounted for 60.6%. The simulated values and observed values of groundwater depth in Daxia irrigation area during two periods are shown in Table 4. Through calculation, the simulated RMSE (2013.3.1 – 2013.4.30) = 92.3 mm, and the simulated RMSE (2013.8.1 – 2013.9.30) = 27.7 mm, indicating that the results are reliable to a certain extent.

Table 3 Simulation results of irrigation water loss in typical plots of Daxia irrigation area during 2013.3.1 – 2013.4.30

Time	Precipitation m	Irrigation water amount mm	Potential evaportranspiration // mm	Actual evapor-transpiration mm	Surface runoff mm	Surface water accumulating volume // mm	Leakage mm	Average moisture content of profile // %	Simulated groundwater level // mm
March	0	127.50	105.40	69.90	0	0	26.70	30.45	3746.68
April	0	66.10	126.10	20.00	0	0	32.00	30.59	3715.37
Total	0	193.60	231.50	89.90	0	0	58.70		

Table 4 Simulated values and observed values of groundwater depth in Daxia irrigation area Unit: mm

Time		Simulated buried depth	Well 1	Well 2	Well 3	Well 4	Well 5	Average buried depth
March	Mean	2780.47	2802.27	2844.13	2866.47	2663.67	2705.95	2776.26
	Standard deviation	1166.35	1183.51	1203.35	1209.68	1126.57	1142.35	1173.33
April	Mean	3681.97	3687.37	3720.47	3750.90	3535.90	3591.57	3657.23
	Standard deviation	88.68	61.01	58.19	49.77	32.82	42.34	48.35
August	Mean	3294.08	3325.00	3377.33	3398.08	3160.25	3203.08	3292.75
	Standard deviation	180.45	166.87	159.05	177.11	168.80	217.42	175.93
September	Mean	3122.67	3146.67	3190.00	3226.67	2993.33	3053.33	3122.00
	Standard deviation	26.58	5.77	0.00	20.82	15.28	5.77	7.21

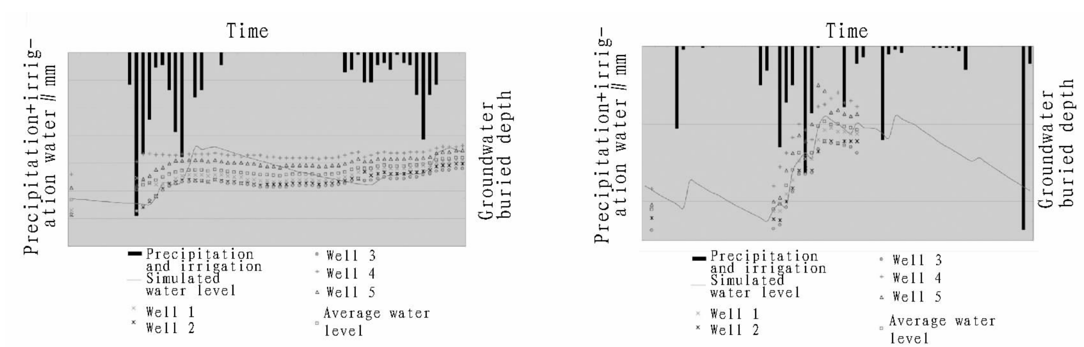

Fig. 3 Simulation results about groundwater buried depth in the typical plots of Daxia irrigation area

4.2 Simulation of irrigation water loss in typical plots of Guanting irrigation area The observation points in Guanting irrigation area are GT – TR_1 and GT – TR_2. The crop planted in GT – TR_1 is corn while the crop planted in GT – TR2 is rape. Both of them are local main crops. The simulation results of irrigation water loss in GT – TR_1 of Guanting irrigation area are shown in Table 5 and Fig. 4a. As shown in Table 5 and Fig. 4a, in 2013, the precipitation was 320.1 mm in Guanting irrigation area, the irrigation water amount was 222 mm and annual potential evapotranspiration was 2143.1 mm in GT – TR_1 (corn). Through simulation, the annual actual evapotranspiration was 632.6 mm and leakage was only 14.9 mm in GT – TR1, that is, leakage accounted for 2.6% of total irrigation water and precipitation, indicating that the leakage was very weak. In order to analyze the simulation accuracy, we list the simulated and observed average soil profile moisture content (last column of Table 5). By calculation, the simulated *RMSE* = 2.04%, indicating that the results are reliable to a certain extent. The simulation method of GT – TR_2 is similar to that of GT – TR_1, and the simulation results are shown in Table 6 and Fig. 4b. As can be seen from Table 6 and Fig. 4b, in 2013, the precipitation was 320.1 mm in Guanting irrigation area, the irrigation water amount was 242 mm and annual potential evapotranspiration was 2143.1 mm in GT – TR_2 (rape). Through simulation, the annual actual evapotranspiration was 646.9 mm and leakage was only 6.7 mm in GT – TR_2, that is, leakage accounted for 1.2% of total irrigation water and precipitation, indicating that the leakage was very weak. In order to analyze the simulation accuracy, we list the simulated and observed average soil profile moisture content (last column of Table 6). By calculation, the simulated *RMSE* = 5.81%.

Table 5 Simulation results of irrigation water loss in GT – TR1 of Guanting irrigation area

Month	Precipitation mm	Irrigation water amount mm	Potential evaportranspiration//mm	Actual evaportranspiration mm	Surface runoff mm	Surface water accumulating volume//mm	Leakage mm	Average moisture content of profile//%	The measured average moisture content of profile %
1	1.3	0.0	67.8	7.5	0.0	0.0	0.0	29.5	–
2	3.6	0.0	95.4	28.6	0.0	0.0	0.0	27.5	–
3	0.0	0.0	210.8	13.4	0.0	0.0	0.0	24.4	–
4	23.2	0.0	252.2	22.5	0.0	0.0	0.0	23.3	21.9
5	24.2	74.2	269.2	94.3	0.5	0.0	14.9	25.4	26.9
6	22.2	30.0	287.3	75.9	0.0	0.0	0.0	21.8	–
7	85.0	52.0	231.0	135.2	0.0	0.0	0.0	22.2	–
8	101.4	0.0	280.0	109.2	0.0	0.0	0.0	18.2	–
9	42.6	0.0	176.8	58.2	0.0	0.0	0.0	16.6	–
10	10.5	0.0	149.2	30.8	0.0	0.0	0.0	13.8	–
11	4.9	87.8	73.8	31.7	0.0	0.0	0.0	18.0	22.2
12	1.2	0.0	49.6	25.3	0.0	0.0	0.0	19.6	–
Total	320.1	244.0	2143.1	632.6	0.5	0.0	14.9	–	–

Table 6 Simulation results of irrigation water loss in GT – TR2 of Guanting irrigation area

Month	Precipitation mm	Irrigation water amount mm	Potential evaportranspiration//mm	Actual evaportranspiration mm	Surface runoff mm	Surface water accumulating volume//mm	Leakage mm	Average moisture content of profile//%	The measured average moisture content of profile %
1	1.3	0.0	67.8	13.8	0.0	0.0	0.0	29.2	–
2	3.6	0.0	95.4	31.6	0.0	0.0	0.0	25.7	–
3	0.0	0.0	210.8	16.3	0.0	0.0	0.0	23.0	–
4	23.2	0.0	252.2	16.1	0.0	0.0	0.0	22.3	–
5	24.2	74.2	269.2	99.3	0.0	0.0	6.7	24.3	19.8
6	22.2	120.0	287.3	146.4	0.0	0.0	0.0	23.5	–
7	85.0	0.0	231.0	102.1	0.0	0.0	0.0	21.0	–
8	101.4	0.0	280.0	105.3	0.0	0.0	0.0	19.1	–
9	42.6	0.0	176.8	43.7	0.0	0.0	0.0	17.7	–
10	10.5	0.0	149.2	18.5	0.0	0.0	0.0	17.0	–
11	4.9	47.8	73.8	33.3	0.0	0.0	0.0	18.9	20.6
12	1.2	0.0	49.6	20.5	0.0	0.0	0.0	18.3	15.3
Total	320.1	242.0	2143.1	646.9	0.0	0.0	6.7	–	–

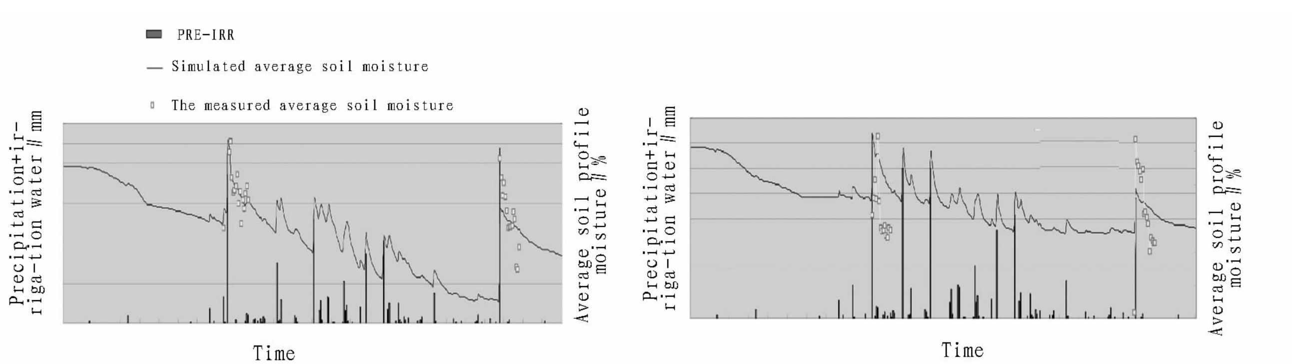

Fig. 4 Simulation results of soil moisture in Guanting irrigation area

5 Conclusions

In this paper, the simulation of irrigation water loss was conducted in the typical plots of Daxia irrigation area in two periods (2013.3.1 – 2013.4.30; 2013.8.1 – 2013.9.30). Results show that the actual evapotranspiration was 89.9 mm and 30.3 mm during the two periods, respectively, and leakage was 58.7 mm and 76 mm, respectively, that is, the water consumption due to soil evaporation and crop transpiration accounted for 46.4% and 24.1% of total irrigation water and precipitation, respectively, and leakage accounted for 30.3% and 60.6%, respectively. The annual irrigation water loss in GT – TR1 and GT – TR2 of Guanting irrigation area in 2013 was also simulated. Results show that the annual actual evapotranspiration in GT – TR1 and GT – TR2 of Guanting irrigation area was 632.6 mm and 646.9 mm, respectively, and leakage was only 14.9 mm and 6.7 mm, respectively, that is, leakage accounted for 2.6% and 1.2% of total irrigation water and precipitation, respectively, indicating that the leakage was very weak. RMSE of the simulation results of the groundwater depth in Daxia irrigation area during the two periods was 92.3 mm and 27.7 mm, respectively. And RMSE of the simulation results of the moisture content of soil profile in the two monitoring sites of Guanting irrigation area was 2.04% and 5.81%, respectively, indicating that the simulation results were reliable.

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