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Design of environmental flow regimes to maintain lakes and wetlands in regions with high seasonal irrigation demand

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ABSTRACT

In arid regions, the construction of dams has led to an increase in irrigated agriculture, resulting in the desiccation of vulnerable lakes and wetlands. In many arid mountainous regions, such as in the Middle East, upstream dams typically feed rivers that flow into lowland terminal (closed) lakes or wetlands. The release of water for environmental purposes is a widely recognised option for reducing such impacts. The present study used monthly hydrological data from the Kor river in southern Iran, its main reservoirs and data above and below the Korbal irrigation system. The Kor river is a major source for feeding the Bakhtegan and Tashk lakes, which have recently started to disappear. An analysis of the water resource system before the dam construction (before 1973) showed that the monthly lake inflow depended on available water in river above the irrigation system (for eight months) and, during the irrigation season, water consumed for irrigation as well (for four months). However, in the post-development period (after 1997), the flow rate to the lake depended almost entirely on the Korbal irrigation system, except during some winter months when little irrigation was needed. Environment flow release has not been effective as it has led to greater water availability in the river, which results in more water being consumed for irrigation, as demonstrated here. To overcome this management mismatch, a new environmental flow release strategy (regime) was designed in which water is released from the upstream reservoirs during periods of low irrigation demand (*e.g.* winter months).

1. Introduction

In arid and semi-arid regions, intensive agriculture has led to a decline in water levels in major lakes such as the Aral Sea (Crétaux et al., 2005; Glantz, 2007; Erdinger et al., 2011) and the large lakes of Iran such as Urmia (Hassanzadeh et al., 2012; Fathian et al., 2014; AghaKouchak et al., 2015), Hamoun (Najafi and Vatanfada, 2011; Sharifikia, 2013; Rashki et al., 2013;) and Bakhtegan (Teimouri et al., 2011; Torabi Haghighi and Kløve, 2015b). While it is difficult to conserve lakes or reverse current trends due to the high demand for irrigation, the main land and water management options are i) a change in agriculture practices, ii) a change in water regulation, iii) inter-basin water transfer, and iv) a reduction in lake area (evaporation). With controlled regulation patterns, water can be allocated as environmental flow (EF) for environmental needs. Two main paradigms are well documented for EF regimes in modified rivers: i) the natural flow regime (Poff et al., 1997; Lytle and Poff, 2004) and ii) the designed regime (Acreman et al., 2009; King et al., 2009; Alfredsen et al, 2012; Acreman et al., 2014).

In regions with high seasonal agricultural water demand, releasing EF from reservoirs to terminate in a lake is a challenge when the water is used for irrigation shortly after its release. Experience from Iran shows that irrigation water use is difficult to control as farmers use the water that is available because demand for it is high, *e.g.* it is one of the major reasons for reducing the inflow to the Urmia lake (Hassanzadeh et al., 2012), Gavkhouni wetlands (Nikouei et al., 2012; Sarhadi and Soltani, 2013) and Bakhtegan lake. This has led to the rapid expansion of agriculture (beyond original plans), resulting in consumption patterns in which most of the available water is used. In Iran this has led to serious falls in lake levels that have socio-economic impacts and are a cause for public concern. New release plans have been suggested that allocate EF to mitigate the lake level declines. Considering farmers' strategies for irrigation, an important target criteria for EF is to maximise lake inflow after a given reservoir release. This is relevant for lakes in arid regions where water quantity is a key concern for ecosystem services.

The present study aimed to develop a new EF water release strategy for arid cases with upstream reservoirs and downstream high

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water demands before a terminal lake. Farmer water-use strategies were analysed based on river flow records. Such records are reliable (compared to information available from crop water demand) for an analysis of water use patterns and can be applied for EF design in regions where water is heavily controlled by irrigation. The river discharge time series showed that during the irrigation season, farmers used almost all of the available water with a minor lake inflow. The discharge to the lake was then mainly a function of irrigation. In winter, with little irrigation, the flow was a function of reservoir outflow (measured discharge before the irrigated area), which was similar to the lake inflow. Based on this conceptual understanding of farmer water use and hydrology, a new method was developed for the EF regime. The method was then demonstrated in water resource systems that are typical for arid regions (upstream reservoir, river system with lowland diversion dams, irrigated agriculture and a terminal lake at the end of the catchment).

2. Material and methods

2.1. Study area and data used

Bakhtegan and Tashk lakes are saline lakes in Fars Province and, together, form the second largest inland waterbody in Iran after Urmia lake. Bakhtegan and Tashk lakes are terminal lakes of the Kor river basin, covering an area of 42,375 km^2 (Fig. 1). The lakes are connected during wet years, extending their area to 1243 km^2.These two lakes (hereafter called Lake Bakhtegan, best known by this name) are considered as shallow lake (Maximum depth is 3 m) and detention time is short and related to hydrological regime (Torabi Haghighi et al., 2016). During dry periods, the lakes are separated by a thin band of land. The Kor river enters the lakes through Kamjan (an area of about 19.62 km^2 based on a 1960 aerial photo) and Doshakh wetlands (an area of about 3.64 km^2). Before 1980, these wetlands provided a 7-km riparian buffer zone that contained a wide variety of endemic flora and was one of the major habitats for wintering water birds. At that time, the return water from irrigation and some of the runoff was stored in this buffer zone and slowly and continuously discharged into the lake throughout the year. In the last decade, however, the narrow buffer zone and wetlands have completely dried out due to the development of the irrigation system in the Korbal plain (Zarakani, 2010). This plain covers an area of about 80,000 ha and lies between the cities of Kherameh and Marvdasht in Fars Province in southern Iran. However, due to extensive water use and recent droughts, lakes has partly vanished (Fig. 1b).

For centuries, the lower part of the Kor river has been regulated by six diversion dams to supply water to irrigate the Korbal plain. The oldest diversion dam is Band-e-Amir, which was constructed more than 1000 years ago. However, the main modification on the Kor river is quite recent and began in 1973 with the opening of the Doroudzan dam. Later, in 1980, the modification and increase in height of the traditional diversion dam began, increasing irrigation for agriculture which is a key business in the region. Recently, the Kor river was further regulated by two new dams, the Mollasadra dam above the Doroudzan dam on the Kor river, and the Sivand dam on the Sivand river, which is a tributary of the Kor river (Fig. 1). Due to this river modification, the inflow to the lake has been significantly decreased (Fig. 1c), despite environmental legislations and environmental flow allocation due to large number of consumers with high dependency (e.g. farmers). Therefore, a challenge for lake rehabilitation in the region is to assure the discharge into the lake while considering the high irrigation demand.

The Kor river flow rate was measured at Polkhan above the Korbal plain, at Jahan-Abad and Hasan-Abad below the Korbal plain, and at the mouth of the Kor river on Bakhtegan lake (Fig. 1). The available data at Polkhan covered the period from 1964 to 2015, at Jahan-Abad from 1964 to 1980 and at Hassan-Abad from 1997 to 2015. The Jahan-Abad gauge station was closed in 1980 and

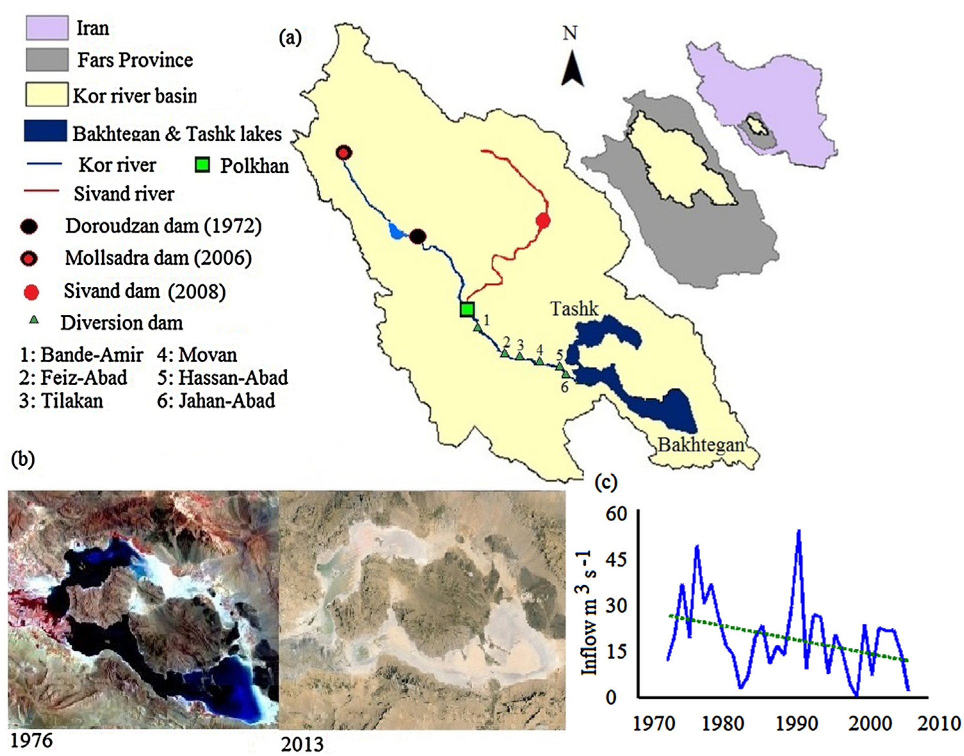

Fig. 1. Bakhtegan lake and it's catchment area with (a) the location of climatology stations, discharge gauging, dams and layout of the Kor river; (b) Bakhtegan lake area in 1976 and 2013; and (c) annual inflow to the lake.