The Response to Comments on Manuscript

"Evolution of the human-water relationships in Heihe River basin in the past 2,000 years"

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Dear Reviewer.

We would like to sincerely thank and acknowledge your efforts for spending your valuable time reviewing our manuscript. We are pleased to resubmit for publication the revised version of hess-2014-560 “Evolution of the human–water relationships in Heihe River basin in the past 2000 years”. We appreciate your constructive comments and criticisms. We have addressed your concerns and provided our response (in red) to your comments (in black) as below. Over the past few weeks and the revision process, we have also improved the paper for clarity. We have also provided two version of the manuscript: one with all changes using the “Track Changes” function in Microsoft Word; and the other one is not highlighted but with has the same content.

Thank you and regards,

Dr. Yongping Wei

Corresponding Author

Responses to major comments of Reviewer #1:

1. Comment: The estimation of E is not clear to me. Is E estimated by equation (2) or (3) for the basin or for cultivated oases and natural oases separately? Is w=3.5 for all the historical periods? Should the value of w be different between cultivated oases and natural oases? Should w even change with time depending on the type and intensity of crops?

E is estimated by equation (2) and (3) for the basin. There are two equations because of different emphasis on E_0 and P, respectively. Throughout the paper *w*=3.5 for all the historical periods.

We totally agree that the value of *w* will vary among different land use types and could change with time depending on the type and intensity of crops. However, due to the lack of historical documents or data for natural oases (forest and grassland) in this region, it is impossible for us to characterize *w* for the natural oases in the historical periods. In addition, in equations (2) and (3), when *w* is larger than 3, the impact of changes in *w* on E is likely to be small, especially in this arid region where E_0/P is large, and the available water for evapotranspiration becomes the determining factor (Zhang et al., 2001; Zhang et al., 2004). Therefore, we consider that using *w*=3.5 for all the historical periods is reasonable. However, we have discussed this issue as a limitation of this manuscript in the Discussions and Conclusions section; see line 41 page 5 to line 6 page 6 and lines 30-36 page 14.

2. Comment: Water supply is computed as the summation of local precipitation and irrigation (or groundwater ET). Is irrigation water pumped from groundwater or surface water withdrawal?

Irrigation water was obtained by surface water withdrawal from upstream reaches in historical periods. It has been both pumped from groundwater and diverted from surface water since the establishment of New China in 1949 as the surface water resource was insufficient for the rapid development of agriculture. The development of pumping and drilling technology during this period also facilitated this change. We have improved the description of irrigation in the revised manuscript to clarify this, see lines 25-29 page 6.

3. Comment: Is a portion of local precipitation recharged to the groundwater? If not, the groundwater is fully replenished by the precipitation recharge at the upstream (mountain).

Yes, a very small part of local precipitation recharges the groundwater in extremely wet years in the mid and lower stream reaches of our study area. We agree that most of the groundwater is replenished by the precipitation recharge in the upper catchment (mountains).

4. Comment: Line 15 page 1061: change to ", e.g., water"

We agree. We have made this change in our revised manuscript, see line 43 page 1.

5. Comment: Lines 1-3 page 1062: There are some recently published papers which are for explanatory and predictive purpose, e.g., "A prototype framework for models of sociohydrology: identification of key feedback loops and parameterisation approach" by Elshafei et al. (2014 HESS)

Thanks for introducing to us this very useful reference to improve the quality of our manuscript. We have read it and referenced it in our revised manuscript, see lines 11-14 page 2.

6. Comment: Lines 24-25 page 1062: some information is repeated at lines 4-9.

We agree. We have deleted the repeated information in our revised manuscript, see lines 35-36 page 2.

7. Comment: Line 15 page 1064: "Budyko and Miller, 1974;" Double check this.

We agree. We have doubled check it and changed it in our revised manuscript, see line 5 page 4 and line 19 page 15.

8. Comment: Line 20 page 1064: change to "respectively; " Similar changes are applicable for other locations.

We agree. We have made this suggested change throughout our revised manuscript, see line 10 page 4.

9. Comment: Line 16 page 1066: correct "Fu (1981) fFor details,"

We agree. We have made this suggested change in our revised manuscript, see line 26 page 5.

10. Comment: Line 24 page 1066: change "PET" to "E0" or define PET.

We agree. We have changed "PET" to "E_0" in our revised manuscript.

11. Comment: Lines 24 page 1066 – line 1 page 1067: E0 is assumed to be the same between the historical period and the instrumental period. This assumption needs to be justified or the uncertainty on estimated E due to this assumption needs to be discussed.

Thanks for the point raised. We have added some sentences to discuss the uncertainty of estimated E in our revised manuscript, see lines 30-41 page 5 and lines 30-34 page 14.

12. Comment: Line 15 page 1067: since "I" has been used for irrigation in Equation (5), you can use "J" to replace "I" in equation (5).

Thanks for the point raised. We have made the suggested change, see lines 8-11 page 6.

13. Comment: Line 2 page 1074: "m3/year"? Check the unit in Table 2 too.

We agree. We have changed "m^3" to "m^3/year" in our revised manuscript.

14. Comment: Lines 10-11 page 1076: The period from 2000-2010 is short. I am not sure whether it has already reached a new equilibrium stage. Natural oasis may continue to increase from Figure 5.

Thanks for the points raised. We have developed in-depth discussion on the equilibrium stage in our manuscript and changed “a new equilibrium stage” to “a new state”, see lines 11- 18 page 8 and lines 22-23 page 13.

15. Comment: Line 13 page 1077: Are predictions of its possible future dynamics discussed? How to predict future dynamics?

Thanks for the point raised. We did not mean that the future dynamics were predictable at this stage, rather that our findings can inform attempts towards this. We have changed, see lines 1-9 page 15.

16. Comment: Lines 15-18 page 1077: I think the claim is over stated. The manuscript can be shortened, but the “transition theory” needs more description and discussion.

Thanks for the point raised. We agree. We have rewritten this section and added more description and discussion on transition theory in our revised manuscript, see lines 11-18 page 8 and lines 1-9 page 15.

Additional references:

Zhang, L., Dawes, W., and Walker, G.: Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water resources research, 37, 701-708, 2001.

Zhang, L., Hickel, K., Dawes, W., Chiew, F.H., Western, A., and Briggs, P.: A rational function approach for estimating mean annual evapotranspiration. Water resources research 40, W02502, doi:10.1029/2003WR002710, 2004.

Responses to major comments of Reviewer #2:

1. Comment: How the past 2000 years were divided into several different periods is not entirely clear. First, Table 1 provides vague timelines for the different dynasties; it would be much better if the authors provided start and end years to these periods. It would also help the reader understand whether these were successive contiguous periods. Second, it is mentioned in Section 2.3.1 that the authors used "precipitation in each historical period reconstructed by Ren et al. (2010)". Are Ren et al. (2010)'s historical periods the same as the seven dynastic periods chosen in this study? If not, how different are Ren et al.'s divisions of the historical period?

Thanks for this point. We have listed the start and end years of related dynasties in the past 2000 years in our revised manuscript. The reason why we selected seven periods, not seven whole dynasties, was because the data of reconstructed land use and land cover were only available during these periods (Xie, 2013; Xie et al., 2013). Ren et al. (2010) reconstructed a complete precipitation sequence spanning 2000 years with a resolution of 50 years, so the precipitation data for the seven chosen periods in this study were directly extracted from Ren et al. (2010). See lines 29-36 page 3.

2. Comment: In Section 2.3.3, three land use types are considered: cultivated oases, natural oases, and unused land. Equation 4 provides how the P (water supply) in the first two land use types was estimated, to be used in equations 2 and 3. However, for the unused land, was precipitation the only water supply considered? If yes, please state it explicitly; if not, please explain how water supply was calculated for unused land.

Yes. Precipitation is the only water considered for the unused land. We have stated this in our revised manuscript, see lines 30-30 page 6.

3. Comment: Sticking with Section 2.3.3, in equation 4, the groundwater irrigation I is kept constant at 500 mm throughout the entire historical period. This assumes that the types of crops cultivated in this basin did not change over 2000 years, and does not take into account the evolution in agricultural technology. Moreover, it directly contradicts the statements made in Section 3.6, such as "In the middle of the Qing Dynasty, the Hexi corridor was politically stable and free from wars and innovative farming and engineering methods were introduced, such as better seeds, new crops, and the steel farm implements".

We fully agree with your comment. We have investigated more historical documents on irrigation development in this region. According to Wang' (2003) research on the development history of water conservancy facilities in Heihe River basin, the main crop varieties, water conservancy facilities, irrigation method and farming conditions almost remained constant from the Han dynasty to the early modern period, so the irrigation was set at 500 mm for the whole historical period. However, it was increased from 500 to 650 mm when the cropping pattern evolved from single wheat to wheat and maize after the 1980s (Wang et al., 2005; Shi et al., 2011), and this is discussed as a limitation of this manuscript in Section Discussions and Conclusions, see lines 12-29 page 6, lines 30-38 page 12 and lines 30-37 page 14.

4. Comment: I think Section 4 of the paper needs to include a paragraph or two on the limitations/assumptions/caveats of the methods used. Historical reconstruction of annual water fluxes over such a long period will most definitely involve huge uncertainties and assumptions (one example pointed out in my point 3 above). These need to be mentioned and discussed in this section.

Thanks for this point. We agree. Several points on key limitations/ assumptions/ caveats of the methods have been raised above and we have used those, plus a careful consideration of other limitations to develop a more detailed discussion of these in an additional paragraph in our revised manuscript, see lines 30-48 page 14.

5. Comment: What is k in Figure 6? I did not find any explanation in the article text.

Thanks for this point. k is the change rate of the factors and it was estimated by dividing the difference between the values at the start and end of the period to the years of the period. We have explained it in lines 25-27 page 8 of the Method Section.

Additional references:

Xie, Y.: Dataset of cultivated oasis distribution in the Heihe River Basin during the historical period. Heihe Plan Science Data Center, DOI: 10.3972/heihe.092.2013.db, 2013.

Xie, Y., Wang, X., Wang, G., and Yu, L.: Cultivated land distribution simulation based on grid in middle reaches of Heihe River basin in the historical periods, Advances in Earth Science, 28, 71-78, 2013.

Ren, Z., Lu, Y., and Yang, D.: Drought and flood disasters and rebuilding of precipitation sequence in Heihe River basin in the past 2000 years, Journal of Arid Land Resource and Environment, 24, 91-95, 2010.

Shi, M., Wang, L., and Wang, X.: A study on changes and driving factors of agricultural water supply and demand in Zhangye after Wwater reallocation of the Heihe River, Resources Science, 33, 1489-1497, 2011.

Wang, G., Yang, L., Chen, L., and Jumpei, K.: Impacts of land use changes on groundwater resources in the Heihe River basin, Acta Geogr. Sin., 60, 456–466, 2005.

Wang, Y.: The development history of water conservancy facilities in Heihe River basin, Gansu Nationalities Press, Lanzhou, 2003.

Abstract

This paper quantitatively analyzed the evolution of human-water relationships in the Heihe River basin of northern China over the past 2000 years by reconstructing the catchment water balance by partitioning precipitation into evapotranspiration and runoff. The ~~reconstruction~~ results provided the basis for investigating the impacts of ~~human~~ societies on hydrological systems. Based on transition theory and the rates of changes of the population, human water consumption and the area of natural oasis, the evolution~~ary processes~~ of human-water relationships can be divided into four stages: predevelopment (206 BC - 1368 AD), take-off (1368 - 1949 AD), acceleration (1949 - 2000 AD), and the start of a rebalancing between the human and ecological needs (~~after~~ post 2000 AD). Our analysis of the ~~The~~ evolutionary process~~ analysis~~ revealed that there were large differences in the rate and scale of changes and the period over which they occurred~~, and~~. The transition of the human-water relationship had no fixed pattern. This understanding of the dynamics of the human-water relationship will assist policy makers to identify management practices that require improvement by understanding how today's problems were created in the past, which may lead to ~~for~~ more sustainable catchment management in the future.

1 Introduction

The development of land and water resources within catchments over thousands of years has led to spectacular growth in agricultural production along with increased human consumption of water, significant modification of catchment vegetation, and serious degradation of ecosystems, worldwide (Carpenter et al., 2011; Falkenmark and Lannerstad, 2005; Röckstrom et al., 2009; Vörösmarty et al., 2010). ~~The f~~Future~~ of~~ human wellbeing may be seriously compromised if we pass a critical threshold that tips catchment ecosystems into irreversible degradation.

Understanding the connections and feedback mechanisms between changes in human activities and hydrological systems in the long term, and uncovering the mechanisms governing the human-water feedback loop, can help us to understand how today's conditions and problems were created in the past, and have important implications for future management (Sivapalan et al., 2012; Liu et al., 2013; Montanari et al., 2013; Savenije et al., 2013). However, ~~there is~~ at present, there is limited understanding of the major modes of interactions between the human and hydrologic systems over long time scales~~, ~~. ~~although~~ Developing such understanding is the aim of social-hydrology ~~as a new discipline emerged in 2012~~ (Savenije et al., 2013).

Historical analysis is a key method of socio-hydrology in which hydrological analysis over a long timeframe is a key component. Accurate historical data for hydrology, climate, land use, ecology and geomorphology are often unavailable, but hydrological reconstruction that aims to generate long-term datasets, could provide a basis for the identification, description and parameterization of feedback mechanisms between human activities and water (Thompson et al., 2013). Empirical reconstructions of changes in single hydrological elements at specific locations have been reported, ~~such as~~including precipitation, streamflow, water salt content and lake levels (Turner et al., 2008; Lowry and Morrill, 2011). Whilst these studies are empirically informative, few of them have been conducted on water balance in basins that are facing significant threats ~~e.g.,~~such as water over-abstraction, sea level rise, or land use change, or in basins ~~and~~ that experience major transitions~~ in different ways~~ (Vörösmarty et al., 2010).

In the social science literature transition is a well-established concept. It is: "*a non-linear process of social change in which the structure of a societal system (energy sector, water management and agriculture) transforms*" (Rotmans, 2005). Although there is a considerable number of empirical studies focusing on the dynamics of transition, and in particular on the different stages and processes of transition, they ~~are~~ have been criticized for empiricism: good at description but weak at explanation (Wimmer, 2006). There have already been several early attempts at exploring the co-evolution of human and water systems. For example, Xiao and Xiao (2004) divided the evolutionary processes of the human-land relationships affected by the water resources in the Ejin region, downstream of the Heihe River basin, into four periods. Geels (2005) studied the trajectories of the co-evolution of water technology and society in present-day Netherlands. Kallis (2010) studied the co-evolution of water resource development in ancient Athens. Pataki et al. (2011) provided an outline of the interplay of sociological and ecological processes in urban water management. Unfortunately, most of them adopted "thick descriptive" approaches that have poor explanatory and predictive ability. Recently, Elshafei et al. (2014) developed a prototype framework for models of social-hydrology including identification of some important feedback loops. The framework aims for more explanatory capability although the fully parameterized dynamic coupled model has yet to be applied.

The Hexi Corridor, located in western Gansu Province, China, is an important part of the ancient Silk Road established in the Han Dynasty (206 BC-220 AD), and was a trade route between China and western countries that facilitated cultural and economic exchange for approximately 1500 years. It is an arid area supported by ~~oases~~ oasis ecosystems where water dominates the dynamics of human society and natural systems, and therefore the interactions and feedbacks between humans and water are very prominent. The region has a rich written history of over 2000 years. Over-development of land and water resources over thousands of years has significantly modified the catchment vegetation conditions and desertification is a continuing process causing environmental degradation in the region (Xiao and Xiao, 2004, 2008).

The overarching goal of this paper is to reveal the evolutionary processes of human-water relationships in the Heihe River basin, an important part of the Hexi Corridor ~~over~~ for a period spanning approximately 2000 years, ~~in~~ over which hydrologic, social and environmental systems ~~were connected~~interacted. The specific objectives are to reconstruct the water balance at the basin scale over the past 2,000 years and to determine the development stages of the evolution~~ary processes~~ of the human-water relationships. The analysis is used~~It is expected~~ to gain important understanding of the human-water relationships and provide guidance for the region's sustainable development.

2 Methods

2.1 Study area

We selected the Heihe River basin (HRB) in northwest inland China as our case study area.~~,~~ The HRB is located in the central Hexi Corridor;~~an important part of the ancient Silk Road, and~~ one of the most arid regions in the world~~, as our case study area~~. It covers~~The HRB, covering~~ approximately 130,000 km^2~~,~~ and is located at the climatic intersection between the Westerlies and the East Asian summer monsoon (Fig. 1). Many civilizations and cultures have flourished~~were found~~ there, ~~such as~~including the Siba culture, ~~and~~ the Juyan Wooden Slips and the Literature of Heishui city ~~in the HRB~~ (Cheng et al. 2011; Shi, 2007). The rise and fall of civilizations in the HRB is closely linked with water: when there is water there are oases and flourishing societies, when there is no water, there is desert and diminished human activities.

Figure 1. Location of the Heihe River basin and locations of ~~data of~~ ice core, tree ring and

lake sediment data.

The Qilian Mountains are the principal water source areas of the Heihe River. They ~~and~~ have an elevation varying between 2000 and 5500 m and a mean annual precipitation varying from 250 to 500 mm. The midstream oases ~~area is~~ are a part of the Hexi Corridor with elevations between 1000 and 2000 m and mean annual precipitation ranging~~es~~ from 100 to 250 mm. The lower reaches are located on the arid Alaxa Plateau where the mean annual precipitation is less than 50 mm (Qin et al, 2010). The Heihe River is the second ~~largest~~ longest inland river in China with a length of 821 km. Starting from the upstream Yingluoxia Hydrological Station (YLX), the Heihe River flows northward into its midstream area.~~,~~ ~~and finally f~~Flows out of the midstream area~~, that is~~ are measured at the Zhengyixia Hydrological Station (ZYX), and if finally flows into ~~the~~ terminal lakes in the downstream areas. ~~Its upstream flow~~Flow from the upper catchment provides water supplies for agricultural production and ecosystem stabilization in the middle and lower reaches of the HRB.

The HRB is an important area for grain production in China and is a highly developed irrigation district with an unremittingly agricultural history dating back nearly 2000 years. ~~The i~~Intensive and ~~non-~~unsustainable utilization of water resources in the middle reaches of the basin has led to a sharp decrease ~~of~~ in water supply ~~in~~ to the lower reaches during the last 50 years (Zhou and Yang, 2006). As a consequence the ecosystems in the lower reaches ~~has~~ have been degraded ~~with~~ by land desertification, more frequent sandstorms, and the drying ~~out~~ of terminal lakes. Therefore the HRB is a compelling case study area for an analysis ~~on~~ of the co-evolution of ~~the~~ human-water systems at the basin scale.

2.2 Study period

We selected the past 2000 years as our study period. This time scale represents a period in which dramatic changes in climate, land use~~s~~, runoff, management policy, population, societal development and catchment ecological conditions have occurred. These are major variables affecting the ~~river basin~~ water cycles of river basins. It is also a time of significant civilisation development in China~~. T~~, for which there is a wealth of documentary evidence available (Holmes et al., 2009; Zheng and Wang, 2005).

We reconstructed the co-evolutionary processes of societal development and hydrological systems based on seven periods~~Due to the limitations of land use information, several periods were selected~~ in the past 2000 years ~~according to~~using the results of Shi (2010), Wang et al. (2013) and Xie et al. (2013) (Table 1). This reconstruction was dependent on adequate land use information, which resulted in some limitations to developing a contiguous hydrological data set over this long timeframe.~~We reconstructed the co-evolutionary processes of societal development and hydrological system based on seven Dynastic periods.~~

Table 1. Seven periods selected in the past 2000 years.

Dynasty	Start	End	Main production	Selected periods
Han Dynasty	206 BC	220 AD	Agriculture	The beginning of the 1st century AD
Wei-Jin Era	220 AD	420 AD	Animal husbandry	The end of the third century AD
Tang Dynasty	618 AD	907 AD	Agriculture	The mid- 8th century AD
Yuan Dynasty	1271 AD	1368 AD	Animal husbandry	The end of the 13th century AD
Ming Dynasty	1368 AD	1644 AD	Agriculture	The mid- 16th century AD

Qing Dynasty	1644 AD	1912 AD	Agriculture	The mid- 18th century AD
The Republic of China Era	1912 AD	1949 AD	Agriculture	The 1940s

2.3 Reconstructing the evolutionary processes of catchment water balance

We used annual water balance partitioning to provide insights into the evolutionary processes of human-water relationships at basin scale.~~, which~~ Such partitioning is widely used as a signature of hydrologic regimes when catchments experience changes in precipitation regimes, temperature and land use change (Budyko~~ and Miller~~, 1974; Sivapalan et al., 2003)~~, to provide insights into the evolutionary processes of human-water relationships at basin scale~~. For this study, the water balance equation can be written as:

$$P + R_{in} = E + R_{out} \quad (1)$$

~~Where~~ where P and E are precipitation and evapotranspiration in the mid- and down- stream areas of HRB, respectively~~,~~; R_{in} is the streamflow ~~in~~ from the upstream part of HRB ~~flowing~~ into the midstream area, and R_{out} is the ~~amount~~ volume of water flowing into the terminal lakes of the downstream areas. In arid regions soil water content is very small and the groundwater levels were stable over historical periods, so changes of soil water content and groundwater are negligible and not included in Eq. (1).

Due to a lack of measured data in historical periods the reconstruction of P, R_{in} and E, and validation of the derived R_{out} from Eq. (1) are important steps for developing catchment water balance over the long-term timeframe necessary for understanding the co-evolutionary process of human-water relationships.

2.3.1 Reconstruction of~~Reconstructing~~ precipitation (P) in the mid- and down-stream areas

We estimated precipitation (P) in historical periods based on instrumental data in the most recent period and changes in paleoclimatic conditions. Ren et al. (2010) reconstructed the mean precipitation sequence of the whole HRB ~~in~~ for the past 2000 years using historical drought and flood sequences, based on the good correlation between drought and flood disasters and precipitation in the 40 years from 1956 to 1995 (R^2 =-0.892). We reconstructed the distributed precipitation (P) in the mid- and down- stream areas in historical periods as follows. ~~by multiplying t~~The mean precipitation from the instrumental record for~~data from~~ 1956 to 1995, when there were continuous records at ten meteorological stations, was multiplied by the ~~proportion~~ ratio of the precipitation in each historical period reconstructed by Ren et al. (2010) to the precipitation~~that~~ in the measured period. The instrumental precipitation data in the recent period were obtained from the China Meteorological Administration~~ of Meteorology~~.

2.3.2 Reconstruction of ~~Reconstructing~~ streamflow ~~flowing~~ into the midstream area: R_{in}

Dendrochronologically-based hydrological reconstructions have been widely used to extend existing instrumental streamflow records, as streamflow variations correlate well with tree ring-width series (Woodhouse et al., 2006; Saito et al., 2008). There are many ~~studies on the~~

streamflow reconstruction studies ~~in Qilian Mountains~~ based on tree ring analyses for the Qilian Mountains. The longest streamflow record in this region is about 1400 years, ~~obtained~~ developed by Yang et al. (2012), then 1300 years by Kang et al. (2002) and 1000 years by Qin et al. (2010). None of these streamflow reconstructions completely span~~ned~~ the 2000 years ~~or more~~of interest.

In order to reconstruct the historical streamflow in the upstream area of HRB (R_{in}) ~~in~~ over the past 2000 years, we firstly analyzed the consistency of the historical streamflow reconstructions ~~by~~ of Yang et al. (2012), Kang et al. (2002) and Qin et al. (2010), and selected the two ~~more~~ most reasonable ~~two~~ reconstructions based on the humidity changes ~~of climate~~ in this region as reflected by other proxy indices, e.g. lake sediments and ice cores~~;~~. ~~then among the two selected streamflow reconstructions, the~~ The shorter one was used to extend the historical series and the longer one was used to validate the extension where these two reconstructions did not overlap~~in the gap period between the shorter and the longer~~. We then extended the selected reconstructed streamflow up to 2000 years by using the reconstructed precipitation ~~based on the~~and a ~~established~~ relationship established between the selected streamflow reconstruction and the existing precipitation reconstruction~~s~~ in the upstream area. ~~As a~~All the streamflow reconstructions focused on the mountainous region of the mainstream of the Heihe River (Figure 1~~),~~). Therefore, in order to obtain the streamflow flowing into the midstream area (R_{in}), we multiplied the streamflow at YLX by ~~a proportion~~the ratio of the total streamflow ~~of~~ from the upstream area of the HRB to the ~~one~~ streamflow at YLX, based on the instrumental data in the recent 50 year period. ~~In addition to the meteorological data mentioned in 2.3.1, t~~The instrumental streamflow in the recent period was obtained from the Hydrographic Service of Gansu ~~province~~Province.

2.3.3 Estimating *E* based on ~~the~~ reconstructed~~ion of~~ land use

E in Eq. (1) was calculated ~~by~~ using the top-down method of the Budyko hypothesis. We used the equations developed by Fu (1981) (For details, see Fu, 1981 and Zhang et al., 2004) which are ~~expressed as~~:

$$\frac{E}{P} = 1 + \frac{E_0}{P} - [1 + (\frac{E_0}{P})^w]^{1/w} \quad (2)$$

$$\frac{E}{E_0} = 1 + \frac{P}{E_0} - [1 + (\frac{P}{E_0})^w]^{1/w} \quad (3)$$

~~Where~~ where E_0 is potential evapotranspiration. E_0 ~~on a daily timescale~~ was estimated on a daily timescale using the Penman-Monteith ~~equation~~Equation for 1966 to 1995~~,~~. The Penman-Monteith Equation~~which was~~ has been acknowledged as the best method for this region (Zhao and Ji, 2010). It is known that many factors influence E_0 and it is difficult to clearly determine the changes of E_0 in historical periods without instrumented data. However, it is recognized that air temperature is one of most important~~key~~ factors ~~that influences~~ influencing E_0~~the *PET*~~. As ~~the oscillating~~ range of the temperature change over the study period was not more than 2 ℃ in ~~the past 2000 years~~this region (Zheng et al., 2010), and as Zhang et al. (2014) found that the E_0 increased by only 1.16 mm per month for a temperature increase of 2 ℃ in the Gulang River Basin (next to the Heihe River basin), it was assumed that ~~the~~ E_0 in the HRB was constant over the study period and the same as ~~the historical period was considered the same as in modern~~ instrumented times. The term *w* is a catchment scale model parameter determining the evaporation~~*E*)~~ ratio (*E*/*P*) for a given E_0/P. Theoretically, *w* should vary between land use types and could change with time depending on the type and intensity of crops. Unfortunately, due to the lack of historical documents or data for the natural oases (forest and grassland) in this region, it is impossible to characterize *w* for the natural oases in historical periods. In addition, in equations (2) and (3), when *w* is larger than 3, the impact of changes in *w* on *E* is small, especially in arid regions where E_0/P is large. In such situations, the available water for evapotranspiration becomes the determining factor (Zhang et al., 2001; Zhang et al., 2004). Therefore, ~~It is a catchment parameter and~~ the value of *w* for HRB was set ~~at~~ to 3.5 ~~according to~~following Yang et al (2007). The sources of water supply for *E* include precipitation, groundwater, and irrigation water~~ in this region~~, so *P* in equations (2) and (3) can be replaced as follows:

For cultivated oases: $P_{crop,i} = P_i + J$

For natural oases: $P_{veg,i} = P_i + G_{veg}$

~~Where~~ where $P_{crop,i}$ and $P_{veg,i}$ are the precipitation equivalent in ~~the~~ period *i* for crop and natural oases respectively; P_i is the actual precipitation in period *i*; *J*~~*I*~~ is irrigation; and G_{veg} is the water consumed from~~consumed~~ groundwater by the natural oases. In this arid region, there is no agriculture without irrigation. According to Xiao and Xiao (2008) flood irrigation has been~~was~~ the main irrigation method in northern China ~~from~~ since the Han dynasty~~ to the early modern period,~~. The main crop varieties, water conservancy facilities, irrigation methods and farming conditions have remained almost unchanged from the Han dynasty to the early modern period according to Wang's (2003) research on the development history of farm irrigation in the Heihe River basin which, to our understanding, is the most comprehensive study on historical agricultural irrigation in this region. The wheat was the major crop and single wheat was the main cropping pattern in this region, therefore the annual irrigation volume~~and the value of *I* in historical period~~ was set at 500 mm for the historical periods. Since the 1980s, annual irrigation applications in this region have increased from 500 to 650 mm as the cropping pattern has evolved from single wheat to double cropping with wheat and maize (Wang et al., 2005; Shi et al., 2011).

Irrigation water was obtained by surface water withdrawal from upstream reaches in historical periods; however, it has been both pumped from groundwater and diverted from surface water since 1949 as the surface water resource was insufficient for rapid development of agriculture. The development of pumping and drilling technology during this period also facilitated this change. G_{veg} was set at 225 mm per year for natural oases ~~according to~~based on Wang et al. (2005). For unused land, where the groundwater level was deep, the only water supply was precipitation.

~~So t~~The total *ET* of the basin is given by:

$$E_{total} = \sum_{l=1}^{3} E_l \times S_l \quad (4)$$

~~Where~~ where E_{total} is the total evapotranspiration of the basin; *l* is the number of the land use types: cultivated oases, natural oases, and unused land. E_l is the evapotranspiration from land use type *l*, and S_l is the area of land use type *l*.

The maps of cultivated oases in historical periods were downloaded from the Heihe Plan Science Data Center: www.heihedata.org/heihe (Xie, 2013). As ~~a~~ the historical reconstructions of the natural oases in this region ~~was~~ were not available~~found~~ in the literature, we ~~used the land use scenario in 1975 as the final land use pattern in order to reconstruct the distribution of natural oases because it is known that the expansion of the farmland was at the expense of the desert after 1975. We made~~ reconstructed them based on the following two assumptions about the reclamation of cultivated oases based on ~~the~~ previous results (Li, 1998; Wu, 2000; Xie et al. 2009): (1) people selected the regions with natural oases (grassland and forest) rather than desert for reclamation in the historical periods because the former has better water and soil conditions in these arid regions, and (2) once the reclaimed farmlands were abandoned and without~~ the~~ vegetation cover, they were subsequently desertified because of wind-driven sand and burial by dunes~~dune coverage~~. The hundreds of ruins of towns along the Silk Road in the vast deserts of northwest China are clear evidence of this change of oases systems. ~~Therefore~~Then, it is known that the expansion of the farmland from the desert in this region started after 1975, we considered the total area of oases from the first period to the period of 1975 as the largest area of ~~the~~ oases in historical periods, which included cultivated ~~oases~~ and natural oases. In each period the area of cultivated oases had reconstructed data (Xie, 2013), then the area of natural oases was obtained by deducting the area of cultivated oases in the particular ~~this~~ period and the area of cultivated oases abandoned in the past periods, from the total oases area, and the remainder was considered unused land.

Based on the land use reconstructions, precipitation reconstructions and estimated E_0~~*PET*~~, the *E* in Eq. (1) was obtained ~~according to~~using Eqs. (2) and (3). The data sources used for calculation~~s~~ of *E* and reconstruction of land use included: land use data obtained for three periods by remote sensing (1975 Landsat MSS, 2000 and 2010 satellite TM and ETM+ data), the historical atlas of China (Tan, 1996), and meteorological data from the China Meteorological Administration~~ of Meteorology~~, including daily mean, maximum and minimum air temperatures, wind speed, and relative humidity.

2.3.4 Validating ~~the derived~~ R_{out} with ~~the~~ reconstructed evolution of the terminal lakes

The input volumes of water to terminal lakes R_{out} were derived from the reconstructed precipitation, *E* based on the reconstructed land use, and reconstructed streamflow R_{in} using Eq. (1). We validated the derived R_{out} with the lake evolution reconstructed by previous research on the lithology, geochemistry and mineralogy of lacustrine sediment depth profile sequences.

As sediment profiles of lakes in arid zones sensitively reflect changes in climate ~~changes~~ and human activities, they are regarded as excellent resources for palaeoclimate research (Jin et al., 2004). Lacustrine sediment sequences have been widely used for deducing the mass balance between the inflow water volume and evaporation from terminal lakes, climate change and human activity (Jin et al., 2004; Jin et al., 2005). For example, grain size distributions of lacustrine sediments directly reflect water dynamics, and soluble salt content reflects the chemical characteristics of lake water, which is affected by climate and inflow water (Jin et al., 2004).

Due to the unavailability of systematic and consistent studies on lake evolution in the HRB, we validated the derived R_{out} values based on the changes of input volumes of water to the terminal lakes in downstream areas as they reflect changes of the hydrologic cycle involving precipitation, land use, evaporation and runoff in the upper and middle reaches. R_{out} directly influences the processes of expansion and shrinkage of surface area, sediment deposition and salinization of the terminal lakes. When the input volume of water to the terminal lakes is relatively abundant, lake area extends, lake water level rise, lake water has smaller salt concentrations, and the sediment deposition environment is relatively stable, and *vice versa*.

The data and information sources used for reconstruction of the evolution of the terminal lakes include all ~~collected research achievements~~ studies on the palaeoenviromental evolution in the downstream area of the HRB from Lakes Sogo Nur, Gaxun Nur and Juyanze. The evolution of the terminal lakes in the Heihe River experienced three periods: Juyanze from Warring States Period to Yuan dynasty, Juyanze-Gaxun Nur from Yuan dynasty to Ming dynasty and Gaxun Nur-Sogo Nur from Ming dynasty to 1961 AD (Chen, 1996). The data include granularity, soluble salt, sedimentary pigment, organic carbon content, and groundwater level (Jin et al., 2004; Jin et al., 2005; Qu et al., 2000; Zhang et al., 1998).

2.4 Determining the development stages of evolutionary processes of human-water relationships

River basins are co-evolvinG~~ed~~ social-ecological systems in which water management decisions affect environmental outcomes that are subject to societal~~sociological~~ conditions. We interpreted and determined the key states of the evolutionary processes of the human-water relationships in the HRB based on the transition theory of social science. Transition theory is one of the most relevant approaches to understand the evolution of societal systems~~evolution~~ and support the management of sustainable development~~societal adaptation to sustainability~~ (Tàbara and Ilhan, 2008). In general terms a transition can be understood as the process of change of a system from one stage of a dynamic state ~~equilibrium~~ to another. According to Rotmans (2005) a set of typological phases can be identified in a transition: (1) predevelopment, (2) take-off, (3) acceleration, and (4) stabilisation. In the predevelopment stage, a change occurs marginally or imperceptibly, while after take-off a rapid process of societal change occurs until another state is reached, in which the speed of change decreases again (Tàbara and Ilhan, 2008). Transitions can fail at any stage.

A transition can be measured and assessed by indicators ~~which~~ that could be variables with actual physical meanings, or their surrogates. In this study we used human water consumption and natural ~~oases~~ oasis area as ~~the~~ indicators to understand the evolutionary processes of the human-water relationships in the HRB over the past 2000 years. Human water consumption, the difference between evapotranspiration and precipitation in cultivated land areas, reflects the consequence of human societal development on water cycles. The area of natural oases ~~area~~ reflects water supporting the environment. We used direction and rate of change (*k*)~~the change trend and rate~~ of these two indicators over time to divide the human-water relationship into different development stages. Both the natural oases area and human water consumption were obtained using the methods above.

3 Results

3.1 Reconstructed precipitation (*P*) in mid- and down- stream reaches

The ~~proportions~~ ratios of ~~the~~ precipitation for seven selected historical periods to the current period for~~of~~ the whole HRB, ~~derived using drought and flood sequence information and data, to that in the most recent period in the seven selected historical dynastic periods over the past 2000 years,~~ were 0.7, 0.95, 1, 0.9, 1, 0.98 and 0.96, respectively. The precipitation in mid- and down- stream areas ~~in the~~for each historical period~~s~~ was then obtained by multiplying the mean instrument-measured precipitation from data 1966 to 1995 at ten meteorological stations by these proportions ~~is shown in~~ (Fig. 2). The precipitation in historical periods decreased from the midstream to downstream reaches, and it was least in the Han Dynasty, and was similar to the present level in the Tang and Ming Dynasties.

Figure 2. The reconstructed precipitation in historical periods in mid- and down- stream areas of the HRB.

3.2 Reconstructed streamflow flowing into midstream reaches (R_{in})

The streamflow reconstruction of Qin et al. (2010) was used to extend the measured streamflow reconstruction, and the streamflow reconstruction of Yang et al. (2012) was used to validate it. It was found that the streamflow record reconstructions obtained by Yang et al. (2012), Qin et al. (2010), and Kang et al. (2002) for the period AD 1000-2000 are generally consistent~~,~~; however, discrepancies occurred around the years of 1290, 1530, 1690, 1840 and 1910. The streamflow reconstructions by Yang et al. (2012) and Qin et al. (2010) were more consistent with the changes in regional humidity suggested by paleoclimate results for this region. The paleoclimatic series were derived from ~~Based on the results from the paleoclimate established in this region with~~ tree rings from living trees or archaeological woods in the Qilian Mountains and the Tibetan Plateau (Yang et al., 2014; Sheppard et al., 2004; Shao et al., 2010), ~~lake~~ sediments in Qinghai Lake (Shen et al., 2001) and ice cores in Dunde (Liu et al., 1998)~~, the~~. Therefore these two reconstructions ~~by Yang et al. (2012) and Qin et al. (2010) were more consistent with the changes of regional humidity and~~ were considered to be the more reasonable.

It is known that the annual streamflow at YLX and mean precipitation in the Qilian Mountains region changed consistently over ~~in~~ the past 50 years (Xiao and Xiao, 2008). It was found that precipitation reconstructions of Yang et al. (2014) (Fig. 3a) and streamflow reconstructions of Qin et al. (2010) (Fig. 3b) changed consistently in the last 1000 years. We derived ~~the~~ a linear relationship between them as follows: $R_{\text{Qin et al. (2010)}} = 0.2771 * P_{\text{Yang et al. (2014)}} + 80.632$. We used this relationship to extend the streamflow reconstruction ~~from~~ back to the period 0 to 1000 AD at YLX (Fig. 3c). The extended streamflow reconstruction is consistent with the streamflow reconstruction of Yang et al. (2012) for the period from 575 AD to 1000 AD. Over the whole study period,~~From historical periods to now~~ the reconstructed streamflows into midstream areas (R_{in}) ~~were~~ varied between about 2.6 and 4.0 billion m^3 per year. ~~It~~ Streamflow peaked in recent years due to abundant precipitation together with glacier and snow melt in the upstream areas due to rises in temperature.

Figure 3. (a) Yang et al.'s (2014) annual precipitation reconstruction for the Qilian Mountains over the last 2000 years, with 50-y smoothing~~ in Qilian Mountains region over the last 2000 years~~. **(b)** Qin et al.'s (2010) annual streamflow reconstruction spanning the last millennium with 50-y smoothing at YLX. **(c)** ~~The~~ Our extension of the streamflow from 0 to 1000 AD ~~by comparing and analyzing~~based on the Yang et al. (2014) precipitation reconstruction and the Qin et al. (2010) streamflow reconstruction.

3.3 Reconstructed historical land use and land cover

The reconstructions of land use ~~in~~ for the seven historical periods and three land use maps for 1975, 2000 and 2010 ~~in modern New China (since 1949)~~ obtained by image interpretation are shown in Fig. 4. The areas of cultivated oases~~ areas~~ changed significantly ~~in~~ over historical periods. It ~~had a~~was large ~~size~~ in the Han Dynasty, and then gradually decreased in area until the Yuan Dynasty. From the Ming Dynasty it increased gradually, and finally reached a peak in the period of ~~New~~ modern China. The cultivated areas were mainly distributed in the downstream area of the basin in the first period, and then moved ~~toward the~~ upstream~~ area~~, ~~and~~ finally ending up focused on the middle reaches. This might suggests ~~could reflect~~ that land reclamation was directly affected by the available water resources.

Figure 4. Land use reconstructions in historical periods and land use through image interpretation in recent periods in mid- and down- stream areas of HRB. (It should be noted

that the grassland, forest and water or wet land were combined ~~into~~ with the natural oases, and the farmland and built-up land were combined ~~into~~ with cultivated oases in the land use in 1975, 2000 and 2010.)

3.4 Validation of derived R_{out} with the reconstructed evolution of the terminal lakes

The average annual volume of water that entered the terminal lakes (R_{out}) in the historical periods is shown in Table 2. The estimates~~data~~ were obtained using~~from~~ Eq. (1) together with~~based on~~ the reconstructed precipitation, streamflow and E related to land use. The reconstruction of the evolution of the lake, ~~evolution reconstruction~~ based on lithological, geochemical and mineralogical data from the lacustrine sediment profile sequences in terminal lakes, together with some interpretation, is also described in Table 2.

There are relatively good relationships between the input volumes of water to the terminal lakes (R_{out}) and the evolution of the terminal lakes in historical periods. The input of water to terminal lakes was not only determined by the streamflow from upstream, but also affected by land use in the mid- and down- stream areas of the basin. When the streamflow from the upstream area was high and the cultivation activity in the middle stream was not intense, the input of water to terminal lakes was high, such as ~~in~~ during the Tang and Ming Dynasties, and *vice versa*. This was reflected by the pigmentation and organic carbon content of the sediments of the terminal lakes (Qu et al., 2000; Zhang et al., 1998). After the turn of ~~this~~ the 21st century R_{out} became negative which meant that there was a deficit in groundwater recharge because of over-extraction of water for irrigation to meet the need of food (Wei, 2013).

Table 2. The input volumes of water to the terminal lakes (R_{out}) and evolution of the terminal lakes in historical periods.

Periods	R_{out} /$10^8 m^3$/year	Evolution of terminal lakes
Han Dynasty	7.5	The lake was shrinking (Qu et al., 2000), and fine magnetic minerals peaked in the sediment profile (Qu et al., 2000; Zhang et al., 1998). This might be affected by low R_{out} and intense reclamation in the downstream areas around the terminal lake.
Wei-Jin Era	9.2	The lake was still shrinking (Qu et al., 2000), and the primary productivity of the lake was low, such as Oscillatoria flavin~~, Myx~~ and ~~CD~~ chlorophyll derivative (Qu et al., 2000; Zhang et al., 1998). This may be because of low R_{out} and weakening reclamation due to war and other factors.
Tang Dynasty	18.1	There were stable water dynamics, a large lake area and deep water reflected by the sediments with higher contents of silt and clay, and relatively low ~~contents of~~ coarse grain~~s~~ content (Jin et al., 2005; Jin et al., 2004). This was consistent with~~indicated~~ a large R_{out} during this period.
Yuan Dynasty	14.9	Same as the Tang dynasty.
Ming	18.9	The salinity of lake water decreased and the lake ~~extended~~ expanded further (Zhang et al., 1998). This was consistent

Dynasty		with ~~indicated by~~ a large R_{out}.
Qing Dynasty	11.8	Same as the Ming dynasty.
~~New~~ Modern China in 1949	15.4	The lakes ~~kept~~ maintained a relatively large area (Zhang et al., 1998; Xiao et al., 2004). This was consistent with~~indicated by~~ a large R_{out}.
1975	2.0	Terminal lake Gaxun nur dried up~~,~~ and Sogo nur ~~came and went~~became ephemeral (Xiao et al., 2004). This ~~is~~ was because of intense exploitation of water for agriculture~~reclamation~~ in the midstream area, which led to ~~and the~~ streamflow decreased and was unstable.
2000	-2.8	The lakes dried out, and the groundwater ~~depth~~ levels decreased (Xiao et al., 2004). This ~~is~~ was because of intense usage of water for agriculture~~reclamation~~ in the midstream area and overexploitation of the groundwater in the basin.
2010	-0.5	Lake restoration started.

3.5 Reconstructed catchment water balance in the past 2000 years

We reconstructed the catchment water cycles ~~at~~ in the HRB ~~in~~ for the past 2000 years from the precipitation reconstruction (P) in mid- and down- stream areas, the streamflow reconstruction (R_{in}), land use reconstruction, evapotranspiration reconstruction (E) and the derived streamflow reconstruction into terminal lakes (R_{out}). Comparison of~~Through validation with~~ the reconstructed lake condition using the sediment record and R_{out} (Table 2)~~evolution reconstruction~~, shows that the reconstructed water cycles reasonably reflects variations in~~reflected~~ the ~~reality of~~ water balance partitioning ~~at~~ in the HRB ~~in~~ over the past 2000 years.

Fig. 5 shows the evolution of the catchment water balance ~~elements~~ in the HRB in the past 2000 years. Human water consumption changed clearly, especially after the founding of modern China in 1949, when streamflows from upstream areas were approximately unchanged. The main cause of the water balance changes~~factor for this~~ was rapid expansion of the cultivated areas around oases, reflecting the increasing population, which was ~~a~~ the primary driver ~~for this~~. The cultivated ~~oases~~ oasis areas shrank from the Han to the Yuan Dynasty ~~but thereafter~~and have expanded until now, the natural ~~oases~~ oasis areas were continually ~~shrinking~~ shrank until 2000, and the areas of desertified land have increased as cultivated land was abandoned due to war, disasters or other causes. The volumes of ~~streamflow~~ water flowing into terminal lakes remained about 1 billion m^3 per year, even more in historical periods, but it decreased sharply after 1975, and even became negative. The negative values (which would be zero in reality) probably indicate that ~~which meant~~ the groundwater was being overexploited so that there was a negative mass balance, which is consistent with falling water tables in recent times. After a water reallocation scheme was implemented in 2000, the ecological and environment deterioration was halted and the lakes were restored. At the same time, the cultivated ~~oases~~ oasis areas, population and human water consumption increased. This was at the expense of groundwater in midstream areas combined with~~and~~ the benefits of a wet period of about ten years.

Figure 5. Changes in elements of the~~of~~ reconstructed catchment water balance ~~elements~~ ~~in~~over the past 2000 years in the mid- and downstream area.

3.6 Determination of the development stages of evolutionary processes of human-water relationships

~~The h~~Human water consumption and natural ~~oases~~ oasis areas changed ~~with~~ at different rates (*k*) in different periods (Fig. 5). Based on their ~~change~~ rates of change with time we divided the evolutionary processes of the human-water relationships in the HRB ~~in~~ over the past 2000 years into four phases (Fig. 6): (1) predevelopment (206 BC - 1368 AD), (2) take-off (1368 - 1949 AD), (3) acceleration (1949 - 2000 AD), and (4) the start of rebalancing~~Starting to rebalance~~ between the human and water relationships (after 2000 AD).

Figure 6. The development stages of evolutionary processes of human-water relationships**.**

The predevelopment phase started after the Han Dynasty. In the Han Dynasty an unprecedented expansion of manmade cultivated areas based on oases occurred associated with~~. This happened because of~~ defence needs, immigration and settling of farms, which changed the production mode from nomadic herding into settled farming (Cheng et al., 2011). It also corresponded with the warm and humid climate in the early Western Han Dynasty (Ren et al., 2010; Xie et al., 2009). However, in the late eastern Han Dynasty, agricultural production levels declined due to population loss and damage to water conservation~~conservancy~~ facilities after long-term warfare. ~~During~~ From the Southern and Northern Dynasties (420-581) to the Yuan Dynasty (1271-1368), the people led nomadic lifestyles and the Hexi corridor was in ~~the~~ a state of frequent wars and dynastic changes~~,~~. ~~and the~~The HRB landuse was primarily pastoral~~ land~~ as most agricultural oases were abandoned (Li, 1998; Xie et al., 2013). In this predevelopment stage of about 1500 years, the population ~~did~~ was stable~~not increase~~, and cultivated area~~reclamation~~ was small and focused on downstream areas. As a result,~~, so~~ humans had ~~little~~ few impacts on the water system and the area of natural oases area did not change significantly.

Since the Ming Dynasty, ~~in which~~when agricultural civilization revived, the evolution~~ary processes~~ of the human-water relationships in the HRB entered the take-off stage. During this phase ~~oases~~ oasis reclamation activities were promoted and moved upstream to the midstream area (Wu, 2000). In the middle of the Qing Dynasty, the Hexi corridor was politically stable and free of wars and the basic requirements for agricultural development were provided by the government, including~~innovative farming and engineering methods were introduced, such as better~~ seeds, ~~new crops~~cattle, and the steel farming implements. This led to expansion of the cultivated land and agricultural development. Therefore the population increased quickly (Shi, 2010). At the same time irrigation technology hardly changed, and with the area of cultivated land expanding, water resource utilization became increasingly intense (Wang, 2003). It was also during this period that ~~water~~ disputes about water arose (Cheng et al., 2011; Shen and He, 2004). This phase was relatively short, lasting about 580 years. During this phase, human water consumption increased at a rate of 1.09 million m^3 per year on average, and the area of natural oases~~ area~~ decreased at an average rate of 1.38 km^2 per year. ~~The h~~Human intervention ~~of~~ in the water system was gradually increasing.

After ~~New~~ modern China was founded in 1949, ~~the social~~societal development in the HRB ~~stepped~~ moved into the acceleration stage. During this stage the population, the area of cultivated land and human water consumption increased sharply, especially after the ~~world-wide~~ green revolution ~~in~~ of the 1960s, and China's reform and opening-up in 1978. In addition, food self-sufficiency ~~has~~ dominated Chinese agricultural and water resources development policy. Many wells, reservoirs and channels were built during this stage. This stage was the shortest, only 50 years long, but the human water consumption increased at an alarming rate of 35.1 million m^3 per year, and the area of natural oases area decreased at an average rate of 58 km^2 per year. The influence of human activities on water resources reached its peak and the environment was seriously degraded as natural wetlands, rivers, and lakes dwindled rapidly (Xiao et al., 2004).

In order to prevent continuing environmental degradation a series of actions and measures were ~~carried out~~implemented, such as the Natural Forest Protection Project after 2001, and another large project ~~of~~ that turning ~~the~~ cultivated land into forests or grasslands from 2002 to 2004~~, and~~. In addition, Zhangye city, in the midstream area, was selected as the first ~~construction~~ experimental construction site by the Water Saving and Conservation Society (WSCS) of China in 2002. This was supported by a water reallocation scheme in 2000 ~~by~~ in which the midstream area should discharge 950 million m^3 ~~of water in normal years~~ (as measured at the ZYX station) to downstream areas in normal years (when the upstream YLX discharges 1,580 million m^3 of water). The Central Government's No.1 Water Document in 2011, which limits total water diversion, promotes water use efficiency and reduces water pollution, reinforces the changes~~signaled a big step~~ in the relationship between humans and water emerging since the early 2000s. All of these actions have resulted in some improvements to downstream ecosystems, including~~such as~~ halting the ecological and environment deterioration and restoring the lakes. The area of natural oases ~~area~~ increased at an average rate of 28 km^2 per year from 2000 to 2010. A new state~~equilibrium stage~~ between the humans and water emerged ~~since~~ after 2000.

4 Discussions and conclusions

This paper represents an attempt to reveal the evolutionary processes of the human-water relationships in the HRB over the past 2000 years. We quantitatively analyzed the dynamics of coupled human and hydrological systems as well as the associated climatic and ecological changes in the past ~~more than~~ 2000 years within the HRB by reconstructing the catchment water balance. Based on transition theory we divided the evolution~~evolutionary processes~~ of the human-water relationship~~s~~ into four stages, which are ~~including~~ predevelopment (206 BC - 1368 AD), take-off (1368 - 1949 AD), acceleration (1949 - 2000 AD), and rebalancing (after 2000 AD).

This study ~~for the first time provided~~ provides new understandings of how societal drivers and societal responses over time interact and feedback with catchment water cycles over a timescale of 2000 years. The pace of~~This~~ the evolutionary process ~~was not at a uniform pace~~varied. The predevelopment stage lasted for~~experienced~~ 1500 years, and the take-off period~~take-off~~ was shorter at only 580 years~~, –~~. ~~and a~~After that, in a period of only 50 years,~~only 60 years'~~ the acceleration period occurred when the population increased ~~up~~ from 0.5 to 1.9 million~~, –~~ and the area of cultivated oases ~~areas~~ expanded by 3649 km^2, which was about ~~two times~~double that ~~in~~ at the beginning of the acceleration~~this~~ stage~~, and h~~. Human water consumption increased by 1.9 billion m^3 per year, resulting in a doubling of water use over~~, which was more than two times of that in the beginning of this~~ the stage. This resulted in volumes of water from midstream areas ~~being discharged~~flowing into terminal lakes decreasing from more than 1 billion m^3/year to 0. This ~~situation~~ became the trigger for a sustainability transition in the HRB in 2000 when a water reallocation scheme was implemented~~, –~~. ~~which~~ This meant that the evolutionary processes of human-water relationships in the basin entered~~started~~ a new stage: rebalancing. This understanding of the dynamics of transitions will assist policy makers to identify management practices that require improvement by understanding how today's conditions and problems were created in the past. It could also help integrate management of land and water use to allow for more sustainable catchment management to combat~~against~~ desertification in this region.

~~This paper, through reconstruction, incorporated metrics of human water interaction into fundamental understanding of complex human water systems. The quantitative historical analysis not only improved our understanding of past human-water relationships but also facilitated improved predictions of its possible future dynamics. It has added a valuable case study for comparative socio-hydrologic studies across different human-water systems around the world. This paper has suggested some guidelines toward an analytical approach to water related societal transitions that should be, on one hand, strongly attached to social science theory, and on the other hand, firmly based on formal hydrological modeling. It can be seen from the four stages of evolutionary processes of human-water relationships in the HRB that transitions have no fixed pattern. The stabilization, a typological phase in the standard transition theory, did not appear. In addition, there were large differences in the rates and scales of changes and the period of time over which they occurred. This happened because during a process of change, humans are able to adapt to, learn from and anticipate new situations (Chen, 2005).~~

An important part of the paper was reconstructing the~~This paper reconstructed~~ catchment water balance. This relied on~~by using~~ a range of data sources, including paleo-climates and paleo-environments reflected by dendrochronology, ice cores, lake sediments and historical drought and flood sequences, a historical atlas of China, remote sensing images and instrumented streamflow and climate data. The resulting reconstructed water balance was consistent with the dynamics of the terminal lakes~~, which explained the evolutionary process of human-water relationship~~ in the HRB ~~in~~ over the past 2000 years~~with relatively good agreement~~. The reconstruction provided ~~the~~ a basis for generating baseline data against which to evaluate recent changes, for investigating the impact of human societies on hydrological systems in historical contexts and for generating datasets for improving models of hydrological systems over timescales that exceed the length of the instrumented record (Savenije et al., 2013).

There are some important limitations on the methods and with the data collection and analysis. Several assumptions and uncertainties in the 2000 year hydrological reconstruction exist due to lack of data. Values for E_0 in the historical periods were assumed to be the same as in recent periods, which is reasonable given the variation in average temperature was less than 2 ℃. Values for *w* may vary among different land use types and could change with time depending on the type and intensity of crops in historical periods, however due to the lack of data, the value of *w* for HRB was set at 3.5. For the same reason, irrigation was set at 500 mm per year for the whole historical period. There was also some inconsistency~~However, there were some discrepancies among the reconstruction methods. They might come from: 1) Inconsistency~~ between the data extracted from the different proxy materials, for example, the streamflow reconstructions by Yang et al. (2012), Qin et al. (2010), and Kang et al. (2002) using tree rings were not completely consistent. There were~~; 2)~~ limitations ~~of~~ due to the available data's representativeness of locations, for example the data from tree rings only focused in the upstream area of the mainstream areas of the Heihe River, and the samples of lake sediment mainly focused ~~in~~ on the terminal lake Sogo Nur. Problems of ~~; and 3) non-~~representativeness of data in various time periods and varying~~different~~ resolutions of data also occurred. For~~, for~~ example, the land use maps only covered several periods, the tree ring dating can be specific to the annual scale, and the information from ice cores and lake sediment profiles was at the century scale. ~~In future, we should improve the consistency, length and quality of historical datasets by advancing data analysis techniques.~~

The transitions seen from the four stages of evolutionary processes of human-water relationships in the HRB did not follow the standard theoretical processes. Stabilization, a typological phase in the standard transition process, did not appear. In addition, there were large differences in the rates and scales of changes and the period of time over which they occurred. Some further theoretical research is needed to explain the transition pattern, but this result evidences that transitions have no fixed pattern. This paper provides a path toward an analytical approach to water related societal transitions that should be, on one hand, strongly attached to social science theory, and on the other hand, firmly based on formal hydrological modeling.

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References

Budyko, M.I.: Climate and Life. Academic, San Diego, CA, pp. 508, 1974.

Carpenter, S. R., Cole, J. J., Pace, M. L., Batt, R., Brock, W. A., Cline, T., Coloso, J., Hodgson, J. R., Kitchell, J. F., Seekell, D. A., Smith, L., and Weidel, B.: Early warnings of regime shifts: a whole-ecosystem experiment, Science, 332, 1079–1083, 2011.

Chen, L.: Land desertification and its control strategies in the low reaches of the Heihe River, J. Nat. Resour., 1, 35–43, 1996.

Cheng, H., Huang, Y., and Zhao, L.: The human activity in Hexi Corridor during historical time, 10 available at: http://www.paper.edu.cn (last access: 5 April 2014), 2011.

Elshafei, Y., Sivapalan, M., Tonts, M., and Hipsey, M.: A prototype framework for models of socio-hydrology: identification of key feedback loops and parameterisation approach, Hydrol. Earth Syst. Sci., 18, 2141-2166, 2014.

Falkenmark, M. and Lannerstad, M.: Consumptive water use to feed humanity – curing a blind spot, Hydrol. Earth Syst. Sci., 9, 15–28, doi:10.5194/hess-9-15-2005, 2005.

Fu, B.: On the calculation of the evaporation from land surface, Sci. Atmos. Sin., 5, 23–31, 1981.

Geels, F. W.: Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Policy, 31, 1257–1274, 2002.

Holmes, J. A., Cook, E. R., and Yang, B.: Climate change over the past 2000 years in Western China, Quatern. Int., 194, 91–107, 2009.

Jin, H., Xiao, H., Sun, L., Zhang, H., Sun, Z., and Li, X.: Vicissitude of Sogo Nur and environmental-climatic change during last 1500 years, Sci. China Ser. D, 47, 61–70, 2004.

Jin, H., Xiao, H., Zhang, H., and Sun, Z.: Evolution and climate changes of the Juyan Lake revealed from grain size and geochemistry element since 1500aBP, J. Glaciol. Geocryol., 27, 233–240, 2005.

Kallis, G.: Coevolution in water resource development the vicious cycle of water supply and demand in Athens, Greece, Ecol. Econ., 69, 796–809, 2011.

Kang, X., Cheng, G., Kang, E., and Zhang, Q.: Mountainous runo_ reconstruction of Heihe River during past 1000 years using tree-ring, Sci. China Ser. D, 32, 49–53, 2002.

Li, B.: An investigation and study on the desertification of the ancient oases from Han to Tang dynasties in the Hexi corridor, Acta Geogr. Sin., 53, 106–115, 1998.

Liu, K., Yao, Z., and Thompson, L. G.: A pollen record of Holocene climatic changes from the Dunde ice cap, Qinghai-Tibetan Plateau, Geology, 26, 135–138, 1998.

Liu, Y., Tian, F., Hu, H., and Sivapalan, M.: Socio-hydrologic perspectives of the co-evolution of humans and water in the Tarim River basin, Western China: the Taiji–Tire model, Hydrol. Earth Syst. Sci., 18, 1289–1303, doi:10.5194/hess-18-1289-2014, 2014.

Lowry, D. P. and Morrill, C.: Changes in the Global Hydrological Cycle: Lessons from Modeling Lake Levels at the Last Glacial Maximum, American Geophysical Union, Fall Meeting, San Francisco, California, USA, 2011.

Montanari, A., Young, G., Savenije, H., Hughes, D., Wagener, T., Ren, L., Koutsoyiannis, D., Cudennec, C., Toth, E., and Grimaldi, S.: “Panta Rhei – Everything Flows”: change in hydrology and society – the IAHS Scientific Decade 2013–2022, Hydrolog. Sci. J., 58, 1256–1275, 2013.

Pataki, E., Carreiro, M., Cherrier, J., Grulke, E., Jennings, V., Pincetl, S., Pouyat, V., Whitlow, H., and Zipperer, C.: Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions, Front. Ecol. Environ., 1, 27–36, doi:10.1890/090220, 2011.

Qin, C., Yang, B., Burchardt, I., Hu, X., and Kang, X.: Intensified pluvial conditions during the twentieth century in the inland Heihe River Basin in arid northwestern China over the past millennium, Global Planet. Change, 72, 192–200, 2010.

Qu, W., Wu, R., Wang, S., and Zhang, Z.: Sedimentary pigment and its environmental signification of East Juanyanhai in Inner Mongolia since the past 2600 years, Acta Sendiment. Sin., 48, 13–17, 2000.

Ren, Z., Lu, Y., and Yang, D.: Drought and flood disasters and rebuilding of precipitation sequence in Heihe River basin in the past 2000 years, J. Arid Land Resour. Environ., 24, 91–95, 2010.

Röckstrom, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahanie, J., and Zhu, Q.: Managing water in rainfed agriculture – the need for a paradigm shift, Agr. Water Manage., 97, 543–550, 2010.

Rotmans, J.: Societal Innovation: Between Dream and Reality Lies Complexity, DRIFT Research Working Paper, Erasmus Research Institute of Management (ERIM), Rotterdam, the Netherlands, doi:10.2139/ssrn.878564, 2005.

Saito, K., Hirai, M., and Yonekura-Sakakibara, K.: Decoding genes with coexpression networks and metabolomics –“majority report by precogs”, Trends Plant Sci., 13, 36–43, 2008.

Savenije, H. H. G., Hoekstra, A. Y., and van der Zaag, P.: Evolving water science in the Anthropocene, Hydrol. Earth Syst. Sci., 18, 319–332, doi:10.5194/hess-18-319-2014, 2014.

Shao, X., Xu, Y., Yin, Z.-Y., Liang, E., Zhu, H., and Wang, S.: Climatic implications of a 3585-year tree-ring width chronology from the northeastern Qinghai-Tibetan Plateau, Quaternary Sci. Rev., 29, 2111–2122, 2010.

Shen, J., Zhang, E., and Xia, W.: Records from lake sediments of the Qinghai Lake to mirror climatic environmental changes of the past about 1000 years, Quaternary Sciences, 21, 508–513, 2001.

Shen, M. and He, L.: Comparison of new and old equal water regime in Heihe River basin, Yellow River, 26, 27–29, 2004.

Sheppard, P., Tarasov, P., Graumlich, L., Heussner, K.-U., Wagner, M., Österle, H., and Thompson, L.: Annual precipitation since 515 BC reconstructed from living and fossil juniper growth of northeastern Qinghai Province, China, Clim. Dynam., 23, 869–881, 2004.

Shi, J.: Integrating humanistic and scientific studies to reveal the changes of Khara Khoto, Studies in humanity and environment of Khara Khoto, in: Proceedings of international symposium on the humanity and environment of Khara Khoto region, Renmin University of China Press, Beijing, 1–4, 2007.

Shi, L.: Study on the spatio-temporal process of oasisization and desertification in the period of the Ming, Qing dynasty and Republic of China in the middle reaches, MD thesis, Lanzhou University, Lanzhou, 2010.

Shi, M., Wang, L., and Wang, X.: A study on changes and driving factors of agricultural water supply and demand in Zhangye after water reallocation of the Heihe River, Resources Science, 33, 1489-1497, 2011.

Sivapalan, M., Blöschl, G., Zhang, L., and Vertessy, R.: Downward approach to hydrological prediction, Hydrol. Process., 17, 2101–2111, 2003.

Sivapalan, M., Savenije, H. H., and Blöschl, G.: Socio-hydrology: a new science of people and water, Hydrol. Process., 26, 1270–1276, 2012.

Tàbara, J. D. and Ilhan, A.: Culture as trigger for sustainability transition in the water domain: the case of the Spanish water policy and the Ebro river basin, Reg. Environ. Change, 8, 59–71, 2008.

Tan, Q.: The Historical Atlas of China, China Cartographic Publishing House, Beijing, 1996.

Thompson, S. E., Sivapalan, M., Harman, C. J., Srinivasan, V., Hipsey, M. R., Reed, P., Montanari, A., and Blöschl, G.: Developing predictive insight into changing water systems: useinspired hydrologic science for the Anthropocene, Hydrol. Earth Syst. Sci., 17, 5013–5039, doi:10.5194/hess-17-5013-2013, 2013.

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann, C., and Davies, P. M.: Global threats to human water security and river biodiversity, Nature, 467, 555–563, 2010.

Wang, G., Yang, L., Chen, L., and Jumpei, K.: Impacts of land use changes on groundwater resources in the Heihe River basin, Acta Geogr. Sin., 60, 456–466, 2005.

Wang, G., Xie, Y., Wang, X., Yu, L., and Shi, Z.: Data reconstruction of Heihe River basin cultivated land area prior to the Ming dynasty, Resources Science, 35, 362–369, 2013.

Wang, Y.: The development history of water conservancy facilities in Heihe River basin, Gansu Nationalities Press, Lanzhou, 2003.

Wei, H.: Groundwater age and sustainability based on process simulation in Zhangye basin, PhD thesis, Cold and Arid Regions Environment and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, 2013.

Wimmer, A.: Models, methodologies, and metaphors on the move, in: Understanding Change

Models, Methodologies, and Metaphors, edited by: Wimmer, A. and Kössler, R., Palgrave MacMillan, London, England, 2006.

Woodhouse, A., Gray, T., and Meko, M.: Updated streamflow reconstructions for the Upper Colorado River Basin, Water Resour. Res., 40, W05415, doi:10.1029/2005WR004455, 2006.

Wu, X.: Historical variance of the ecological environment in the inland river area along the Hexi corridor, J. Lanzhou Univ. (Social Sciences), 28, 46–49, 2000.

Xiao, S. and Xiao, H.: Farming-grazing vicissitude and man–land relation evolution of Ejin Banner in historical period, J. Desert Res., 24, 449–451, 2004.

Xiao, S. and Xiao, H.: Advances in the study of the water regime process and driving mechanism in the Heihe River basin, Adv. Earth Sci., 23, 748–755, 2008.

Xiao, S., Xiao, H., Zhou, M., Si, J., and Zhang, X.: Water level change of the west Juyan Lake in the past 100 years recorded in the tree ring of the shrubs in the lake banks, J. Glaciol. Geocryol., 26, 557–562, 2004.

Xie, Y.: Dataset of cultivated oasis distribution in the Heihe River Basin during the historical period, Heihe Plan Science Data Center, Lanzhou, China, doi:10.3972/heihe.092.2013.db, 2013.

Xie, Y., Chen, F., and Qi, J.: Past desertification processes of Minqin Oasis in arid China, Int. J. Sust. Dev. World, 16, 260–269, 2009.

Xie, Y., Wang, X., Wang, G., and Yu, L.: Cultivated land distribution simulation based on grid in middle reaches of Heihe River basin in the historical periods, Adv. Earth Sci., 28, 71–78, 2013.

Yang, B., Qin, C., Shi, F., and Sonechkin, D. M.: Tree ring-based annual streamflow reconstruction for the Heihe River in arid northwestern China from AD 575 and its implications for water resource management, Holocene, 22, 773–784, 2012.

Yang, B., Qin, C., Wang, J., He, M., Melvin, T. M., Osborn, T. J., and Bri_a, K. R.: A 3,500-year tree-ring record of annual precipitation on the northeastern Tibetan Plateau, P. Natl. Acad. Sci. USA, 111, 2903–2908, 2014.

Yang, D., Sun, F., Liu, Z., Cong, Z., Ni, G., and Lei, Z.: Analyzing spatial and temporal variability of annual water-energy balance in nonhumid regions of China using the Budyko hypothesis, Water Resour. Res., 43, W04426, doi:10.1029/2006WR005224, 2007.

Zhang, L., Dawes, W., and Walker, G.: Response of mean annual evapotranspiration to vegetation changes at catchment scale, Water resources research, 37, 701-708, 2001.

Zhang, L., Hickel, K., Dawes, W., Chiew, F. H., Western, A., and Briggs, P.: A rational function approach for estimating mean annual evapotranspiration, Water Resour. Res., 40, W02502, doi:10.1029/2003WR002710, 2004.

Zhang, L., Pang, B., Xu, Z., and He, R.: Impacts of climate change and LULC on hydrological processes in the Gulang River basin, Sounth-to-North Water Transfers and Water Science & Technology, 12, 42-46, 2014.

Zhang, Z., Wu, R., Wang, S., Xia, W., Wu, Y., and Qu, W.: Environmental changes recorded by lake sediments from East Juyanhai Lake in Inner Mongolia during the last 2600 years, J.Lake Sci., 10, 44–51, 1998.

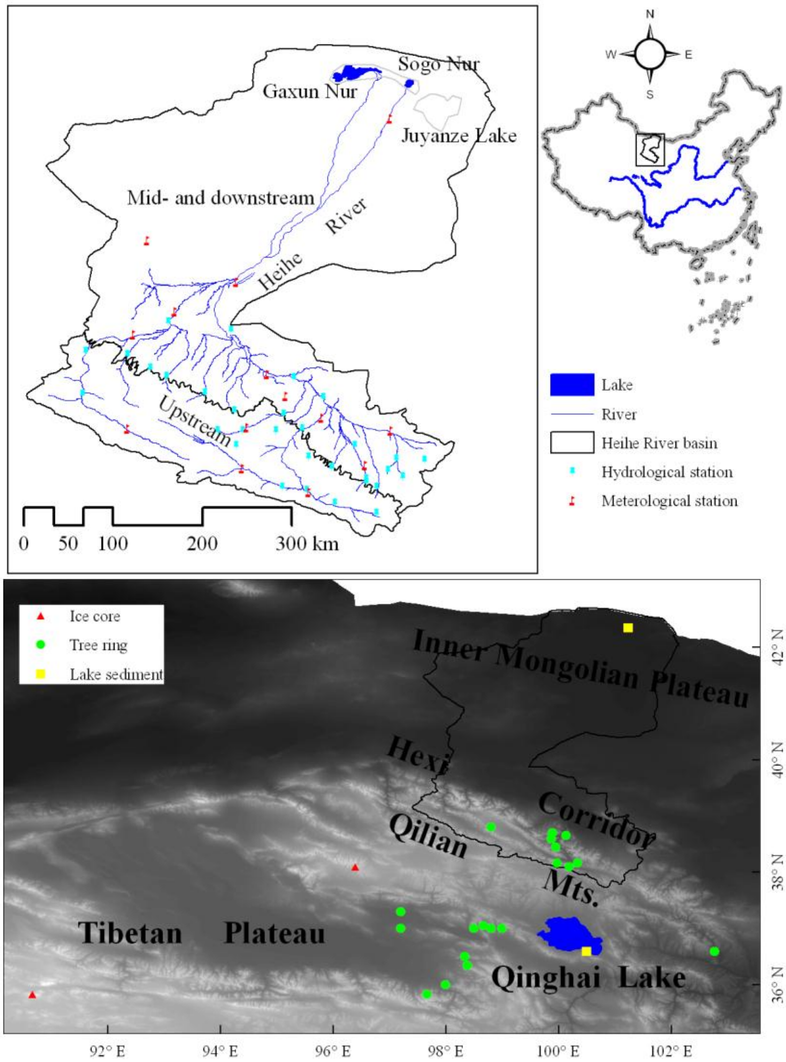
Zhao, J., Xu, Z., and Zuo, D.: Spatiotemporal variation of potential evapotranspiration in the Heihe River basin, Journal of Beijing Normal University (Natural Science), 49, 164-169, 2013.

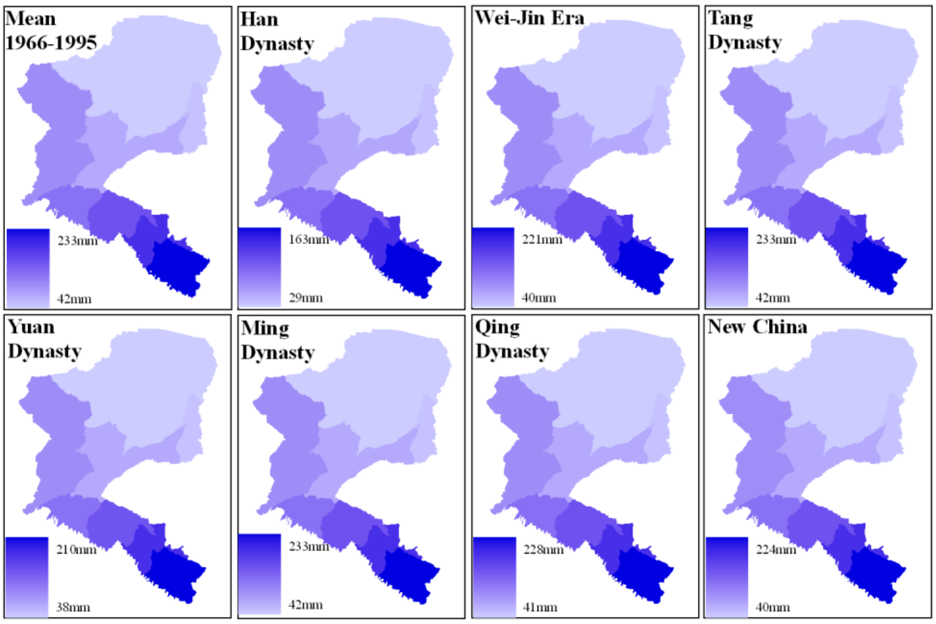
Zhao, L. and Ji, X.: Quantification of transpiration and evaporation over agricultural field using the FAO-56 Dual Crop Coe_cient Approach – A case study of the maize field in an oasis in the middlestream of the Heihe River Basin in northwest China, Scient. Agr. Sin., 43, 4016–4026, 2010.

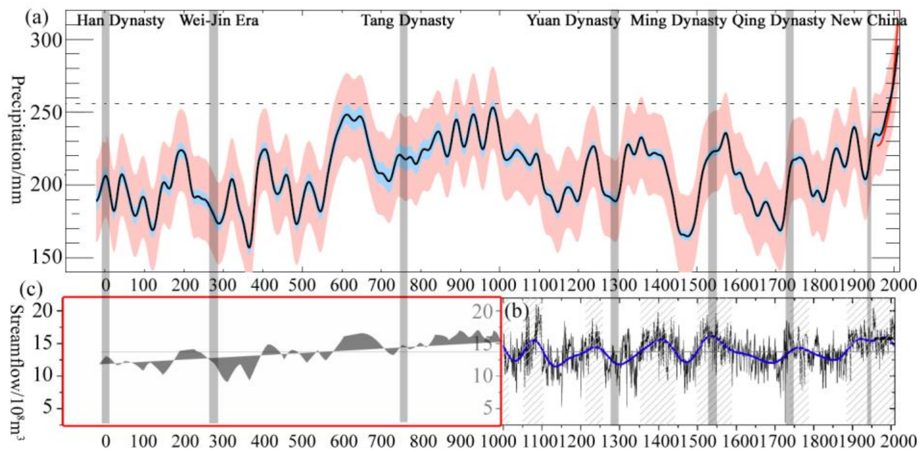
Zheng, J. and Wang, S.: Assessment on climate change in China for the last 2000 years, Acta Geogr. Sin., 60, 21–31, 2005.

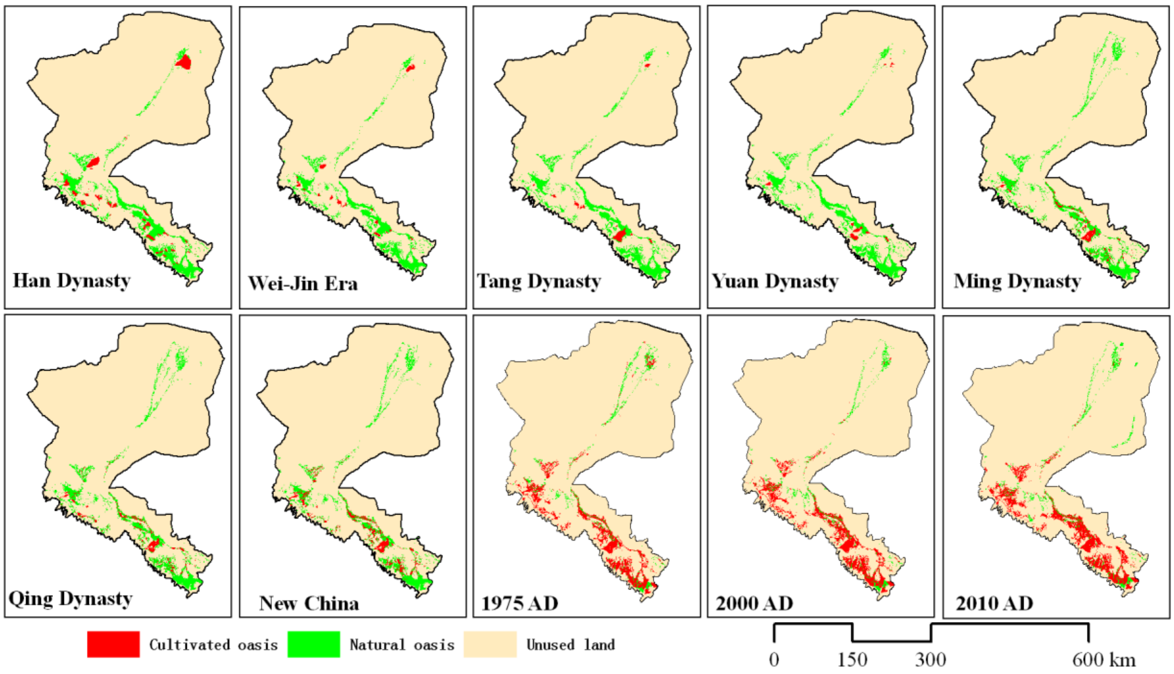
Zheng, J., Shao, X., Hao, Z., and Ge, Q.: An overview of research on climate change in China during the past 2000 years, Geogr. Res., 29, 1561–1570, 2010.

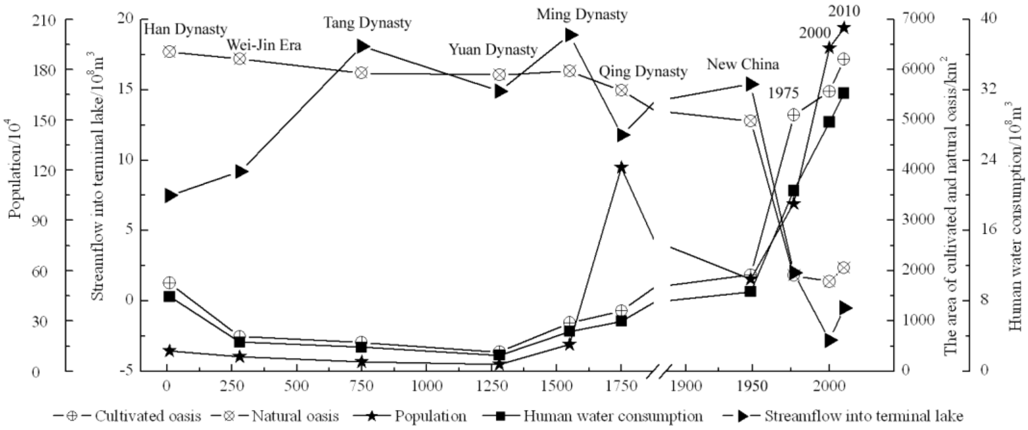
Zhou, L. and Yang, G.: Ecological economic problems and development patterns of the Arid Inland River Basin in Northwest China, Ambio, 35, 316–318, 2006.


N
S
W
E
Sogo Nur
Gaxun Nur
Juyanze Lake
Mid- and downstream
River
Heihe
Upstream
0 50 100 200 300 km
Lake
River
Heihe River basin
Hydrological station
Meterological station
Ice core
Tree ring
Lake sediment
Inner Mongolian Plateau
Hexi
Corridor
Qilian
Mts.
Tibetan Plateau
Qinghai Lake
42° N
40° N
38° N
36° N
92° E
94° E
96° E
98° E
100° E
102° E

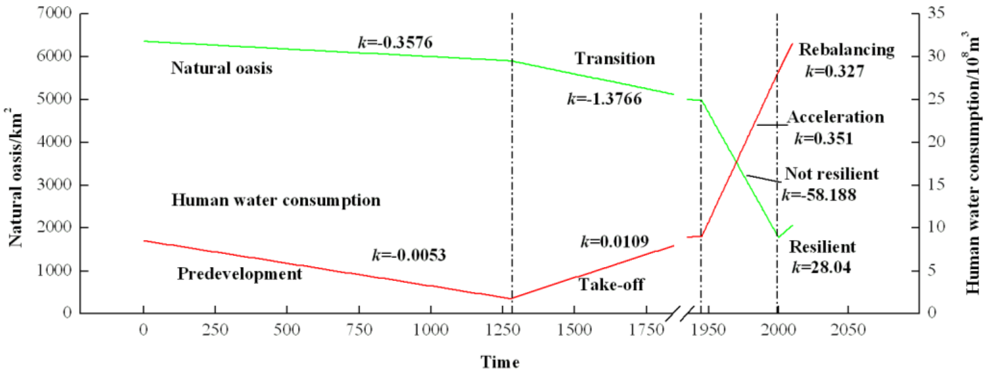

Mean
1966-1995
233mm
42mm
Han
Dynasty
163mm
29mm
Wei-Jin Era
221mm
40mm
Tang
Dynasty
233mm
42mm
Yuan
Dynasty
210mm
38mm
Ming
Dynasty
233mm
42mm
Qing
Dynasty
228mm
41mm
New China
224mm
40mm


(a)
Han Dynasty
Wei-Jin Era
Tang Dynasty
Yuan Dynasty
Ming Dynasty
Qing Dynasty
New China
Precipitation/mm
300
250
200
150
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
(c)
(b)
Streamflow/10^8m^3
20
15
10
5
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000


Han Dynasty
Wei-Jin Era
Tang Dynasty
Yuan Dynasty
Ming Dynasty
Qing Dynasty
New China
1975 AD
2000 AD
2010 AD
Cultivated oasis
Natural oasis
Unused land
0
150
300
600 km


Han Dynasty
Wei-Jin Era
Tang Dynasty
Yuan Dynasty
Ming Dynasty
Qing Dynasty
New China
1975
2000
2010
Population/10^4
Streamflow into terminal lake/10^8m^3
The area of cultivated and natural oasis/km^2
Human water consumption/10^8m^3
Cultivated oasis
Natural oasis
Population
Human water consumption
Streamflow into terminal lake

1
2


7000
6000
5000
4000
3000
2000
1000
0
Natural oasis/km^2
35
30
25
20
15
10
5
0
Human water consumption/10^8 m^3
Natural oasis
k=-0.3576
Transition
k=-1.3766
Rebalancing
k=0.327
Acceleration
k=0.351
Not resilient
k=-58.188
Human water consumption
Resilient
k=28.04
k=0.0109
k=-0.0053
Predevelopment
Take-off
0
250
500
750
1000
1250
1500
1750
1950
2000
2050
Time

1