<u>Responses to Peer Reviewers</u>

<u>Reviewer #3</u>

Interactive comment on "Impacts of human activities and climate variability on green and blue water flows in the Heihe River Basin in Northwest China" by C. Zang et al.

Knowledge on the dynamics of stream flow with climate variability and human interferences is very important for water resources managements. However, it is difficult to separate impacts of climate variability and human interferences from stream flow and meteorological records. This paper tried to separate them using a semi-distributed hydrological model SWAT via different scenarios. Doing in this way is smart but this paper was not strong enough at current stage. I am reporting below a few main comments and some specific remarks, which I hope the authors will find to be useful while revising their manuscript.

We agree that it is difficult to separate impacts of climate variability and human interferences. This is partly a reason for our attempt to do the current research. In our paper, we try to separate human activities influence types by controlling the model scenario sets. Therefore, we set up four simulation experiments: *scenario A* to *scenario D.* Based on these scenarios, we analyse the impacts on green and blue water flows of climate variability (difference between B and A), land use change (difference between C and B), irrigation expansion (difference between D and C) and all factors (difference between D and A), respectively. We hope such scenario analysis approach will be valuable for the separation of impacts between climate variability and human interferences.

General comments

(1).The novelty of this study was very limited at current stage. Essentially, what was investigated in this paper was the partition of precipitation between ET and runoff. Storage change was neglected in this study and quantity changes in ET and runoff were the same, so this study should be defined as impact of human activities and climate variability on ET or runoff. It is not necessary at all to dress up this issue with "New Clothes", i.e. "green and blue water".

Authors' response:

First of all, blue water flow includes surface runoff, lateral flow and groundwater recharge; hence, blue water flow is more than runoff alone. The conventional water-resource planning and management focus is on liquid water, or blue water. It served the needs of engineers who were involved in water supply and infrastructure projects quite well. However, the blue water that has dominated the water perceptions in the past only represents one-third of the real freshwater resource, the rainfall over the continents. Most rain flows back to the atmosphere as a vapor flow, dominated by consumptive water use by the vegetation. We therefore need to incorporate a second form of water resource, the rainfall that naturally infiltrates into the soil and that is on its way back to the atmosphere. Due to the above reasons, we consider the concepts of "green and blue water" important in the field of hydrology and water resources, and they are widely used already in the scientific community.

One novelty of the paper is the analysis of green-blue water transformation under climate variability and human activities. This novelty will be explicitly mentioned in the revised manuscript. Based on our best knowledge, green-blue water transformation has been poorly studied in the literature, but strong human interventions to the natural hydrological processes have led to such transformation in many river basins all over the world. Therefore, we will revise the manuscript title to "Green-blue water transformation due to human activities and climate variability: a case study of the Heihe River Basin in Northwest China", and emphasize this novel topic in the revised introduction section.

Reviewer #3

To my understanding, this study is about assessing human activities and climate variability on the catchment water budgets at mean annual time scale. For this kind of issues, complex process-based model may be not a good option because this method subjected to various uncertainties, difficulties in validation and scale issues (Blöschl and Sivapalan, 1995; Sivapalan et al., 2003a; Nalbantis et al., 2011). As a result, complex bottom-up model may not be able to provide more reliable and more accurate estimations. An appropriate scale-dependent parameterization might be more robust to for a certain hydrological issues (Sivapalan et al., 2003b; Beven and Cloke, 2012). Some empirical methods based on data analysis in a top-down manner may be more reliable to solve the issues in this study (e.g., Koster and Suarez(1999), Zhang et al.(2001), Milly and Dunne(2002), Zhao et al.(2010), Li et al.(2012), etc.). The authors also can try to use both bottom-up and top-down methods Page 2 of 7 to find interesting coupling relationships and derived more reliable estimates (Sivapalan et al., 2011).

Authors' response:

We agree that the selection of an appropriate approach is important for studying the catchment water budgets. It is ideally to try to use both bottom-up and top-down methods to find interesting coupling relationships. However, the SWAT model has been tested to be a reliable model for our case area. Considering this, we will not try the top-down approach here. However, we will mention the key issues mentioned by the reviewers and discuss the shortcomings of not comparing both the bottom-up and top-down methods in the revised version.

For the impacts of human activities, I would like to see that human and natural are coupled systems. Human activities can change water cycle dynamics and they basically co-evolute with societal driver and climate variability (Liu et al., 2007; Sivapalan et al., 2012). Regarding irrigation, I would like expect coupling between water demand and

climate variability. Unfortunately, human activities in this modelling experiment are just a simple prescribed scenario. Coupling between human activities and climate variability were not discussed.

Authors' response:

We thank the reviewer's suggestion. We share some opinions with the reviewer. Human activities can change water cycle dynamics in a river basin (Liu et al., 2007; Sivapalan et al., 2012), this is mainly blue water flow; but green water (ET) changed by humans could move through the atmosphere to areas outside the basin (Vander Ent et al., 2010). However, human activities also can change climate variability patterns, but separating human activities influences from climatic influences is difficult (Sivapalan et al., 2012) and beyond the scope of this study.

Studies of the coupling between human activities and climate variability have high scientific significance for improving water resources management research (Sivapalan et al., 2011). Many methods have been used to describe interactions between human activities and climate change, e.g. the weighting method and entropy method; but this needs collection of many social-economic data and observed hydrological and climate data, which we cannot accomplish in a short time period, thus we will have to leave a deeper investigation for future studies.

(2). **Land use change and irrigation expansion scenarios and modelling results. From the manuscript, it is difficult to know how land use change and irrigation expansion scenarios were set in the SWAT model.**

Authors' response:

The land use change scenario was set as follows: we have used land use data in 2000 to calibrate and validate the parameters. This part of work has been finished by Zang et al., (2012). Now we use land use data in 1986 as scenario A, and land use data in 2005 as scenario D. We will offer more information about the land use change data set as implemented in the SWAT model in the revised manuscript.

The irrigation expansion scenario was set as follows: The scenario A did not consider irrigation and scenario D consider all cropland was irrigated. The irrigation for cropland in upstream and midstream is from surface water, and that in downstream is from shallow aquifer. Meanwhile, the values of several parameters i.e. IRRSC, FLOWMIN, DIVMAX, et al. were obtained from published literature (Ge et al., 2011; Wang et al., 2012) and the Ministry of Water Resources irrigation test web site (http://www.syzz.org.cn/about.asp?id=23). More information on the irrigation settings will be shown with Table A1 (Table A1, see page 18 in this Response Letter).

To my knowledge, land use and land cover information in the SWAT model can be significantly different from that was provided in Table 2, which was derived from remote sensing product sand considered as real changes. Because small patches of land use types was usually neglected when hydrological response units was delineated in the SWAT model. About 309 HRUs were generated considering both land use (23 types) and soil types (63 types) for the whole catchments about 240000 km^2. On average, area of a HRU was about 800km^2. It could result in that land use patches, which smaller than 100 km^2, were all neglected. Distributed land use types including villages, towns, and stream networks may be not considered in the SWAT model.

Authors' response:

We set the thresholds to get hydrologic response units (HRUs) as follows: 8% for Land Use, and 8% for Soil Class. These thresholds will often not make the small patches of land use types neglected. Furthermore, The HRUs are obtained based on land use, soil types and topography; hence, the area of HRUs is not homogenous. In our study, the max HRU area is 8607 km^2 located in downstream, while the min HRU area is only 17 km^2 located in midstream. We will show this as an appendix to the revised manuscript. In downstream, the soil and land use are very homogeneous; hence, a large HRU area is expected. In upstream and midstream, the area of HRU is generally small enough to reflect the land use types, e.g. forestry, villages and towns (the HRUs area information will be offer in revised manuscript).

Furthermore, how land use change scenario was set in SWAT model was also not provided. To my knowledge, land use change scenarios can only be set with the HRUs. The HRUs cannot be changed once they were delimitated, and they has unique land use or soil types. So, land use change information provided in Table 2 was also not helpful at all for understanding the modelling results.

Authors' response:

The HRU definition relies on topography, land use type, soil attributes, and management. When we change the land use data input, we needed to redefine HRUs (for 2005 as opposed to 1986). Different land use data will generate different HRUs quantities; the HRUs quantities with 1986 land use is 308, and with 2005 land use is 310. The HRUs area also will be changed with different land use; we will offer the HRUs area information with 2005 land use in revised manuscript as supplementary for understanding the HRUs information easily. The land use change provided in Table 2 gives partial information for understanding the model simulation results, so will provide maps (Fig. A3, see in Page 8 in this Response Letter)) in revised manuscript as supplementary.

Regarding irrigation expansion scenario, it is difficult to know how much irrigated land increased, how much water was used and where Did the water come from (streamflow or groundwater).

Authors' response:

We assume that all cropland is irrigated. This is because that in the Heihe river basin, precipitation is too low to have rainfed agriculture. In this case, irrigated area is the same as the cropland area. The irrigation amount is automatically calculated by the SWAT model, and it is assumed that water is always available when needed. In upstream, water is mainly from streamflow (based on our investigation at the sites) and in downstream, irrigation water is from groundwater because river is almost dry there. We will clarify the description of the irrigation expansion scenario in the revised version.

Similarly, estimated change in irrigated land from remote sensing products did not equal to that was modelled in the SWAT model. These should be introduced in the data section.

Authors' response:

SWAT model does not model irrigated land area, but simulate irrigation volume (which of course is influenced by the area). We will introduce this in the data section in the revised version..

From Figure 3 and 5, it seems (cannot see clearly) that land use change has caused ET and runoff changes in the headwater region, and irrigation expansion has caused changes in ET and runoff not only in the irrigated districts but also non-irrigation expansion regions.

Authors' response:

Land-use-change induced hydrological changes are NOT significantly in the headwater region because the land use change is not sharp there. However, there still exists land use changes in upstream; hence, the reviewer is correct, ET and runoff also change in the headwater region. Such changes are not significant for all headwater sub-basins except for sub-basin 32, where forest expansion was large (see Fig. A3 in Page 20 in this Response Letter).

We assume that all cropland is irrigated. Rainfed agriculture cannot harvest due to the low precipitation in this river basin. Cropland is distributed not only in the irrigation districts, but also in other regions. Hence, irrigation expansion has caused changes in ET and runoff not only in the irrigated districts but also non-irrigation expansion regions. We will clarify this in the revised manuscript.

Page 3 of 7 I was wondering that whether estimated water flux changes in this study can support the "natural flow" estimated in the previous study by Zang, et.al.(2012). If the headwater region can be considered as "natural", water flux of the headwater region should not be influenced by the land use change or irrigation expansion.

Authors' response:

The previous paper does not consider land use change, so we consider their results to be for "natural" conditions. This study also considers land use changes; hence, this is no longer a "natural" condition, but is a condition modified by human activities. Even the headwater region was also experiencing gradual land use change and was not a real natural condition.

I was also wondering that how irrigation expansion (shown in Figure 4) can change ET and runoff in the headwater region and un-connected sub-basins in the down streams (eastern and western tributaries).

Authors' response:

We assume that all cropland is irrigated. Rainfed agriculture cannot harvest due to the low precipitation in this river basin. Cropland is distributed not only in the irrigation districts, but also in other regions. Hence, irrigation expansion has caused changes in ET and runoff not only in the irrigated districts but also non-irrigation expansion regions. That's a reason why irrigation expansion can change ET and runoff in the headwater region and un-connected sub-basins in the down streams (eastern and western tributaries). We will clarify this in the revised manuscript.

Anyway, the authors may be right but more information on how scenarios were set should be provided and why land use change and irrigation expansion caused relatively different changes in ET across different sub-basins should be interpreted.

Authors' response:

Agree, we will add more scenario information. We also will interpret why land use change and irrigation expansion caused relatively different changes in ET across different sub-basins, as clarified above.

(3). Problems with separated impacts of climate variability, land use change and irrigation expansion.

Assuming that catchment actual evapotranspiration *E= f(c, l, i, ...)*, where *c* for climate, *l* for land use and *i* for irrigation. Function *F* is a highly nonlinear one. Then, changes in *E* due to *c* can be approximated as:

$$\lhd E_c \approx \frac{\partial f}{\partial c} \lhd c + \frac{1}{2!}\frac{\partial^2 f}{\partial c^2} \lhd c^2 + ...$$

Similarly, changes in *E* due to *l* and *i* can be approximated as:

$$\triangleleft E_l \approx \frac{\partial f}{\partial l} \triangleleft c + \frac{1}{2!}\frac{\partial^2 f}{\partial l^2} \triangleleft l^2 + \ldots$$

$$\triangleleft E_i \approx \frac{\partial f}{\partial i} \triangleleft c + \frac{1}{2!}\frac{\partial^2 f}{\partial i^2} \triangleleft i^2 + \ldots$$

Differences between scenario B and scenario A in this study are ΔE_c here. The differences between scenario C and scenario A are

$$\triangleleft E_l \approx \triangleleft E_c + \triangleleft E_l + \frac{1}{2!}\frac{\partial^2 f}{\partial c \partial l} \triangleleft c \triangleleft l + \ldots \approx \triangleleft E_c + \triangleleft E + \left(nonlinear\text{-}interacti\right)$$

If impacts of climate and land use change on *E* are independent, then nonlinear interaction terms are usually negligible. However, *E* of land use is usually dependent on climate conditions, epically for vegetated land(Zhang et al., 2001; Troch et al., 2009; Cheng et al., 2011). So, separated impacts of land use change (difference between scenario C and B) in this study, i.e., $\triangleleft E_{cl} + \triangleleft E_c$ here, included not only impacts of land use change but also changes in *E* of land use caused by changes in climate conditions. This is likely the reason why ET and runoff of headwater regions, where supposed to be under natural and land use should be not changed, were changed.

Authors' response:

We agree with the reviewer's comments. However, E of land use is usually dependent on climate conditions, epically for vegetated land (Zhang et al., 2001; Troch et al., 2009; Cheng et al., 2011). So, separated impacts of land use change (difference between scenario C and B) in this study, here, included not only impacts of land use change but also changes in E of land use caused by changes in climate conditions. This is likely one reason (there are other reasons, see clarifications above) why ET and runoff of headwater regions, where supposed to be under natural and land use should be not changed, were changed. We will mention the shortcomings of neglecting the interaction between the impacts of climate and land use change in the revised paper.

Similarly, separated impacts of irrigation expansion were not solely changes caused by irrigation. Differences between scenario D and scenario C included impacts of irrigation expansion, interactions between E of vegetated land and changes in climate conditions as well as interactions between E of irrigated land and changes in climate conditions (assuming that impacts of land use change and irrigation expansion were independent). This is likely the reason why separated impacts of irrigation expansion can change ET of all sub-basins no matter whether there was irrigation.

Authors' response:

As stated above, we assume that all cropland is irrigated. Rainfed agriculture cannot harvest due to the low precipitation in this river basin. Cropland is distributed not only in the irrigation districts, but also in other regions. Hence, irrigation expansion has caused changes in ET and runoff not only in the irrigated districts but also non-irrigation expansion regions. That's the most important reason why irrigation expansion can change ET and runoff in the headwater region and un-connected sub-basins in the down streams (eastern and western tributaries). We will clarify this in the revised manuscript.

We agree with the reviewer that separated impacts of irrigation expansion were not solely changes caused by irrigation. Differences between scenario D and scenario C included impacts of irrigation expansion, interactions between E of vegetated land and changes in climate conditions as well as interactions between E of irrigated land and changes in climate conditions (assuming that impacts of land use change and irrigation expansion were independent). This may also contribute to the impacts of irrigation expansion, although we are not clear the exact extent of the role of the interactions.

Therefore, this study cannot be considered purely as either sensitivity analysis or scenarios analysis. It is not an assessment of real conditions at all and cannot be considered to benchmark the water resources in the Heihe River basin or as a general approach as claimed by authors.

Authors' response:

We will modify the scope of the paper in the revision and clarify shortcomings, as spelled out in the above responses. We also deleted the sentence regarding the "benchmark the water resources" through the previous version.

(4).Storage changes

Storage changes in snow cover, soil water content and groundwater were not mentioned in this the manuscript.

Authors' response:

The glacier area of Heihe river basin was about 180 km^2, so storage of melting water was considered in the manuscript. Four model parameters (SFTMP, SMFMX, SMFMN and TIMP) actually describe snow or glacier water content. The SWAT model also considers soil water content and groundwater during simulation, and we will briefly mention the storage changes in snow cover, soil water content and groundwater in the revised manuscript.

I suspect that estimated impacts may be biased by the storage change. For this large catchment (0.24 M km^2), 1.0mm differences in the depth of water can resulted in 240

million m^3 change in the ET or runoff. In this study, estimated biggest change was ET caused by climate variability ~469 million m^3, which was only about 2 mm changes in depth and it can be smaller than errors in water balance or bias in estimated areal rainfall. To my understanding, inter-annual variability of ET or runoff is much smaller than precipitation, which infers that inter-annual soil water storage can change significantly to stabilize annual ET flux. Storage between two different periods can be large if one is picked out from a wet period and the other is picked out from a dry period. Moreover, storage difference between beginning and ending of a short period, for instance, 3 years in this study, can also much larger than 2 mm.

Authors' response:

It is true that the average change is about 2 mm. However, this does not mean that 2 mm of change will happen everywhere. Due to the spatial differences, the changes vary very differently with a max change of 41 mm in midstream (see Table 2 in P19 in this Response Letter). Such a change is big enough in relative to precipitation there.

The authors mentioned that irrigation relies on not only surface water but also groundwater. I believe that sharp increase in water use irrigation in arid region, such as scenario set in this study, can cause significant change in groundwater storage.

Authors' response:

The irrigation districts in midstream mainly rely on surface water. Only a small part of cropland in downstream relies on groundwater, and the water use is about 0.5 - 0.8 billion m^3 (Yang et al., 2004). We believe irrigation can influence groundwater storage in the downstream. The SWAT model can be used to study the storage change for unsaturated shallow groundwater. However, in the downstream of the Heihe river basin, irrigation is often from deep groundwater, andt the model at the current stage cannot be used to study the change of groundwater storage. We will mention this shortcoming in the revised version.

Authors provided glacier area was about 180 km^2. The glacier coverage decreased about 2% and temperature of the glacier covered region increased significantly between two periods. This can also resulted in significant storage change. Another storage may change is water storage in reservoirs, authors indicated that area of reservoirs and lakes interpreted from 1km^2resolution satellite images was about 450 km^2. I guess that this area may be much larger if small water bodies were considered. I was wondering whether water bodies were modelled in SWAT in this study and previous study and whether there was storage change between two periods or due to irrigation.

Authors' response:

We agree that the about 2% decrease in glacier coverage and temperature change will result in significant storage change. But the SWAT model is not well validated for the glacier storage simulation. Water bodies have been modelled in SWAT in this study and the previous study. However, the input data resolution is 1 km^2; so, this can miss parts of water storage change (though such small water bodies are rare in the basin). Storage of water bodies has changed between two periods or due to irrigation, but the variation is small (1-2 mm). We will clarify these in the revised version.

Regarding the separated values, ET and runoff were exactly the same in quantity. It suggests that storage change was zero. I am not sure how it was achieved between two 3-year long scenarios.

Authors' response:

Storage change is not zero, but it is very small (0.21-0.43 million m^3).

The author should carefully do water balance check considering changes in water flux in depth is very small.

Authors' response:

Agree. We thank reviewer's suggestion. We will carefully do water balance check.

Specific remarks

(1).P9478L12: "water flow increased from 1980 to 2005". Water flux of two different periods (1986s and 2005s) was compared and it was not appropriate to say that increased from 1980 to 2005.

Authors' response:

Agree. We thank reviewer's suggestion. We will improve our expression.

(2). P9478L12: it is better to use mm rather than m^3 in this study.

Authors' response:

Agree. We will change it to use mm.

(3). P9479: Introduction section: climate variability, climate change and global change were all mentioned. I think that they are not similar and have different research scopes. And, introduction was not well written.

Authors' response:

Agree. We thank for the reviewer's suggestion. We will rewrite the introduction.

(4). P9482L1: mountains are land cove types?

Authors' response:

We will improve our expression.

(5). P9482: simulation experiments: add figures show land use changes were set in the SWAT model and provide more information about how irrigation scenario was set.

Authors' response:

Agree. We thank the reviewer for this suggestion. We will do it in the revised manuscript.

(6). P9483L5: Is interception accounted in actual ET in the SWAT model?

Authors' response:

The interception is accounted for in actual ET, we will mention that.

(7). P9483L16-18: Both E_{ns} and R^2 quantify correlation between predicted and observed time series. If two series are closely correlated but with huge differences in total quantity, very high E_{ns} and R^2 can also be expected. Another systematic balance criterion should be used.

Authors' response:

Agree. If two series are closely correlated but with huge differences in total quantity, we should use another systematic balance criterion. Fortunately, total quantity in our model calibration and validation series are not huge differences (Average discharge in calibration period of Zhamushike is 22.34 m^3, and in validation period is 22.07 m^3; Average discharge in calibration period of Yingluo Canyon is 35.85 m^3, and in validation period is 45.66 m^3. Average discharge for validation in Zhengyi Canyon from 1981 to 1987 is 34.26 m^3, and from 2000 to 2006 is 35.83 m^3). So we need not use another systematic balance criterion. We will add this information in revised paper.

(8). P9483L21: "natural conditions were defined without considering human activities". I was wondering whether streamflow was influenced by human activities. If it was, how model was calibrated using human interfered streamflow. How "natural flow" was estimated. The "natural flow" is very important information for this study. Please provide more information.

Authors' response:

In this paper, we do consider the human activities. We agree with the reviewer that the results should be tested not only for natural conditions, but also for the “real” conditions. We have taken the reviewer’s advice, and provided additional validation of the model results by comparing them with observations for the Zhengyi Canyon in midstream, where high intensive human activities occur. The validation results are satisfying as shown in Fig. 3 (see Page 21 in this Response Letter), which will be added to the revised manuscript. The results also show good performance of the model. We will combine such a validation (Fig. 3) in the revised paper.

(9). P9483L25: E_{ns} and R^2 were estimated on which time scale?

Authors’ response:

E_{ns} and R^2 were estimated on monthly time scale.

(10). P9484L2: What was the modelling period? There was a missing year 2006 in the second period, i.e., 2004-2006.

Authors’ response:

The first simulation period is from 1971 to 2004; after collect new climate data, the second simulation period is from 1971 to 2010. We choose the average simulation results from 2004-2006 and land use data for 2005 for the study.

(11). P9484L11: add “subscript” before “0 indicates...” and “i indicates”

Authors’ response:

Agree, we thank reviewer's suggestion.

(12).P9484L28: Was soil depth modelled 100 cm in depth across the whole basin? Page 6 of 7

Authors’ response:

The soil depth modelled 100 cm in depth across the whole basin.

(13). P9485L21-22: how much groundwater for irrigation was set in this study?

Authors’ response:

We didn't calculate how much groundwater for irrigation, we set cropland close to Juyanhai Lake to be irrigated by groundwater.

(14).P9486L10: how much did precipitation change at different regions and over whole basin? This information is important.

Authors' response:

The annual average precipitation is 198 mm in the 1980s, and 204 mm in the 2000s in entire river basin. The annual average precipitations are 312, 200 and 45 mm in up-, mid-, and downstream in the 1980s, separately; and 318, 207 and 51 mm in up-, mid-, and downstream in the 2000s. We will provide the information in revised paper.

(15). P9486L12: There was a sub-basin in the downstream showing decrease in blue water in Figure 3. Not all.

Authors' response:

Agree, we will revise this section.

(16).P9499-P9501: please change order of Figure 4 and Figure 3. I think that change in depth is more informative than relative change rate in Figure 3 and Figure 5. What does the residential points means in Figure 4? Does every point represent a certain population density? Page 7 of 7

Authors' response:

Agree. We will change order of Fig. 4 and Fig. 3. We also show depth in Fig. 3 and Fig. 5. The residential points means 100/km^2, every point represent a certain population density.

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Table A1 Irrigation scenarios sets information in SWAT model

Parameters	**Upstream**	**Midstream**	**Downstream**
IRRSC	1	1	3
IRRNO	32	30	5
IRRNO,cont	32	30	5
FLOWMIN	50	70	
DIVMAX	90	100	
DIVMAX,cont	1	1	
FLOWFR	0.5	0.7	
DDRAIN	100	100	100
TDRAIN	36	36	36
GDRAIN	48	48	48

Note:IRRSC: irrigation code. The options are: 0, no irrigation; 1, divert water from reach; 2, divert water from reservoir; 3, divert water from shallow aquifer; 4, divert water from deep aquifer; 5, divert water from unlimited source outside watershed. IRRNO: irrigation source location. IRRNO, cont: the definition of this variable depends on the setting of IRRSC; IRRSC=1, IRRNO is the number of the reach that water is moved from; IRRSC=2, IRRNO is the number of the reservoir that water is moved from; IRRSC=3 or 4; IRRNO is the number of the sub-basin that water is removed from; IRRSC=0 or 5; this variable is not used; Required if 1≤IRRSC≤4. FLOWMIN, minimum in-stream flow for irrigation diversions (m^3/s). DIVMAX, maximum daily irrigation diversion from reach (mm). DIVMAX,cont, it is may be set when IRRSC=1. FLOWFR, fraction of available flow that is allowed to be applied to the HRU. DDRAIN, depth to subsurface drain (mm). TDRAIN, time title drain soil to filed capacity (hours). GDRAIN, drain tile lag time (hours).

Table 2 Variability of green/blue water flows among difference scenarios (Units: mm)

Sub-basins number	GB (S_B-S_A)	GB (S_C-S_B)	GB (S_D-S_C)	GB (S_D-S_A)	B (S_B-S_A)	B (S_C-S_B)	B (S_D-S_C)	B (S_D-S_A)	G (S_B-S_A)	G (S_C-S_B)	G (S_D-S_C)	G (S_D-S_A)
1	4	-1	0	3	0	1	0	1	3	-2	0	1
2	6	0	0	6	0	0	0	0	6	0	0	6
3	4	-1	0	3	0	1	0	1	3	-2	0	1
4	7	0	0	7	3	-3	-2	-2	5	2	3	10
5	6	0	0	6	0	1	1	2	6	-1	0	5
6	5	0	0	5	0	-1	0	-1	5	1	-1	5
7	5	0	0	5	0	-1	0	-1	5	1	-1	5
8	7	0	0	7	3	-3	-2	-2	4	3	3	10
9	6	0	0	6	2	0	1	3	3	0	-1	2
10	2	0	0	2	0	0	0	0	2	0	0	2
11	-10	1	0	-9	-5	2	0	-3	-6	0	0	-6
12	-10	0	0	-10	-4	1	-4	-7	-7	0	0	-7
13	-10	2	0	-8	-7	2	0	-5	-2	-1	0	-3
14	-10	1	0	-9	-8	5	-1	-4	-2	-4	6	0
15	-7	0	0	-7	-7	1	-8	-14	0	3	4	7
16	-7	0	0	-7	-8	0	0	-8	1	0	0	1
17	4	1	0	5	2	3	0	5	2	-2	0	0
18	1	0	0	1	0	9	-1	8	2	-9	4	-3
19	-10	1	0	-9	-8	2	-5	-11	-2	-2	10	6
20	1	0	0	1	0	9	-1	8	1	-9	4	-4
21	1	0	0	1	-2	1	0	-1	2	0	0	2
22	-1	0	0	-1	-2	0	0	-2	1	0	0	1
23	-1	0	0	-1	-4	1	0	-3	4	-2	0	2
24	-16	0	0	-16	-19	-5	-6	-30	2	6	7	15
25	-10	1	0	-9	-4	2	0	-2	-6	-1	0	-7
26	0	-1	-2	-3	-9	-9	-4	-22	8	9	8	25
27	20	1	0	21	2	11	0	13	18	-10	0	8
28	-3	0	0	-3	-3	10	-2	5	0	-10	4	-6
29	-11	0	0	-11	-2	6	-9	-5	-9	-6	7	-8
30	41	0	0	41	14	20	0	34	27	-21	0	6
31	1	0	0	1	0	0	0	0	1	0	0	1
32	51	0	0	51	29	-7	-13	9	21	8	9	38

Note: GB is total green and blue water flows; B is blue water flow; G is green water flow; S_A is scenario A; S_B is scenario B; S_C is scenario C; S_D is scenario D. S_j-S_i is difference between scenario j and i.

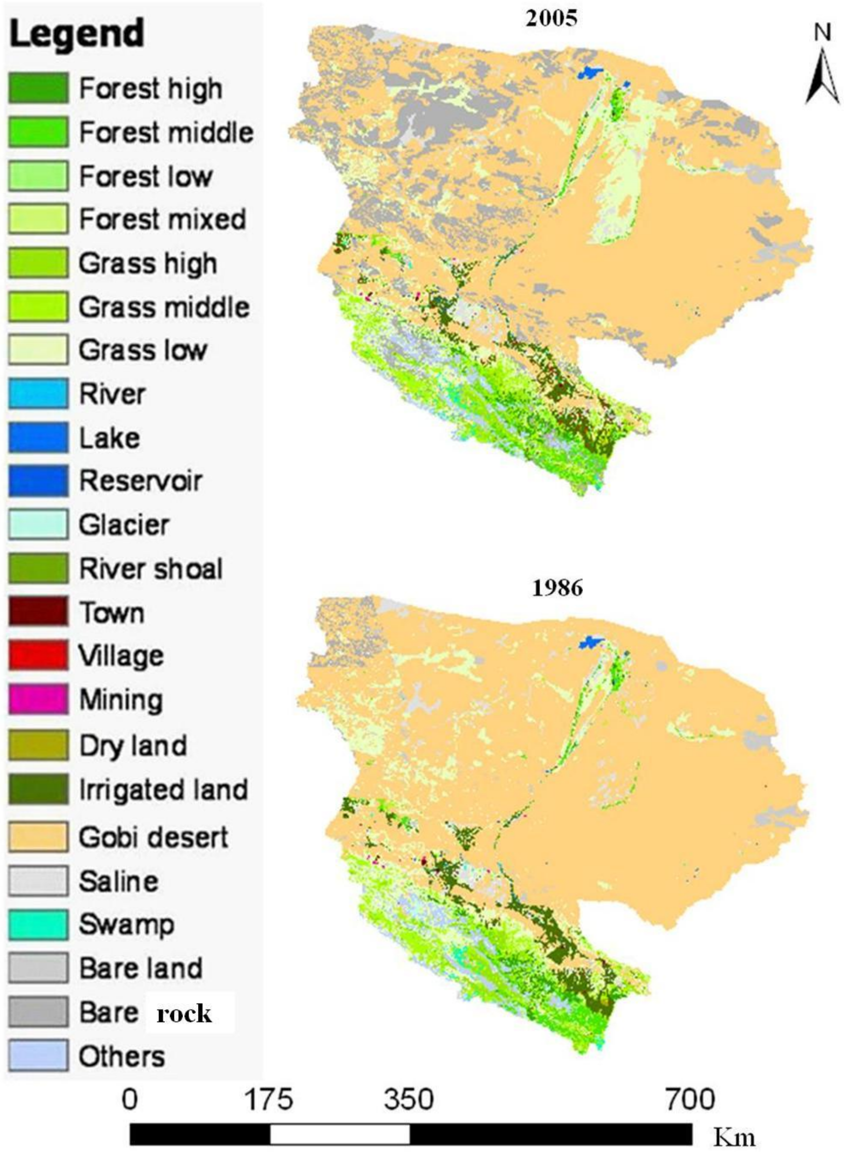

Fig. A3. Land use map in the Heihe river basin in 1986 and 2005

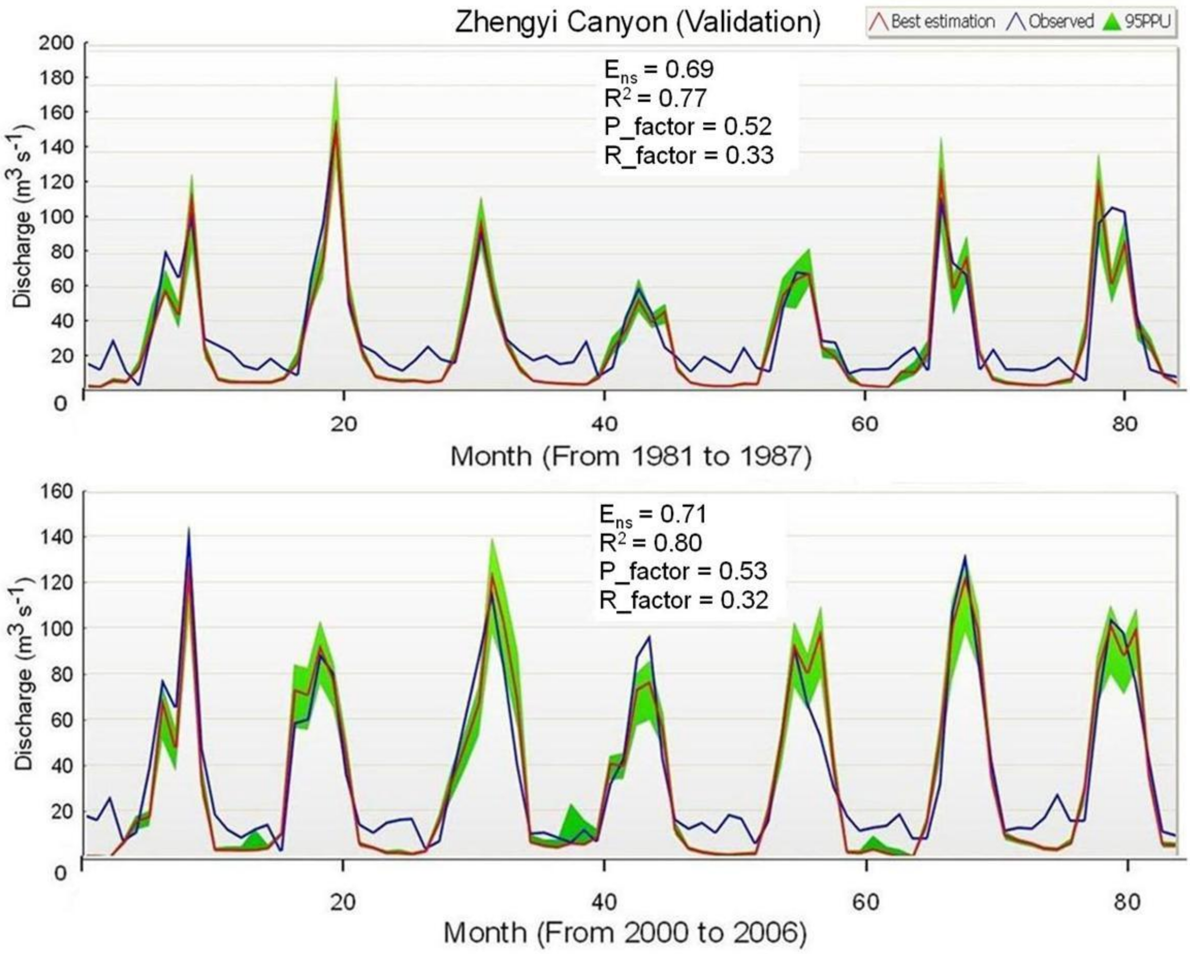

Fig. 3. The validation of the SWAT model at Zhengyi Canyon