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Simulation and evaluation of ecohydrological effect of water transfers at Alagan in lower Tarim River

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Abstract. The riparian vegetation is highly dependent on the groundwater which is recharged by the river in arid regions. Water is the most important limiting factor for riparian vegetation in arid regions. From 1970s to 2000, the lower Tarim River almost dried up and the groundwater table fell down obviously. The riparian vegetation degraded seriously due to the low groundwater table. From 2000 to 2006, water transfers were implemented in the lower Tarim River to restore the ecological environment. Although the observation of groundwater and vegetation was carried out along lower Tarim River, the dynamics of the groundwater and vegetation along the cross section of the river were unknown. Ecohydrological evolution model on Riparian Vegetation in hyper-arid regions (ERV model) is a distributed ecohydrological model and has been validated at Yingsu in lower Tarim River. In this paper, the ERV model is applied to analyze the ecohydrological effect of water transfers at Alagan in lower Tarim River. At the same time, the ERV model is further validated. The simulation result is validated by observed groundwater table and vegetation coverage computed from remote sensing data. The result shows that the average groundwater table at Alagan increased by 4.74m from 2000 to 2006 and the average groundwater depth reached 6.36m. The average vegetation coverage increased from 0.130 to 0.194. In order to recover the green corridor, the further water transfers are required. The results are helpful for the ecohydrological research and water resources management in lower Tarim River.

Introduction

In arid regions, the distribution, growth and succession of the plants are closely related to groundwater [1]. In the lower Tarim River, which is in the inland arid region of Northwest China, the river channel locates at the east of Taklimakan Desert. The precipitation is scarce and potential evaporation is very high in the lower Tarim River. So, the natural vegetation in lower Tarim River greatly depends on groundwater [1].

In history, there was a green corridor along the lower Tarim River and the green corridor is vital to the society and the economy of the West of China. From 1970s to 2000, the lower Tarim River almost dried up and the groundwater table fell down obviously. The riparian vegetation degraded seriously due to the low groundwater table. The green corridor along Tarim River was threatened by the desertification. From 2000 to 2006, water transfers were implemented in the lower Tarim River to restore the ecological environment. During the period, the groundwater and vegetation recovered quickly [2]. In order to evaluate the ecohydrological effect of the water transfers, the responses of groundwater and plant communities to water transfers were studied on the basis of the field observation along nine transects crossing the Tarim River [3]. The groundwater rising process at Yingsu section of Tarim River were simulated using numerical models and were validated by monitored data [4, 5, 6]. The groundwater and vegetation are coupled by the evapotranspiration of the vegetation and the vegetation coverage rose in evidence from 2000 to 2006 in lower Tarim River. It is difficult for the hydrological model to continuously simulate the dynamical process of groundwater table near the lower Tarim River. So, a distributed ecohydrological model, i.e. Ecohydrological evolution model on Riparian Vegetation in hyper-arid regions (ERV model) [7], is applied to continuously simulate the dynamical processes of groundwater table and vegetation coverage and evaluation of ecohydrological effect of water transfers in lower Tarim River. ERV model has been validated at Yingsu in lower Tarim River [7].

The study area and data used in the paper is presented in the next section. Following this, Ecohydrological evolution model on Riparian Vegetation in hyper-arid regions (ERV model) is described briefly. And then the ERV model is applied at Alagan in lower Tarim River and the ecohydrological effect of water transfers is evaluated. The paper is closed by the section "Discussion and conclusion".

Study Area and Data

Study area. Tarim River is located in the northwest of China and is the largest inland river in China. Tarim River locates at the east of Taklimakan Desert. Till 2000, the green corridor along the lower Tarim River degraded seriously because the lower Tarim River dried up and the groundwater wasn't recharged by stream. From 2000 to 2006, Chinese government implemented water transfers from Daxihaizi Reservior in the lower Tarim River to restore the ecological system.

In the lower Tarim River, the mean annual potential evaporation is 1585.9mm [2] and the mean annual precipitation from 1993 to 2002 is only 27.7mm, both of which are observed at Tieganlike. So the water supply of the precipitation to the soil water can't be ignored in this highly dry environment and the precipitation is neglected in the modeling.

Alagan is 204.5km away from Daxihaizi Reservior in the lower Tarim River and Alagan section is selected as the study area. There are few types of riparian vegetation at Alagan. The main arbor is *Populus euphratica*, the main shrub is *Tamarix ramosissima*, and the main grass vegetation is *Poacynum hendersonii* [8].

Data. At Alagan, there are 7 observation wells on the right riverbank of the river monitoring the groundwater table and the distribution of the wells is shown in Fig. 1. The observed groundwater table data are used to validate the simulation result of groundwater table.

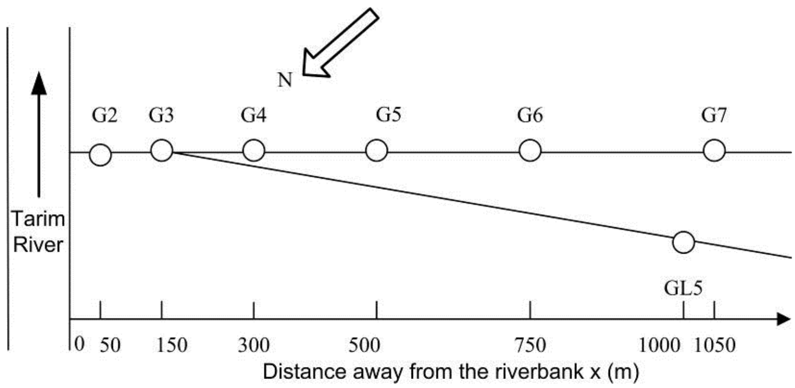

Fig. 1. Distribution of the groundwater observation wells at Alagan

The study area at Alagan is the range of 20~1200m away from the riverbank as shown in 0NDVI from MODIS products, "MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V005" (MOD13Q1), is applied to calculate vegetation coverage at Alagan. The spatial resolution of the data is 250m. So there are 4 grids of data in the study area and they are corresponding to the wells of G2, G5, G7 and GL5. The vegetation coverage at G2, G5, G7 and GL5 are applied to validate the simulated vegetation coverage.

Ecohydrological Evolution Model on Riparian Vegetation in Hyper-Arid Regions

Ecohydrological evolution model on Riparian Vegetation in hyper-arid regions (ERV model) is a 1-dimension distributed ecohydrological model [7] and please refer to [7] for detail. ERV model can continuously simulate the dynamical processes of groundwater table and vegetation coverage at the riverside area in arid regions, where the influence of precipitation can be neglected because of the highly dry environment. The framework of ERV model is shown in Fig. 2. The ecological process and hydrological process are coupled the vegetation coverage and the groundwater depth. In ERV model, the groundwater movement modeling is based on Boussinesq equation. Vegetation dynamic modeling is based on the vegetation dynamic equation in ecohydrology, which was originally introduced by Levins and Culver [9]. The ERV model has been successfully applied at Yingsu [7], which is 61km away from Daxihaizi Reservior in the lower Tarim River.

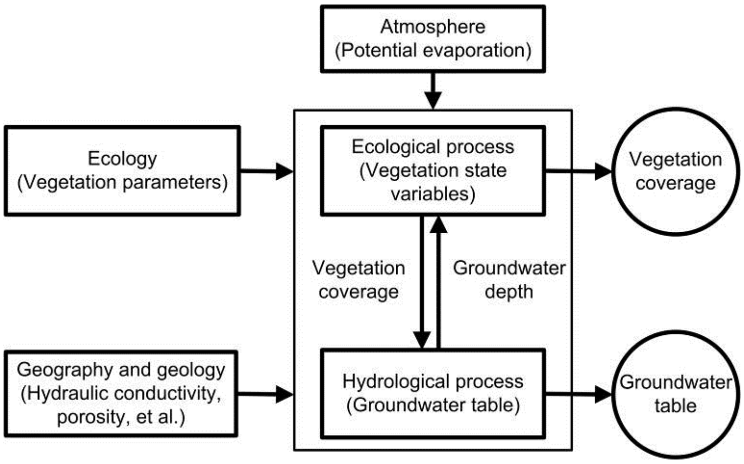

Fig. 2. Schematic diagram of coupling of hydrological process and ecological process

Application at Alagan

The ERV model is applied at Alagan to simulate the dynamical processes of groundwater table and vegetation coverage from 2000 to 2006 at the daily time step.

Boundary conditions. For groundwater movement, the left boundary condition is groundwater recharge from Tarim River. In lower Tarim River, there is water in the river channel only in the water transfer period. So, in water transfer period, the left boundary condition is set as constant water level. In non-water-transfer period, the left boundary condition is set as constant hydraulic gradient.

The right boundary is groundwater outflow from the study area and the right boundary condition is set as constant hydraulic gradient.

Simulation result of groundwater table. The simulated groundwater table processes at G2, G3, G4, G5 and G6 are shown in Fig. 3 ~Fig. 7 The simulated groundwater is consistent with the observed groundwater table. The groundwater profile at Alagan on November 22, 2006 is shown in Fig. 8. The groundwater table across the study area fit the groundwater observation very well and the observation on November 22, 2006 is the last one in the simulation period. The result shows that the average groundwater table at Alagan increased by 4.74m from 2000 to 2006 and the average groundwater depth reached 6.36m.

The groundwater table at G2 increased by 5.85m from 2000 to 2006 and the groundwater depth reached 5.82m. The groundwater table at G5 rose by 4.84m and the groundwater depth arrived at 6.64. The groundwater table at G7 ascended by 4.07m and the groundwater depth got to 6.81m. The rise of the groundwater table illuminated that the water transfers evidently raised the groundwater table at Alagan.

In order to evaluate the simulated groundwater table quantitatively, the mean bias (MB) and correlation coefficient (R) are employed. The groundwater table measurement was not conducted daily and therefore only part of the simulated groundwater table values are evaluated against the corresponding observed data. The mean bias is defined as in Eq. 1.

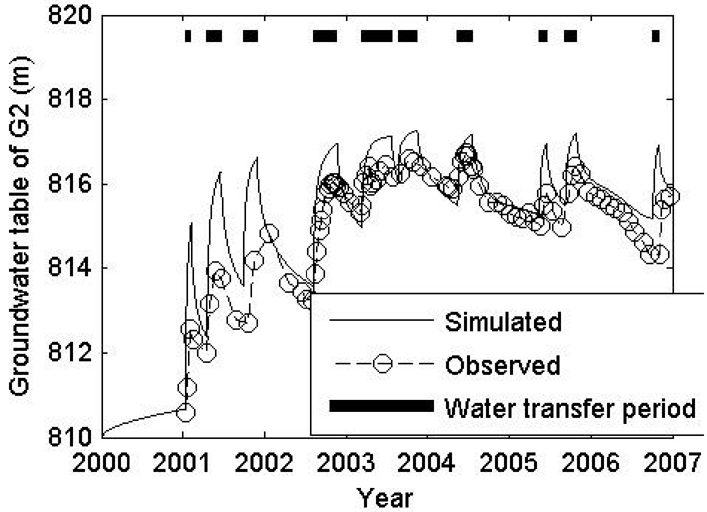

Fig. 3. Comparison of the simulation and the observation of the groundwater table at G2

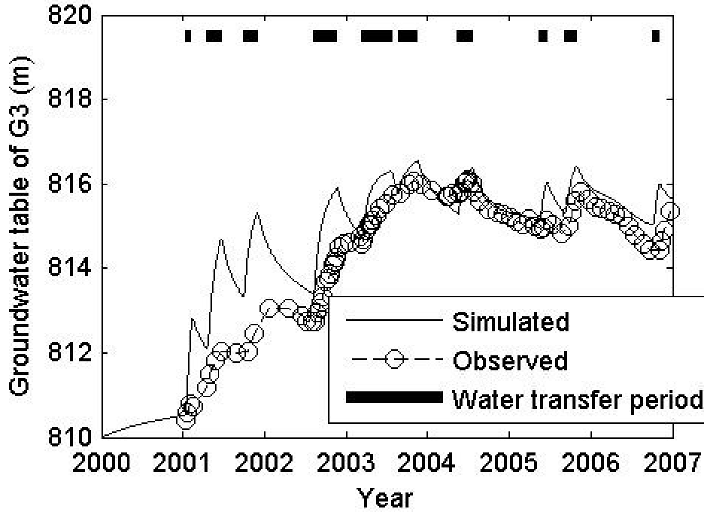

Fig. 4. Comparison of the simulation and the observation of the groundwater table at G3

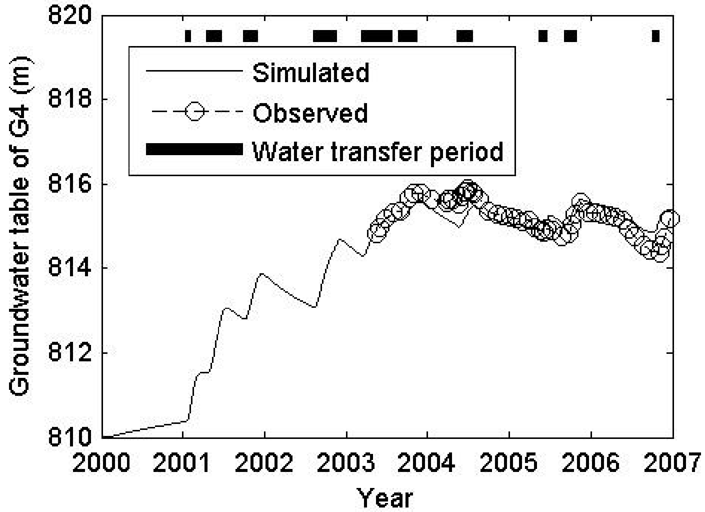

Fig. 5. Comparison of the simulation and the observation of the groundwater table at G4

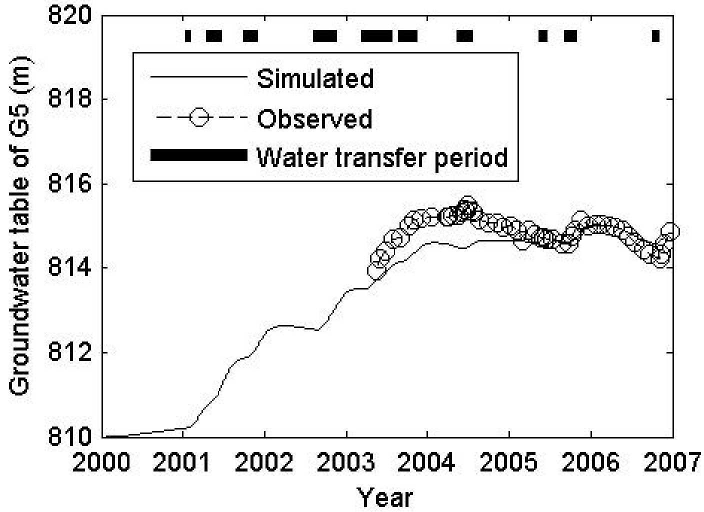

Fig. 6. Comparison of the simulation and the observation of the groundwater table at G5

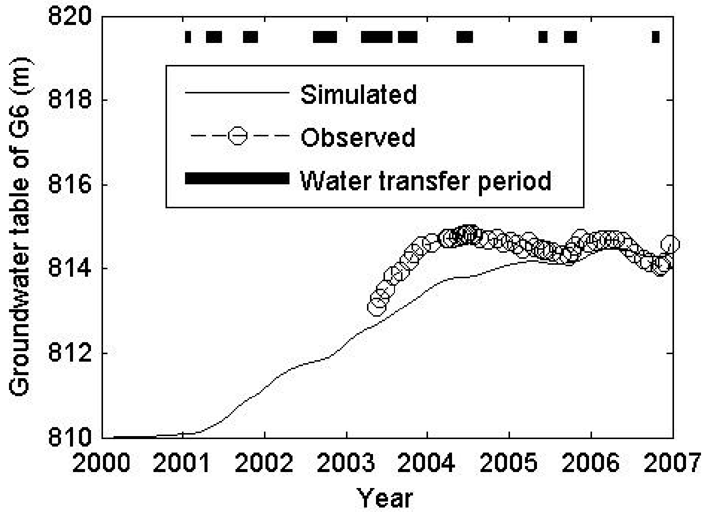

Fig. 7. Comparison of the simulation and the observation of the groundwater table at G6

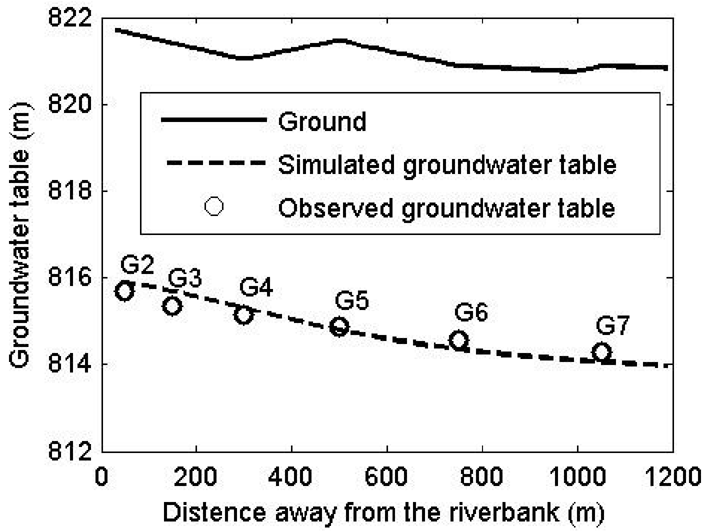

Fig. 8. Groundwater profile at Alagan on November 22, 2006

$$MB = \frac{1}{n}\sum_{i=1}^{n}\left|Z_{si} - Z_{oi}\right|. \quad (1)$$

where, Z_{si} is the simulated groundwater table; Z_{oi} is the observed groundwater table; n is number of the observed data.

The correlation coefficient is computed as in

$$R = \frac{\sum_{i=1}^{n}(Z_{si} - \overline{Z}_s)(Z_{oi} - \overline{Z}_o)}{\sqrt{\sum_{i=1}^{n}(Z_{si} - \overline{Z}_s)^2 \sum_{i=1}^{n}(Z_{oi} - \overline{Z}_o)^2}} . \quad (2)$$

where, $\overline{Z}_s$ is the average of the simulated groundwater table and $\overline{Z}_o$ is the average of the observed groundwater table.

The quantitative evaluation of the groundwater table simulation is shown in Table 1. The mean bias is in the range of 0.278~0.726m. The correlation coefficient is in the range of 0.327~0.976. Except the correlation coefficient at G5, it is larger than 0.520.

Table 1 Evaluation of groundwater table at Alagan

Observation well	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**GL5**
Mean bias (m)	0.726	0.316	0.278	0.370	0.545	0.529	0.467
Correlative coefficient	0.847	0.937	0.520	0.327	0.582	0.766	0.976

Simulation result of vegetation coverage. The simulated vegetation coverage at G2, G5, G7 and GL5 are shown in Fig. 9~Fig. 12. The trend of the simulated vegetation coverage is in accord with the observed vegetation coverage i.e. vegetation coverage derived from NDVI. The fluctuation of the observed vegetation coverage is very large and the annual vegetation coverage is used to quantitative evaluation. From 2000 to 2006, the spatial average vegetation coverage at Alagan increased from 0.130 to 0.194. In 2000, the evapotranspiration at Alagan is 2.2mm/year. And then the evapotranspiration reached 154.6mm/year in 2006 and it played an important role in the groundwater balance.

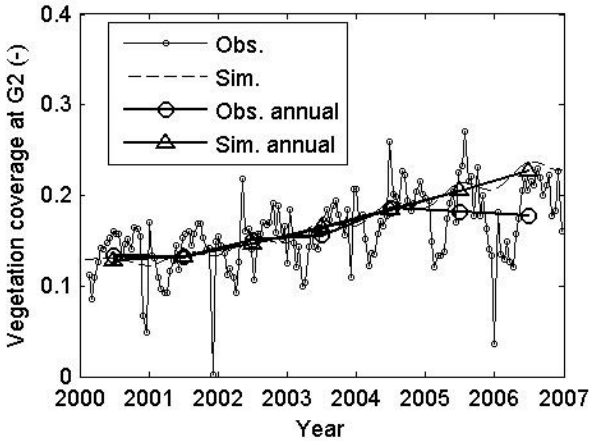

Fig. 9. Comparison of the simulation and the observation of the vegetation coverage at G2

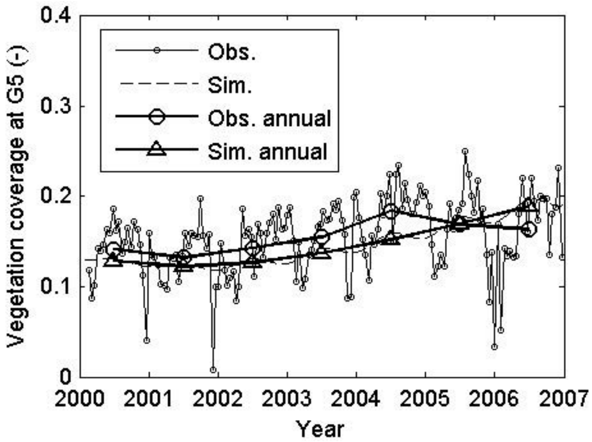

Fig. 10. Comparison of the simulation and the observation of the vegetation coverage at G5

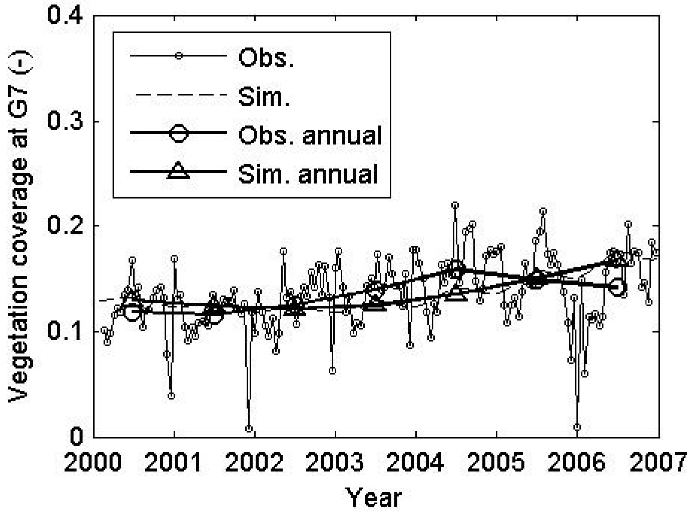

Fig. 11. Comparison of the simulation and the observation of the vegetation coverage at G7

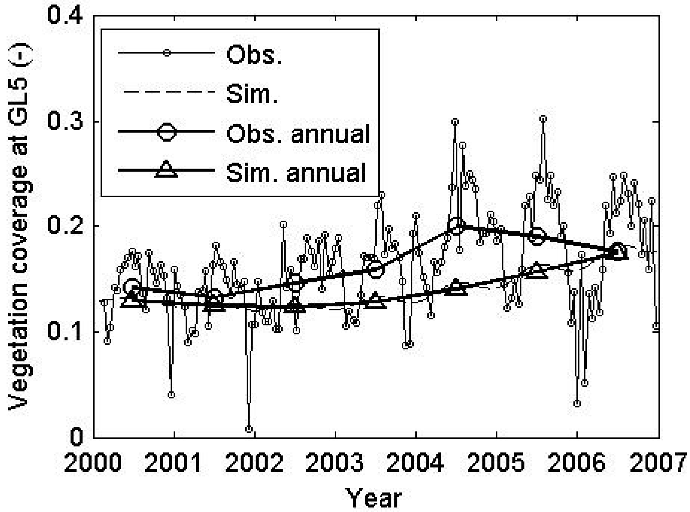

Fig. 12. Comparison of the simulation and the observation of the vegetation coverage at GL5

To evaluate the simulated vegetation coverage quantitatively, the mean bias (MB) and mean relative bias (MRB) are used. The mean relative bias is calculated as in

$$MRB = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|v_{csi} - v_{coi}\right|}{v_{coi}}. \quad (3)$$

where, v_{coi} is annual mean observed vegetation coverage; v_{csi} is annual mean simulated vegetation coverage; n is number of the observed data.

The evaluation of the simulated vegetation coverage is shown in Table 2. The mean bias is in the range of 0.013~0.024m. The mean relative bias is in the range of 7.61% ~13.78%.

Table 2. Evaluation of vegetation coerage at Alagan

Observation well	**G2**	**G5**	**G7**	**GL5**
Mean bias (-)	0.013	0.016	0.013	0.024
Mean relative bias (-)	7.61%	10.42%	9.16%	13.78%

Discussion and Conclusion

In the paper, a distributed ecohydrological model, i.e. Ecohydrological evolution model on Riparian Vegetation in hyper-arid regions (ERV model), is applied to analyze the ecohydrological effect of water transfers at Alagan in lower Tarim River. The simulation result is validated by observed groundwater table and vegetation coverage computed from remote sensing data. The result shows that the average groundwater table at Alagan increased by 4.74m from 2000 to 2006 due to the water transfers and the average groundwater depth reached 6.36m. The average vegetation coverage increased from 0.130 to 0.194. From 2000 to 2006, the evapotranspiration at Alagan increased from 2.2mm/year to 154.6mm/year.

Because the groundwater is still very deep for the growth of the plants at Alagan, the restoration of the plants is not enough to maintain the green corridor along the lower Tarim River. In order to recover the green corridor, the further water transfers are required.

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