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Effects of Channel Lining on Evapotranspiration in the Yellow River Irrigation District in Ningxia Hui Autonomous Region of China

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Abstract: Evapotranspiration is a central process of the hydrological cycle, and various water saving measures are based on it. However, there is little research work on evapotranspiration in the world. In particular, there is rare hydrological cycle-based research on the impact of channel lining on evapotranspiration in arid and semi-arid regions. This paper applies a hydrological cycle model to examine the effect of channel lining on evapotranspiration in the Yellow River Irrigation District in Ningxia Hui Autonomous Region of China where agriculture consumes over half of the total water consumption in the irrigation district. The results show that channel lining can effectively reduce the diversion and consumption of water from the Yellow River. When lining rate is increased from 30% to 60%, the total water diverted from the Yellow River will be reduced by 7.1%, while water consumption is decreased by 3.2%. A higher channel lining rate reduces infiltration into groundwater and lowers the groundwater level, which results in less ecological water consumption.

Keywords: evapotranspiration; channel lining; hydrological cycle; water utilization; Yellow River Irrigation; district of Ningxia Hui autonomous region

1. Introduction

In practice, agricultural irrigation and drainage activities are complicated social actions. Water-saving reconstruction projects in medium- and large-sized irrigation districts significantly alter underlying surface conditions and are bound to have a profound impact on the hydrological cycle. In an effort to unravel the mechanisms and processes of water resources conversion in changing environments, Freeze and Harlan were the first to develop a concept of distributed hydrological models (Freeze et al, 1969). The hydrological models have now become the most widely used models for the simulation of the natural hydrological cycle (Wang et al, 2004). The System Hydrological European (SHE), a model jointly develo ped by Danish, French and British- research institutions, is considered to be a typical example of the earliest distributed hydrological models.

It adopts vigorous hydrodynamic transient partial differential equations to describe overland flow, river flow, soil seepage and underground runoff and possesses a sound physical basis (Abbott et al, 1986). Compared with SHE, the Soil and Water Assessment Tool (SWAT) is a relatively simplified hydrological model. Developed by the United States Department of Agriculture-Agricultural Research Service in 1994, this flexible model has a sound physical basis and covers a long forecast time span. Chinese researchers have also made significant progress in their research on hydrological cycle processes in natural basins (Zhao et al., 2007; Jia et al., 2006). As human activities exert a greater impact, research on their driving role in the hydrological cycle is also deepening. Academician Wang Hao of China has put forward the basic structure and modes of a natural-artificial dualistic hydrological cycle model (Wang, 2006). In their research on the patterns of water extraction and consumption in the

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Yellow River Irrigation District of Ningxia Hui Autonomous Region (Pei et al, 2006) has also developed a natural-artificial compound hydrological cycle model to suit agricultural water use characteristics in plains irrigation districts and to forecast the impact of agricultural activities on the hydrological cycle. However, all these theoretical and numerical models lack to analyze of individual water-saving measures' impact on the hydrological cycle and ET. To address this gap, this paper will take the Yellow River Irrigation District of Ningxia as an example and adopt the hydrological cycle model which the authors have developed for plains irrigation districts to study the trends of local ET as affected by channel lining, a typical engineering water-saving measure in arid and semi-arid regions.

2. The research area

This paper conducts research on the Yellow River Irrigation District in northern Ningxia Hui Autonomous Region, China. This irrigation district with the total area of 6573km2 is located in an arid and semi-arid area under a continental climate, characterized by rain scarcity, high aridity and high evaporation. Average annual evaporation amounts to about 1200mm, while average annual rainfall stands at about 180mm. The Yellow River runs through the northern part of the irrigation district and is an important source of water to support local social and economic development. The Qingtongxia Water Control Project divides the district into Weining Irrigation District in the upper reaches and Qingtongxia Irrigation District in the lower reaches. With the Yellow River as the natural boundary, Weining Irrigation District is further divided into a Northern Irrigation District and a Southern Irrigation District, and Qingtongxia Irrigation District into an Eastern Irrigation District and a Western Irrigation District. In present, there are 16 main water diversion channels in the Yellow River Irrigation District of Ningxia. 11 of them are distributed on the Yinchuan Plain and the remaining 5 are distributed on the Weining Plain. The drainage system in the Yellow River Irrigation District is a common passageway for groundwater and surface return flow.

3. The modeling approach

In addition to water from the Yellow River, the irrigation district under research also receives a small amount of groundwater supply from surrounding areas, Helan Mountain floodwater and surface water. Water for industrial and domestic uses is mainly extracted from groundwater. In the study, water extraction and consumption for industrial and domestic uses are assumed to be unchanged. Consideration is mainly given to lining-induced changes in agricultural ET and changes in ET of ecosystems which are dependent on irrigation return flow and groundwater level. To reflect the use of rainfall in ecosystems and the multiple forms of existence of water resources, the generalized water resources concept is chosen to examine the overall demand for water resources in the irrigation district so as to compare it with the amount of Yellow River water consumed. Generalized water resources include runoff resources as well as effective rainfall consumed by ecosystems. Atmospheric rainfall constitutes the primary source of generalized water resources, while surface water, soil water and groundwater are their main forms of existence.

A. Model overview

In this paper, the authors adopt a hydrological cycle model which they have developed for plains irrigation districts to analyze changes in the regional hydrological cycle and water consumption under various channel lining rates. Detailed model description can be found in relevant references (Zhao et al, 2007). Taking water balance as its basis, the model divides similar subbasins in artificial irrigation and drainage areas as the unit for hydrological computation, with day as the time step. It can simulate and compute the spatial and temporal patterns of water transfer under different land uses, including water bodies, vegetation, bare land, cropland and impervious areas. Along the vertical direction, each computation unit of the model is divided into a vegetation canopy, a ground surface storage layer, a shallow soil layer, a deep soil layer, unconfined a quifer and confined aquifer.

Simulation of components of the hydrological cycle includes ET simulation, diversion system simulation, drainage system simulation, lake and wetland simulation, domestic and industrial water use system simulation, soil water system simulation and groundwater system simulation. For each computation unit, water equilibrium as well as groundwater, soil water and regional water balances can be calculated for different land use types. In the simulation and computation of various components of the hydrological cycle, ET is at the core of water conversion of the hydrological cycle and the key to research on water consumption and water use efficiency. Based on land use practices in the research area, computations are respectively made for water evaporation, vegetation interception evaporation, vegetation transpiration, soil evaporation and impervious area evaporation. In accordance with the soil-plant-atmosphere flux exchange method, the Penman formula, the Noilhan-Planton model and the Penman-Monteith formula are adopted for detailed computations.

The diversion canal system is generalized into a main diversion canal and a branch canal system to simulate water balances. The drainage system receives groundwater discharge, and runoff therefore increases from branch drainage ditches to the main drainage ditch.

In the Yellow River Irrigation District of Ningxia, there are a large number of lakes and wetlands. With recharge from Helan Mountain floodwater, irrigation return flow and groundwater recharge, these lakes and wetlands are mainly subject to evaporation and leakage. In the consideration of the water balance of these lakes and wetlands, special care must be given to their relationship with the groundwater level.

Domestic and industrial water use systems are complicated. Survey data and planning materials are used to analyze domestic and industrial water consumption.

The upper boundary of the soil water system receives rainfall, irrigation and evaporation, while the lower boundary of the system is a changing phreatice surface. To compute drainage and surface runoff from the surface of the irrigation field, the model allows a ground surface storage layer and divided soil into 2 layers. The Richards equation is adopted for computations. The model employs a balance approach to simulate the groundwater system and examines water flow changes in the equilibrium zone from an input/output perspective. To examine the balance of confined water, consideration is given to the balance between the extraction and the supply of regional confined water.

B. Data sources

Model data involve various types, including data relating to hydrology, meteorology, physical geography, topography and land cover. Hydrological and metrological data mainly include rainfall, sunshine hours, air temperature relative humidity, wind speed, and are available from the hydrological and meteorological departments. In the study area, there are 8 meteorological stations, including those in Yinchuan, Shizuishan and Letao. Land use information consists of Landsat-TM image data taken during the June-October period in 2000. The images were taken from a geographical area of N35′14″~39′23″and E104′17″~107′39″, with a spatial resolution of 30m. The 2-level classification system for national land remote sensing survey is adopted as the land use type classification system in the current study. There are 12 Level-2 land use types in a total of 6 Level-1 types (as shown in Table 1). Land surface sampling surveys show a remote sensing image interpretation precision of 83.13%. The vegetation index is obtained from NOAA/AVHRR images taken in 2000, with a surface resolution of 8km. From this source of information, vegetation-related information such as vegetation index, vegetation coverage and leaf area index is extracted. Other basic data such as irrigation, rock types and soil information can be obtained from on-site surveys and research.

4. Results and discussion

In relation to the specific situation of the irrigation district and local social and economic development in Ningxia and assuming that other factors do not change, this paper sets out to apply a hydrological cycle model to simulate and compare scenarios in the irrigation district when channel lining rate is respectively increased to 30%, 40%, 50% and 60% and the water saved from agriculture is transferred for industrial use. The purpose is to examine the impact of channel lining on the hydrological cycle and ET in the Yellow River Irrigation District of Ningxia.

A. Effects of channel lining on the regional hydrological cycle

The results of hydrological circulation and conversion in the Yellow River Irrigation District of Ningxia under a channel lining regime shows that total generalized water resources consumption in the irrigation district amounts to 4.955 billion m3, while the amount of Yellow River water consumed stands at 3.288 billion m^3, accounting for 66.3% of the total consumption of generalized water resources. Agriculture makes up 80.5% of the total amount of Yellow River water consumed, fully indicating the tremendous role which the passing Yellow River play

in supporting local development. In the irrigation district, natural ecosystems consume 1.22 billion m^3 of generalized water resources but only 359 million m^3 of Yellow River water. This shows that rainfall is the main source of water consumption in the irrigation district. When channel lining rate is increased from 30% to 60%, the total amount of water diverted from the Yellow River will be reduced by 441 million m^3. This shows that channel lining as a water-saving engineering measure can significantly reduce water diverted for irrigation which resulted in that infiltration from the canal system and field irrigation decreases, while total groundwater recharge also falls significantly. Infiltration recharge from the canal system is reduced by 28%, from 1.077 billion m^3 when lining rate is 30% to 778 million m^3 when lining rate is 60%. But, infiltration recharge from cropland is much less reduced, only by 5.2%.

Due to reduced infiltration recharge into groundwater, the groundwater level falls and groundwater depth continues to increase. Compared with the current status year, when lining rate is increased to 60%, the groundwater level will fall by 25.2cm. This will have a certain impact on ecosystems which depend on groundwater level in the irrigation district. Falling groundwater level induces changes in the relationship of supply and drainage between groundwater and the drainage system. Agricultural irrigation and rainfall drainage will decrease, lateral drainage from groundwater will also fall significantly while domestic and industrial drainage will remain unchanged. Total drainage from the irrigation district will be reduced significantly. This will notably improve the current situation of large diversion and large drainage in the district.

B. Effect of channel lining on regional ET

In the economic system of the Yellow River Irrigation District of Ningxia, water for industrial and ecosystem use is mainly extracted from groundwater. In the current study, water consumption rate is assumed to be unchanged and channel lining only happens inside the agricultural irrigation system. Urban water consumption

lining rate. Inside the agricultural irrigation system, increased channel lining rate induces rather significant changes (see Table 1). A higher channel lining rate results in a significant reduction in the amount of Yellow River water diverted for irrigation, agricultural soil evaporation and vegetation transpiration, thus effectively reducing agricultural water consumption. When channel lining rate is increased from 30% to 60%, total agricultural water consumption is reduced by 80 million m^3. What is worth noting is that while vegetation transpiration, soil evaporation and total agricultural evaporation in the agricultural irrigation system are on a falling trend, the rate of such decrease gradually levels off. This shows that there is a certain limit to the effect of water saving by channel lining.

Table 1. Changes in ET in the economic system of the irrigation district Unit: 100 million m^3

Channel lining rate	**Town**			**Agriculture**					**Total evaporation**
	Residential district	**Industrial production and domestic consumption**	**Subtotal**	**Vegetation interception transpiration**	**Vegetation transpiration**	**Soil evaporation**	**Diversion & drainage channels**	**Subtotal**	
30%	0.26	2.81	3.08	0.71	14.98	17.2	1.39	34.28	37.36
40%	0.26	2.81	3.08	0.71	14.81	17.06	1.39	33.97	37.05
50%	0.26	2.81	3.08	0.71	14.65	16.95	1.39	33.70	36.78
60%	0.26	2.81	3.08	0.71	14.53	16.85	1.39	33.48	36.56

Secondly, in total agricultural evaporation, field soil evaporation always exceeds vegetation transpiration. Half of such water returns to the atmosphere by way of field soil evaporation. This is mainly because most cropland is bare except during the crop growth stages. Even during the growth stage, vegetation coverage is also rather low during the early and later periods. Consequently, there still exists a large amount of low-efficiency water consumption in total agricultural evaporation which does not play a critical role in crop production. As channel lining rate increases, the overall trend of water consumption in ecosystems in the Yellow River Irrigation District of Ningxia is basically the same as that in the economic system (Table 2). A higher channel lining rate reduces infiltration recharge into groundwater and thus results in a falling groundwater level and less phreatic evaporation. Ecological water consumption is in a falling trend for all land use types. The largest water consumption reduction is with unused land, followed by grassland, forestland and lakes and wetland in a descending order. When lining rate is increased from 30% to 60%, total water consumption by natural ecosystems will be reduced by 29 million m^3. In the Yellow River Irrigation District of Ningxia, ecosystems are mainly sustained by the groundwater

therefore does not change with an increase in channel

level and irrigation return flow, and thus bear a close relationship with the amount of water irrigated. Channel lining reduces ecological water consumption. This shows the negative impact which channel lining as a water-saving measure has on ecological water consumption. This requires special attention in water-saving reconstruction work in the irrigation district.

Among the ecosystems, evaporation from lakes and wetlands belongs to high-efficiency water, while evaporation from unused land is low-efficiency water. As far as natural forestland and grassland ecosystems are concerned, forest and grass coverage in the Yellow River Irrigation District of Ningxia is rather low, with wide areas of bare soil. As a result, low-efficiency water consumption is more than high-efficiency water consumption.

Table 2. Changes in ET and its use efficiency in the economic system of the irrigation district Unit: 100 million m^3

Channel lining rate	Lakes & wetland	Forestland				Grassland				Evaporation from unused land	Total evaporation
		Vegetation interception	Vegetation transpiration	Soil evaporation	Subtotal	Vegetation interception	Vegetation transpiration	Soil evaporation	Subtotal		
30%	2.29	0.02	0.26	0.88	1.16	0.07	0.93	2.46	3.45	5.30	12.20
40%	2.29	0.02	0.25	0.86	1.13	0.07	0.91	2.42	3.40	5.25	12.07
50%	2.29	0.02	0.24	0.86	1.12	0.07	0.90	2.38	3.34	5.22	11.97
60%	2.29	0.02	0.24	0.86	1.11	0.07	0.89	2.36	3.32	5.20	11.92

5. Conclusion

Channel lining is an important measure which affects the hydrological cycle and ET efficiency in the Yellow River Irrigation District of Ningxia Hui Autonomous Region. Increased channel lining weakens the driving forces of external water sources, the intensity of hydrological circulation and the conversion fluxes, and causes a falling groundwater level and reduced regional water diversion and drainage. Agriculture is a main source of water consumption, accounting for 75.4% of the total water consumption in the irrigation district. However, almost 50% of the total agricultural water consumption there is still of low efficiency. As channel lining rate increases, water consumption by ecosystems is reduced with a small margin. Channel lining also has a fairly significant impact on regional ET efficiency. A higher lining rate can reduce regional ET. In the economic system, high-efficiency water consumption is greater than low-efficiency water consumption. In the ecosystems, however, low-efficiency water consumption is more than high-efficiency water consumption.

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