Supplementary Materials

1. Groundwater recharge items

1.1 Precipitation infiltration recharge

The amount of water that rainfall infiltrates into soil to replenish groundwater. Calculation formula:

$$Q_1 = 0.1PF\alpha \quad \text{(S1)}$$

In the formula, Q_1 is the amount of precipitation infiltration recharge, $10^4 m^3/a$; P is the effective annual precipitation, mm/a; F is the area of the equilibrium calculation zone, km^2; α is the coefficient of precipitation infiltration.

The calculation period for precipitation infiltration recharge is from January 1, 2016 to December 31, 2016. The precipitation infiltration coefficient α is mainly influenced by factors such as the size and intensity of rainfall, soil moisture content before rain, soil properties and structure, and groundwater depth. Based on the precipitation infiltration coefficient table for plain areas in various river basins in Xinjiang Groundwater Resources [57], the values of precipitation infiltration recharge coefficient for the Shihezi Irrigation District located in the middle section of the northern foot of Tianshan Mountains are determined in Table S1.

Table S1. Values of precipitation infiltration coefficient α in the study area

Groundwater depth（m）	≤1	1~3	3~6	≥6
α	0.12	0.10	0.08	0.10

P is the effective annual precipitation, as precipitation infiltration is related to secondary precipitation. Here, the effective precipitation is taken as the value of secondary precipitation greater than 10 mm, and the rainfall interval of no more than 24 hours is defined as once. The research area has a typical temperate continental climate, with precipitation mainly distributed from April to September. The spatial distribution map of groundwater depth in Shihezi Irrigation District is shown in Figure S1. The groundwater depth in Shihezi Irrigation District is mostly greater than 6 meters, and there is no effective precipitation infiltration. Therefore, areas with groundwater depth greater than 6 meters are not considered for calculation.

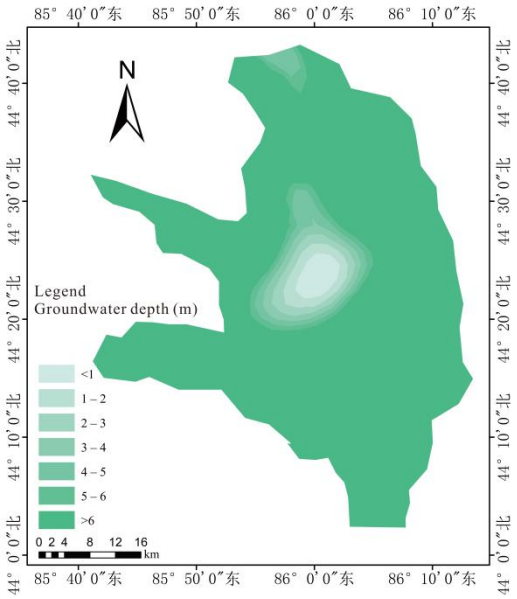

Figure S1. Groundwater depth distribution in Shihezi Irrigation District in 2016

Table S2. Calculation results of precipitation infiltration recharge

Groundwater depth（m）	Area F （km^2）	Effective precipitation P （mm/a）	Precipitation infiltration coefficient α	Rainfall infiltration recharge Q_1（10^4m^3）
≤1	113.47	117.8	0.12	160.4
1-3	79.13	117.8	0.10	93.2
3-6	74.18	117.8	0.08	69.9
Total	266.78			323.5

According to calculations, the total amount of precipitation infiltration recharge in the Shihezi Irrigation District in 2016 was 323.5 × 10^4 m^3 .

1.2 Canal system leakage supply volume

Formula for calculating the amount of leakage supply in the canal system:

$$Q_2 = mQ \quad \text{(S2)}$$

$$m = (1 - \eta)\gamma \quad \text{(S3)}$$

$$\gamma = \gamma'\gamma'' \quad \text{(S4)}$$

In the formula, $Q_2$is the leakage supply volume of the canal in the Shihezi Irrigation District, measured in 10^4 m^3 ; Q is the water intake volume of the canal; M is the leakage supply coefficient of the canal system; η is the water utilization coefficient of the canal system; γ is the correction factor for leakage supply; γ' is the correction coefficient for leakage in the canal system; γ'' is the anti-seepage correction coefficient for the canal system.

According to the "Xinjiang Groundwater resources" and the results of 20 sets of canal seepage experiments completed by Xinjiang Agricultural University, and referring to the "Technical Manual for Mechanical Wells", the correction coefficient γ' for canal system water seepage in the Xinjiang plain area is shown in Table S3.

Table S3. Correction coefficient of canal system leakage

Lithology	Buried depth（m）			
	0~1	1~3	3~6	>6
Sandy soil, gravel and sand	0.75~0.80	0.70~0.75	0.60~0.70	0.50~0.60
Cohesive soil	0.70~0.75	0.65~0.75	0.5~0.6	0.40~0.50

The correction coefficient for canal system anti-seepage, γ'' is based on the anti-seepage rate and an empirical coefficient is taken, as shown in Table S4

Table S4. Anti-seepage correction coefficient (γ) table

Anti-seepage rate（%）	<20	20~40	40~60	60~80	80~100
γ"	0.97	0.90	0.85	0.80	0.75

According to the 2016 Water Resources Annual Report of Shihezi City, the total length of irrigation channels in Shihezi Irrigation District throughout the year is 1946.21km, with a total anti-seepage of 809.56km. The specific situation of the main and branch irrigation channels for farmers is shown in Table S5.

Table S5. Irrigation channel construction in the study area

Irrigation Canal	Total length（km）	Anti-seepage length（km）	Anti-seepage rate（%）
Main canal	163.06	129.55	79.4
Branch canal	228.68	206.08	90.1
Bucket canal	424.66	301.72	71.1
Agricultural canal	1129.81	172.21	15.2
Total	1946.21	809.56	41.6

According to the "Xinjiang Groundwater resources", the slope of the main and branch canals is 0.20658, and the intercept is 0.73349; The slope of Dounong Canal is 0.15337 and the intercept is 0.79524. The calculation of water utilization coefficient for the canal system in Shihezi Irrigation District is shown in Table S6.

Table S6. shihezi irrigation canal water use coefficient η

Canal system	Main canal	Trunk canal	Branch canal	Bucket canal	Agricultural canal
Water utilization coefficient of canal system η	0.86	0.90	0.92	0.90	0.82

Table S7. Calculation table of leakage supply of canal system

	Q（10^4m^3）	γ′	γ″	η	m	Q_2（10^4m^3）
Shihezi Irrigation District	34070.54	0.79	0.85	0.86	0.098	2243.75

According to the above calculation results, the leakage supply value of the canal system in Shihezi Irrigation District in 2016 was 2243.75 × 10^4 m^3 .

1.3 Field infiltration supply

Field infiltration supply mainly occurs after irrigation in the field. The field infiltration supply in the research area is divided into two types: leakage supply from the Dounong Canal and irrigation infiltration supply. According to the "Groundwater Resources in Xinjiang", the correction coefficient γ for canal system leakage recharge is determined to be 0.678-0.736. The calculation of the leakage recharge amount of Dounong Canal is the same as that of canal system leakage calculation, referring to formulas (2), (3), and (4), combined with relevant data from the "Annual Report on Diversion, Storage, and Supply of Shihezi City in the Eighth Division (2014-2020)". The calculation results are shown in Table S8.

Table S8. Leakage supply of Dounong Canal system in Shihezi Irrigation District

	Q_3（10^4m^3）	γ	η	Q_4（10^4m^3）
Shihezi Irrigation District	32695	0.7	0.83	3890.705

The formula for calculating the infiltration supply in irrigated fields is:

$$Q_5=Q_6\beta \quad \text{(S5)}$$

In the formula, β is the field infiltration supply coefficient; Q_5 irrigation refers to the field infiltration supply in the Shihezi irrigation area, with a unit of 10^4 m^3 ; Q_6 refers to the amount of water entering the field through irrigation channels in the Shihezi Irrigation District, with a unit of 10^4 m^3 .

Table S9. Calculation table of irrigation infiltration recharge in Shihezi Irrigation District

	Q_5（10^4m^3）	β	Q_6（10^4m^3）
Shihezi Irrigation District	7827.859	0.12	939.34

According to Tables S8 and S9, the field infiltration supply of Shihezi Irrigation District is 4830.045 × 10^4m^3 .

1.4 Reservoir infiltration recharge amount

Calculation formula for reservoir infiltration recharge:

$$Q_7 = \alpha_1 Q_8 \quad \text{(S6)}$$

In the formula, $\alpha_1$is the leakage replenishment coefficient of each reservoir in the Shihezi Irrigation District; Q_7 reservoir infiltration refers to the infiltration supply of various reservoirs in the Shihezi Irrigation Area, with a unit of 10^4 m^3 ; Q_8 refers to the storage capacity of each reservoir in the Shihezi Irrigation District, with a unit of 10^4 m^3 .

There are three reservoirs in the Shihezi Irrigation District, namely Moguhu Reservoir, Daquangou Reservoir, and Jiahezi Reservoir. According to the "Xinjiang Groundwater Resources",

considering the storage capacity and dam lithology, the range of values for the reservoir leakage recharge coefficient α is shown in Table S10.

Table S10. Recharge coefficient of reservoir leakage α_1

Rock type of dam foundation	Large scale reservoir Storage capacity $>1.0\times10^8$ m³	Medium-sized reservoir storage capacity $0.1\sim1.0\times10^8$ m³	Small reservoir storage capacity $<0.1\times10^8$ m³
Cohesive soil	0.06~0.1	0.15~0.2	0.25~0.3
Sandy soil	0.08~0.16	0.2~0.3	0.3~0.5

Table S11. Calculation table of reservoir leakage and supply in Shihezi Irrigation area

Reservoir	Q_8（10^4 m³）	α_1	Q_7（10^4 m³）
Moguhu Reservoir	13475	0.1	1347.5
Daquangou Reservoir	3028	0.2	605.6
Jiahezi Reservoir	8521	0.2	1704.2
Total	25024	-	3657.3

The infiltration recharge of the reservoir in Shihezi Irrigation District is 3657.3×10^4 m³.

1.5 River infiltration recharge volume

Calculation formula for river infiltration recharge:

$$Q_9 = MQ_{10} \quad (S7)$$

In the formula, M is the leakage recharge coefficient, and Q_9 River seepage is the amount of infiltration recharge in the waterway of Shihezi Irrigation District, including Manas River and Ningjia River, with a unit of 10^4 m³; The Q_{10} diameter refers to the runoff of the Manas River and Ningjia River in the Shihezi Irrigation District, with a unit of 10^4 m³.

The Manas River is the main river flowing through the Shihezi Irrigation District. According to the "Xinjiang Groundwater Resources", the infiltration recharge coefficient M of the river channel is taken as 0.157. The flow rates of the Manas River and Ningjia River are determined based on the measured data from the Ningjiahe Canal Head Station and Hongshanzui Hydrological Station. The runoff of the river channel is calculated by the water distribution ratio flowing through the Shihezi Irrigation District. The calculation process of the infiltration recharge of the river channel is shown in Table S12.

Table S12. Calculation table of river infiltration recharge

River	Q_{10}（10^4 m³）	Water allocation in Shihezi Irrigation District（10^4 m³）	M	Q_9（10^4 m³）
Manas River	101960	65582.03	0.157	10296.38
Ningjiahe River	4630	514	0.157	80.698

Total	106590	66096.03	10377.078

The infiltration supply volume of the river channel in Shihezi Irrigation District is 10377.078 × 10^4 m^3 .

1.6 Supply volume in front of the mountain and outside the area

The formula for calculating the lateral supply amount in front of the mountain and outside the area is:

$$Q_{11}=KIA_1t \quad \text{(S8)}$$

In the formula, Q_{11} replenishment refers to the replenishment amount in front of the mountain and outside the area, that is, the replenishment amount under the boundary conditions of the Shihezi irrigation area, in m^3; K is the permeability coefficient of the aquifer, m/d; I is the hydraulic slope perpendicular to the supply boundary profile of the Shihezi Irrigation Area; A_1 is the cross-sectional area perpendicular to the groundwater flow direction under the boundary conditions of the Shihezi Irrigation District, in m^2; t is the calculation period, in days.

The lateral supply calculation adopts the cross-sectional method and uses Darcy's formula for calculation. The Shihezi Irrigation District mainly receives lateral supply from rivers at the boundary between the southern mountainous area and the plain area, as well as in the southwest. According to the table of aquifer permeability coefficient (K) in "Xinjiang Groundwater Resources", determines the value of aquifer permeability coefficient and calculate the mountain front and outer lateral recharge of Shihezi Irrigation Area. The calculation process is shown in Table S13.

Table S13. Aquifer permeability coefficient (K)

Lithology	Sub sandy soil	Silty fine sand	Medium fine sand	Medium coarse sand	Sand and gravel	Gravel
K（m/d）	0.2~0.7	1~6	5~10	15~35	50~100	80~200

Table S14. Calculation table of piedmont and outlying lateral supply

Boundary	K（m/d）	I	A_1（m^2）	T（d）	Q_{11}（10^4 m^3）
Southern border 1	80	0.0007	2896407.15	365	5920.26
Southern border 2	32	0.0007	4607376.9	365	3766.99
Western boundary	25	0.0007	4560682.35	365	2913.14
Total					12600.39

The supply volume in front of the mountains and outside the Shihezi Irrigation District is 12600.39 × 10^4 m^3 .

2.Groundwater discharge item

2.1 Spring water overflow volume

The groundwater level in some areas of the irrigation area is higher than the ground and is naturally discharged in the form of spring water. The amount of spring water overflow usually refers to the sum of the spring water volume of various springs that are not included in the river

runoff. It is usually distributed in the form of self flowing wells near the boundary between the southern hilly area and the plain area of the Shihezi irrigation area. Most of the research area is well irrigated, so the self flow time is often affected by the irrigation water use time of crops. It will start again from the end of the first irrigation period to the beginning of the second irrigation period (around early May to early June), but the flow rate will be relatively small; This is one cycle. By consulting relevant materials and literature, referring to the implementation table of the water supply plan, it is determined that the spring water overflow volume in the study area is 2069 $\times 10^4 m^3$ /a.

2.2 Submersible evaporation rate

The calculation formula for diving evaporation is as follows:

$$Q_{12} = E_0 C F C_1 \quad \text{(S9)}$$

In the formula, Q_{12} represents the groundwater evaporation in the Shihezi irrigation area, with a unit of 10^4 m^3; E_0 represents the water surface evaporation in the Shihezi irrigation area, with a unit of mm; F represents the regional area of the Shihezi irrigation area, km^2; C is the coefficient of underwater evaporation; C_1 is the vegetation condition correction coefficient.

The ability of groundwater evaporation varies in areas with different depths of burial. Submersible evaporation is the main discharge method in areas with low groundwater depth. For areas with groundwater depth greater than 6 meters, the amount of groundwater evaporation is recorded as 0 [58]. For areas with groundwater depth less than 6 meters, the calculation of groundwater evaporation is carried out, and the final calculation process of total groundwater evaporation is shown in Table S15.

Table S15. phreatic evaporation coefficient C

	≤1 m	1~3 m	3~6 m	≥6 m
Sub clay	0.33~0.53	0.10~0.33	0.01~0.1	0
Sub sandy soil	0.3~0.5	0.1~0.3	0.01~0.1	0
Silty fine sand	0.4~0.5	0~0.4	0	0
Sand and gravel	0.02~0.45	0~0.02	0	0

Table S16. Correction coefficient C1 of vegetation state under vegetation cover in the middle part of the northern foot of Tianshan Mountains

	≤1 m	1~3 m	3~6 m	≥6 m
Irrigation district	1.31	1.18	1.06	1
Non irrigated vegetation area	1.32	1.28	1.25	1

Table S17. Calculation table of phreatic evaporation in Shihezi Irrigation Area

Groundwater depth（m）	F （km^2）	E_0 （mm）	C	C_1	Q_{12}（$10^4 m^3$）
<1	113.47	1340	0.30	1.32	6021.17
1~3	79.13	1340	0.10	1.23	1304.22

3~6	74.18	1340	0.01	1.16	115.31
Total	266.78				7440.70

The groundwater evaporation rate in Shihezi Irrigation District is 7440.70 × 10^4 m^3 .

2.3 Artificial mining output

Irrigation, drinking water for residents, and water for livestock are the main water sources for groundwater extraction. According to the Implementation Table of Groundwater Supply Plan of Shihezi City of the Eighth Division, the groundwater mining output in 2016 is shown in Table S18.

Table S18. Groundwater exploitation of regiments in the study area in 2016

Region	143 Regiment	Shi Zongchang	152 Regiment	Shihezi City	Shihezi Town	Total
Water supply（10^4m^3）	3134	5375	188	6125	100	14922

The artificial mining output of Shihezi irrigation area is 14922 × 10^4 m^3 .

2.4 Mountain front and outer lateral excretion

The calculation method for the excretion in front of the mountain and outside the area is the same as the supply in front of the mountain and outside the area. The calculation process for the excretion in front of the mountain and outside the area is shown in Table S19.

Table S19. Calculation table of piedmont and outlying lateral supply

Boundary	K（m/d）	I	A_1（m^2）	T（d）	Q_{13}（10^4m^3）
Northern boundary	25	0.002	2621330.95	365	4783.93
Eastern boundary	25	0.0007	2039539.25	365	1302.76
Total	-	-	-	-	6086.69

3.Groundwater equilibrium analysis

Table S20. Calculation of water balance results

	Equilibrium term	Equilibrium quantity（10^4 m^3）
Supply items	Precipitation infiltration	323.50
	Canal leakage	2243.75
	Field infiltration	4830.05
	Reservoir recharge	3657.30
	River recharge	10377.08
	Mountain-front/peripheral recharge	12600.39
	Total	34032.06
Excretion item	Spring overflow	2069

Groundwater evaporation	7440.70
Artificial extraction (pumping)	14922.00
Outflow to mountain/peripheral zones	6086.69
Total	30518.39
Difference between groundwater recharge and discharge	3513.67
Changes in groundwater storage	6211.11
Absolute equilibrium error	2697.44
Relative equilibrium error（%）	7.9

References

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The reference numbers in the supplementary materials are based on the order of the manuscript.