Response to the second reviewer

General comments

1) It would be helpful for the reader if concepts were clearly defined from the start. Currently, the use of concepts is mixed and includes the use of Taiji Tire model, the concept of pendulum swing (Kandasamy et al. 2014) and the concept of community sensitivity (Elshafei et al., 2014). While the pendulum swing is not defined as such, the concept of community sensitivity is introduced in the discussion, but at the same time forms a major part of the discussion. If the authors wish to use more than one concept, the reader would benefit from a more comprehensive introduction of these concepts early in the paper, possibly including their purpose and/or limitations, and how these concepts are used for the current analysis of the Cangzhou case. The latter would give the reader a clearer indication of what it can and cannot expect from the current analysis. For example, the Taiji-Tire model is merely offered as an organizing framework to represent and explain the human-water relationships (Liu et al., 2014). The conceptualization of interactions serves as a first step to a quantitative (numerical) model that can be used to explain the past and develop predictive insights (Liu et al., 2014). The pendulum swing refers to “an exclusive focus on agricultural development and food production in the initial stages and its attendant socioeconomic benefits, followed by the gradual realization of the adverse environmental impacts, subsequent efforts to mitigate these with the use of remedial measures, and ultimately concerted efforts and externally imposed solutions to restore environmental health and ecosystem services” (Kandasamy et al., 2014).

Response: We agree with the comment. In the revised manuscript, we will add an introduction about the “pendulum swing” at first, and point out that the history of co-evolution of the human-groundwater system in Cangzhou fits a “pendulum swing”:

"Linked by the processes of adaption, the human society co-evolves with the hydrological system, often resulting a "pendulum swing" around the balance point of the human-water system (Kandasamy et al. 2014, Sivapalan 2015). The concept of pendulum swing was first characterized by Kandasamy et al. (2014), through tracing the 100 years history of the competition for water between agricultural development and environmental health within the Murrumbidgee River Basin. Similar dynamics was also found in the human-water system in the arid Tarim Basin (Liu et al. 2014), and the case of human-flood interactions (Baldassarre et al. 2015). A pendulum swing can be specified into three or four typical stages: the initial exploitation stage exclusively focusing on economic development, the onset environmental degradation stage accompanying with the introduction of remedial infrastructure, the widespread environmental degradation stage led to mitigation measures, and the recovery stage along with the implementation of ultimately solutions.

We also add a more detailed introduction of the Taiji-Tire model, and clarify that the Taiji-Tire model is specified to the groundwater system:

"A specific social hydrological system contains human, hydrological and environmental sub-systems. The Taiji-Tire model proposed by Liu et al. (2014) is a framework to represent and explain a specific social-hydrological system under its outer environmental system. In the model, a Taiji wheel, a term from a special concept in Chinese philosophy, is used to describe the direct human–water relationship of a specific social hydrological system. While a human–water tire is used to represent the indirect impact of external natural and social factors

that affect the water. The pendulum swing of the water competition between agriculture and environment in the Tarim Basin in a long history was revealed by the Taiji-Tire model, with attention on the interactions between natural variability and social productive force (Liu et al. 2014).

We will add an introduction of the concepts of restorative force and community sensitivity, and point out that they will be incorporated into the Taiji-Tire model:

In order to interpret the drivers of the reallocation of water from social-economy to the environment under the recovery stage of the pendulum swing, a concept of "environmental restorative force", which is comparative to "social productive force" was proposed (van Emmerik et al. 2014). It should be noted that the environmental protection actions during the recovery stage are usually conducted upon a high social awareness of environment risk or welfare, which was taken as a variable of the model (Di Baldassarre et al. 2013). Elshafei et al. (2014) uses a new concept of community sensitivity to represent this social awareness of environment welfare. Community sensitivity is the sensitivity of human society to the changing environment. The high community sensitivity represents that humans feel the pressure of environmental deterioration, and tend to restrain human activities to restore environmental health. The concept of community sensitivity was used to analyze the switching of the favoring between flood protection and wetlands in the Kissimmee River Basin, Florida (Chen et al. 2016). Above new concepts can be incorporated into the Taiji-Tire model to improve its explanatory power on a specific human-water system."

2) The primary goal as defined by the authors is the interpretation of the case study using the Taiji Tire model. It remains however unclear which methods are used to relate the observed feedbacks in the case study to the more abstract concepts in the model: what is used to distinguish endogenous from exogenous variables? How are the major drivers of the system resolved? When is a feedback considered to be productive or restorative? Currently, his seems to be dependent on your system boundary? The environmental burden seems to be partly shifted from groundwater to the surface water systems that deliver the water transfers?

Response: The inner Taiji represents the direct interacting human activities and hydrologic variables at short-term, reflecting the human-water relation. In Cangzhou, the Taiji represents the direct interactions between groundwater utilization and the water table. Therefore, he groundwater withdrawal from the shallow and deep aquifers, as well as the status of the aquifers (denoted by the shallow water table depth and water table depth of the depletion cone) are taken as the endogenous variables. The outer Tire represents all those social and natural factors that indirectly influence the system. Environmental change, especially precipitation and surface water change/variability, is an external driver of the human-groundwater system within Cangzhou. The social productive force is another external driver of the co-evolution of the human-groundwater system in Cangzhou. The social productive force is another external driver of the co-evolution of the human-groundwater system in Cangzhou. It should be noted that the Taiji-Tire model is specified to the groundwater system in Cangzhou. Therefore, the surface water systems is taken as a external driver.

As for the productive and restorative forces, as mentioned in the paper, for example Fig. 3a, the restorative forces is explained as a new kind of social productive forces. The social

productive force refers to the combination of all factors that help humans to utilize the resources and create better material and spiritual products that makes life better and easier. While the social productive force itself only emphasize the production but not the cost, including the direct production cost and the environmental externalities, the restorative forces refers to the specific productive forces that aiming at further increase the production by mainly lowering the environmental externalities, or, in another word, the green productivities. For Cangzhou, the emphasis level of the social productive force, can be detected from the changes in well numbers, the irrigated area with groundwater, as well as the policy for groundwater exploitation. While, the social restorative force can be detected from the changes in water saving irrigation area, as well as the policy to incent water-saving technologies.

3) Environmental awareness/ community sensitivity/ natural restorative force is ultimately put forward as a driver of groundwater table restoration. It is however unclear at the moment how this is inferred from the case study. The description of the case study is detailed and shows the complexity of the system including groundwater changes in both the shallow and deep water aquifer, resulting in policy developments aimed at improved groundwater management and ultimately an increase in groundwater tables. At the same time, it is mentioned that pumping costs increase due to the deeper groundwater table, land subsides (up to almost a meter), salt intrudes and additional water is available due to water transfers. How does environmental awareness relate to economic incentives or the availability of an alternative water source? If the paper would include an interpretation (qualitative or quantitative) of the strength of the various feedbacks, if would make the current conceptualization much stronger.

Response: Environmental awareness is not only related to the measurable economic costs or incentives or the availability of an alternative water source. Community sensitivity is the sensitivity of human society to the changing environment (Elshafei et al. 2014). High community sensitivity represents that humans feel the pressure of environmental deterioration, and tend to restrain human activities to restore environmental health. The increasing economic costs would result in the increasing community sensitivity. The economic incentives can be taken as a response or adaption of the increasing community sensitivity. The water transfers may reduce the community sensitivity at a local scale during a short period, but the impacts can not last for long-term if the human-groundwater relationship is not change intrinsically.

4) The text would benefit from editing and proof reading to improve its readability.

Response: We will follow closed the suggestions made by referees, and improve the use of English. The revised manuscript will be edited by a native English speaker.

Specific comments

Page 3, line 3. Please lengthen, since it is currently the core of the article. By which measure are feedbacks categorized? How exactly is a social productive force defined? How are main drivers distinguished among all plausible drives? Zhang et al. (2011), for example use five steps to deduct causal mechanisms in their research to link climate change and large-scale human crises.

Response: We will make a detailed statement on the method about categorizing the

feedbacks, defining a social productive force and distinguishing plausible drives. Please refers to the response to 2nd comment of 2# referee. And also, we agree that distinguishing the main drivers from all other plausible drivers are important. For current, however, it still need more case studies to complete. We will try to answer this question in further works.

Page 4, line 12 to 16, please check era titles with paragraph titles; not all of them match.

Response: We will check the era titles.

Page 4, paragraph 3.1, what are the sources used for this paragraph?

Response: The data is from the Water Resource Annals of Cangzhou (Xue 1994). We will add the citation.

Page 4, paragraph 3.1, while the statements related to irrigated area argue in favor of natural variability dominating socio-hydrological change, the statements related to reservoirs, diversion projects and drainage-oriented policy currently imply that humans seems to have considerable impact already during this period. Adding a statement on the (limited?) effects of these policies on groundwater would strengthen the argument.

Response: Since we focus on human-groundwater system, so the title will be revised to "Natural variability dominates human-groundwater system". In Cangzhou, "reservoirs, diversion projects" were conducted on surface water resources, and the "drainage-oriented policy" was restrained to low lands. The groundwater sub-system was not affected by humans at a large scale. We will add a statement as follow:

Because of serious salinization problems, a drainage-oriented policy for low lands was established in Cangzhou. A large number of reservoirs and diversion projects were constructed, which reduced the need for groundwater resources.

Therefore, owing to the low demand and the technological limitation, the scale of groundwater utilization was very small during this era. The relationship between the human and groundwater was weak. The society was more sensitive to the natural variability than the groundwater change, and the groundwater sub-system was not affected by humans at a large scale.

Page 5, figure 2, please check the figure references: subfigure d is referred to twice, resulting in a mismatch (e to i) from there on.

Response: We will revise the figure references.

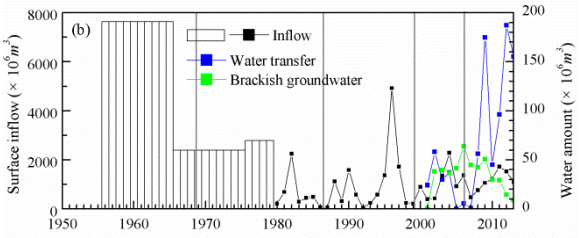
Page 5, figure 2f (irrigated area), what is meant by irrigated area, is this total irrigated area or irrigated area using surface water?

Response: It means total irrigated area. We have revised it.

Page 5, figure 2, having a figure here showing the incoming water from all or the most important diversions/transfers into the region would complete the story. I can imagine that the availability of an alternative water source plays a significant role in the restoration of groundwater levels.

Response: We have added a figure for the variations of water diversion from outside the

basin and the amount of brackish water. We think the new figure can be help.



Page 7, line 18, “Groundwater then became an important water resource for agricultural irrigation.” Should this be “the most important water resource”? Given that well drilling for groundwater started a few years earlier?

Response: During this era, surface water was still more important than the groundwater. In 1983, the irrigated area with groundwater was 43.1% of the total irrigated area of Cangzhou. We have revised it as "Groundwater then became more and more important as a source for agricultural irrigation."

Page 7 to 10, paragraphs 3.2, 3.3., 3.4, what are the sources used for these paragraphs?

Response: The data used for paragraph 3.2 is from the Water Resource Annals of Cangzhou (Xue 1994). The data of agricultural infrastructures and production used for paragraphs 3.3, 3.4, and 3.5 is from the National Bureau of Statistics of China (2010), the Hebei Rural Statistics yearbook (from 1994 to 2013). The data of annual precipitation, groundwater withdrawal from both the shallow and deep aquifers, groundwater table depth is from the Hydrology and Water Resources Investigation Bureau of Cangzhou. The data of policies and initiatives before 1985 is acquired from the Water Resource Annals of Cangzhou (Xue 1994), the data after 1985 is detected from the announcements, documents of the Ministry of Water Resources, the Government of Hebei, the Water Resources Department of Hebei, the Government of Cangzhou, the Water Resources Bureau of Cangzhou. We will add the citations in the revised manuscript.

Page 9, line 19. “the environment noticeably deteriorated”. How was this the case?

Response: We will add a specific statement about it, as follow:

In 2001, the cumulative subsidence was 2236 mm, with a rate of 100.45 mm/ a. The areas with subsidence larger than 500 and 800 mm are 9,717 and 3042 km2, respectively, which are 92.9% and 29.1% of the total area of Cangzhou. Besides, the interface of salt and fresh water declined around 10 m, with a maximum depth of 30 m, which threaten the fresh water in the deep aquifer (Han and Han 2006).

Page 9 & 10, has the reduction of overexploitation become a goal in itself or are earlier mentioned problems such as subsidence or salt water intrusion still an issue in the region? Are there specific quotes from governmental documents you could use to strengthen your argument?

Response: Subsidence and salt water intrusion are still issues in the region. According to the Geological environment bulletin of Hebei of 2013, the depression cone of the deep aquifer within Cangzhou is 5,551km^2.

From Page 11 onwards, How, using what method/definitions, are the more abstract general concepts as mentioned in figure 3 related to the individual, observed feedbacks as mentioned in the text? How are productive, restorative and healthy status defined? Can anything be said about what triggered the restorative force (e.g. economic motives, a change of norms and values) and/or what is meant by the steady state of the system?

Response: The emphasis level of the social productive force, can be detected from the changes in well numbers, the irrigated area with groundwater, as well as the policy for groundwater exploitation. While, the social restorative force can be detected from the changes in water saving irrigation area, as well as the policy to incent water-saving technologies. The changes in the aquifers (both shallow and deep) healthy status can be detected from the changes of the average water table depth of the shallow aquifer, and the water table depth of the depletion cone of the deep aquifer.

We think that high community sensitivity represents that humans feel the pressure of environmental deterioration, and tend to restrain human activities to restore environmental health. The change of community sensitivity is related to the change of norms and values. However, economic costs and incentives are also very important. Please refer to the response to the 2nd and 3rd comments.

Page 12, figure 4a, how are the axis defined? Is a decrease in groundwater table indicated with a positive sign? Are values calculated with regard to the groundwater table of the previous year? Has a correction been applied for water inflow (e.g. precipitation)?

Response: In the revised manuscript, we revised it as "change in shallow water table depth", and added a explanation "a negative change means a rise of the groundwater table".

Page 12, figure 4b, out of interest, how can it be that with a larger withdrawal the center of depression in 2013 is equal to 1984?

Response: The reason is that the center of the depression cone moved from urban areas to the rural area, and the average water table of the aquifer still declined. We will add a figure showing the changes in the water table depth of the aquifer Ⅲ along the cross-section from the west to the east.

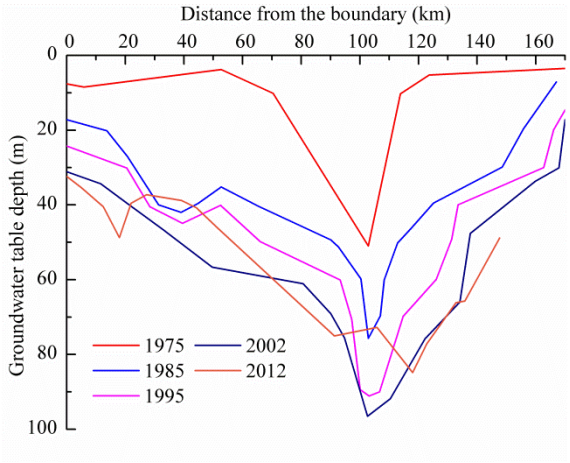


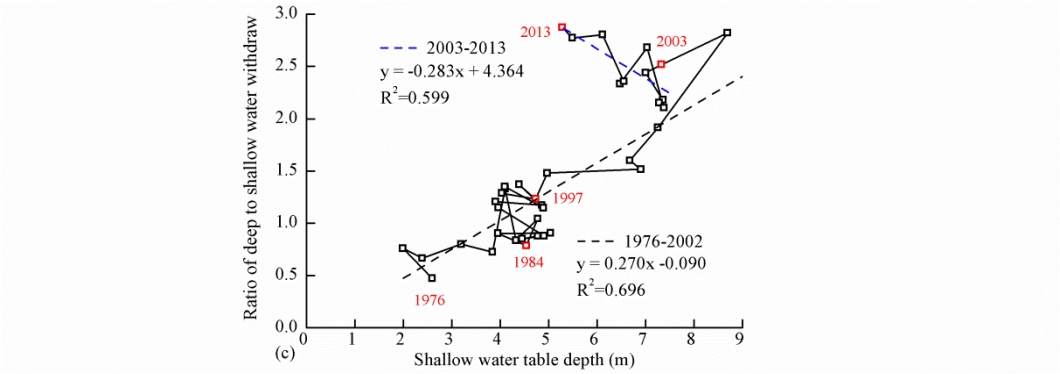
Figure. Changes in the water table depth of the aquifer Ⅲ along the cross-section from

the west to the east.

Page 12, figure 4c. The description of this figure is quite difficult to follow. Since two sets of data are presented in the figure, i.e. black (1976 - 2002) and blue (2003 – 2013) a discussion of these different trends would be appreciated. If individual data points are discussed as is the case now, maybe the individual years could be marked in the plot?

Response: We will mark the individual years in the plot, and add a discussion of the different trends as follow:

The dataset was divided into two periods (before and after 2002) based on the narrative of different eras, and significant changes in water user behaviour and social response to groundwater system could be found. The ratio of deep to shallow water withdrawal negatively correlated with the shallow water table depth after 2002, which is absolutely different from that before (Figure 4(c)). However, the correlation of the negative relationship is much weak with a start point before 2002 (for example, the determine coefficient is only 0.11 with data from 2002 to 2013). As shown in Fig. 2(), the deep groundwater withdrawal began to decrease slowly since 2002, while the shallow groundwater withdrawal continued to decrease rapidly as before. It indicates that people did not turn to shallow water with increasing shallow water table since the infrastructure of deep water with high quantity exploitation has already existed.



Page 12, line 14. “The interactions of inner Taiji : : : of blind development.” On which literature is this statement based? Elinor Ostrom has, among others, done a lot of research aimed at understanding the circumstances under which overexploitation takes place.

Response: First of all, the part of sentences is trying to explain that the interactions of inner Taiji that only captures the main processes that how humans adapt to the natural variabilities and utilitze the natural resources are not enough to describe the behaviors of socio-hydrologic systems at all time and space scales. There are many cases back up the statement that without fully awareness of natural deterioration, humans development pattern will still remain blind. The most famous one is the global warming issue, even today we are not taking enough measures in coping with the overexploitation of natural resourses and over consumption of chemical fuels.

Second, E. Ostrom has done great job on socio-ecological system (SES), and based on many cases, summarized many situations that leads to overexploitation. We believe we are working on the same direction with Ostrom. While Ostrom focus on her SES framework developed from IAD framework (institutional analysis and development), our works are

mainly focus the water issue, which is quite different from other natural resources that are easily located and dividable, like woods, mines, fishery and wild animals. In future, in socio-hydrology, we believe more cases shall be studies.

Page 13, line 13, it would be helpful to see the definition of the restorative and productive force earlier in the paper, for example when introducing the Taiji Tire model.

Response: We will add the definition of the restorative and productive force when when introducing the Taiji Tire model.

In order to interpret the drivers of the reallocation of water from social-economy to the environment under the recovery stage of the pendulum swing, a concept of "environmental restorative force", which is comparative to "social productive force" was proposed (van Emmerik et al. 2014).

Page 14, line 6, “This is because at : : : protections (Elshafei et al., 2014).” On what evidence is this statement based? How is community sensitivity defined? How is it measured in the case study?

Response: In 2004, a leading group with the executive vice-mayor as the leader was established to prevent and treat the subsidence in Cangzhou. Measures for sustainable groundwater management was emphasised in the Cangzhou government work report.

Page 14, line 13. “The social productive : : : extremely costly”. On what are these statements based? Is there evidence that technology and management tools are developed solely for environmental protections? Costly in relation to what (alternative)?

Response: In this paper environment is specified to the aquifers. The "new technology and management tools" denotes those for water saving. It is costly in relation to traditional groundwater exploitation. We will make the statement more clear in the revised manuscript.

Reference:

Kandasamy, J., Sounthararajah, D., Sivabalan, P., Chanan, A., Vigneswaran, S. and Sivapalan, M. (2014) Socio-hydrologic drivers of the pendulum swing between agricultural development and environmental health: a case study from Murrumbidgee River basin, Australia. Hydrology And Earth System Sciences 18(3), 1027-1041.

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Han, Z. and Han, Y. (2006) Groundwater geo-environmental problems and control measures in Cangzhou. GroundWater 28(3), 61-64.