available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/agwat

Adapting to intersectoral transfers in the Zhanghe Irrigation System, China
Part I. In-system storage characteristics

N. Roost [a,*], X.L. Cai [a,b], D. Molden [a], Y.L. Cui [b]

[a] International Water Management Institute (IWMI), PO Box 2075, Colombo, Sri Lanka
[b] Wuhan University, Wuhan 430072, China

ARTICLE INFO

Article history:
Received 28 July 2007
Accepted 15 January 2008
Published on line 5 March 2008

Keywords:
Intersectoral transfers
Farm ponds
Irrigation
Water reuse
Remote sensing
China

ABSTRACT

The Zhanghe Irrigation System (ZIS), in Central China, has drawn attention internationally because it managed to sustain its rice production in the face of a dramatic reallocation of water to cities, industries and hydropower uses. Ponds, the small reservoirs ubiquitous in the area, are hypothesized to have been instrumental in this. Ponds are recharged by a combination of return flows from irrigation and runoff from catchment areas within the irrigated perimeter. They provide a flexible, local source of irrigation water to farmers. This paper assesses the storage capacity and some key hydrological properties of ponds in a major canal command within ZIS. Using remote sensing data (Landsat and IKONOS) and an area–volume relationship based on a field survey, we obtained an overall pond storage capacity of 96 mm (per unit irrigated area). A comparative analysis between 1978 and 2001 reveals that part of this capacity results from a very significant development of ponds (particularly in the smaller range of sizes) in the time interval, probably as a response to rapidly declining canal supplies. We developed a high-resolution digital elevation model from 1:10,000 topographic maps to support a GIS-based hydrological analysis. Pond catchments were delineated and found to extensively overlap, forming hydrological cascades of up to 15 units. In a 76-km^2 area within the irrigation system, we found an average of close to five 'connected' ponds downstream of each irrigated pixel. This high level of connectivity provides opportunities for multiple reuses of water as it flows along toposequences. A fundamental implication is that field 'losses' such as seepage and percolation do not necessarily represent losses at a larger scale. Such scale effects need to be adequately taken into account to avoid making wrong assumptions about water-saving interventions in irrigation.

1. Introduction

The Zhanghe Irrigation System (ZIS), in the Yangtze River basin, Central China, is served by a 2 billion m^3 multipurpose reservoir. Over the last few decades, water from this reservoir has been largely reallocated out of agriculture to serve higher valued users: hydropower, cities and industries. Yet, over the same period of time, the production of rice (the main crop in ZIS) has been roughly sustained (Fig. 1). This remarkable fact has drawn some attention to ZIS, with international research projects recently carried out in the area (ACIAR projects LWR/2000/030 and LWR/2001/001—see www.aciar.gov.au).

* *Corresponding author*. Tel.: +61 416 362567.
E-mail address: nd_roost@yahoo.com.au (N. Roost).
0378-3774/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2008.01.010

Farm reservoirs, in their thousands dotted across the system, have most probably played a major role in coping with shrinking canal supplies. These small reservoirs, or ponds, capture runoff from catchment areas within the system and return flows from irrigation. They provide a flexible, local source of irrigation water to farmers and also support a significant aquaculture industry in the area (Loeve et al., 2001; Dong et al., 2004; Mushtaq et al., 2007a).

Despite their importance, little is known about ponds in ZIS. Lack of knowledge primarily stems from the fact that ponds were built by groups of farmers or individual villages in response to declining supplies with limited involvement from the system's management. Also, distributed storage generally adds a fair amount of complexity to a system's hydrology, posing a challenge to the system managers.

This paper and its companion (Roost et al., 2008) bridge some knowledge gaps by undertaking a systematic assessment of ponds in ZIS. This assessment, based on a range of tools including field survey, remote sensing and simulation modelling, aims to provide a better understanding of the role and impacts of ponds in the irrigation system. A fundamental question it aims to address is: How have ponds helped the system cope with intersectoral transfers of water? Drawing lessons from ZIS, the papers more broadly seek to contribute ideas and knowledge to save water and enhance the productivity of water in agriculture elsewhere.

The present paper focuses on the estimation of in-system storage capacities and key hydrological properties, with emphasis on hydrological connectivity and the related potential for multiple reuses of water. The second paper builds on this to undertake a more functional analysis, looking at how ponds impact water availability, overall water balance and water productivity in ZIS.

2. The study area

ZIS is located north of the Yangtze River, in Central China (Fig. 2). With a total area of 5540 km^2, of which about 1600 km^2 of irrigated land, ZIS is one of the important centres of grain production in the Hubei Province. The main crop cultivated in ZIS is rice. Other crops, all rainfed, include cotton and peanut during the summer, and rapeseed and winter wheat during the winter. The area receives an average annual rainfall of 960 mm. Rainfall variability is important, both within and between years. On average, close to 60% of the yearly rainfall occurs between May and September, thus significantly contributing to rice water requirements. Salient features of ZIS, in addition to the high density of farm ponds, include its hilly landscape and a relative abundance of natural vegetation (forest), especially at the hilliest locations.

The assessment presented in this paper focuses on a 325-km^2 area served by the 3rd Main Canal (Fig. 2), the most important canal in ZIS. This area received about 25% of the total ZIS supply between 2001 and 2004. It includes 2 medium-sized reservoirs (36×10^6 m^3 storage in total), a few small-sized reservoirs (11×10^6 m^3 in total) and thousands of ponds. It is bounded by natural streams in the west and south, by the 3rd Main Canal in the north and by a large branch canal in the east. It ranges in altitude between 130 m (a.s.l.) in the north and about 40 m (a.s.l.) in the south. Clay loam and silty clay loam are the dominant soil types. Both have characteristics that make them suitable for rice cultivation.

Because of preferred allocation to other users by the irrigation agency, relatively abundant rainfall and widespread use of local storage, there are typically only 2–3 bulk releases from the Zhanghe reservoir into the 3rd Main Canal each year. Decisions to release water are based on available storage, rainfall conditions and an overall view on crop water requirements in the system (Loeve et al., 2001). Since farmers place orders for canal supplies, an element of demand is also involved in canal operation. The medium- and small-sized reservoirs included in the study area are operated independently from the ZIS main canals. Users in their command areas seem to benefit from more flexible supplies. When not owned by single individuals, ponds are often managed through collective arrangements within villages (Mushtaq et al., 2007b). Access to ponds greatly enhances flexibility, generally allowing farmers to get water on-demand.

ZIS lies immediately upstream of a large lake (the Chenghu Lake), which receives the system's drainage flows. The lake itself drains into the Yangtze River, running just a few

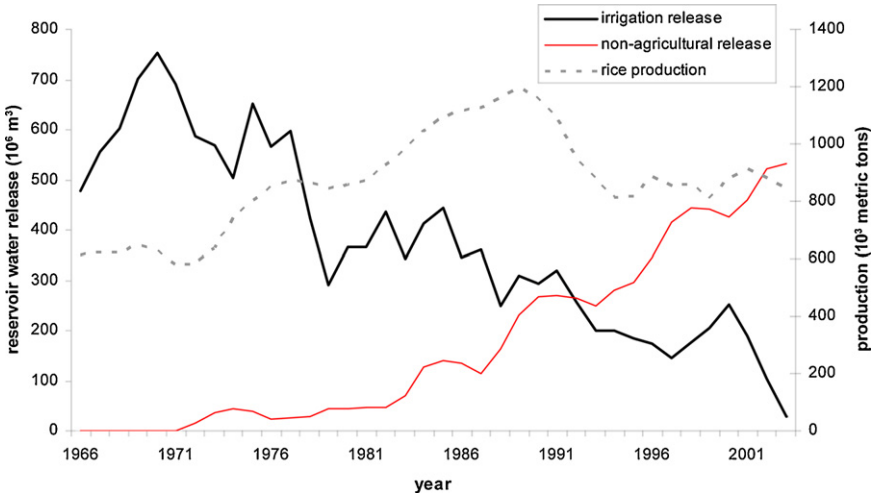

Fig. 1 – Water allocation and rice production in ZIS (3-year moving averages).