Estimation of Water Balance of Hetao Irrigation District by Model Application

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1. Introduction

Hetao Irrigation District (HID), in the Yellow River basin, China, the irrigated area of which is 500,000 ha, should strongly affect basin hydrology as well as it is one of the major consumers of water resource in the basin. HID is in an arid zone with 100-200mm and 1300mm of annual precipitation and potential evaporation. Agriculture can be hardly practiced in this area without irrigation. Quantitative estimation of water balance and determination of a hydrological structure should be an important subject for water management of the whole basin as well as for local peoples who are engaged in agricultural activities. Several field observations and measurements have provided some fragmental information about water balance such spatial distribution and temporal variation of groundwater level, actual evapo-transpiration and soil moisture fluxes at some experimental plots, etc., in the district. On the other hand, through observations of several hydrological phenomena and experiments, qualitative knowledge about water balance structure of the district is accumulated. However, quantitative estimation of water balance and determination of water balance structure has not been done enough as the irrigation district has so large area and water balance structure may be complicated. Water balance depends on management of water and crop, topography, soil texture, irrigation and drainage facilities that varies spatially. Hydrological information that were obtained measurements or experiments at some points or narrow areas cannot be enhanced to the whole irrigation district directly. This study aimed to integrate these existing results of measurement and accumulated knowledge about hydrology in the district to provide a quantitative estimation of water balance and to determine hydrological structure in HID by applying IMPAM (Irrigation Management Performance Assessment Model), a distributed numerical model that was developed for simulation of hydrology in irrigated agricultural areas.

2. Materials and Methods

2.1 Model application area

The model was applied to an area around Yongji Main Irrigation Canal (Yongji Ganqu) that is surrounded by a total main and main drains and a total main canal (Figure 1). As this area contains almost the whole system of a main canal and parts of the total main canal and drain, it sufficiently represents the irrigation district in terms of water balance. In addition, this area should have little enough water exchange with the surrounding areas as it is surrounded by the main canals and drains that should make borders of groundwater flux. We can assume zero horizontal fluxes at the border.

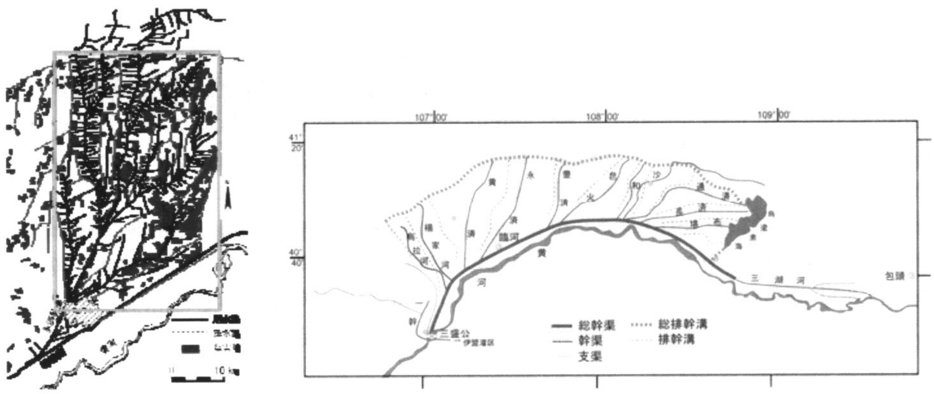


Figure 1: Model application area

Model

A quasi three-dimensional hydrological model IMPAM (Irrigation Management Performance Assessment Model) (Figure 2 and 3) that was developed by the authors was used in this study. The scope of IMPAM is from a command area consisting of a main or secondary canal up to the whole project area and can calculate temporal and spatial variation of evaporation, transpiration, groundwater level, crop growth, amount of drainage and seepage etc. All major factors and components in hydrological processes such as crop calendar and its spatial distribution, irrigation and drainage facility arrangement, topography, etc. are included within the spatial scope of the model.

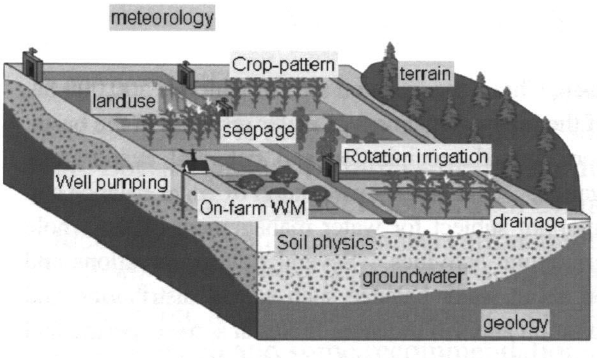


Figure 2 hydrological components included in IMPAM

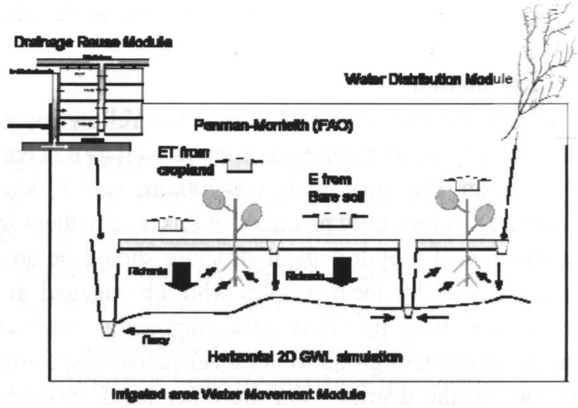


Figure 3 Concept of calculation of IMPAM

Resolution and simulation period

IMPAM is a grid-based distributed model. Spatial and temporal resolutions for the model application were 500 x 500 m and 0.5 day respectively. Simulation was conducted continuously for ten years with meteorological data during 1991 to 2000.

3. Results and Discussion

3.1 Groundwater level

Higher groundwater level was seen along main canals because of seepage (Figure 4). In agricultural plots, groundwater level rose just after irrigation. Peaks at post-harvest irrigation in autumn were most significant. It should be notable that groundwater level in non-irrigated bare land also rose and just after irrigation in surrounding field. Soil water conductivity of a semi-confined aquifer is 8 – 24 m d-1 and thick of the aquifer is tens to two hundreds meters around Yongji area (Inner-Mongolia Autonomic District Survey, et al., 2000). Pressure head that was raised by irrigation and seepage should be quickly transmitted to surrounding areas.

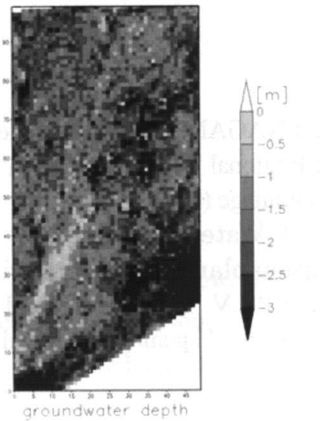
3.2 Evaporation and transpiration

Evaporation from soil surface was apparently much along major canals where groundwater is higher because of seepage (Figure 4, 5). High evaporation rate occurred just after the first irrigation in early spring when vegetation coverage was sparse and after post-harvest irrigation in autumn. Increase of evaporation after irrigation was also seen in non-irrigated areas with rise of groundwater level. As annual potential evaporation in Hetao Irrigation District is almost twice of total amount of precipitation and irrigation, shallow groundwater was dried up quickly. High transmissivity of the aquifer, mixed landuse (crop and bare areas), heavy seepage and surplus irrigation resulted in vast soil surface evaporation in the area.

Evaporation at the soil surface should be restricted when groundwater level is not high enough to supply sufficient moisture to the surface by capillary rise (Figure 6). On the other hand, little restriction of transpiration was seen as crop roots withdraw soil moisture in deeper (wetter) zone. Ratio of actual transpiration to potential was more than 90% except for some areas along the main canals where water logging occurred.

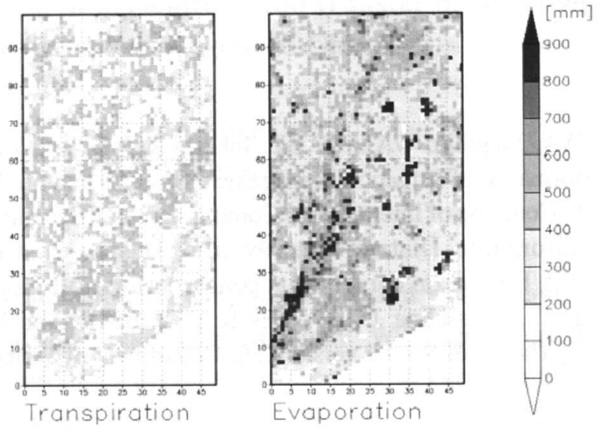
3.3 Water balance

A simulated water balance of the model applied area was similar to a water balance of whole the irrigation district in ratio (Figure 7). About 90% of precipitation and water withdrawn from the Yellow River is consumed in Hetao Irrigation District. According to the simulation result, two-third of the consumed water may evaporation from soil surface.



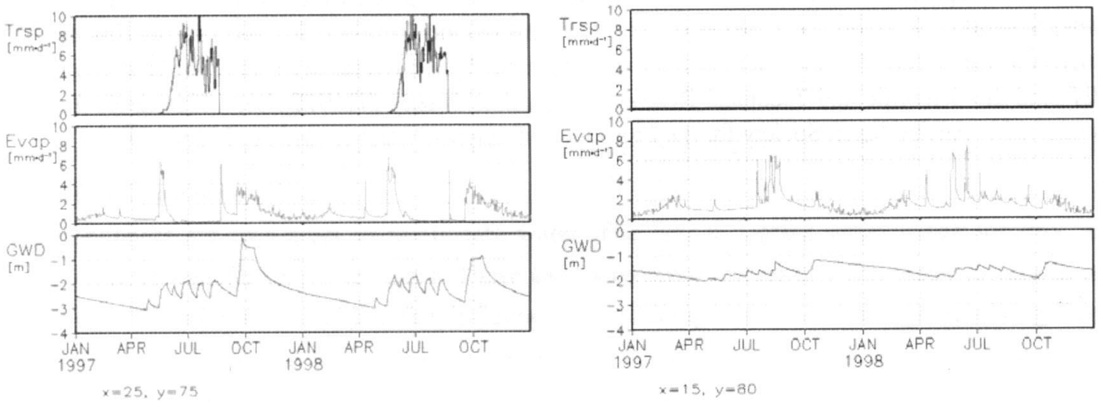
5-year mean of 1996-2000

Figure 4 Groundwater depth



5-year mean of 1996-2000

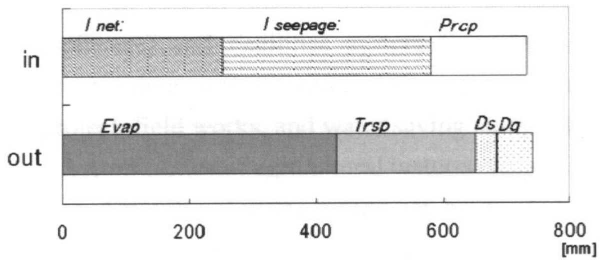
Figure 5 Annual transpiration and evaporation



(a) Wheat field

(b) Bare land

Figure 6 Transpiration, evaporation, and groundwater-level from the ground surface at (a) a wheat field and (b) bare land during 1997 to 1998



Inflow
I: irrigation water diverted from the YR (=I net + I seepage)
Precip: Precipitation

Outflow
Evap: Evaporation
Transp: Transpiration
D: Drainage (=Ds(from soil) + Dq(tailwater))

Figure 7 Estimated water balance of Hetao Irrigation District

4. Conclusions

Nearly two-thirds of diverted water should be consumed as evaporation. Therefore water consumption in the area may also increase without increase of cropped area. In terms of basin hydrology, water consumption in HID should be hardly estimated only with landuse and irrigated area that are obtained remote sensing and statistics. It is important to pay more attention to water management policies and methods in the area.

In terms of irrigation management, modification of irrigation schedule and water management at on-farm level can decrease water consumption in HID drastically as well as lining of irrigation canals. It may be attained through decrease of post-harvest irrigation in autumn and decrease of water requirement at on-farm level through leveling of land surface.

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