To: Hydrology and Earth System Sciences (HESS)

Subject: Revise the manuscript (#hess-2016-332)

The Authors: Wang & Sun

The Title: Impact of LUCC on Streamflow Based on the SWAT Model over the Wei River Basin on the Loess Plateau of China

Response:

The authors appreciate the editor and reviews for helpful criticism and constructive comments that improved our original manuscript. We have addressed the comments below (part 1) and supplemented details for review #1 (part 2: Author's Response-RC1) and review #2 (part 3: Author's Response-RC2). And the changes being made are marked in the manuscript (part 4: a marked-up manuscript).

Part 1

Response to the comments:

1. In your response to reviewer #1, I don’t think it is appropriate to use the Thiessen polygon method to calculate basin-scale precipitation. The SWAT allocate each subbasin with a precipitation gauge (or using the lapse rate and elevation bands), therefore, using the SWAT generated precipitation will be more appropriate.

Thank you for this criticism and this is an important suggestion for keeping consistency and continuity though the manuscript. We have recalculated the average values of regional precipitation using elevation bands method of ArcSWAT 2009.93.7b, which can account for orographic effects on precipitation (Neitsch et al., 2011). (Figure 6 and Line 184-204 in marked-up manuscript).

Orographic precipitation is a significant phenomenon in certain areas of the world. To account for orographic effects on both precipitation and temperature, SWAT allows the subbasin to be split into a maximum of ten elevation bands. Precipitation and maximum and minimum temperatures are calculated for each band as a function of the respective lapse rate and the difference between the gage elevation and the average elevation specified for the band.

$$R_{band} = R_{day} + \left(EL_{band} - EL_{gage}\right) \cdot \frac{plaps}{days_{pcp,yr} \cdot 1000} \text{ when } R_{day} > 0.01$$

where R_{band} is the precipitation falling in the elevation band (mm H_2O), R_{day} is the precipitation recorded at the gage or generated from gage data (mm H_2O), EL_{band} is the mean elevation in the elevation band (m), EL_{gage} is the elevation at the recoeding gage (m), plaps is the precipitation lapse rata (mm H_2O/km), $days_{pcp,yr}$ is the average number of days of precipitation in the subbasin in a year, and 1000 is a factor needed to convert meters to kilometers.

Once the precipitation values have been calculated for each elevation band in the subbasin, new average subbasin precipitation value is calculated:

$$R_{day} = \sum_{bnd=1}^{b} R_{band} \cdot fr_{bnd}$$

where R_{day} is the daily average precipitation adjusted for orographic effects (mm, H_2O), fr_{bnd} is the fraction of subbasin area within the elevation band, and b is the total number of elevation bands in the subbasin.

Reference:

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R.: Soil and Water Assessment Tool (SWAT) Theoretical Documentation: Version 2009, Texas Water Resources Institute Technical Report No. 406, 2011.

2. "The impacts of terrace and dam on streamflow are clear". Please clarify and add convincing reference.

Thank you for your suggestion. We have added more details and references (Line 105-108 in marked-up manuscript). The impacts of terrace and check dam had a regular and negative effect on annual streamflow. They could reduce the runoff in the flood season, increased the baseflow and guarantee the river ecological flows in non-flood season on the Loess Plateau (*Shao, et al., 2012, 2013a, 2013b; Zhang, et al., 2014a, 2014b; Xu, et al., 2013*). For example:

(1) The impact of terrace on streamflow:

In order to address the lack of tools in researching terrace impact on watershed soil and water loss, a process-based terrace algorithm within the SWAT model was developed by Shao Baffaut and Gao et al (*2012,2013a*), which has been incorporated into SWAT (version 2009). The responses of soil and water loss toward terraces over the Weihe River basin were detected using this verified model (*Shao, 2013b*). Results showed the terrace in the main Weihe River basin could delay the flood and add the drought season runoff, which reduced the annual streamflow in general. Terrace in 2000 could decrease about 37 million m^3 annual water yield in the whole watershed and increased the most dry month runoff by 3.5% in the Xianyang station. Zhang et al (*2014a, 2014b*) used this model to study the terrace measures of Yanhe river watershed, typical basin of the Loess Plateau, and results showed that the terrace measures could reduce the runoff in the flood season, increased the base flow and guarantee the river ecological flows in non-flood season. And the 1 m^3 water could be supplied to the river while 5~ 6 m^3 water stored by the terrace of Yanhe river watershed.

References:

Shao, H., Baffaut, C., Gao, J. E.: A Process-Based Method for Evaluating Terrace Runoff and Sediment Yield [J], 2012.

Shao, H., Baffaut, C., Gao, J. E., et al. Development and application of algorithms for simulating terraces within SWAT [J]. Transactions of the Asabe, 2013a, 56(5):1715-1730.

Shao, H.: Simulation of Soil and Water Loss Variation toward Terrace Practice in the Weihe River Basin, Doctor, Northwest A & F University, Yangling Shaanxi, 2013b.

Zhang, Y. X., Gao, J. E., Shao, H., et al. The Terraced Fields Environmental Impact Assessment in Data-Scarce Areas Based on the Embedded Terraced Module SWAT Model [J]. Nature Environment & Pollution Technology, 2014a.

Zhang, Y. X.: The research of watershed runoff and sediments variation toward to the soil and water conservation terrace measure, Doctor, Northwest A & F University, Yangling Shaanxi, 2014b.

(2) The impact of check dam on streamflow:

Xu and Fu et al (2013) applied the SWAT (Soil and Water Assessment Tool) model to simulate the streamflow in the Yanhe watershed and results showed that the check dams had a regulation effect on streamflow. From 1984 to 1987, the streamflow in rainy season (from May to October) decreased by 1.54 m^3s^{-1} (14.7 %) to 3.13 m^3s^{-1} (25.9 %) due to the check dams; while in dry season (from November to the following April), streamflow increased by 1.46 m^3s^{-1} (60.5%) to 1.95 m^3s^{-1} (101.2 %); From 2006 to 2008, the streamflow in rainy season decreased by 0.79 m^3s^{-1} (15.5 %) to 1.75 m^3s^{-1} (28.9 %), and the streamflow in dry season increased by 0.51 m^3s^{-1} (20.1 %) to 0.97 m^3s^{-1} (46.4 %).

References:

Xu, Y. D., Fu, B. J., He, C. S.: Assessing the hydrological effect of the check dams in the Loess Plateau, China by model simulations, Hydrology & Earth System Sciences Discussions, 2013, 9(12):13491-13517.

But the impacts of vegetation on streamflow are controversial and complicated and results are different among different basins. So the forest was selected to analyze in detail.

3. Some items have been left out. For example, "Splitting the section "Results and discussion" into two distinctive sections "Results" and"Discussion" would certainly help the authors clarifying their scientific demonstration" In reviewer #1; "more information on check dams" in review #2. Please provide a point to point response to these comments.

Thank you for your suggestion. We have revised the manuscript completely and provide a point to point response to the comments (in Author's Response-RC1 and Author's Response-RC2). And the changes being made are marked in the manuscript.

4. Please clarify what's the dominate vegetation for Range-Brush, Forest-mixed, forest-deciduous, etc.

Thank you for your suggestion. There are 79 plant species in the plant growth database of SWAT 2009 version. The generic land covers in the model are: RNGB uses values for Little Bluestem (LAI_{max} = 2.0); FRST and FRSD use values for oak; FRSE uses values for pine (Arnold et al., 2011). And the specific and dominate vegetation for Range-Brush, Forest-mixed, forest-deciduous, etc. in study area are as follows:

(1) Range-Brush (RNGB): Vitex negundo L. var. heterophylla (Franch.) Rehd, Exochorda racemosa (Lindl.) Rehd, Forsythia suspense, Quercus variabilis Bl., Platycarya strobilacea Sieb.et Zucc., Lespedeza Formosa, Abelia parvifolia, Corylus mandshurica, Lindera obtusiloba, etc.

(2) Forest-Mixed (FRST): Oak, Quercus aliena var. acuteserrata, Platycarya strobilacea Sieb. et Zucc., Pinus armandi, etc.

(3) Forest-Deciduous (FRSD): Larix gmelinii (Rupr.) Kuzen, Acer Davidii, Juglans cathayensis Dode, Morus alba L., Toxicodendron vernicifluum, etc.

(4) Pine (PINE): Pinus tabuliformis Carrière, Larix principis-rupprechtii, Larix principis-rupprechtii, etc.

(5) Forest-Evergreen (FRSE): Abies fabri (Mast.) Craib, Picea asperata Mast., etc.

（Note: The Vegetation type data is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC)）

5. A lot of unreadable characters are found in your response. Please do correct them.

Thank you for your suggestion. We have checked and revised them.

6. Check “the annual streamflow is 2.0 mm/yr for study area”. It seems too little for the WeiRiver.

Thank you for your suggestion. We have checked the result. The annual average reduction of streamflow was 94 million m^3 in study area and the area of the study basin is 4.68×10^4 km^2.

$$\frac{94\ \times 10^6\ \mathrm{m}^3}{4.68\times 10^4\ \times 10^6 \mathrm{m}^2}\times 10^3\frac{\mathrm{m}}{\mathrm{mm}} = 2.0085\ \mathrm{mm}$$

So it was about 2.0 mm/yr to in study area.

7. One figure showing the observed and simulated runoff/streamflow is enough.

Thank you. As your suggestion, only one figure showing the observed and simulated streamflow was kept in the manuscript.

Part 2: Author's Response-RC1

Response:

The authors appreciate Dr. Lacombe for helpful criticism and 8-pages constructive comments that improved our original manuscript. We have addressed the comments below and have made corrections. The changes being made are marked in red in the manuscript.

Response to the main comments:

1: *First of all, I am questioning the significance of the hydrological changes that actually occurred in the catchment over the studied period. Although figure 1 indicates that forested areas increased by about 65.10^4 hm^2 (unusual unit used on the Y axis), which is equivalent to 14% of the upper catchment area, figure 3 inconsistently shows that forested area increased by only 0.81% (line 137) over the same period (1980 to 2005). How to explain this difference? If we rely on figure 2 (which is likely the most reliable source), we can expect minor nfluence of forestation on the basin hydrology.*

Thank you for pointing this out, which makes us think it through. In fact, these two datasets are from different sources. First of all the number in Fig. 1 is for 6.53% (instead of 14%) as shown in detailed explanation below, which is still higher than 0.81% as pointed by the referee. This is a classic issue in the national survey on soil and water conservation where they only take the revegetation implemented into account and ignores for example possible death of vegetation, which is important in the land use map. One more thing is that the national survey when counting the revegetation areas does not consider the vegetation coverage, which is in fact important in any hydrological modelling including the SWAT model. We agree with the referee on that point. With that caution, however, Figure 1 is just for a reference on the development of the soil and water conservation project in China. The data we are relying on are the land use maps. Detailed explanation below:

(1) There are some detailed descriptions about Fig.1. The same legends for Fig.1 (a) and (b) brought some confusion, so we revised the legends of Fig. 1. Figure 1 is the developing process of the soil and water conservation measures in the main stream basin of Wei River, including the upper and middle reaches (4.68×10^4 km^2) and the downstream of the main stream (1.65×10^4 km^2). Figure 1 involves about 6.33×10^4 km^2. Figure 1 (a) is the area developing of forestation, terraces, grass and dam land separately. The area of forestation was about 57.43×10^4 hm^2 during 1980s and it increased to 98.75×10^4 km^2 in 2006, which equivalent to 6.53% of the main stream basin of Wei River. And Fig. 1 (b) is the sum area of the forestation, terraces, grass and dam land in upstream, midstream and downstream. And the sum area increased by about 66.15×10^4 hm^2 in upstream.

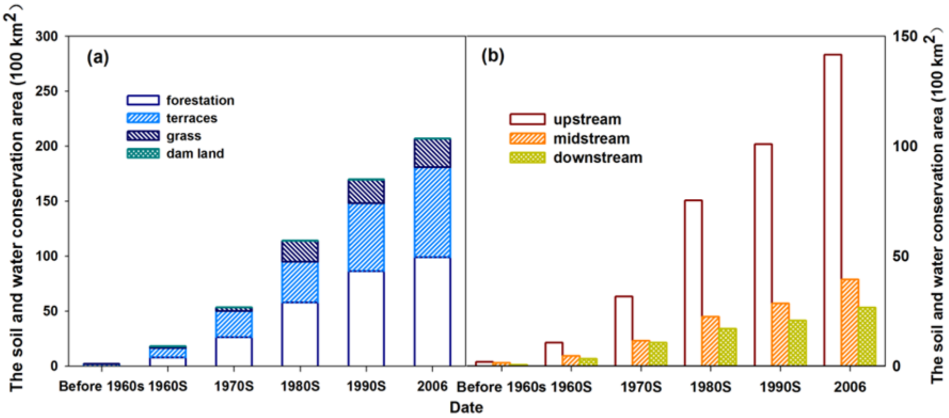


Fig. 1 The development of soil and water conservation measures in the main stream basin of Wei River over last 50 years

(2) Figure 1 is the statistical data of government based on natural forest before and artificial planting area, which involves all planting of forestation without considering canopy density, surviving or deforestation and so on. The forest of the LUCC data refers to the natural forest and plantation, which canopy density is larger than 30% (Table 3: note ②).

(3) The forest data of Fig. 1 also includes planting land used as agro-fruit, agro-mulberry, agroforestry and replanting land for trees. While land used for agro-fruit, agro-mulberry, agroforestry is classed as Agricultural land (Table 3: note ①) in LUCC.

(4) There are also some screening conditions for land use types dividing in SWAT model. For hydrological response unit (HRU) analyst, the Dominant Land Use method was used for HRU definition. So the dominant unique combination of land use in the subbasin is used to simulate the HRU. Figure 1 shows the area of grass is smaller than forest's, while it is opposite in LUCC and SWAT model attributed to canopy density and the dominant method.

2: *(1) The main issue of this paper is that all the demonstration relies on simulated flows only. Flow simulated over the period 1980-2009 with land-use from 1980 should be compared to actual flow recorded over the period 1980-2009.*

Thank you for your comments. We add a new figure (Fig. 1.1) to show the time-series graph of calculated streamflow vs. observed streamflow during 1980-2009 for hydrological stations. We can see the calculated streamflow matched well with the observed values during 1980s. The observed values were measured daily based on the actual LUCC, while the calculated streamflow was got based on LUCC of 1980. So Fig. 1.1 shows the calibrated SWAT model played well in our study area and the changing LUCC can affect streamflow gradually. The streamflow of typical year, the same year with LUCC, is the results of by LUCC and meteorological conditions. To reduce influence of meteorological condition and isolate the impact of the LUCC on streamflow, 30-year average of the streamflow for forest and agricultural land were taken, respectively. For period of 1980-2009, we just used their measured and long-term daily meteorological data in the study area to drive the validated model for the designed hydrological experiments.

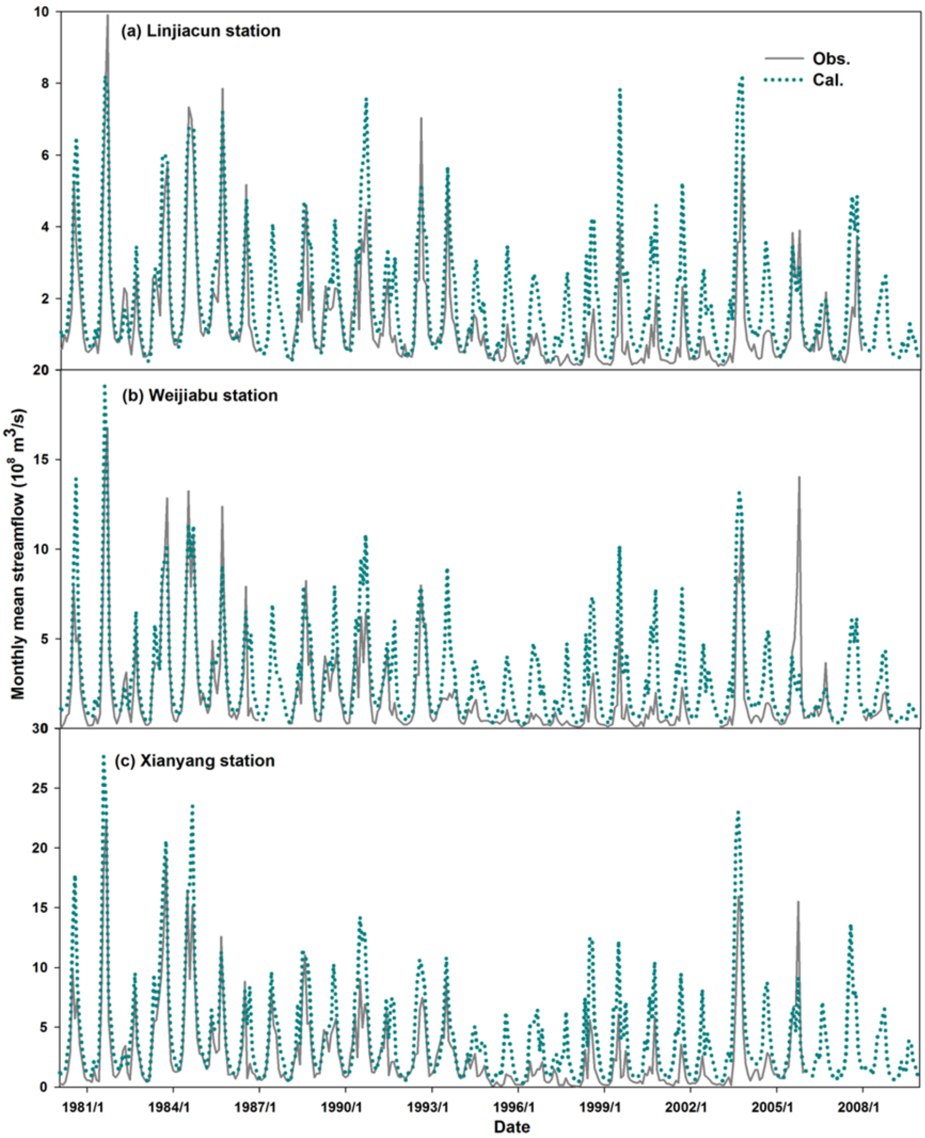


Fig. 1.1 The time-series graphs of calculated vs. observed streamflow during 1980-2009 for hydrological stations.

(2) Another issue is the implicitly presumed stability of the catchment behaviour over each of the 2 periods 1960-79 and 1980-2009. A graphic showing annual flow, rainfall (both in mm) and runoff coefficients in each of the 3 nested catchments and intermediary catchments (e.g. the colored areas in figure 2) would provide a first assessment of the possible effects of the land-use changes (as done in Lacombe et al. (2008)). A statistical assessment quantifying change and/or trend significance is also missing (cf. Lacombe et al. (2016) for an example).

Thank you for your comments. For period of 1980-2009, we used their measured and long-term daily meteorological data of the study area to drive the validated model. There was only one variable (LUCC or vegetation) to analyze its impacts on streamflow quantitatively. So the soil data, DEM and meteorological data are all same. The figures of annual flow, rainfall and runoff coefficients for 3 regions of Fig. 2 in the study area are added as Fig. 6. The time series of annual average precipitation for the 3 regions of the study area were calculated respectively using elevation bands method of ArcSWAT 2009.93.7b, which can account for orographic effects on precipitation (*Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R.: Soil and Water Assessment Tool (SWAT) Theoretical Documentation: Version 2000, Texas Water Resources Institute Technical Report No. 406, 2011*). Orographic precipitation is a significant phenomenon in certain areas of the world. To account for orographic effects on both precipitation and temperature, SWAT allows the subbasin to be split into a maximum of ten elevation bands. Precipitation and maximum and minimum temperatures are calculated for each band as a function of the respective lapse rate and the difference between the gage elevation and the average elevation specified for the band.

$$R_{band} = R_{day} + \left(EL_{band} - EL_{gage}\right).\frac{plaps}{days_{pcp,yr}.1000} \text{ when } R_{day} > 0.01$$

where $\mathrm{R_{band}}$ is the precipitation falling in the elevation band (mm H_2O), $\mathrm{R_{day}}$ is the precipitation recorded at the gage or generated from gage data (mm H_2O), $\mathrm{EL_{band}}$ is the mean elevation in the elevation band (m), $\mathrm{EL_{gage}}$ is the elevation at the recoeding gage (m), plaps is the precipitation lapse rata (mm H_2O/km), $\mathrm{days_{pcp,yr}}$ is the average number of days of precipitation in the subbasin in a year, and 1000 is a factor needed to convert meters to kilometers.

Once the precipitation values have been calculated for each elevation band in the subbasin, new average subbasin precipitation value is calculated:

$$R_{day} = \sum_{bnd=1}^{b} R_{band} \cdot fr_{bnd}$$

Where R_{day} is the daily average precipitation adjusted for orographic effects (mm, H_2O), fr_{bnd} is the fraction of subbasin area within the elevation band, and b is the total number of elevation bands in the subbasin. And the runoff coefficients were 0.13, 0.35 and 0.17 on average for region 1, 2 and 3 over the past 50 years (1960-2009). (Line 184-204)

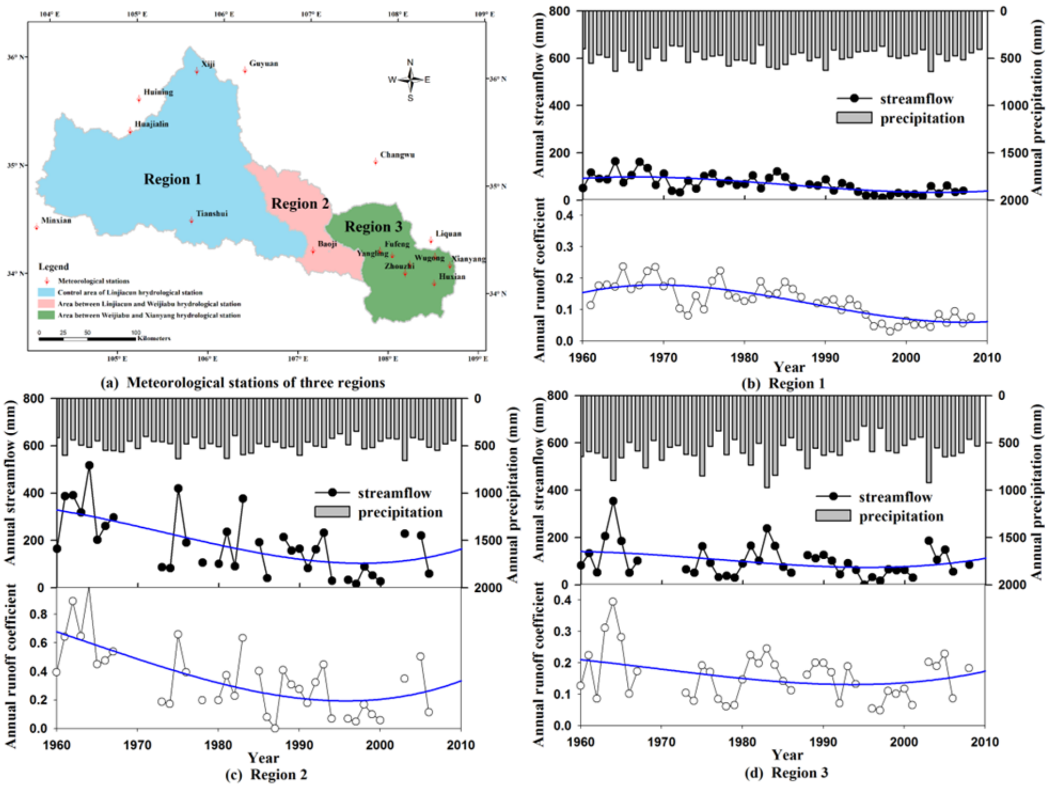


Fig.6 The time-series of precipitation, annual streamflow and runoff coefficients for the regions of study area

(3) There is an overall lack of clarity in the writing. The methods used should be explained in more details and with more precision. Figure 1 shows 4 types of treatments for water and soil conservation that occurred in the study area: forestation, terraces, grass and dam. The hydrological impact assessment focuses exclusively on forestation while the 3 others are completely ignored in the analysis. They certainly have altered river flows too. How to account for their effect in the SWAT model? The maps of the study area (figures 2 and 3) do not show where these technics have been implemented. Splitting the section "Results and discussion" into two

distinctive sections "Results" and "Discussion" would certainly help the authors clarifying their scientific demonstration. As it stands, in many places, actual results are juxtaposed with results of previous research which are not referenced.

Thank you for your criticism. We have revised the manuscript carefully and add more details to make the writing clarify and avoid possible grammar or syntax error. There were measures of forestation, terrace, grass and dam for soil and water conservation. According to Fig.1, we could see the soil and water conservation measures were mainly implemented in the study area after the 1980s in study area. Hence we choose 1960-1969 and 1970-1979 for the model calibration and validation respectively. For period of 1980-2009, we just used their measured and long-term daily meteorological data in the study area to drive the validated model for the designed hydrological experiments. Measures of soil and water conservation are classified according to LUCC types, which are divided into six types and further 25 subtypes. And the six types included forest, pasture, cropland, water body, residential area and bare.

The impacts of terrace and check dam had a regular and negative effect on annual streamflow. They could reduce the runoff in the flood season, increased the baseflow and guarantee the river ecological flows in non-flood season on the Loess Plateau (Shao, et al., 2012, 2013a, 2013b; Zhang, et al., 2014a, 2014b; Xu, et al., 2013). For example:

The impact of terrace on streamflow:

In order to address the lack of tools in researching terrace impact on watershed soil and water loss, a process-based terrace algorithm within the SWAT model was developed by Shao Baffaut and Gao et al (*2012,2013a*), which has been incorporated into SWAT (version 2009). The responses of soil and water loss toward terraces over the Weihe River basin were detected using this verified model (*Shao, 2013b*). Results showed the terrace in the main Weihe River basin could delay the flood and add the drought season runoff, which reduced the annual streamflow in general. Terrace in 2000 could decrease about 37 million m^3 annual water yield in the whole watershed and increased the most dry month runoff by 3.5% in the Xianyang station. Zhang et al (2014a, 2014b) used this model to study the terrace measures of Yanhe river watershed, typical basin of the Loess Plateau, and results showed that the terrace measures could reduce the runoff in the flood season, increased the base flow and guarantee the river ecological flows in non-flood season. And the 1 m^3 water could be supplied to the river while 5~6 m^3 water stored by the terrace of Yan river watershed.

References:

Shao, H., Baffaut, C., Gao, J. E.: A Process-Based Method for Evaluating Terrace Runoff and Sediment Yield [J], 2012.

Shao, H., Baffaut, C., Gao, J. E., et al. Development and application of algorithms for simulating terraces within SWAT [J]. Transactions of the Asabe, 2013a, 56(5):1715-1730.

Shao, H.: Simulation of Soil and Water Loss Variation toward Terrace Practice in the Weihe River Basin, Doctor, Northwest A & F University, Yangling Shaanxi, 2013b.

Zhang, Y. X., Gao, J. E., Shao, H., et al. The Terraced Fields Environmental Impact Assessment in Data-Scarce Areas Based on the Embedded Terraced Module SWAT Model [J]. Nature Environment & Pollution Technology, 2014a.

Zhang, Y. X.: The research of watershed runoff and sediments variation toward to the soil and water conservation terrace measure, Doctor, Northwest A & F University, Yangling Shaanxi, 2014b.

The impact of check dam on streamflow:

Xu and Fu et al (2013) applied the SWAT (Soil and Water Assessment Tool) model to simulate the streamflow in the Yanhe watershed and results showed that the check dams had a regulation effect on streamflow. From 1984 to 1987, the streamflow in rainy season (from May to October) decreased by 1.54 m^3s^{-1} (14.7 %) to 3.13 m^3s^{-1} (25.9 %) due to the check dams; while in dry season (from November to the following April), streamflow increased by 1.46 m^3s^{-1} (60.5%) to 1.95 m^3s^{-1} (101.2 %); From 2006 to 2008, the streamflow in rainy season decreased by 0.79 m^3s^{-1} (15.5 %) to 1.75 m^3s^{-1} (28.9 %), and the streamflow in dry season increased by 0.51 m^3s^{-1} (20.1 %) to 0.97 m^3s^{-1} (46.4 %).

Xu, Y. D., Fu, B. J., He, C. S.: Assessing the hydrological effect of the check dams in the Loess Plateau, China by model simulations, Hydrology & Earth System Sciences Discussions, 2013, 9(12):13491-13517.

But the impacts of vegetation on streamflow are controversial and complicated and results are different among different basins. We also analyzed the impact of grass on streamflow monthly. The result was similar with forest and its impact on stream was smaller than that. So the forest was selected to analyze in detail.

The results involve two different experiments based on different conditions. Firstly, the impacts of different LUCC data on streamflow, surface runoff, soil flow and baseflow, we found the streamflow decreased in agricultural land but increased in forest area. To investigate that, we then designed five scenarios including (S1) the present land use (1980), (S2) 10%, (S3) 20%, (S4) 40% and (S5) 100% of agricultural land was converted into mixed forest. When we tried to split the section "Results and discussion", the different experiments and their conditions also confused. But we have added more details to make the writing clarify. The actual results were also added as showed in Fig.6 and Fig.1.1.

Detailed comments:

(1) The title should be improved. *Currently, it says that LUCC is impacted by the SWAT model.*

We changed the title to be "Impact of LUCC on Streamflow Based on the SWAT Model over the Wei River Basin on the Loess Plateau of China"

(2)Abstract: *in line 29, it is mentioned that SWAT is applied to the upper and middle reach of the Wei River Basin. It is not clear what is the role of the hydrological station at the outlet of the lower reach.*

Thank you for your suggestion. The Linjiacun, Weijiabu and Xianyang hydrological stations are used in our study (Fig. 2). Linjiacun station locates at the control section of the upstream and Xianyang station is the control station of middle reaches (line 142-143). And Weijiabu station locates between them. The hydrological stations of downstream or the outlet of Wei River were not in our study area. Three regions of different colors in Fig. 2 are divided by 3 hydrological stations of upper and middle reaches.

(3) Introduction:

Line 46: a/ the location of the Grain for Green project is missing. b/ Which trees are used for the reforestation? This information is important because, depending on the trees (e.g. deciduous or not), their effect on seasonal flow may be different. c/ the mode of forestation is also primordial when assessing hydrological impacts. For exam-ple, natural forest regrowth or tree plantation can have opposite hydrological effects, depending on how the soil is altered. (cf. Lacombe et al. 2016). The authors should provide more details on the type of forestation.

Thank you for your suggestion. The Grain for Green project involves most area of China, including 1897 counties of 25 provinces (autonomous regions and municipalities), which covers our study area entirely. When the LUCC data are classified and re classified in SWAT model, the tree types are summarized as Range-Brush (RNGB), Forest-Mixed (FRST) and Forest-Deciduous (FRSD). Different types have different hydrological responses for their leaf, roots and so on. We also analyzed the streamflow generation of the main types of forest (RNGB, FRST and FRSD) in study area further. Results showed that the streamflow yield of FRST and FRSD were about 1.20 and 1.60 times of that of RNGB respectively. In Part 2 and 4.1, the forest included all these types, while for the hydrological experiments (part 4.2 and 4.3) the agricultural land was converted into Forest-Mixed (FRST) only.

There are 79 plant species in the plant growth database of SWAT 2009 version. The generic land covers in the model are: RNGB uses values for Little Bluestem (LAImax=2.0); FRST and FRSD use values for oak; FRSE uses values for pine (Arnold et al., 2011). And the specific and dominate vegetation for Range-Brush, Forest-mixed, forest-deciduous, etc. in study area are as follows:

Range-Brush (RNGB): Vitex negundo L. var. heterophylla (Franch.) Rehd, Exochorda racemosa (Lindl.) Rehd, Forsythia suspense, Quercus variabilis Bl., Platycarya strobilacea Sieb.et Zucc., Lespedeza Formosa, Abelia parvifolia, Corylus mandshurica, Lindera obtusiloba, etc.

Forest-Mixed (FRST): Oak, Quercus aliena var. acuteserrata, Platycarya strobilacea Sieb. et Zucc., Pinus armandi, etc.

Forest-Deciduous (FRSD): Larix gmelinii (Rupr.) Kuzen, Acer Davidii, Juglans cathayensis Dode, Morus alba L., Toxicodendron vernicifluum, etc.

Pine (PINE): Pinus tabuliformis Carrière, Larix principis-rupprechtii, Larix principis-rupprechtii, etc.

Forest-Evergreen (FRSE): Abies fabri (Mast.) Craib, Picea asperata Mast., etc.

（*The Vegetation type data is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC)*）

***(4)** Lines 62-65 do not provide much information, saying that streamflow can increase whether the vegetation increases or decreases. Too many references here, should be split in two groups (case studies with vegetation increase and case studies with vegetation decrease).*

Thank you. We have revised the sentence as your suggestion. Quite a few catchment studies indicated that annual streamflow decreased with revegetation increasing (Zhang and Hiscock, 2010; Bosch and Hewlett, 1982; VanShaar et al., 2002; Mango et al., 2011; Farley et al., 2005; Liu and Zhong, 1978) or increased with vegetation destruction (Bosch and Hewlett, 1982; Woodward et al., 2014; Hibbert, 2001). (Line 63-68)

(5) Line 73-75. I don't think that catchment size is the primary control influencing the direction of flow change following land-use change. It is more a question of trade-off between modified infiltration rate and evapotranspiration rate which depends on soil structure, surface properties, depth, slope, vegetation species, etc...

Thank you for your suggestion. We agree with the referee on that point. Some of them thought it was probably the large amount of transpiration water played the main function in hydrological process when the watershed was smaller. And some thought that the different impacts of area probably because the forest of larger watershed could increase precipitation and forest was also conducive to the infiltration of water, which increased the proportion of the underground flow of sreamflow in forest region (Line 77-82).

(6) Lines 79-82. The explanation lacks clarity. Again, latitude may indirectly control the hydrological impact of land-use change, but this is certainly not the primary key player.

Thank you for your suggestion. More details are used to explain this. Huang (1982) analyzed Soviet research results found that 48% runoff coefficients increased, 32% has no change, and 20% decreased with watershed forest increasing. The increased regions were located at high latitude and humid areas. Under this condition, the total evaporation in wooded areas and woodless area are equal. The speculation was that snow may be blown away or to wooded areas from woodless area, which could enhance the coefficient of streamflow but these factors would be weaker over low to middle latitude than that in high latitude. (Line 88-94)

(7) Line 89: it is not clear if 43% corresponds to the total treated area included in the Wei Basin or if 43% of treated areas corresponds to afforestation.

Thank you for your suggestion. It is "more than 43% of the total treated area was the forestation in the main stream of Wei River basin".

(8) Line 90: This statement should be supported by a figure showing the time series of actual annual flow (cf. main comments).

Thank you for your suggestion. The figure of actual annual flow has been added (Fig.6).

(9) Lines 91-92: "streamflow" and "observed annual streamflow". Are you referring to the same variable? Please keep using the same wording when referring to the same variable.

Thank you for your suggestion. Done! (Line 104)

(10) Lines 93-95. Description of geology should be included in the section "study area".

Thank you for your suggestion. Done! (Line 103)

(11) Line 96: "And that drying layer is in great water deficit". Why? Reference required.

Thank you for your suggestion. A dried soil layer is generally formed in the soil profile at a particular depth owing to serious soil desiccation in water-limited ecosystems. The residual maximum likelihood analysis demonstrated that land use, rainfall, soil type and slope gradient had a significant impact on dried soil layer thickness, while only land use, rainfall, and soil type influenced the dried soil layer depth of formation significantly. (Line 114-118)

References:

Wang Y., Shao M., Shao H.: A preliminary investigation of the dynamic characteristics of dried soil layers on the Loess Plateau of China, Journal of Hydrology, 381, 9-17,2010a.

Wang Y., Shao M., Liu Z.: Large-scale spatial variability of dried soil layers and related factors across the entire Loess Plateau of China, Geoderma, 159, 99-108, 2010b.

(12) Lines 95 to 103: The explanations of the contrasting hydrological behaviours between the "earth-rock mountain landscape" and the Loess Plateau are not clear and not convincing. You did not mention the possible role of slope which is very different between the two types of landscape.

Thank you for your suggestion. Slope is one of the impact factors and it is also a significant impact on dried soil layer thickness (Line 117-118, Wang, 2010a). And for Loess Plateau, which also has lots of mountains, its infiltration water flowing into river is related to slope indeed, while the amount is smaller than that generated from earth-rock mountain landscape.

Study Area

(13) Lines 117-118: need to explain what the units provided define exactly.

Thank you for your suggestion. It may be clear if the sentence is revised as "We choose basin of the upper and middle reaches (4.68×10^4 km^2) of the Wei River basin (103.97° ~ 108.75° E, 33.69° ~ 36.20° N, 13.48×10^4 km^2) .". (Line 139-140)

(14) Line 132: MODIS?

Thank you for your suggestion. Done! (Line 154)

(15) Line 134: cannot see the six types of LUCC in figure 3.

Thank you for your suggestion. There are more details about legend of Fig. 3. Figure 3 is preliminary classification results of the 25 subtypes of LUCC types. And then it is classified to the six types including forest, pasture, cropland, water bodies, residential areas and the bare. The corresponding relations between Fig. 3 and these six types are: ① The forest type includes Range-Brush (RNGB), Forest-Mixed (FRST), Forest-Deciduous (FRSD), Pine (PINE) and Forest-Evergreen (FRSE); ② The pasture type includes Pasture (PAST), Winter Pasture (WPAS) and Range-Grasses (RNGE); ③ The cropland means Agricultural Land (AGRL); ④ Water includes water (WATR) and Wetlands-Mixed (WETL); ⑤ The residential areas include area of Residential-High Density (URHD) and Residential-Medium Density (URMD); ⑥ The code of bare type is BARE. (Line 158-164).

***(16)** Lines 136-137: Forest area increased by 0.81% only. It is hardly believable that thehydrological impact quantified later (line 270), (annual average reduction of 94 million m3) was caused by this very minor change.*

Thank you for your suggestion. The annual average reduction of streamflow was 94 million m^3 in study area and the area of the study basin is 4.68×10^4 km^2.

$$\frac{94\ \times 10^6\ \mathrm{m}^3}{4.68\times 10^4\ \times 10^6\ \mathrm{m}^2}\times 10^3\frac{\mathrm{m}}{\mathrm{mm}} = 2.0085\ \mathrm{mm}$$

So it was about 2.0 mm/yr to in study area, which is the average result of annual streamflow decreased during 20 years. And the average annual streamflow decreased 0.62 mm for all 30 years (1980-2009). These results are in ranges of existing research result also. (Line 311)

***(17)** Line 141: unlike what is written, the soil characteristics are not indicated on the map,(only the names of the soil types are provided).*

Thank you for your suggestion. This map means “the soil data map”, which is a vector data including much information and did not just Fig. 4 (a). The detailed soil characteristics can be found from data base we offered. There are 83 types of soil in study area and the types are classed according to soil composition, soil particle size and so on. There are some soil characteristics of HRU 1 in study area for example.

Land use: AGRL

Soil Name: QSHMT

Depth [mm]:	120.00	620.00	1280.00
Bulk Density Moist [g/cc]:	1.33	1.46	1.50
Ave. AW Incl. Rock Frag:	0.19	0.18	0.17
Ksat. (est.) [mm/hr]:	16.58	4.93	3.73
Organic Carbon [weight %]:	2.80	1.00	0.50
Clay [weight %]:	23.00	24.00	25.00
Silt [weight %]:	62.00	60.00	58.00
Sand [weight %]:	15.00	16.00	17.00
Rock Fragments [vol. %]:	0.00	0.00	0.00
Soil Albedo (Moist) :	0.16	0.16	0.16
Erosion K :	0.34	0.40	0.34
Salinity (EC, Form 5) :	0.00	0.00	0.00

***(18)** Line 145: meaning of HRUs?*

Thank you for your suggestion. HRUs are "Hydrological response units" and the full name has been added. (Line 173)

***(19)** Lines 154, 239 and 264-265: avoid "and so on".*

Thank you for your suggestion. Done!

***(20)** Line 160: cf. advices provided in my main comments.*

Thank you for your suggestion. Done!

***(21)** Line 179: need to provide much more information on the input data used to run SWAT.*

Thank you for your suggestion. The input data refers to data involved in the last sentence "It is forced with meteorological data and input with soil properties, topography, land use, and land management practices in the catchment". (Line 215-217)

***(22)** Lines 185-186: what is an "extraction threshold"?*

Thank you for your suggestion. The extraction threshold area defines the minimum drainage area required to form the origin of a stream (Line 224-225). The user has the ability to set the minimum size of the subbasins.This function plays an important role in determining the detail of the stream network and the size and number of sub-watersheds. *(Arcswat interface for SWAT 2009 User's guide, 2010).*

(23) Line 190: if subdivided into 1 HRU, then it is not subdivided. Please clarify.

Thank you for your suggestion. Delineate the watershed into subbasins using Digital Elevation Model (DEM) data and define the HRUs are key and necessary procedures for SWAT model building. Each watershed is first divided into subbasins and then in hydrologic response units (HRUs) based on the land use and soil distributions. And they have different functions. When a watershed is divided into subbasins, lots of information is loaded into the model from five sections: DEM setup, stream definition, outlet and inlet definition, watershed outlet selection and definition and subbasin parameters. And HRU analysis allows users to load land use and soil layers into the model, evaluate slope characteristics, and determine the land use/soil/lope class combinations and distributions for the delineated watershed and each subbasin. *(Arcswat interface for SWAT 2009 User's guide, 2010).*

(24) Page 11: many parameters and initial values used to calibrate the SWAT model wereissued from previous research and experiments (e.g. lines 219: "derived from simulated rainfall experiments", 228: "We have done some research", 230: "Based on the experiments", 234: "were gotten based on experiments"). No references and no explanations are provided. We need more details to understand what has been done.

Thank you for your suggestion. We have added the references (Line 258-259). The SWAT model offers initial values and ranges (minimum and maximum) for all parameters. We used the previous research of the study area to give more accurate ranges for parameters used in our study to make the model calibrate quicker.

(25) Lines 237: It is not clear how the authors have accounted for the "management operation of forest" which affect "leaf area index [...], plant biomass [...], age of trees". Need to provide some explanations here. Which management operations are accounted in the model and how do they affect the variables listed here?

Thank you for your suggestion. SWAT model can simulate 15 different types of management operations. The primary file used to summarize the land and water management practices taking place is the HRU management file (.mgt). This file contains input data for planting, harvest, irrigation applications, nutrient applications, pesticide applications, and tillage operations. In our modeling process, the agricultural land includes operations: planting/ beginning of growing season, auto fertilization initialization, harvest and kill operation. The forest just includes planting/

beginning of growing season. The planting/ beginning of growing season operation initialize the growth of a specific land cover/ plant type in the HRU. For example:

① HRU 1

Land use: AGRL

Operation Schedule:

Operation Schedule:

0.150	1	1	967.69930	0.00	0.00000	0.00	0.00	0.00
0.160	11	1	0.75000	0.00	0.00000	0.00	0.00	
1.200	5		0.00000					

The first line is the planting/ beginning of growing season operation. The parameters of the first four numbers are HUSC, MGT_OP, PLANT_ID, HEAT UNITS in turn.

HUSC is the timing of planting operation, which is the fraction of total base zero heat units at which operation takes place.

MGT_OP is operation code. MGT_OP=1 is for plant operation.

PLANT_ID is plant/ land cover code from crop.dat. PLANT_ID=1 means that the crop is warm season annual legume. For this crop type, the root depth varies during growing season due to root growth and heat unit theory is used to regulate the growth cycle of plants.

HEAT UNITS is the total heat units for cover/plant to reach maturity. Temperature is one of the most important factors governing plant growth. For any plant, a minimum or base temperature must be reached before any growth will take place. Above the base temperature the more rapid the growth rate of the plant. Once the optimum temperature is exceeded the growth rate will begin to slow until a maximum temperature is reached at which growth ceases. The heat unit theory postulates that plants have heat requirements that can be quantified and linked to time to maturity. For example, assume sweet peas are growing with a base temperature of 5 ^{o}C. If the mean temperature on a given day is 20 ^{o}C, the heat units accumulated on that day are 20-5 =15 heat units.

MGT_OP=5 is for harvest and kill operation plant operation. This operation harvests the portion of the plant designated as yield, removes the yield from the HRU and converts the remaining plant biomass to residue on the soil surface. The harvest and kill operation stops plant growth in the HRU. The fraction of biomass specified in the land cover's harvest index is removed from HRU as yield.

② HRU 307

Land use: FRST

Operation Schedule:

0.150 1 6 50 1043.40000 5.00 1000.00000 0.00 0.00 0.00

The parameters of the first seven numbers are HUSC, MGT_OP, PLANT_ID, CURYR_MAT, HEAT UNITS, LAT_INIT, BIO_INIT in turn. The HUSC and MGT_OP are the same with AGRL.

PLANT_ID=6 means that the crop is perennial which root depth always equal to the maximum allowed for the plant species and soil and plant goes dormant when day length is less than the threshold day length.

CURYR_MAT is the current age of trees (years).

LAT_INIT is the initial leaf area index. This variable is used only for covers/ plants which are transplanted rather than established from seeds. LAI is the leaf area index of the canopy. The plant canopy can significantly affect infiltration, surface runoff and evaporation. Canopy storage is the water intercepted by vegetative surface where it is held and made available for evaporation. When precipitation falls on any given day, the canopy storage is filled before any water is allowed to reach ground. Potential soil water evaporation and plant transpiration are estimated as a function of potential evapotranspiration and LAI. The leaf area index (LAI) for the reference crop is estimated using an equation developed by Allen et al. (1989) to calculate LAI as a function of canopy height. For trees, the fraction of potential heat units accumulated for the plant on a given day in the growing season, the fraction of growing season, the number of years for the tree species to reach development.

BIO_ INIT is the initial dry weight biomass (kg/ha). This variable is used only for covers/ plants which are transplanted rather than established from seeds. The potential increase in plant biomass on a given day is a function of intercepted energy and the plant's efficiency in converting energy to biomass. Energy interception is estimated as a function of solar radiation and the plant's LAI.

Results and discussions

(26) *Line 253: It is not clear if the model efficiencies provided correspond to an average for each hydrological unit or for the whole basin.*

Thank you for your suggestion. They were corresponding statistic results of Fig. 7 (The time-series graphs of calculated vs. observed values during calibration period and verification period for hydrological stations) for each hydrological station. (Line 293)

__(27) Lines 257, 258: unlike what is written, the trend is not obvious in fig. 6. It would beclearer to redraw the figure at the monthly and annual time steps to visualize possible trends over years.__

Thank you for your suggestion. The monthly time-series graph of calculated vs. observed values during calibration period and verification period for hydrological stations is as follows (Fig.1.2).

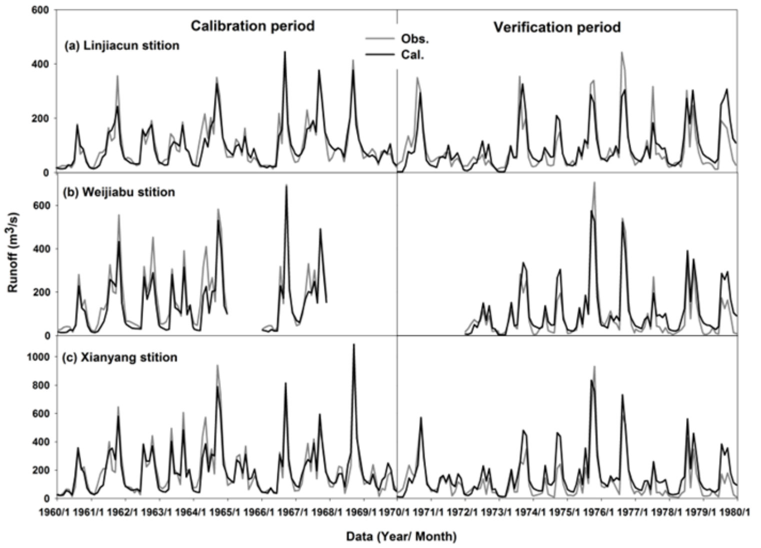


Fig. 1.2 The monthly time-series graphs of calculated vs. observed values during calibration period and verification period for hydrological stations

__(28) Line 269: it is not clear what is the 20-year period referred here. Calibration and validation periods are 10 years long and simulation period include 30 years. Further explanations are required. Line 270: there are 3 problems here. 1/ it is not clear in which catchment the hydrological change (annual average reduction of 94 million m3) was assessed, upper or middle ?. b/ this hydrological change should be translated into millimeters of runoff reduction to assess its magnitude and significance. c/ the text indicates that this change is caused by forestation. Indeed, it only reflects the change in the model parameters between the calibration/validation and the simulation periods. But, as already indicated, it does not reflect the actual changes that occurred in the catchment.__

Thank you for your suggestion. We have revised this part (Line 309-311). It is 20 years in 30 simulation years (1980-2009), which annual streamflow decreased. In other 10 years, the streamflow did not decrease. (a) It changed in the study area (upper and middle reaches of the Wei River basin). (b) The annual average reduction was 2.0 mm/yr for these years in study area. (c) The text indicates that the change is caused by LUCC and hydrological conditions. Because the LUCC involves too many types of land uses, we then designed the experiments for forest changing only to study its impact. Because under the same hydrological condition, the streamflow reduced in most years and increased in other years, 30-year average of the streamflow for forest and agricultural land were taken, respectively to reduce influence of meteorological conditions and isolate the impact of the LUCC on streamflow.

(29) *Line 273: reference required when referring to previous experiments.*

Thank you for your suggestion. We have added the references. (Line 315)

(30) *Lines 278-279: "30-year average of the streamflow for forest and agricultural land weretaken". Please explain what was done exactly here. Are you referring to the two sets of simulated flow described in lines 263-267? or different hydrological units with agricultural land or forest cover for a given period?*

Thank you for your suggestion. The 30-year (1980-2009) average values of the streamflow for forest and agricultural land were averaged respectively. The same period was used. (Line 320-323)

(31) *Lines 291-294. This paragraph is about method and should be moved in the appropriate section. It is referring to 3 regions. Which ones? Three different approaches re described to define the LUCC scenarios but the results of each approach are not resented. It seems that figures 8, 10 and 12 only present results for approach 1.*

Thank you for your suggestion. The 3 regions were divided by 3 Linjiacun, Weijiabu and Xianyang hydrological stations (three different color regions with number of Fig. 2 and 3 regions of Fig. 6) (Line 343-344). They were just 3 control conditions when the land use converted from agricultural land to forest. The second and third conditions were considered as much as possible to reduce impacts of other factors based on the first condition.

(32) *Line 306: the authors indicate that the actual change in forest cover calculated using he land-use maps displayed in figure 3 (0.8% increase) would lead to less than 1% hange in* *streamflow. I agree with this realistic statement but: is it consistent with the hydrological change quantified in line 270?*

Thank you for your suggestion. Line 358 is the result of conversion of agricultural land to forest on streamflow. Line 311 is the result of LUCC changes on streamflow, which involves many types of land use conversion measures and is a balanced result among these measures. So the changes of streamflow, surface runoff, soil flow and baseflow between agricultural land and forest were singled out (Fig.8 The changes of 30-year (1980-2009) averages of streamflow, surface runoff, soil flow and baseflow between agricultural land and forest.). We can see the impacts are consistent.

(33) *Lines 314-325. the authors explain differences in hydrological behaviour of the Loess Plateau and earth-rock mountain, based on other publications, but this paragraph is not linked to the result of the study. The authors need to evidence how these distinctive hydrological behaviours influence their results.*

Thank you for your suggestion. As suggested, we have revised this paragraph carefully and add more details to make it clean. (Line 367-384)

Figures

(34) *Fig. 1: Areas under different treatments are expressed in 104 hm2 (i.e. squared hectometers?). This is an atypical unit which is different from the unit used for the study area in the text (104 km2). All areas should be provided in same unit to allow easier comparison. It would be clearer to provide the percentage area so that we anticipate the possible effect of the land treatment on the catchment hydrology.*

Thank you for your suggestion. Figure 1 is revised as suggestion.

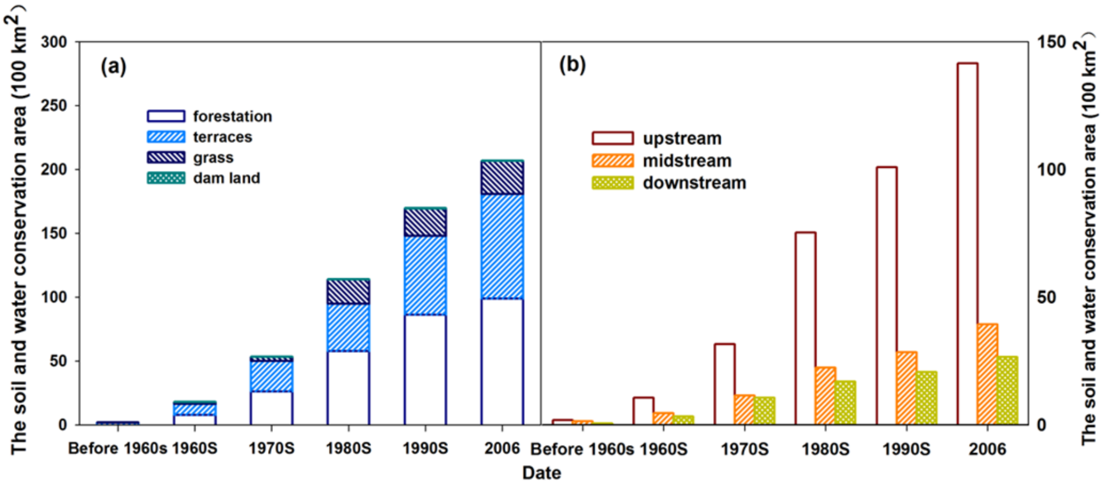


Fig.1

<u>(35) Fig.2. What is the meaning of all small numbers written on the map of the study area? If they correspond to hydrological units, it is surprising to see numbers in the downstream part which is not included in the study area.</u>

Thank you for your suggestion. The numbers of Fig. 2 are serial number of subbasins/ HRUs (Line 208). All numbered area is study area. Linjiacun station locates at the control section of the upstream and Xianyang station is the control station of middle reaches (Line 133-135). And the upper and middle reaches of the Wei River basin is the study area.

<u>(36) Fig. 6. The scale on the X axis is too big: we cannot see the details in the daily flow variations and in the matching between observed and simulated flow. The figure should be bigger or all panels (calibration and verification should be put in the same column to allow larger size.</u>

Thank you for your suggestion. It is more clearly indeed as suggestion (Fig. 7).

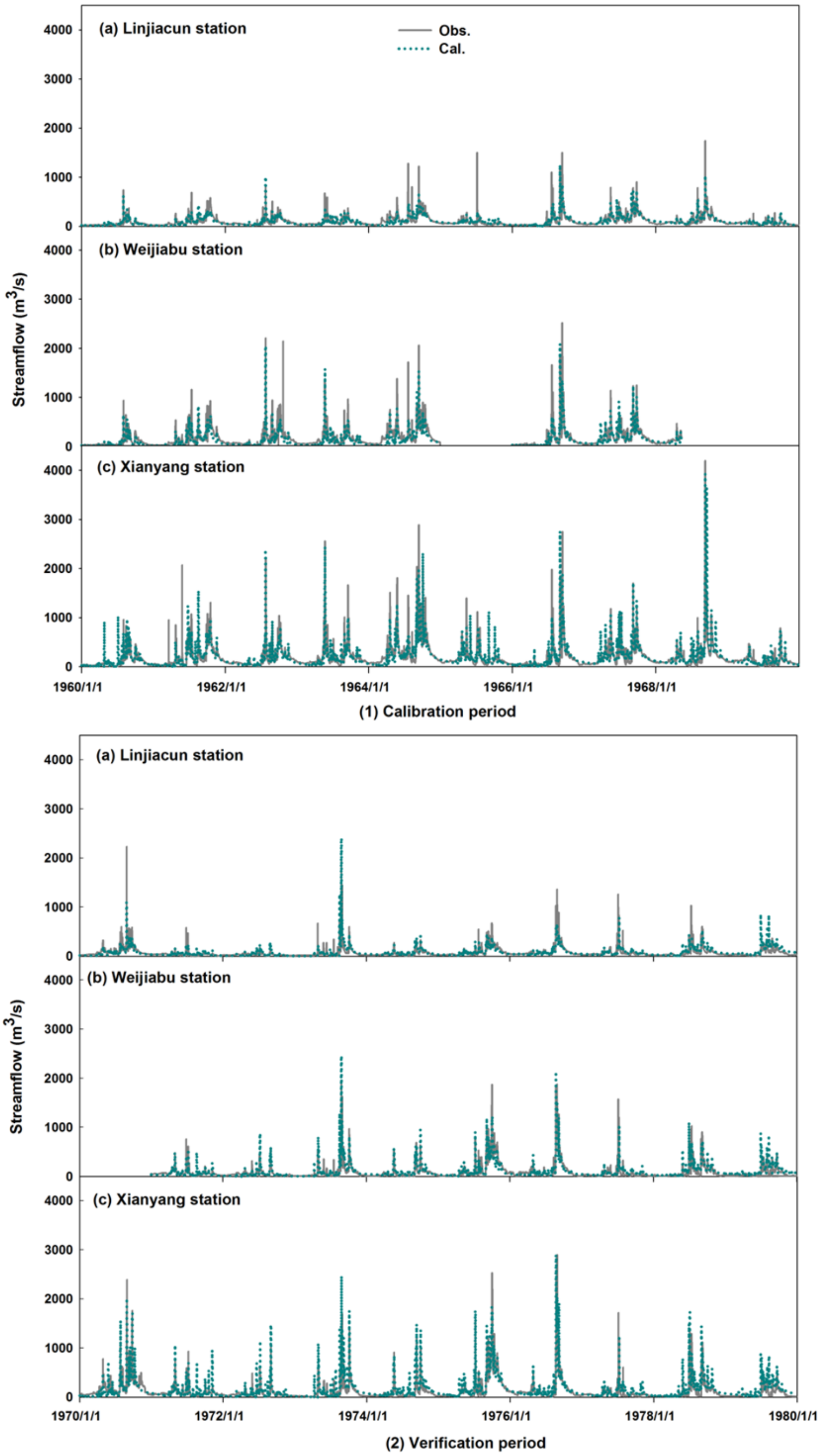
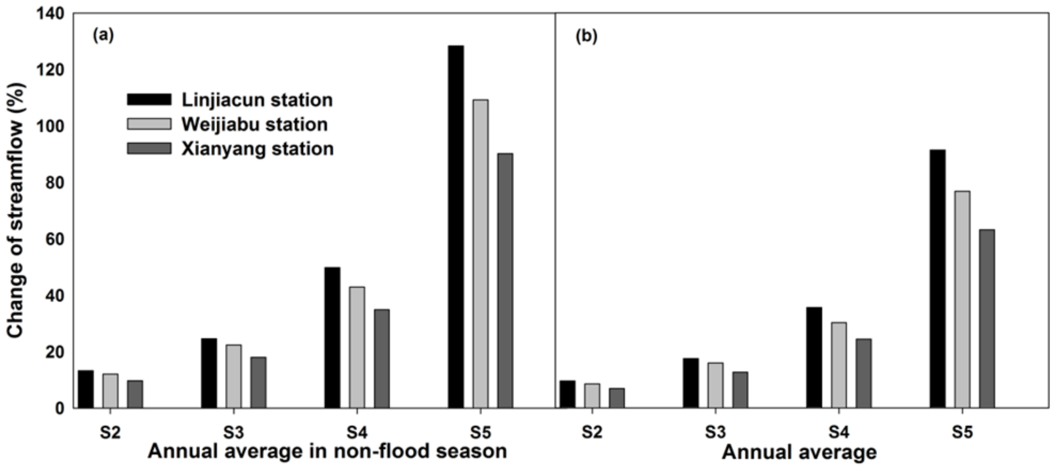


Fig. 7

__(37) Fig. 9: What is the meaning of "corresponding proportional change rate"?__

Thank you for your suggestion. It is the change rate of streamflow at the Linjiacun, Weijiabu and Xianyang stations correspondingly. We have revised the figure (Fig.10).



References:

Lacombe G, Cappelaere B, Leduc C. 2008. Hydrological impact of water and soil conservation works in the Merguellil catchment of central Tunisia. Journal of Hydrology. 359: 210-224.

Lacombe G, Ribolzi O, de Rouw A, Pierret A, Latsachak K, Silvera N, Pham Dinh R, Orange D, Janeau JL, Soulileuth B, Robain H, Taccoen A, Sengphaathith P, Mouche E, Sengtaheuanghoung O, Tran Duc T, Valentin C. 2016. Contradictory hydrological impacts of afforestation in the humid tropics evidenced by long-term field monitoring and simulation modelling. Hydrology and Earth System Sciences. 20:2691-2704.

Thank you for your recommendations. We have studied the references and cited them in manuscript (Line 53-54, line 84).

Part 3: Author's Response-RC2

Response:

The authors appreciate the reviewers for helpful and constructive comments that improved our original manuscript. We have addressed the comments below and have made corrections. The changes being made are marked in the manuscript.

Response to the detailed comments:

1. Could you add the assessment of model performance for use period (1980-2009) except calibration and validation periods?

Thank you for your suggestions. We add a new Fig. 2.1 to show the time-series graph of calculated streamflow vs. observed streamflow during 1980-2009 for hydrological stations. We can see the calculated streamflow matched well with the observed values before 1990. The observed values were measured daily based on the actual LUCC, while the calculated streamflow was got based on LUCC of 1980. So Fig. 2.1 shows the calibrated SWAT model played well in our study area and the changing LUCC can affect streamflow gradually. The streamflow of typical year, the same year with LUCC, is the results of by LUCC and meteorological conditions. To reduce influence of meteorological condition and isolate the impact of the LUCC on streamflow, 30-year average of the streamflow for forest and agricultural land were taken, respectively. For period of 1980-2009, we just used their measured and long-term daily meteorological data in the study area to drive the validated model for the designed hydrological experiments.

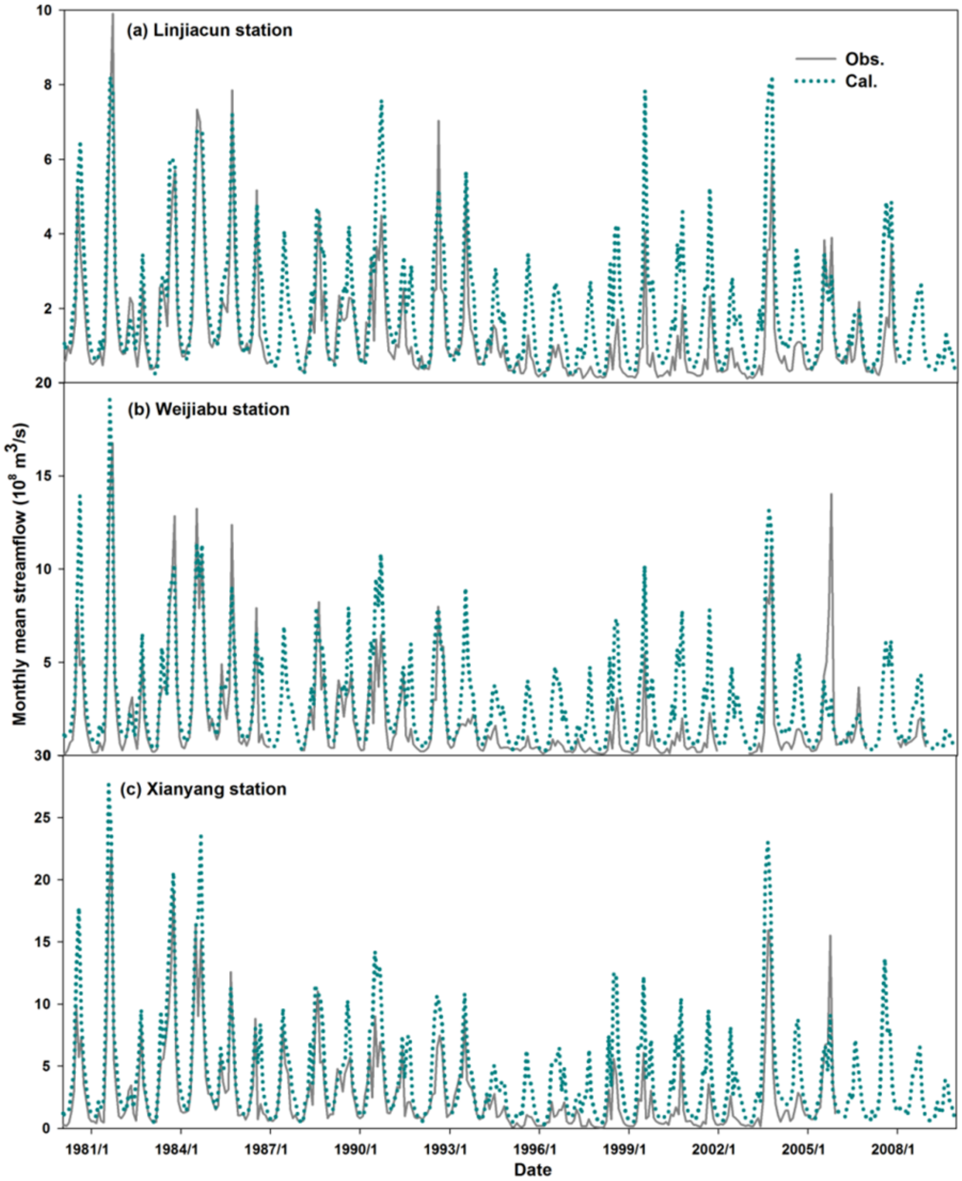


Fig. 2.1 The time-series graphs of calculated vs. observed streamflow during 1980-2009 for hydrological stations.

2. Could you provide the water balance (soil moisture, ET, streamflow, baseflow etc.) for each scenario in a Table? And try to analyze how ET change?

Thank you for your suggestions. Table 2.1 shows the water balance for different scenarios. The ET values decreased with increasing of forest area overall.

Table 2.1 The water balance for different scenarios

	S1	S2	S3	S4	S5
ET (mm)	388.98	380.39	373.38	358.87	311.47

Streamflow (mm)	Surface runoff (mm)	21.19	21.13	21.43	21.58	21.53
	Soil flow (mm)	68.42	69.52	70.63	72.57	77.22
	Baseflow (mm)	29.92	36.99	42.37	54.06	94.24
Precipitation (mm)		509.62				

3. Part 2.2, the LUCC data were divided into six types which included forest land and shrub land. As we know, similar to forest land, shrub land is also important for water and soil conservation in (semi)arid area. So, could you make a comparison about stream flow change caused by forest and shrub land change? Could you show more data and function about check dams, reservoirs, water channels, and water conservancy projects from 1980 to 2009, even for the calibration and validation periods? I understand this is a virtual experimental (or scenario) study, but the results would provide some implications for land use policy, and therefore need carefully check anything related with hydrology cycle. To my knowledge, there are a lot of check dams for agriculture catchments on loess plateau, which might change hydrology (streamflow) as well. If they are not considered in calibration and validation periods, SWAT model may get wrong parameters for different land use types even if the model results (streamflow) is correct.

Thank you for your suggestions. The forest type includes Range-Brush (RNGB), Forest-Mixed (FRST), Forest-Deciduous (FRSD), Pine (PINE) and Forest-Evergreen (FRSE). In Part 2 and 4.1, the forest included all these types, while for the hydrological experiments (part 4.2 and 4.3) the agricultural land was converted to FRST only. The comparison of per unit streamflow between forest and shrub land for 2 LUCC types from 1980 to 2009 is showed in box figure as figure 2.2. The annual average streamflow increased 0.81% in Range-Brush (RNGB) land and the streamflow yield of forest is about 1.18 times of that of RNGB respectively. We also analyzed the streamflow generation of the main types of forest (RNGB, FRST and FRSD) in study area further. Results showed that the streamflow yield of FRST and FRSD were about 1.20 and 1.60 times of that of RNGB respectively.

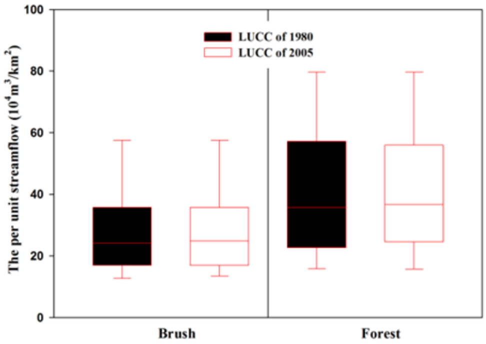


Figure 2.2 The per unit streamflow generation between forest and shrub land for 2 LUCC types

Figure 2.3 showed the development of different soil and water conservation measures (including forestation, terraces, grass and dam land) in the whole and main stream basin of Wei River respectively. According to this figure, we could see the soil and water conservation measures were mainly implemented in the study area after the 1980s in study area. Hence we choose 1960-1969 and 1970-1979 for the model calibration and validation respectively. For period of 1980-2009, we just used their measured and long-term daily meteorological data in the study area to drive the validated model for the designed hydrological experiments. The long-term data could reduce influence caused by meteorological conditions and isolate the impact of the LUCC on streamflow.

And the impacts of terrace and check dam had a regulation effect on streamflow that they could reduce the runoff in the flood season, increased the base flow and guarantee the river ecological flows in non-flood season on the Loess Plateau (Shao, 2013; Xu, 2013). For example： Xu and Fu et al (2013) applied the SWAT (Soil and Water Assessment Tool) model to simulate the runoff in the Yanhe watershed and results showed that the check dams had a regulation effect on runoff. From 1984 to 1987, the runoff in rainy season (from May to October) decreased by 1.54 m^3s^{-1} (14.7 %) to 3.13 m^3s^{-1} (25.9 %) due to the check dams; while in dry season (from November to the following April), runoff increased by 1.46 m^3s^{-1} (60.5%) to 1.95 m^3s^{-1} (101.2 %); From 2006 to 2008, the runoff in rainy season decreased by 0.79 m^3s^{-1} (15.5 %) to 1.75 m^3s^{-1} (28.9 %), and the runoff in dry season increased by 0.51 $m^3 s^{-1}$ (20.1 %) to 0.97 m^3s^{-1} (46.4 %). While the impacts of vegetation on streamflow are controversial and complicated and results are different among different basins, so the forest was selected to analyze in detail.

References:

Xu, Y. D., Fu, B. J., He, C. S.: Assessing the hydrological effect of the check dams in the Loess Plateau, China by model simulations, Hydrology & Earth System Sciences Discussions, 2013, 9(12):13491-13517.

Shao, H., Baffaut, C., Gao, J. E., et al. Development and application of algorithms for simulating terraces within SWAT [J]. Transactions of the Asabe, 2013a, 56(5):1715-1730.

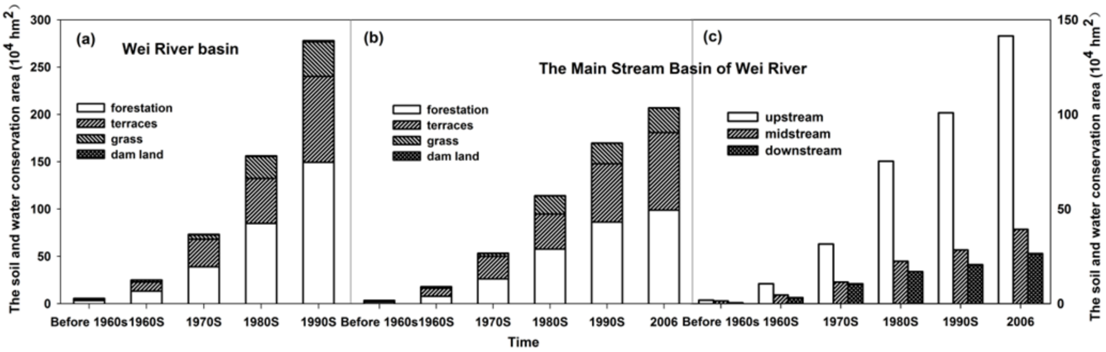


Figure 2.3 The development of different soil and water conservation measures in the whole and main stream basin of Wei River respectively.

Part 4: a marked-up manuscript

Impact of LUCC on Streamflow ~~using~~ Based on the SWAT Model over the Wei River Basin on the Loess Plateau of China

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Abstract: Under the Grain for Green project in China, vegetation recovery constructions have been widely implemented on the Loess Plateau for the purpose of soil and water conservation. Now it becomes controversial whether the recovery constructions of vegetation, particularly forest, is reducing streamflow in rivers of the Yellow River Basin. In this study, we choose the Wei River, the largest branch of the Yellow River and implemented with revegetation constructions, as the study area. To do that, we apply the widely used Soil and Water Assessment Tool (SWAT) model for the upper and middle reaches of the - Wei River basin. The SWAT model was forced with daily observed meteorological forcings (1960-2009), calibrated against daily streamflow for 1960-1969, validated for the period of 1970-1979 and used for analysis for 1980-2009. To investigate the impact of the LUCC (Land Use and land Cover Change) on the streamflow, we firstly use two observed land use maps of 1980 and 2005 that are based on national land survey statistics emerged with satellite observations. We found that the mean streamflow generated by using the 2005 land use map decreased in comparison with that using the 1980 one, with the same meteorological forcings. Of particular interest here, we found the streamflow decreased in agricultural land but increased in forest area. More specifically, the surface runoff, soil flow and baseflow all decreased in agricultural land, while the soil flow and baseflow of forest were increased. To investigate that, we then designed five scenarios including (S1) the present land use (1980), (S2) 10%, (S3) 20%, (S4) 40% and (S5) 100% of agricultural land was converted into mixed forest. We found that the streamflow consistently increased with agricultural land converted into forest by about 7.4 mm per 10%. Our modeling results suggest that forest recovery constructions have positive impact on both soil flow and base flow compensating reduced surface runoff, which leads to a slight increase in

streamflow in the Wei River with mixed landscapes of Loess Plateau and earth-rock mountain.

1. Introduction

Since 1999, China's Grain for Green project has greatly increased the vegetation cover (Chen et al., 2015) and the total conversion area reaches 29.9 million ha until 2014 (Li, 2015). And the proposals are to further return another 2.83 million ha farmland to forest and grassland by 2020 (NDRC, 2014). The establishment of either forest or grassland on degraded cropland has been proposed as an effective approach to mitigating climate change because these types of land use can increase soil carbon stocks (Yan et al., 2012; Deng et al., 2013). Implementation of large scalar Grain for Green project is undoubtedly one type of geoengineering which not only mitigates climate change but also is expected to alter hydrological cycle (Lacombe et al., 2016; Lacombe et al., 2008).

Some researchers have urged a cessation on Grain for Green expansion on the Loess Plateau of China and argued that continued expansion of revegetation would cause more harm than good to communities and the environment (Chen et al., 2015). One important reason was that the Grain for Green project lead to annual streamflow of the Yellow River declining (Chen et al., 2015; Li, 2001). Land use change can disrupt the surface water balance and the partitioning of precipitation into evapotranspiration, runoff, and groundwater flow (Sriwongsitanon and Taesombat, 2011; Foley et al., 2005; Wagner et al., 2013). Large scale revegetation constructions change hydrologic cycle process and distribution of water resources. There are three controversial points of view about the impact of vegetation on streamflow as a whole. Quite a few catchment studies indicated that annual streamflow decreased with revegetation ~~increased~~ increasing (Zhang and Hiscock, 2010; Bosch and Hewlett, 1982; VanShaar et al., 2002; Mango et al., 2011; Farley et al., 2005; Liu and Zhong, 1978) or increased with vegetation destruction (~~Zhang and Hiscock, 2010;~~ Bosch and Hewlett, 1982; ~~VanShaar et al., 2002; Waring et al., 1998; Mango et al., 2011;~~ Woodward et al., 2014~~; Farley et al., 2005~~; ~~Liu and Zhong, 1978;~~ Hibbert, 2001), where some catchment studies indicated baseflow of forests was lower due to their high evapotranspiration rates (Lørup et al., 1998; Lorup and Hansen, 1997; Smith and Scott, 1992), while other studies indicated the baseflow increased in the dry season due to higher infiltration and recharge of subsurface storage (the "sponge-effect hypothesis") (Price, 2011; Lørup et al., 1998; Ogden et al., 2013). In contrast, other studies showed that vegetation has a positive impact on streamflow (Tobella et al., 2014; Li et al., 2001) or no impact on streamflow (Wang, 2000; Beck et al., 2013).

To interpret the controversial results, it was argued that the impact of vegetation on annual streamflow depends on watershed area and the relationship between them was negative in smaller watershed and positive in larger watershed (Huang et al., 2009; Zhang, 1984). Some of them thought it was probably the large amount of transpiration water played the main function in hydrological process when the watershed was smaller. And some thought that the different impacts of area probably because the forest of larger watershed could increase precipitation and vegetation was also conducive for the infiltration of precipitation, which increased the proportion of the underground flow of streamflow in forest region. Some researchers indicated tree planting has both negative and positive effects on water resources and the overall effect was the result of a balance between them, which were strongly dependant on tree density (Tobella et al., 2014). Lacombe et al. (2016) found soil infiltrability was an important factor for explaining two modes of afforestation (natural regeneration vs. planting) led to opposite changes in streamflow regime. ~~Some results showed that regions of increasing streamflow with forest usually occur at high~~

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~~latitude area~~Huang (~~Huang,~~ 1982)~~.~~ analyzed Soviet research results found that 48% runoff coefficients increased, 32% has no change, and 20% decreased with watershed forest increasing. The increased regions were located at high latitude and humid areas. Under this condition, the total evaporation in wooded areas and woodless area are equal. The speculation was that snow may be blown away or to wooded areas from woodless area, which could enhance the coefficient of streamflow but these factors would be weaker over low to middle latitude than that in high latitude (Huang, 1982). Further, vegetation may change hydrological cycle as follows (Le Maitre et al., 1999): redirection of precipitation by the canopy; branches, stem and litter tends to intercept more water into the soil; roots may provide channels for the flow infiltrating to groundwater and extract soil water as evaporation. Hence different results have led to contentious relationship between vegetation and streamflow (Bradshaw et al., 2007; Dijk et al., 2009).

The Wei River is one main branch of the Yellow River and has been widely implemented measures of soil and water conservation since the 1980s (Fig. 1)~~.~~ Meanwhile the annual streamflow of the Wei River has decreased significantly since the 1980s (Liu and Hu, 2006; Lin and Li, 2010; Wang et al., 2011). Since the 1990s, the streamflow has sharply dropped and the observed streamflow of Linjiacun station in the 1990s was less than one third of that before 1990s ~~Until 2006, the treated area accounted for about one third of the watershed, more than 43% of which was the forestation in the main stream of Wei River basin~~. The terrace and check dam both had a negative effect on annual streamflow which was a result of the balance between the streamflow reducing in the flood season and baseflow increasing in non-flood season on the Loess Plateau (Shao et al., 2013a; Xu et al., 2013). But the impacts of vegetation on streamflow are controversial and complicated~~Meanwhile the annual runoff of the Wei River has decreased~~

~~significantly since the 1980s (Liu and Hu, 2006; Lin and Li, 2010; Wang et al., 2011). Since the 1990s, the streamflow has sharply dropped and the observed annual streamflow of Linjiacun station in the 1990s was less than one third of that before 1990s. Meanwhile the Wei River basin consists of Loess Plateau landscape and earth-rock mountain landscape, which induce different mechanisms transforming rainfall into streamflow~~. –Meanwhile ~~On~~ on the Loess Plateau, it was found that there is a drying layer of soil underneath forest with a depth of over 1 m to 3 m from the soil surface owing to serious soil desiccation in water-limited ecosystems (Li, 2001; Wang, 2010a). The land use, rainfall, soil type and slope gradient had a significant impact on dried soil layer thickness (Wang, 2010b). ~~And~~ And the~~that drying layer is in~~ great water deficit~~, which~~ prevents gravitational infiltration of rainfall and replenishment of groundwater. So forests on the Loess Plateau reduced streamflow as the results of increased retention of rainfall and reduced recharge into ground water (Li, 2001; Tian, 2010). But for earth-rock mountain landscape, vegetation grows on thinner soil layer of rock mountain, which is apt to be saturated and produce soil flow on relatively impermeable rock. So the streamflow in wooded areas might be larger than that in adjacent woodless areas. Under this situation, forests may have positive impact for producing streamflow (Liu and Zhong, 1978).

To investigate that, we develop hydrological experiments based on the widely used SWAT model and observed hydrological/ meteorological data and land use data in the Wei River. We aim at understanding possible impact of revegetation constructions, especially the forest restoration on streamflow and its components in the Wei River, which is not only the largest branch of the Yellow river but also with very mixed landscape with the loess plateau and earth-rock mountain. In Sect. 2, we describe the study area and data. In Sect. 3, we set up, calibrate, and validate the

SWAT model in the Wei River. Section 4 reports the numerical experiment results, which is then followed by the conclusion in Sect. 5.

2. Study area and data

2.1 Study area

Wei River is the largest tributary of the Yellow River, which originates from the north of the Wushu mountain at an altitude of 3495 m (involving Gansu, Ningxia and Shaanxi Provinces), and runs across 818 km through into the Yellow River at Tongguan County, Shaanxi Province. In this study, we choose the basin of the upper and middle reaches (4.68×10^4 km^2) of the Wei River basin (103.97° ~ 108.75° E, 33.69° ~ 36.20° N, 13.48×10^4 km^2). And the Linjiacun, Weijiabu and Xianyang hydrological stations are used from upstream to ~~downstream~~ midstream in this study (Fig. 2~~). ~~), which divided the study area into 3 regions. Linjiacun station locates at the control section of the upstream and Xianyang station is the control station of middle reaches.

Geologically, the basin consists of the Loess Plateau and Qinling Mountain in the respective north and south of the Wei River (Fig. 2). In the north, there are fewer tributaries, whose lengths are further and the gradient is smaller. While in the south, abundant tributaries originate from Qinling Mountain which ~~are~~is steep and close to the river. So the tributaries are shorter and the flows are swifter. And there distribute lots of earth-rock mountain landscape and gravel riverbed in the piedmont.

2.2 Land Use and land Cover Change (LUCC) data

We obtained observed LUCC data from National Science & Technology Infrastructure of China, National Earth System Science Data Sharing Infrastructure (Fig. 3) (http://www.geodata.cn). Land use maps for the years of 1980 and 2005 were interpreted based on the corresponding national land use survey data (1:100,000), satellite image, the ~~MODUS~~ MODIS data, 250-meter space resolution data and combined with pasture resources map (1:500,000), soil type map (1:1,000,000), vegetation type map (1:1,000,000) and other auxiliary data. The LUCC data were divided into six types and further 25 subtypes. And the six types included forest, shrubland, pasture, cropland, water bodies and residential areas~~.~~: ① The forest type includes Range-Brush (RNGB), Forest-Mixed (FRST), Forest-Deciduous (FRSD), Pine (PINE) and Forest-Evergreen (FRSE); ② The pasture type includes Pasture (PAST), Winter Pasture (WPAS) and Range-Grasses (RNGE); ③ The cropland means Agricultural Land (AGRL); ④ Water includes water (WATR) and Wetlands-Mixed (WETL); ⑤ The residential areas include area of Residential-High Density (URHD) and Residential-Medium Density (URMD); ⑥ The code of bare type is BARE. The area of agricultural land decreased about 7.26% and forest area increased 0.81% in 2005 compared with 1980 for the study area.

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2.3 Soil data

Soil data were obtained from National Science & Technology Infrastructure of China, National Earth System Science Data Sharing Infrastructure (Fig. 4(a)) (http://www.geodata.cn). This soil data map reflects the distribution and characteristics of different soil type and digitized based on 1:500,000 remote sensing digital figures of environment on Loess Plateau.

Based on the soil data, the distribution of earth-rock mountain in study area is drawn as Fig. 4(b). There were 83 soil types in the study area and 15 of them are composed of earth and rock involving 70 hydrological response units (HRUs) (Table 1). At the same time, these 15 soil types distribute mainly in the Qinling Mountain and Liupan Mountain (Fig. 2). And the earth-rock mountain area accounts for 24% of study area.

2.4 Meteorological and hydrological data

The meteorological data were obtained from the China Meteorological Data Sharing Service System (http://www.escience.gov.cn/metdata/page/index.html) and some ~~additional sites from~~ local rainfall stations. The data include atmospheric pressure, mean (minimum and maximum) temperature, vapor pressure, relative humidity, rainfall, wind speed, wind direction, sunshine time~~, and so on~~. Figure 5 (a) shows the distribution of meteorological stations and the annual average precipitation over Wei River basin, which was calculated using kriging interpolation method of ArcGIS 9.3 based on annual average precipitation of 34 meteorological stations. Then the time series of annual average precipitation for the three regions of ~~over~~ the study area ~~whole basin~~ w~~as~~ere calculated respectively using elevation bands method of ArcSWAT (Soil and Water Assessment Tool) 2009.93.7b, which can account for orographic effects on precipitation (Neitsch et al., 2011). SWAT allows the subbasin to be split into a maximum of ten elevation bands. Precipitation is calculated for each elevation band as a function of the respective lapse rate and the difference between the gage elevation and the average elevation specified for the band. Once the precipitation values have been calculated for each elevation band in the subbasin, new average subbasin precipitation value is calculated based on the fraction of subbasin area within the elevation band (Neitsch et al., 2011).

~~using Thiessen polygon method of ArcGIS 9.3, which divided the basin and gave the weight of each meteorological station according to its control area. It was 544.8 mm/yr on average varying from 267 to 920 mm (from northwest to southeast) over the past 55 years (1956-2010). The time series of rainfall over the basin was for a slight increase since 1956 and then it started to~~

~~decline. After the minimum of rainfall in the 1990s, it began to increase subsequently. The annual average rainfall of 2000-2010 increased by about 6% compared with the 1990s.~~ And the daily streamflow data of three hydrological stations were obtained ~~came~~ from Ecological Environment Database of Loess Plateau (http://www.loess.csdb.cn/pdmp/index.action) and the Hydrological Year books of China. Figure 6 shows the time-series of average precipitation, annual streamflow and runoff coefficients for the 3 regions of study area. And the runoff coefficients were 0.13, 0.35 and 0.17 on average for region 1, 2 and 3 over the past 50 years (1960-2009).

90-meter resolution digital elevation model (DEM) (Fig. 5 (b)) was used to define the topography and delineate the watershed boundary. It was obtained from the Computer Network Information Center, Chinese Academy of Sciences (http://srtm.datamirror.csdb.cn/), based on the Shuttle Radar Topography Mission (SRTM) version 4.1.

3. Methods

3.1 The SWAT model

The SWAT ~~(Soil and Water Assessment Tool)~~ model is developed by the USDA Agricultural Research Service (ARS). It is a physically based and distributed hydrological model. The SWAT model has been widely applied to understand the impact of land management practices on water, sediment and agricultural yields over large complex watersheds with varying soils, land use and management conditions over long periods (Arnold et al., 2009). It is forced with meteorological data, and input with soil properties, topography, land use, and land management practices in the catchment. The physical processes associated with hydrological cycle and sediment movement etc. are directly modeled by SWAT using ~~this~~ these input data (Arnold et al., 2009). In addition, the ArcSWAT extension (ArcSWAT 2009.93.7b version) is used as the graphical user interface for the

SWAT model (Gassman et al., 2007; Arnold et al., 1998).

3.2 The SWAT Model setup

The SWAT model setup includes four steps: watershed delineation, hydrological response unit (HRU) analyst, input database building and modification and model operation. Based on research of the Wei River (Shao, 2013b; Wang, 2013), the extraction threshold, which is the minimum drainage area required to form the origin of a stream, of subbasin area was 80 km^2. The Linjiacun, Weijiabu and Xianyang hydrological stations were loaded manually as subbasin outlets and one whole watershed outlet was defined. The study area was divided into 308 subbasins (Fig. 2). The land area in a subbasin can be further divided into the HRUs, which is the basic computing element of the SWAT model. In this study, a subbasin was subdivided into only one HRU that was characterized by dominant land use and soil type. Then the daily meteorological data, including temperature, relative humidity, sunshine duration, wind speed, rainfall, were input and all data were written into database building and modification to force the SWAT model.

For evaluating the performance in the model calibration and validation, we use the R^2 and NS coefficient to evaluate the performance rating of the model (Nash and Sutcliffe, 1970) (Equation (1) & (2)).

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(O_i^{obs} - \overline{O_i^{obs}}\right)\left(O_i^{sim} - \overline{O_i^{sim}}\right)\right]^2}{\sum_{i=1}^{n}\left(O_i^{obs} - \overline{O_i^{obs}}\right)^2\left(O_i^{sim} - \overline{O_i^{sim}}\right)^2} \qquad \text{Eq. (1)}$$

$$NS = 1 - \frac{\sum_{i=1}^{n}\left(O_i^{obs} - O_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(O_i^{obs} - \overline{O_i^{obs}}\right)^2} \qquad \text{Eq. (2)}$$

where n is the number of observations, O^{obs} is the observed value, O^{sim} is the simulated value, and the overbar means the average of the variable. The R^2 describes the proportion of the variance in

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measured data explained by the model and typically 0.5 is considered an acceptable threshold (Santhi et al., 2001; Van Liew and Garbrecht, 2003). The SWAT model simulation can be judged as "satisfactory" if the NS > 0.50 for a monthly time step simulation and the performance rating of the SWAT model was very good when the NS > 0.75, and the model performed good when the NS > 0.65 (Moriasi et al., 2007).

3.3 Calibration and validation of the SWAT model

We setup the SWAT-CUP procedure for the sensitivity analysis, calibration and validation in our study (Abbaspour, 2007). The sensitivity analysis is carried out by keeping all parameters constant to realistic values, while varying each parameter within the range assigned in step one. The sensitive parameters were calibrated using LH-OAT (Latin-Hypercube-One Factor-At-a-Time) method of the Sequential Uncertainty Fitting (SUFI2) program (Abbaspour, 2007; Xu et al., 2012). And the t-stat and p-value were used to evaluate the sensitivity of parameters. The t-stat is the coefficient of a parameter divided by its standard error and the larger values are more sensitive. And the p-value determines the significance of the sensitivity and a value close to zero means more significant. The most sensitive (seven) parameters were selected by the SWAT-CUP module. Combined with previous research in Wei River, two additional parameters (SOL_K and GW_DELAY) with the seven parameters were selected in this study (Table 2).

The initial value and the range of relevant parameters were derived from simulated rainfall experiments, regional monitoring data and previous research in study area (Wang, 2014; Shao, 2013b; Zuo et al., 2015). Vegetation construction changes undelaying surface and affects quantity of surface runoff and recharge of both soil and ground water. It has a significant impact on infiltration by providing canopy and litter cover to protect the soil surface from raindrop impacts and producing organic matter which can bind soil particles and increase soil porosity (Le Maitre et al., 1999). These impacts of vegetation on hydrological process ~~were~~ are epitomized and reflect~~ed~~ by CN and management operation in the SWAT model. the Soil Conservation Service (SCS) curve number equation is the model for computing the amounts of streamflow in SWAT model and its comprehensive parameter is CN which relates to the soil's permeability, land use and antecedent soil water conditions. We have done some research on the impacts of LUCC changes on runoff, infiltration and groundwater under different soil, slope and rainfall intensity in Wei River basin based on simulated rainfall experiments before (Wang, 2014). Based on the experiments, the SCS model and the three-dimensional finite-difference groundwater flow model (MODFLOW) were calibrated and applied also. So values of parameters related to runoff, infiltration and groundwater, such as the initial CN values and recharge rates for different LUCC, specific yield of soil layer etc. were gotten based on experiments and mathematical simulation (Wang, 2014). Meanwhile in the SWAT model, agricultural land and forest have different heat units required for plant maturity and different management operations. The agricultural land ~~includs~~includes plant, harvest~~-~~/ kill and auto-fertilizer operation and the forest only has plant operation. And the management operation of forest involves leaf area index (LAT_INIT), plant biomass (BIO_INIT), age of trees (CURYR_MAT)~~ and so on~~.

According to Fig. 1, we could see the revegetation was mainly implemented in the study area after the 1980s. Hence we choose 1960-1969 and 1970-1979 for the model calibration and validation respectively and used the daily streamflow data of the Linjiacun, the Weijiabu and the Xianyang hydrological stations from the upper to middle reaches (~~in the Weijiabu station, ~~the data of 1965 and 1968-1971 are missing in the Weijiabu station). The parameters were calibrated for hydrological stations by the order of upstream to ~~downstream~~ midstream using the daily streamflow of 1960-1969. Firstly, the parameters against the streamflow at the Linjiacun control station were calibrated. Secondly, based on the premise of the calibrated parameter values of the Linjiacun station, the parameters were calibrated for the subbasin controlled by the Weijiabu station. In that way, the parameters for the subbasin controlled by the Xianyang station were then calibrated. Then the SWAT model was validated for the three hydrological stations respectively against the streamflow from 1970 to 1979 (Fig. 7).

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4. Results and discussions

~~Then the SWAT model was validated for the three hydrological stations respectively against the streamflow from 1970 to 1979 (Fig. 6).~~ The corresponding statistic results of three hydrological stations showed that the ranges of NS and R^2 were 0.59~0.66 and 0.63~0.68 respectively in the calibration period for a daily time step. And they were 0.57~0.62 and 0.61~0.65 respectively in the validation period. At a monthly time step, the results of the NS and R^2 were 0.82~0.84 and 0.79~0.86 respectively in the calibration period. And they were 0.70~0.76 and 0.74~0.79 respectively in the validation period demonstrating good performance of the model. In addition, the time-series and the patterns of the simulated and observed streamflow during the calibration period and validation period showed similar trends. Our conclusion is that the SWAT model can be used in upper and middle reaches of the Wei River basin.

4.1 Impact of the observed LUCC on streamflow

In order to analyze the impact of the LUCC on streamflow, the land use data of the 1980 and 2005 were used in the validated SWAT model. Firstly, the daily streamflow from 1980 to 2009 were simulated using observed daily meteorological forcing data and topography, soil data ~~and so~~

~~on~~in study area. Secondly, the LUCC data of 1980 was replaced by that of 2005 and their relevant parameters of corresponding land use type were also replaced. We used the LUCC data of 2005 but the same meteorological data to simulate the daily streamflow from 1980 to 2009.

The change of annual streamflow based on LUCC data of 2005 compared with LUCC data of 1980 showed that annual streamflow decreased during ~~20~~ 20-year~~s~~ in 30-year ((1980-2009)) and the annual average reduction was ~~94~~ 2.0 mm/yr ~~million m^3~~ for these 20- year~~s~~ in study area. This is mainly because over different land use types hydrological responds differently even to the same meteorological forcings. For example, rainfall intensity ~~is~~ was of great importance influencing to hydrological process of the Wei River, which locates in semi-dry and semi-humid region (Lacombe et al., 2008; Wang, 2014). Results of rainfall numerical experiments showed when the rainfall intensity was smaller or larger, the rainfall would infiltrate into soil or flow away as surface runoff mainly on both grass land and bare slope, while when the rainfall intensity was medium, the rainfall would infiltrate into grass land and flowed away as surface runoff on bare slope (Tobella et al., 2014; Wang, 2014). To reduce influence of meteorological conditions and isolate the impact of the LUCC on streamflow, the 30-year (1980-2009) ~~average~~ values of the streamflow for forest and agricultural land were averaged respectively~~taken, respectively~~. For period of 1980-2009, we just used their measured and long-term daily meteorological data in the study area to drive the validated model for the designed hydrological experiments. Figure ~~7~~ 8 shows the changes of streamflow, surface runoff, soil flow and baseflow between agricultural land and forest. The surface runoff, soil flow and baseflow all decreased for agricultural land, while the soil flow and baseflow of forest increased. Overall, the streamflow decreased in agricultural land and increased in forest area. When the LUCC data are classified and re classified in SWAT model, the tree types are summarized as Range-Brush (RNGB), Forest-Mixed (FRST) and Forest-Deciduous (FRSD). Different types have different hydrological responses for their leaf, roots and so on. We also analyzed the streamflow generation of the main types of forest (RNGB, FRST and FRSD) in study area further. Results showed that the streamflow yield of FRST and FRSD were about 1.20 and 1.60 times of that of RNGB respectively.

4.2 Hydrological experiments on the impact of conversion of agricultural land to forests on streamflow

Because the LUCC data involves various land use interconversions, of particular interest here the impact of conversion of cropland to forest on streamflow cannot be distinguished. Starting from the LUCC data of 1980 as (S1) the present land use, we design other four scenarios (Table 3) that (S2) 10%, (S3) 20%, (S4) 40% and (S5) 100% of the agricultural land was converted into Forest-Mixed (FRST)~~forest~~ respectively.

Based on the five scenarios, the SWAT simulations ~~was~~ were conducted to analyze the effect of forest constructions on the streamflow in upper and middle reaches of the Wei River basin. Firstly, the converted agricultural land area was controlled proportionately as same as the variational area ratios of set scenarios in 3 regions divided by Linjiacun, Weijiabu and Xianyang hydrological stations (Fig. 6(a)). Secondly, lands with the same soil type and similar slope were the priorities choosing as the converted land. Thirdly, the converted lands were distributed evenly as much as possible in 3 regions. The simulation period was from 1980 to 2009.

We present the distribution of average streamflow change under S2 ~ S5 scenarios compared with S1 scenario in Fig. ~~8~~9. It shows that the streamflow generally increased when the land use converted from agricultural land into forest in the upstream. And Fig. ~~9~~ 10 shows the

~~corresponding proportional~~ change rate of streamflow at the Linjiacun, Weijiabu and Xianyang stations correspondingly for its annual average and annual average over non-flood season (Jan - Jun and Nov - Dec). Compared with the S1 scenario, the annual average streamflow increases in the non-flood season were 12.70 %, 11.21 % and 9.11% for the Linjiacun, Weijiabu and Xianyang stations with per 10% area of agricultural land converted into forest. Interestingly the average annual streamflow increases were 11.61%, 21.63%, 42.51% and 109.25% for S2, S3, S4 and S5 scenario respectively (Fig. ~~9~~ 10 (b)), which almost consistently suggested about 1.1% per 1% change of the agricultural land. The results are important in that one can expect that for a 0.8% increase in the forest in the observed LUCC would lead to less than 1% change in the streamflow, which is negligible.

To be more comparable, Fig. ~~10~~ 11 ~~shows~~shows the distribution of the annual runoff coefficients with the scenario changed from S1 to S5. The spatial variability in mean runoff coefficient ~~is~~ was large, which ranges from 0.03 to 0.68 and increased with more forest converted from agricultural land. The annual average runoff coefficient of study area increased from 0.21 to 0.37 with forest area increasing from S1 to S5 (Fig. ~~11~~12). On average, the runoff coefficient increased about 0.014 (i.e., 1.4% of rainfall transformed into streamflow) with per 10% area of agricultural land converted into forest.

The landscape of the Wei River is mixed with the Loess Plateau and earth-rock mountain landscapes, which induce different mechanisms of transforming rainfall into streamflow. The earth-rock mountain area accounts for 24.03% of study area (Fig. 4 (b)). In earth-rock mountain area, vegetation grows on much thinner soil layer over the earth-rock mountain. And the soil has high infiltration ability for high stone fragment content. The thin soil is apt to be saturated and produce more soil flow on relatively impermeable rock, hence the streamflow in wooded areas is larger than that in adjacent woodless areas favoring streamflow production (Liu and Zhong, 1978). On the contrary, in Loess Plateau there is exiting a drying layer of soil underneath forestland in great water deficit. When the agricultural land converted into forest, the precipitation, intercepted by vegetation, infiltrated into soil and supplied the drying layer of soil, vegetation growth, etc. Together with much thicker soil layer on the Loess Plateau, it usually prevents gravitational infiltration into groundwater and reduces streamflow recharge (Li, 2001; Tian, 2010). –The observed results of precipitation and streamflow in study area also showed the runoff coefficients had obviously positive correlation with rates of earth-rock mountain area. The regional annual averages of runoff coefficient were 0.13, 0.17 and 0.35 for Fig. 6 (b), (d) and (c), while the rates of earth-rock mountain area were opposite correspondingly (Fig. 4 (b)). T~~So t~~he complication is that the overall effect of forest on the streamflow is in fact a balance between earth-rock mountain positive and Loess Plateau negative effects on the streamflow.

Combined with the spatial distribution of precipitation (Fig. 5 (a)), we can see earth-rock mountain landscapes are mainly distributed in regions with more rainfall. To be precise, the whole earth-rock mountain area located where rainfall was greater than 500 mm/yr and over 62% of the study area where the annual rainfall is greater than 600 mm was in earth-rock mountain. Meanwhile, the river network over the earth-rock mountain is denser and most of tributaries in the earth-rock mountain are close to the main stream of the Wei River. Moreover, there distribute a lot of developed gravel riverbed in piedmont, sandy soil along the river and its groundwater level is shallow, which facilitate rainfall infiltration and recharging streamflow. Therefore although the area of earth-rock mountain accounts for 24% of the study area, its distribution areas are concentrated in the main regions of streamflow yield of the study area. Therefore the overall result of balance among all factors was that the forest constructions have positive effect on streamflow.

4.3 Impact of conversion of agricultural land to forests on baseflow

In Fig. ~~9~~ 10 (a), one important point is that the average increase in the non-flood season was about 1.41 times larger than the annual increase of the streamflow. To understand that, Fig. ~~12~~ 13 shows distribution of the baseflow index, i.e., the ratio between baseflow and streamflow, under S1~S5 scenarios. We can see that the baseflow index also increased with land use converted from agricultural land into forest, which means that groundwater contribution to the streamflow increased with the overall increase of forest area. Putting the pictures together, Fig. ~~13~~ 14 shows the changes of the streamflow and the baseflow under the S2~S5 scenarios minus those results under the S1 scenario ~~for annual average streamflow and the baseflow~~ in the non-flood season. The average increas~~cing~~s of streamflow and baseflow were 1.14 and 0.98 mm/yr with per 1% increase of forest area respectively. For the non-flood season, they were 0.60 and 0.53 mm/yr. The increase of the streamflow contributed by the increased baseflow was about 88.33% in the non-flood season. So the increasing streamflow was mainly contributed by groundwater with increasing of forest area overall.

5. Conclusion

The large scalar implementation of Grain for Green project in China is expected to alter hydrological cycle, in particular on the Loess Plateau, within the Yellow River Basin. The scientific question is how large the impact of the LUCC on the streamflow and its components in that area. We choose the Wei River as the study area, in that it has been widely implemented revegetation constructions since the 1980s. Of particular interest here, the landscape of the upper and middle reaches of the Wei River basin is mixed with the Loess Plateau and rocky mountain, which would induce different mechanisms of generating surface runoff, soil flow, base flow and therefore streamflow.

To investigate it, we setup the SWAT model for the upper and middle reaches of the Wei River basin with the inputs of long term observed meteorological forcing data, hydrological data, and observed land use data. We use daily and monthly streamflow of the Linjiacun, Weijiabu and Xianyang hydrological stations from upper to middle reaches during 1960-1969 and 1970-1979 respectively for the model calibration and model validation. The results showed that the Nash-Sutcliffe (NS) coefficients and the coefficients of determination (R^2) were > 0.57 and 0.61 for daily streamflow and 0.70 and 0.74 for monthly streamflow respectively demonstrating that the SWAT model can be used in this study.

We analyse the impact of the LUCC on streamflow based on the observed LUCC data of 1980 and 2005. The daily streamflow from 1980 to 2009 were simulated using observed daily meteorological data with the two different land use data. The results showed that two-thirds of annual streamflow decreased and the change of streamflow was different among different land use. On the overall average, the 30-year averages of the streamflow decreased in agricultural land but increased in forest. To interpret the overall result, we design five scenarios in this study including (S1) the present land use of 1980 and the scenarios where agricultural land was converted into forest by 10% (S2), 20% (S3), 40% (S4) and 100% (S5) respectively. Based on the five scenarios, we use the calibrated and validated SWAT model to analyze the effect of forest constructions on the streamflow in detail. The results confirm that annual streamflow consistently increased with more forest converted from the agricultural land. Interestingly, the rate is almost consistently 7.41

mm/yr per 10% increase of forest converted from the agricultural land. Based on detailed analysis of each component of streamflow, we found it was most attributed by the baseflow. The overall effect of LUCC on the streamflow in the Wei River basin, the largest branch of the Yellow River is the result of the balance between Loess Plateau negative and earth-rock mountain positive effects. Our results here are not only of great importance in understanding the impact of LUCC on streamflow for a catchment with much complicated and mixed landscape, but also of significance for water resources managing practice.

Data availability

The data used in this manuscript were obtained from reliable public data repositories. The LUCC and soil data were obtained from the National Science & Technology Infrastructure of China, the National Earth System Science Data Sharing Infrastructure (http://www.geodata.cn). The DEM data were obtained from the Computer Network Information Center, the Chinese Academy of Sciences (http://srtm.datamirror.csdb.cn/). The meteorological data were obtained from the China Meteorological Data Sharing Service System (http://www.escience.gov.cn/metdata/page/index.html). The daily streamflow data were from the Ecological Environment Database of Loess Plateau (http://www.loess.csdb.cn/pdmp/index.action) and the Hydrological Year books of China.

Acknowledgment

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References

Abbaspour, K. C.: User manual for SWAT-CUP, SWAT calibration and uncertainty analysis programs, Swiss Federal Institute of Aquatic Science and Technology, Eawag, Duebendorf, Switzerland, 2007.

Arnold, J., Srinivasan, R., Neitsch, S., George, C., Abbaspour, K., Gassman, P., Hao, F. H., Van Griensven, A., Gosain, A., and Debels, P.: Soil and Water Assessment Tool (SWAT): Global Applications, WASWC, 2009.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., and Williams, J. R.: Large area hydrologic modeling and assessment part I: Model development1, JAWRA Journal of the American Water Resources Association, 34, 73-89, 1998.

Beck, H. E., Bruijnzeel, L. A., Dijk, A. I. J. M. V., and Mcvicar, T. R.: The impact of forest regeneration on streamflow in 12 meso-scale humid tropical catchments, Hydrology & Earth System Sciences Discussions, 10, 3045-3102, 2013.

Bosch, J. M., and Hewlett, J.: A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration, Journal of hydrology, 55, 3-23, 1982.

Bradshaw, C., Sodhi, N., Peh, K., and Brook, B.: Global evidence that deforestation amplifies flood risk and severity in the developing world, Global Change Biology, 13, 2379–2395, 2007.

Chen, Y., Wang, K., Lin, Y., Shi, W., Song, Y., and He, X.: Balancing green and grain trade, Nature Geoscience, 8, 739-741, 2015.

Deng, L., Liu, G. B., and Shangguan, Z. P.: Land-use conversion and changing soil carbon stocks in China's 'Grain-for-Green' Program: a synthesis, Global Change Biology, 20, 3544–3556, 2013.

Dijk, A. I. J. M. V., Noordwijk, M. V., Calder, I. R., Bruijnzeel, S. L. A., Schellekens, J., and Chappell, N. A.: Forest–flood relation still tenuous – comment on 'Global evidence that deforestation amplifies flood risk and severity in the developing world' by C. J. A. Bradshaw, N.S. Sodi, K. S.-H. Peh and B.W. Brook, Global Change Biology, 15, 110-115, 2009.

Farley, K. A., Jobbágy, E. G., and Jackson, R. B.: Effects of afforestation on water yield: a global synthesis with implications for policy, Global Change Biology, 11, 1565-1576, 2005.

Foley, J. A., Ruth, D., Asner, G. P., Carol, B., Gordon, B., Carpenter, S. R., F Stuart, C., Coe, M. T., Daily, G. C., and Gibbs, H. K.: Global consequences of land use, Science, 309, 570-574, 2005.

Hibbert, A. R.: Forest Treatment Effects on Water Yield, Pennsylvania Univ University, 527-543, 2001.

Huang, B. W.: Several issues of the impact of forest on environment, China Water Resouces, 4, 29-32, 1982.

Huang, Z. G., Ouyang, Z. Y., Li, F. R., Zheng, H., and Wang, X.: Progress in the Effects of Forest Ecosystem on Runoff Based on Forest Catchments, World Forestry Research, 22, 36-41, 2009.

D., Janeau, J. L., Soulileuth, B., Robain, H., Taccoen, A., Sengphaathith, P., Mouche, E., Sengtaheuanghoung, O., Tran Duc, T., Valentin, C.: Contradictory hydrological impacts of afforestation in the humid tropics evidenced by long-term field monitoring and simulation modelling, Hydrology & Earth System Sciences, 20, 2691-2704, 2016.

Lacombe, G., Cappelaere, B., Leduc C.: Hydrological impact of water and soil conservation works in the Merguellil catchment of central Tunisia, Journal of Hydrology, 359, 210-224, 2008.

Lacombe, G., Ribolzi, O., de Rouw, A., Pierret, A., Latsachak, K., Silvera, N., Pham Dinh, R., Orange,

Lørup, J. K., Refsgaard, J. C., and Mazvimavi, D.: Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: case studies from Zimbabwe, Journal of Hydrology, 205, 147-163, 1998.

Le Maitre, D. C., Scott, D. F., and Colvin, C.: Review of information on interactions between vegetation and groundwater, Water Research Commission, 25, 137-152, 1999.

Li, W. H., He, Y. T., and Yang, L. Y.: A summary and perspective of forest vegetation impacts on water yield, Journal of Natural Resources, 16, 398-406, 2001.

Li, Y. S.: Effects of forest on water circle on the Loess Plateau, Journal of Natural Resources, 16, 427-432, 2001.

Lin, Q. C., and Li, H. E.: Influence and guarantee on ecological basic flow of Weihe River from Baojixia water diversion, Journal of Arid Land Resources and Environment, 24, 114-119, 2010.

Liu, C. M., and Zhong, J. X.: The influence of forest cover upon annual runoff in the Loess Plateau of China, Acta Geographica Sinica, 33, 112-126, 1978.

Liu, Y., and Hu, A. Y.: Changes of Precipitation Characters Along Weihe Basin in 50 Years and Its Influence on Water Resources, Journal of Arid Land Resources & Environment, 20, 85-87, 2006.

Lorup, J. K., and Hansen, E.: Effect of land use on the streamflow in the southwestern highlands of Tanzania, International Symposium on Sustainability of Water Resources Under Increasing Uncertainty, at the 5th Scientific Assembly of IAHS, RABAT, MOROCCO, 1997.

Mango, L., Melesse, A., McClain, M., Gann, D., and Setegn, S.: Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management, Hydrology and Earth System Sciences, 15, 2245-2258, 2011.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., and Veith, T. L.: Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Trans. Asabe, 50, 885-900, 2007.

Nash, J., and Sutcliffe, J. V.: River flow forecasting through conceptual models part I—A discussion of principles, Journal of hydrology, 10, 282-290, 1970.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R.: Soil and Water Assessment Tool (SWAT) Theoretical Documentation: Version 2000, Texas Water Resources Institute Technical Report No. 406, 2011.

Ogden, F. L., Crouch, T. D., Stallard, R. F., and Hall, J. S.: Effect of land cover and use on dry season river runoff, runoff efficiency, and peak storm runoff in the seasonal tropics of Central Panama, Water Resources Research, 49, 8443-8462, 2013.

Price, K.: Effects of watershed topography, soils, land use, and climate on baseflow hydrology in humid regions: A review, Progress in physical geography, 35, 465-492, 2011.

Shao, H., Baffaut, C., Gao, J. E., Nelson, N. O., Janssen, K. A., Pierzynski, G. M., Barnes, P. L.: Development and application of algorithms for simulating terraces within SWAT, Transactions of the Asabe, 56, 1715-1730, 2013a.

Shao, H.: Simulation of Soil and Water Loss Variation toward Terrace Practice in the Weihe River Basin, Doctor, Northwest A & F University, Yangling Shaanx, 2013b.

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Smith, R., and Scott, D.: The effects of afforestation on low flows in various regions of South Africa, Water S. A., 18, 185-194, 1992.

Sriwongsitanon, N., and Taesombat, W.: Effects of land cover on runoff coefficient, Journal of Hydrology, 410, 226-238, 2011.

Tian, J. L.: Environmental effects of Loess Plateau Ecological Construction, China Meteorological Press, beijing, 2010.

Tobella, A. B., Reese, H., Almaw, A., Bayala, J., Malmer, A., Laudon, H., and Ilstedt, U.: The effect of trees on preferential flow and soil infiltrability in an agroforestry parkland in semiarid Burkina Faso, Water Resources Research, 50, 3342-3354, 2014.

Van Liew, M. W., and Garbrecht, J.: Hydrologic simulation of the Little Washita River experimental watershed using SWAT, Journal of the American Water Resources Association, 39, 413-426, 2003.

VanShaar, J. R., Haddeland, I., and Lettenmaier, D. P.: Effects of land‐cover changes on the hydrological response of interior Columbia River basin forested catchments, Hydrological Processes, 16, 2499-2520, 2002.

Wagner, P. D., Kumar, S., and Schneider, K.: An assessment of land use change impacts on the water resources of the Mula and Mutha Rivers catchment upstream of Pune, India, Hydrology & Earth System Sciences, 10, 1943-1985, 2013.

Wang, F.: Study of runoff and value of ecosystem based on landuse change in Weihe River basin, Master, Northwest A & F University, Yangling Shaanxi, 2013.

Wang, H.: The Effects of Typical Measures of Soil and Water Conservation on Ecological Basic Flow Recharged from Groundwater,Doctor,University of Chinese Academy of Sciences, Beijing, China, 2014.

Wang, L. X.: Effect of construction and protective of vegetation on protection and utilization of water resources, Xiangshan Conference, Beijing, 2000.

Wang, Y. H., Yu, P. T., Feger, K. H., Wei, X. H., Sun, G., Bonell, M., Xiong, W., Zhang, S. L., and Xu, L. H.: Annual runoff and evapotranspiration of forestlands and non‐forestlands in selected basins of the Loess Plateau of China, Ecohydrology, 4, 277-287, 2011.

~~Waring, R. H., Landsberg, J. J., and Williams, M.: Net primary production of forests: a constant fraction of gross primary production?, Tree Physiology, 18, 129-134, 1998.~~

Woodward, C., Shulmeister, J., Larsen, J., Jacobsen, G. E., and Zawadzki, A.: Landscape hydrology. The hydrological legacy of deforestation on global wetlands, Science, 346, 844-847, 2014.

Wang, Y., Shao, M., Shao, H.: A preliminary investigation of the dynamic characteristics of dried soil layers on the Loess Plateau of China, Journal of Hydrology, 381, 9-17,2010 a.

Wang, Y., Shao, M., Liu, Z.: Large-scale spatial variability of dried soil layers and related factors across the entire Loess Plateau of China, Geoderma, 159, 99-108, 2010 b.

Xu, Y. D., Fu, B. J., and He, C. S.: Assessing the hydrological effect of the check dams in the Loess Plateau, China by model simulations, Hydrology & Earth System Sciences Discussions, 9, 13491-13517, 2012.

Yan, Y., Tian, J., Fan, M. S., Zhang, F. S., Li, X. L., Christie, P., Chen, H. Q., Lee, J., Kuzyakov, Y., and Six, J.: Soil organic carbon and total nitrogen in intensively managed arable soils, Agriculture, ecosystems & environment, 150, 102-110, 2012.

Zuo, D., Xu, Z., Zhao, J., Abbaspour, K. C., and Yang, H.: Response of runoff to climate change in the wei river basin, china. Hydrological Sciences Journal/journal Des Sciences Hydrologiques, 60, 1-15, 2015.

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Zhang, H., and Hiscock, K.: Modelling the impact of forest cover on groundwater resources: A case study of the Sherwood Sandstone aquifer in the East Midlands, UK, Journal of hydrology, 392, 136-149, 2010.
Zhang, T. Z.: Based on hydrological characteristics of Donggou and Xigou catchment in Yongding River to analyze the hydrological function of forest vegetation, Resources Science, 90-98, 1984.

Figure Captions:

Fig. 1 The development of soil and water conservation measures in the main stream basin of Wei River over last 50 years.

Fig. 2 The study area: the Wei river basin on the Loess Plateau.

Fig. 3 The observed land use data of the year 1980 and the year 2005 in study area.

Fig. 4 The Soil data and the distribution of earth-rock mountain in study area.

Fig. 5 The spatial distribution of annual average precipitation in Wei River basin over the past 55 years (1956-2010) and the DEM of study area.

Fig. 6 The time-series of precipitation, annual streamflow and runoff coefficients for the regions of study area.

Fig. ~~6~~7 The time-series graphs of calculated vs. observed values during calibration period and verification period for hydrological stations.

Fig. ~~7~~8 The changes of 30-year (1980-2009) averages of streamflow, surface runoff, soil flow and baseflow between agricultural land and forest.

Fig. ~~8~~9 The watershed distribution of average streamflow change under S2~S5 scenarios compared with S1 scenario.

Fig. ~~9~~10 The corresponding proportional change rate of streamflow at Linjiacun, Weijiabu and Xianyang station for annual average and annual average in non-flood season.

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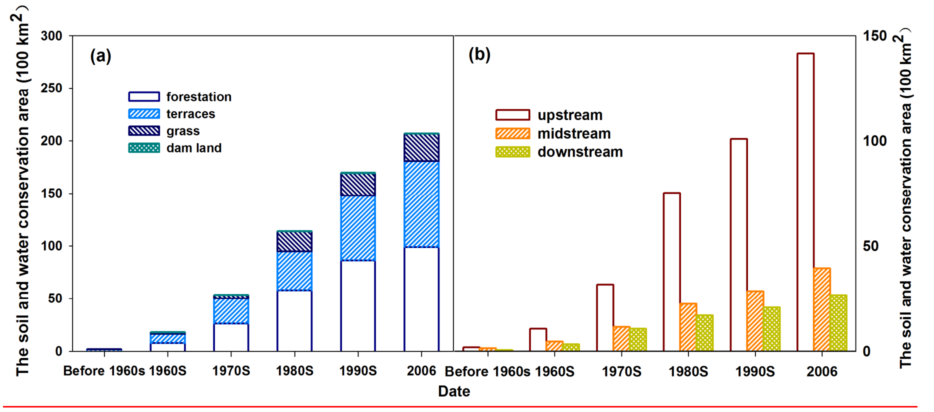
Fig. ~~10~~ 11 The distribution of annual runoff coefficient with the scenario changed from S1 to S5.

Fig. ~~11~~ 12 The annual average runoff coefficient of study area with forest area increasing from S1 to S5.

Fig. ~~12~~ 13 The distribution of baseflow index under S1~S5 scenarios.

Fig. ~~13~~ 14 The corresponding change of streamflow and baseflow under S2~S5 scenarios compared with S1 for annual average of year and non-flood season.



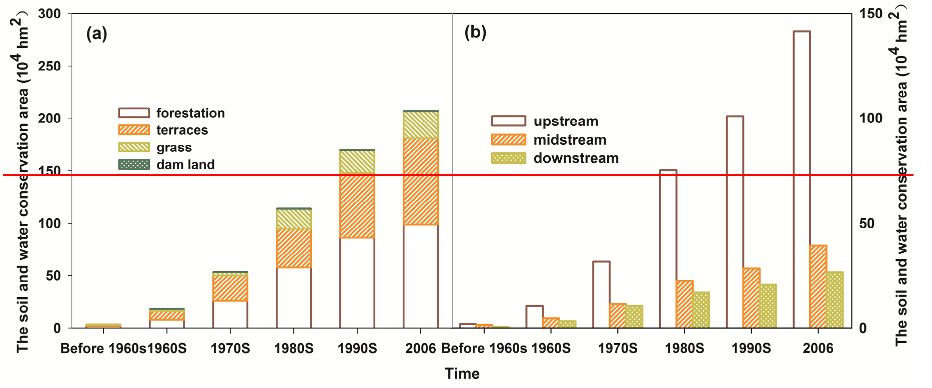


Fig. 1 The development of soil and water conservation measures in the main stream basin of Wei River over last 50 years

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Figure 1 (a) is the area developing of forestation, terraces, grass and dam land separately. Figure 1(b) is the sum area of the forestation, terraces, grass and dam land in upstream, midstream and downstream.

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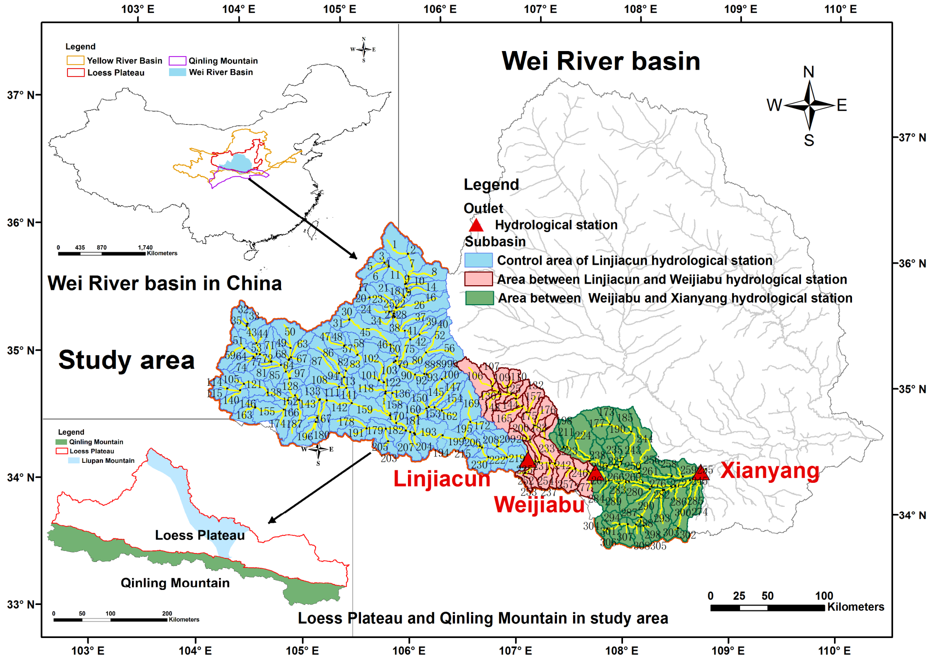

Fig. 2 The study area: the Wei river basin on the Loess Plateau.

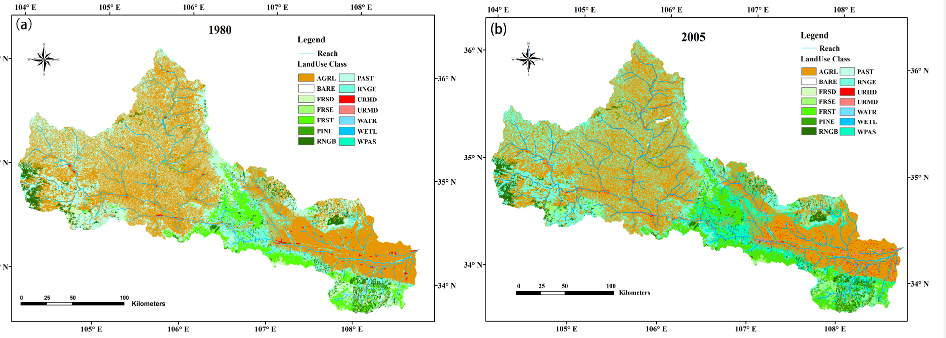

Fig. 3 The observed land use data of the year 1980 and the year 2005 in study area

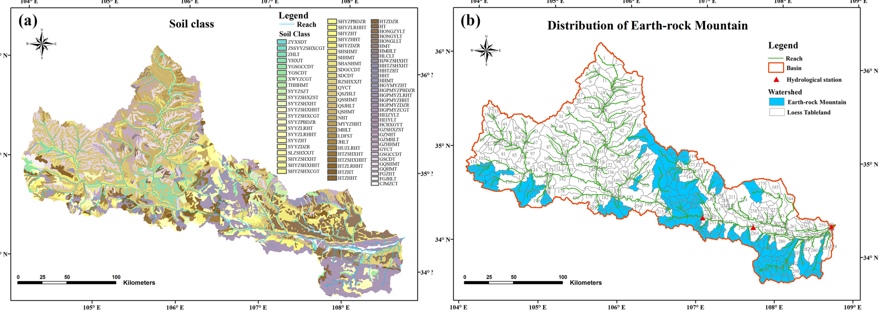

Fig. 4 The Soil data and the distribution of earth-rock mountain in study area

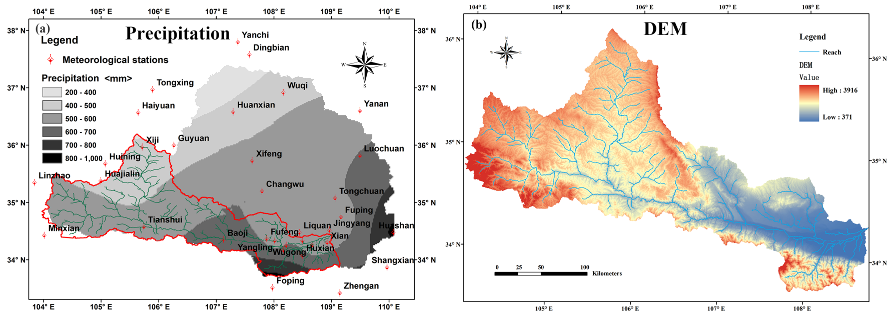

Fig. 5 The spatial distribution of annual average precipitation in Wei River basin over the past 55 years (1956-2010) and the DEM study area

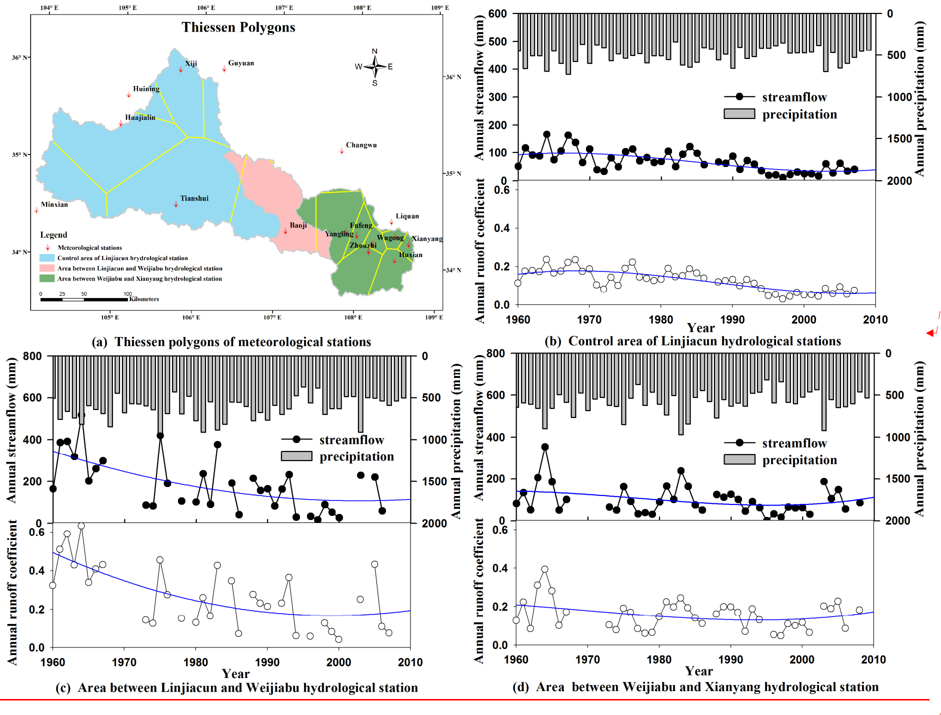

Fig. 6 The time-series of precipitation, annual streamflow and runoff coefficients for the regions of study area

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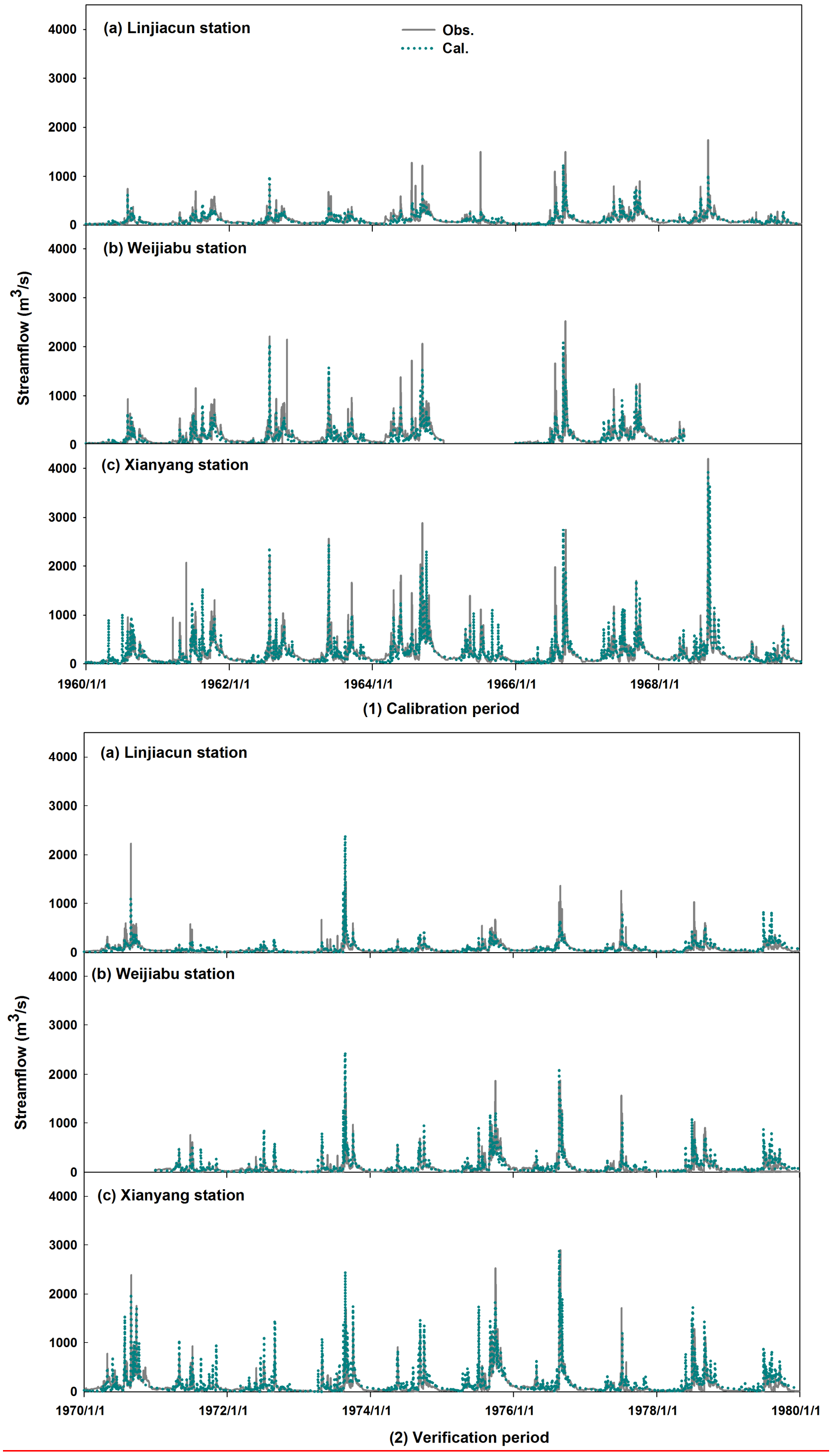
(a) Linjiacun station
Obs.
Cal.
(b) Weijiabu station
(c) Xianyang station
Streamflow (m3/s)
1960/1/1
1962/1/1
1964/1/1
1966/1/1
1968/1/1
(1) Calibration period
(a) Linjiacun station
(b) Weijiabu station
(c) Xianyang station
Streamflow (m3/s)
1970/1/1
1972/1/1
1974/1/1
1976/1/1
1978/1/1
1980/1/1
(2) Verification period

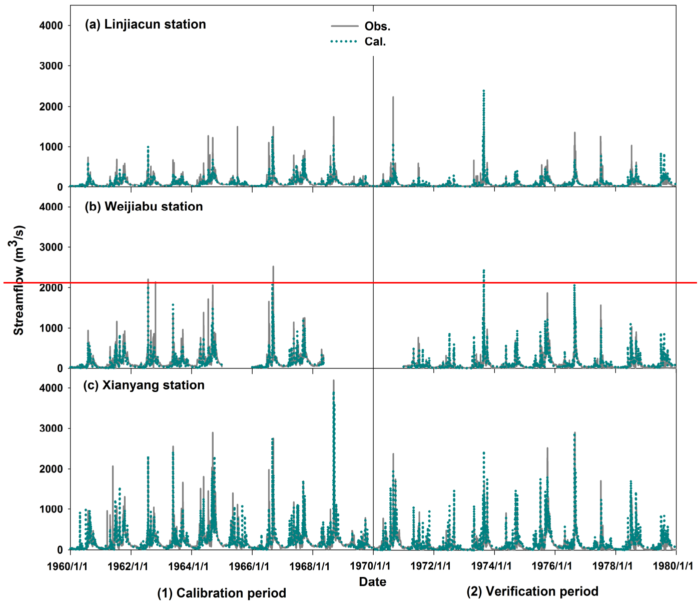

Fig. ~~6~~ 7 The time-series graphs of calculated vs. observed values during calibration period and verification period for hydrological stations

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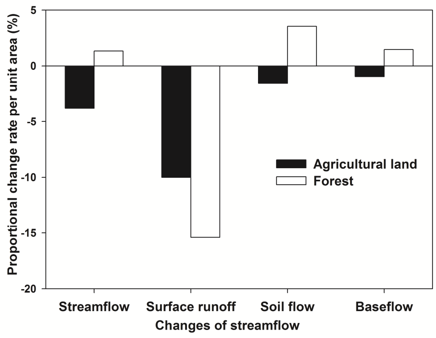

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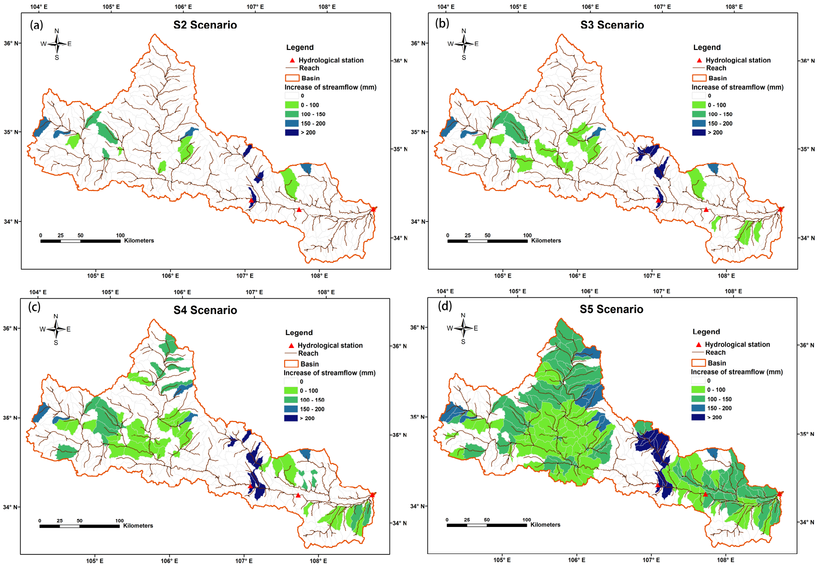

Fig. ~~8~~ 9 The watershed distribution of average streamflow change under S2~S5 scenarios compared with S1 scenario

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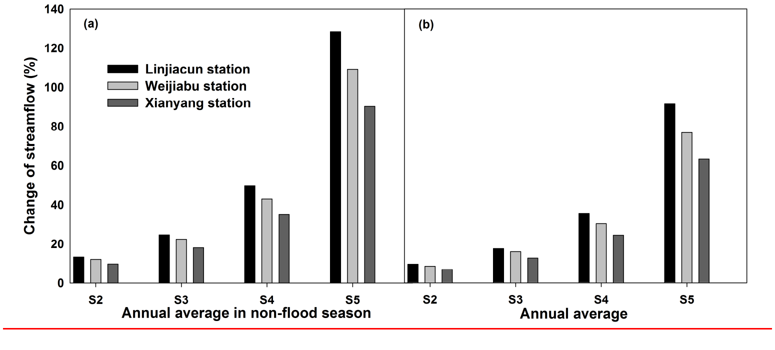

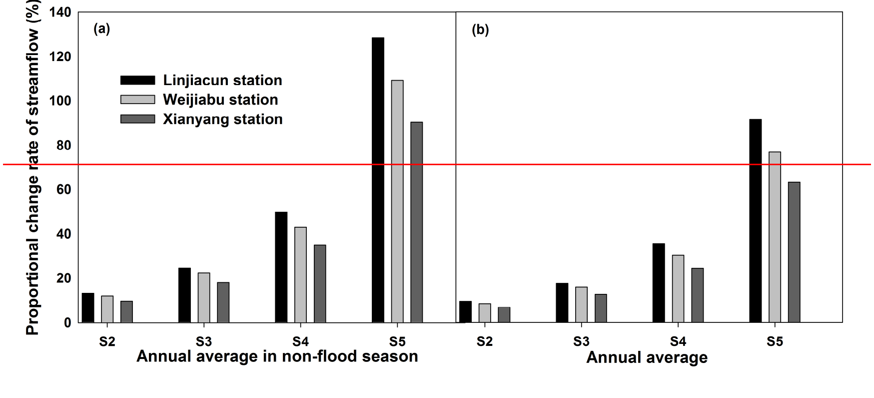

Fig.~~9~~ 10 The corresponding proportional change rate of streamflow at Linjiacun, Weijiabu and Xianyang station for annual average and annual average in non-flood season

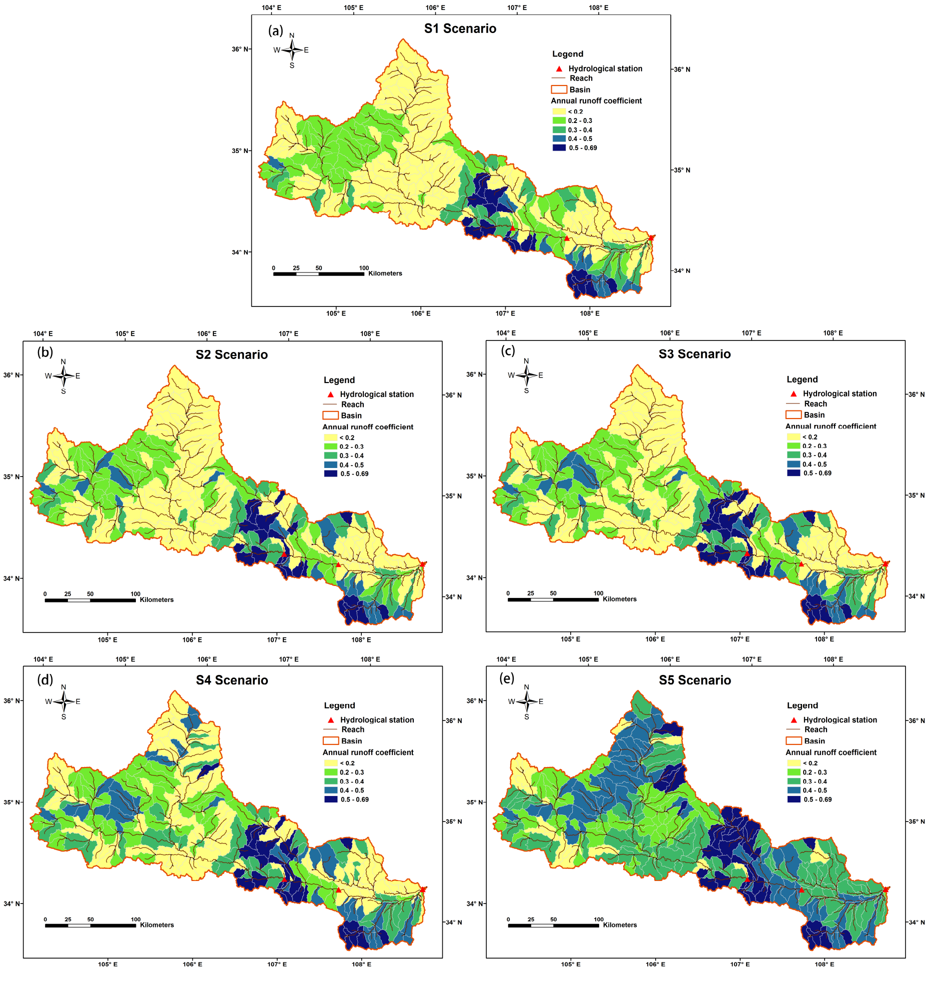

Fig. ~~10~~ 11 The distribution of annual runoff coefficient with the scenario changed from S1 to S5

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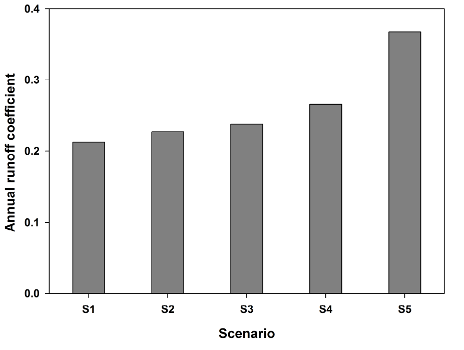

Fig. ~~11~~ 12 The annual average runoff coefficient of study area with forest area increasing from S1 to S5

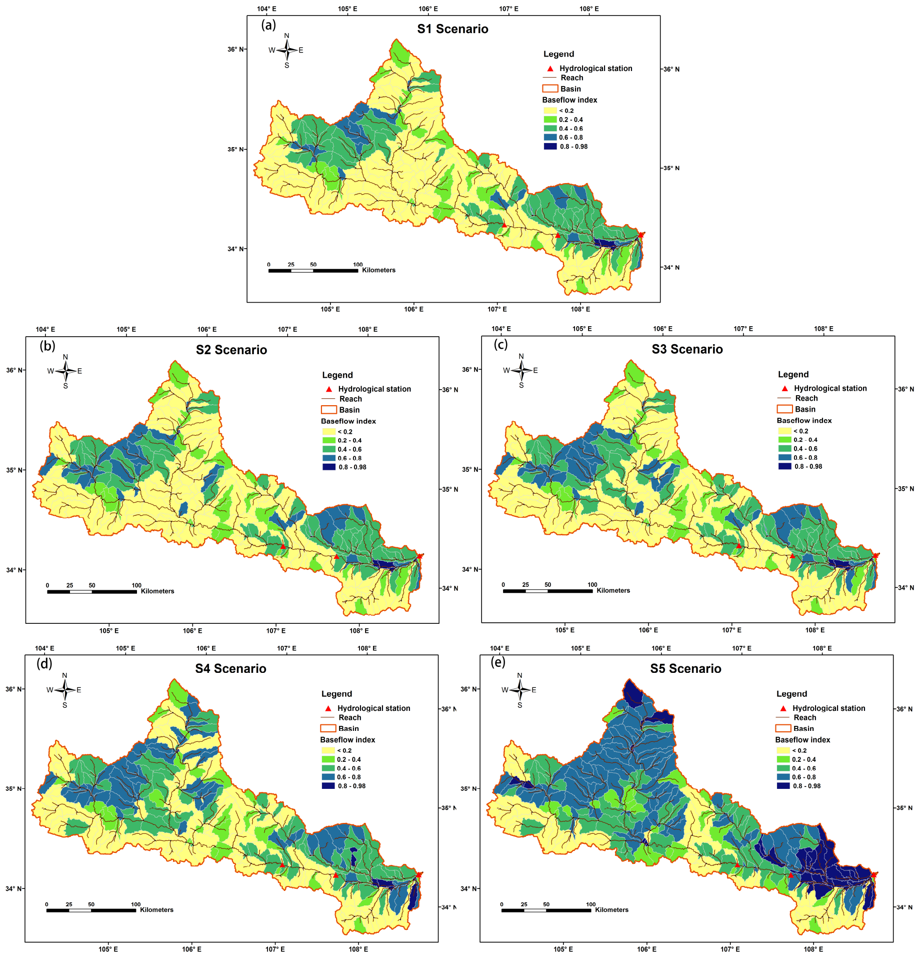

Fig. ~~12~~ 13 The distribution of baseflow index under S1~S5 scenarios

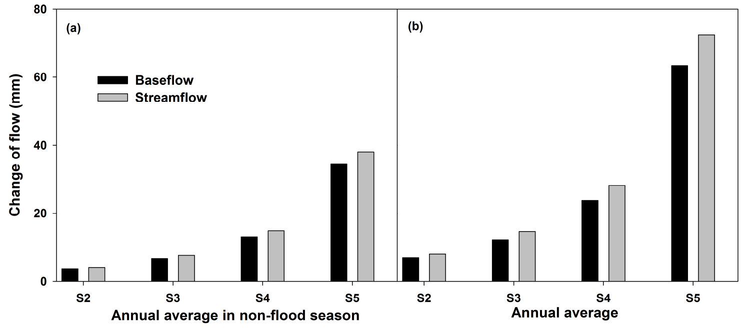

Fig.~~13~~ 14 The corresponding change of streamflow and baseflow under S2~S5 scenarios compared with S1 for annual average of year and non-flood season

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Tables

Table 1 The soil type and its distribution of earth-rock mountain in study area

带格式表格

No.	Code of Soil type	Physical meaning of the code	HRU	Area (km^2)
1	SHYZHT	Limestone Cinnamon soil	220, 257	26316.90
2	SHYZSHXHT	Limestone Calcic cinnamon soil	153	11471.22
3	SYYZLRHT	Sandstone—shale Luvie cinnamon soil	166, 203, 207	50065.29
4	HGPMYZLRHT	Granite—gneiss Luvie cinnamon soil	174, 180, 187, 201, 204, 221, 277, 283, 287	158397.93
5	SYYZDZR	Sandstone—shale Light brown earth	106, 169, 299	103955.40
6	HGPMYZDZR	Granite—gneiss Light brown earth	130, 148, 172, 209, 252, 284, 289, 290, 291, 293, 294, 300, 301, 302, 303, 305, 306, 307, 308	299737.26
7	HGPMYZPBDZR	Granite—gneiss Light brown earth	253	8739.90
8	MYYZHHT	Sandstone—shale Grey cinnamon soil	115, 117, 146, 163	51204.96
9	SYYZSHXHHT	Sandstone—shale Calcic grey cinnamon soil	99, 129	19392.21
10	SHYZSHXHHT	Limestone Calcic Grey cinnamon soil	56	33885.54
11	SYYZSHXZST	Sandstone—shale Purple soil	109, 176, 177, 184, 200	106159.41
12	HGPMYZCGT	Granit—gneiss Rhogosol	165, 230, 237, 254, 271, 292, 295, 296, 297, 304	112136.40
13	SYYZSHXCGT	Sandstone—shale Rhogosol	107, 208, 213, 216, 218, 219, 248	87612.84

14	SHYZSHXCGT	Limestone Rhogosol	222	23375.79
15	SYYZLRHHT	Sandstone—shale Luvic grey cinnamon soil	116, 140	30320.73

Table 2 Calibrated values of model parameters

Parameters	Physical meaning	Calibration range	Calibration result		
			Linjiacun	Weijiabu	Xianyang
r__CN2	Initial SCS runoff curve number for moisture condition Ⅱ	-0.3~0.3	-0.27	0.05	-0.17
r__SOL_AWC	Available water capacity of soil layer	-0.6~0.6	0.01	-0.01	-0.01
r__SOL_K	Saturated hydraulic conductivity of soil layer (mm/hr)	-0.5~0.5	0.5	0.3	0.5
r__HRU_SLP	Average slope stepness (m/m)	-0.5~1.5	1.5	0.41	0.52
r__SLSUBBSN	Average slope length (m)	-0.5~1.5	1.17	0.70	1.20
v__ALPHA_BF	Baseflow alpha factor	0~1.0	0.48	0.61	0.61
v__GW_DELAY	Groundwater delay (days)	0~500	220	38	62
v__ESCO	Soil evaporation compensation factor	0 ~1.0	0.65	0.90	0.80
v__CH_K2	Effective hydraulic conductivity in main channel alluvium	0~130	5	30	30

带格式表格

Notes: v__ means the existing parameter value is to be replaced by the given value; r__ means the existing parameter value is multiplied by (1+ a given value).

Table 3 Scenarios for simulation

Scenario	Description	Area (km^2)	The average simulated streamflow (1980-2009) (10^8 m^3/yr)

S 1	present situation	0	50.44
S 2	10% agricultural land → forest	2937.63	53.92
S 3	20% agricultural land → forest	5875.26	56.83
S 4	40% agricultural land → forest	11750.53	62.73
S 5	100% agricultural land → forest	29376.32	82.28

Notes: ① Agricultural land refers to the land for crops planting, including cultivated land, newly cultivated soil, fallow field, rotation plot, pasture-crop rotation and land used for agro-fruit, agro-mulberry, agroforestry (The code in model is AGRL). ② Forest refers to the natural forest and plantation, which canopy density is larger than 30%, including timberland, economic forest, protection forest (The code in model is FRST).