Green Water Management & Credits Toolbox China

Green and Blue Water Resources and Management Scenarios using the SWAT model for the Upper Duhe Basin, China - Feasibility Study

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Abbreviations and Acronyms

APAR	Absorbed Photosynthetical Radiation
AWC	Available Water holding Capacity
CFSR	Climate Forecast System Reanalysis
DEM	Digital Elevation Model
EEA	European Environment Agency
ENVISAT	Environmental Satellite
ESA	European Space Agency
eSOTER	Soil and Terrain database
FAO	Food and Agriculture Organisation
GAEZ	Global Agro-ecological Assessment study
GLC2000	Global Land Cover 2000
GlobCover	Global Land Cover Map
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GSOD	Global Summary of the Day
GWC	Green Water Credits
HRU	Hydrological Response Unit
HWSD	Harmonized World Soil Database
ISRIC	International Soil Reference and Information Center
LCCS	Land Cover Classification System
LUE	Light Use Efficiency
MRP	Middle Route Project
MERIS	Medium Resolution Imaging Spectrometer
NCDC	National Climatic Data Center
NCEP	National Center for Environmental Prediction
PTF	Pedotransfer Functions
RMSE	Root Mean Squared Error
SPAM	Spatial Production Allocation Model
SRTM	Shuttle Radar Data Topography
SWAT	Soil and Water Assessment Tool
TRMM	Tropical Rainfall Measuring Mission
UNEP	United Nations Environment Programme
USDA – ARS	Agricultural Research Service
USLE	Universal Soil Loss Equation
WISE	World Inventory of Soil Emission Potentials
WMO	World Meteorological Organization
WOCAT	World Overview of Conservation Approaches and Technologies

Preface

The Netherlands' "Partners for Water" program has supported our project. This program states the following:

> 'The Netherlands has a solid reputation in water management. Its knowledge and powers of innovation enable the Dutch water sector to make significant advances internationally. We can achieve much more if we work together. This is why the Partners for Water program brings the water sector together via networks, platforms and other innovative forms of partnership. In addition, the program helps the water sector tap into new markets. Through improved coordination and a joint approach, we can ensure that the Netherlands, Water Management Nation, is placed firmly on the map. Businesses, government agencies, NGOs and knowledge institutes with international ambitions can apply to Partners for Water for subsidies to fund water projects abroad. With its 'Working with Water Worldwide' (Wereldwijd Werken met Water) subsidy scheme, the program supports the projects of cooperating parties from the Dutch water sector in some 26 countries.'

A call for proposal was announced by "Partners for Water" in tender 2012-1. A consortium of three Netherlands' partners developed a proposal on request of two Chinese partners under the name "Refinement and capacity building of green water management and credits toolkit for China". Our proposal was submitted on March, 7, 2012. The project was granted on 6-Jun-2012 and will run from 1-Jul-2012 to 31-Dec-2013.

The contract number is PVWS12001.

The project partners are:

- Changjiang Water Resources Protection Institute of the Changjiang Water Resources Commission, Wuhan, China.
- Huazhong Agricultural University, Wuhan, China.
- ISRIC-World Soil Information, Wageningen, The Netherlands.
- FutureWater, Wageningen, The Netherlands.
- Nelen&Schuurmans, Utrecht, The Netherlands.

Executive summary

The Green Water Credits (GWC) concept (www.greenwatercredits.net) is brought to China by the Dutch consortium of ISRIC, FutureWater and Nelen-Schuurmans. The concept was developed by ISRIC and allows quantification of erosion reduction, yield increase, sedimentation amounts, water availability, and electricity production that is needed to calculate the economic costs and benefits of environmental protection measures. This information allows the development of a financial mechanism in *e.g.* river basins, based on upstream supply and downstream demand of water services for long term investments in communities. In order run this concept, an analytical toolkit in combination with adequate database resources and know how is necessary. The toolkit consists of two simulation models, SWAT and WEAP, and a data and presentation portal Lizard. GWC for a region can only be developed and implemented by a team of experts from ISRIC/FutureWater and a strong leveled local counterpart.

For this report, we have performed the biophysical modelling using the SWAT model for the Upper Duhe basin, part of the Danjiangkou Reservoir catchment area. We have quantified the GWC-measures and effects on hydrology and erosion within the basin, in both space and time. This leads to scenario development in case policy makers want to preview results of future measures to be taken to *e.g*. generate more blue water and reduce sediment loads of Upper Duhe.

The calculation results of this demonstration project for the five GWC-interventions are plausible and mutual consistent. Based on the model calculations for the agricultural area, it can be concluded that for the overall Upper Duhe basin, the proposed GWC-measures will lead to further reduction of soil erosion and sediment loads to the streams. At the basin scale, there is little effect on blue water volumes generated for downstream use. The green water that is generated by the measures because of reduced surface runoff and increased groundwater recharge, leads to increased plant transpiration *i.e.* crop production. This benefits the local farmer’s income, and does not increase the downstream blue water. The overall influence of measures taken in the agricultural area on the Upper Duhe basin as a whole is basically a matter of area, with agriculture covering less than 6% of the surface area. On the contrary, the forest land covers about 76%. Any significant measure taken in this area to decrease evapotranspiration and keep the erosion protection of forest land, will lead to increased blue water production for downstream use. Locally, improved agricultural practices by incorporating GWC-measures will lead to small changes in evaporation and transpiration, but to larger reductions of surface runoff, to less erosion, and to increased groundwater recharge.

We have used regional data and on-site knowledge, provided for by our Chinese partners in good cooperation. We have processed these data to be used in the modelling environment. The partnership between the CWRPI and HAU and our consortium has been set up and works efficiently and effectively. In a parallel process, we have been working on capacity building and training of employees of our Chinese partners. Currently, we are investigating and exploring possibilities of generating follow-up projects together with our partners through various funding channels. This would allow us to further work together on solutions, based on tools that work, for the water challenges that China faces.

It is important that the follow-up of this demonstration project, using the initial results, leads to further exploration of the GWM&C concept within the Chinese legal framework for eco-compensation. Also, the credits of green water in China should be addressed in the framework of effective use of the water from the Changjiang Basin. Possibly, a water service market should be combined with payments and supervision by the national or regional governments. Finally, international cooperation appeared fruitful in this project.

1 Introduction

1.1 Context

The Changjiang (Yangtze River) provides water for the Middle Route Project (MRP) for South-to-North Water Transfer. This water will be extracted from the Danjiangkou Reservoir, situated in the Danjiangkou City, Hubei province, which will divert water from Danjiangkou Reservoir on the Hanjiang (Han River), a tributary of Changjiang River, to Beijing City through canals along Funiu and Taihang Mountains. Heightening the Danjiangkou Dam will increase the ability for flood control of middle and lower Hanjiang (Han River) and assure the safety of Wuhan City and the plain in the north of Hanjiang Basin.

Figure 1: Danjiangkou Reservoir or the Small Pacific at Danjiangkou City, Hubei province

The Duhe basin is one of the contributors to the Danjiangkou Reservoir. Within the Duhe basin, the pressure on the water resources is increasing as large scale water allocation is planned within the South-to-North Water Transfer. Water efficiency is getting more and more important to increase the amount of water available for downstream users and to increase the inflow of Danjiangkou reservoir. Over the last three decades, the Chinese government has been preparing the transfer, and several measures have been taken to reduce the pressure on the water. Mainly land use has been changed, forest area increased, and the area of cultivated land decreased by over 40% from 1978 to 2007 (see Table 1). People have been actively stimulated to move from the rural area towards the urban areas. However, the separate effects of these measures are unclear and measurements show that stream flow decreased over the last decades (see Figure 6). Major problems identified remain the erosion rate, the loss of fertile soil, the corresponding sedimentation of reservoirs, and the amount of water available for downstream users.

A mind-shift is necessary regarding the way we think about water and agriculture, instead of a narrow focus on utilisation of surface water and groundwater. It is important to be aware that precipitation is the ultimate source of water that can be managed. There is high potential to improve the use and management of rainwater in upstream rain-fed agriculture: this is termed *green water management* (see Figure 3). Current land management practices by farmers show loss of rainwater by (i) surface runoff, enhancing both flash floods and erosion (see Figure 2), and (ii) losses of water by evaporation directly from the soil, not by plant transpiration.

The knowledge and tools to improve upstream management and land use in arable, range and forest areas are available, but these need to be more widely implemented. Upstream land users can effectively provide rainwater management services to water users downstream, to improve the available *blue water* resources in terms of quantity and quality.

The implementation of *green water* management options can enhance water availability, but farmers need incentives to put them in place. At the same time, downstream users may be unaware of the benefits they can gain through farmer's implementation of these measures in upstream areas. This is the reason why part of the 'Green Water Credits' concept is about upstream and downstream cooperation (www.greenwatercredits.net).

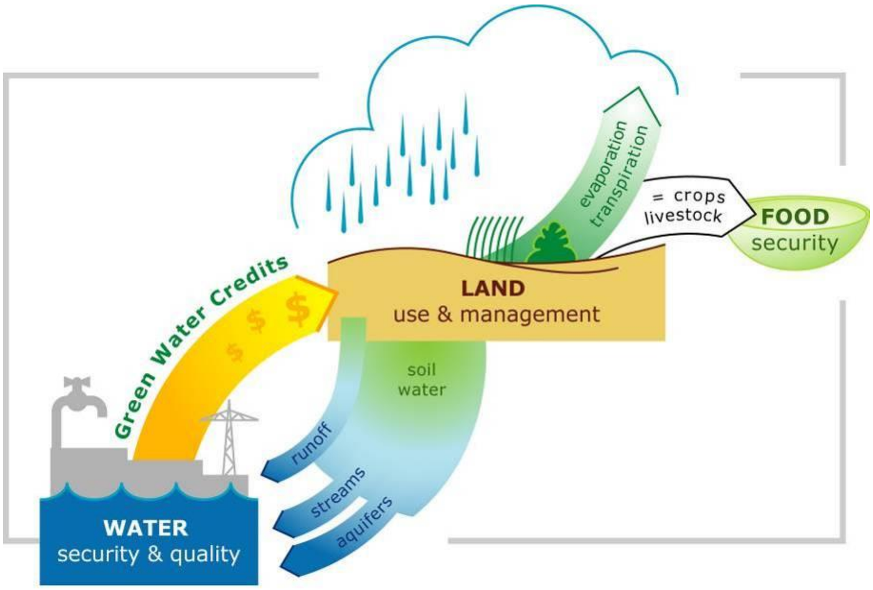

Figure 2: 'Green Water Credits' concept

1.2 Principles of Green Water Credits

The 'Green Water Credits' concept (GWC) aims first and foremost to create a sustainable relationship between the beneficiaries of watershed development and those who carry out the management, to encourage a financial relationship with the latter. The GWC system therefor enhances a payment system which rewards the people in rural areas which implement the green water measures, and carry out the soil and water management.

The watershed management is to reduce runoff and promote infiltration of precipitation to reduce water erosion. The water running off loosens soil particles, reducing soil fertility and increasing turbidity of the water. These transported solids settle downstream in the reservoirs of dams and reduce their ability to regulate water intake. When the ratio of infiltrated water and rainfall improves, the residence time of water in the watershed grows, floods are reduced, the erosive power of rain is reduced, plant production increases, which increases the resistance to soil erosion on the one hand and soil fertility on the other. In other words, increase the proportion of infiltrated water precipitated improves the quality of water from the catchment and reduces siltation of reservoirs and dams. The connection between the concept of green water and basin-scale water management is direct. Green water is infiltrated water used preferably for biomass production where it falls as precipitation. Green water should be used for plant transpiration, not for soil evaporation. Development of the use of green water reduces surface runoff and erosion effects, local as well as remote (see Figure 3).

Figure 3: Example of land erosion.

The overall goals of GWC are to enable upstream rural people to better manage soil and water resources leading to benefits including:

- Enhanced water flows;
- Reduced erosion and siltation of reservoirs downstream;
- Reduced non-point source surface pollution to downstream water bodies;
- Mitigation of floods;
- Mitigation of droughts;
- Mitigation of climate change impacts;
- Improved food and water security and public health;
- Improved local resilience to economic, social and environmental change by asset building: stable soils, improved water resources, reduced rate of poverty, and diversification of rural farmers' income.

A study was undertaken for the implementation of GWC within the Tana basin in Kenya (Hunink *et al.* 2009). The analysis of this basin showed that the implementation of GWC could significantly reduce problems related to the growing demands for hydropower generation, and of both municipal water utilities, and irrigators. Different *green water* management options were analysed, which showed that considerable improvements could be obtained in terms of water security for both upstream as well as downstream stakeholders.

Table 1: Land use change within Duhe catchment (Yan *et al.*, 2013).

Land use types	1978	1987	1999	2007	Change rates (1978–2007)
	(%)	(%)	(%)	(%)	(%)
water body	0.4	0.4	0.3	0.3	-25
residential area	0.8	0.9	1.1	1.4	+75
bare soil	0.3	0.4	0.4	0.7	+133
forest land	70.9	70.4	69.3	76.2	+7.5
shrub land	10.2	10.4	9.4	9.5	-6.9
grassland	7.6	7.3	5.9	6.1	-19.7
arable land	9.8	10.2	13.6	5.8	-40.8

1.3 Study area and background

1.3.1 Problem definition and background of Danjiangkou catchment

Danjiangkou Reservoir Dam is situated in the Danjiangkou City, Hubei province. It is the water source for the Middle Route Project (MRP) for South-to-North Water Transfer which will divert water from Danjiangkou Reservoir on the Hanjiang (Han River), a tributary of Changjiang River, to Beijing City through canals along Funiu and Taihang Mountains. The MRP will mitigate the crisis of water resources in Beijing, Tianjin and North China, and increase irrigated area by 0.6 million ha, 6.4 billion m^3 for municipal and industrial water supply, 3.0 billion m^3 for agriculture, for Beijing, Tianjin, Hebei and Henan provinces, and significantly improve the biological environment and investment environment of receiving areas, and boost the economic development in China.

Heightened the Danjiangkou Dam will increase the ability for flood control of middle and lower Hanjiang and assure the safety of Wuhan City and the plain in the north of Hanjiang Basin (http://www.nsbd.gov.cn/zx/english/mrp.htm).

Hanjiang, upper Danjiangkou Reservoir, is approximately 925 km in length; catchment area is 91,388 km^2, of which 62,263 km^2 in Shanxi Province, 7,911 km^2 in Henan Province and 21,214 km^2 in Hubei Province. It covers three provinces, six cities and 33 counties (see Figure 8). Distributing in the surroundings of Danjiangkou Reservoir, upper and middle stream of the Hanjiang, catchments of Xunhe River and Jinqian River, valley of Hanjiang, the peripheral area of Hanzhong Basin and the area of Hanjiang head.

There are various issues on the protection and management of eco-environment of the water resources of the Danjiangkou Reservoir:

- Vulnerable ecosystems: In the Qinling and Bashan rocky mountain region in the Reservoir Basin, soil is thin, eco-environment is frail, and soil erosion and water loss is severe. Spatial distribution of soil erosion corresponds to population density, mainly distributing in the surroundings of Danjiangkou Reservoir, upper and middle stream of the Han River, catchments of Xun River and Jinqian River, valley of Han River, the peripheral area of Hanzhong Basin and the area of Han River head. With increasing population and human activities in the region, soil erosion will no doubt be worsening: rocky desertification, lessening water source resulting in increase of river sedimentation, pollution of water resources. If the current situation could not be mitigated now, The Middle Route Project (MRP) for South-to-North Water Transfer would be at risk.
- Vulnerable environmental supporting capacity: In the surroundings of the Danjiangkou Reservoir, the submergence intensified conflict between population and arable land, e.g., in the Shiyan City region, average arable land per capita is only 0.92 mu (1 ha equals 15 mu), less than the average of the nation-wide (1.43 mu), Hubei provincial mean (0.96 mu). Immigration from the submerged area also caused problem that some immigrants return home from the new setting places because of un-acclimatization.
- Serious water pollution: Due to the historical and some objective reasons, the Reservoir receives large amounts of waste water derived from upstream industrial development and sewage. Recent monitoring at the 20 cross-sections on the 16 distributaries flowing into the Reservoir indicates that the water quality at 12 cross-sections (60% of all the sections) belongs to the standard of Grade IV; 8 sections belong to V or worsening. Organic pollutants, phosphorus and nitrogen are dominant; eutrophication is approaching due to increasing “non-point source” pollution from cultivated land e.g., chemical fertilizer, pesticide application. In addition, rapid development of fishery cultivation in the Reservoir also pollutes the Reservoir water quality.
- Lagged economic development: Poverty appears in the most region of the Reservoir Basin. There is a prominent contradiction between local economic development and water source protection: the central government has formulated and implemented series strict policies and regulations on energy saving and CO_2 reduction for environmental protection; concrete standards have been implemented, which have restricted the local economic development by forbidding mining and so on; the mining industries and companies which could not meet the standards have to be closed leading to reduction of local government’s treasury and lots of jobless, taking Hanzhong City as an example: due to the limitation, Hanzhong City reduces industrial GDP US$140 million, lessens profits and taxes US$ 13million, jobless 22,000.

All these eco-environmental issues are greatly affecting the protection of the Reservoir at source.

1.3.2 Sub basin selection

During the project's kick-off meeting in Wuhan, China on 17-21 September 2012, the selection for the Upper Duhe catchment was made. During a field visit to the Danjiangkou reservoir Dam an interactive session with delegates from all partners and local experts decided that the Upper Duhe catchment was most suitable for the demonstration of the GWC concept as the catchment was representative for the greater Danjiangkou catchment, and data sources where available to carry out the study. Also, Chinese partners have already been studying the Upper Duhe basin, looking at land use, streamflow, and soil losses by erosion. In Figure 4 an overview is given from China, Yangtze River basin, the Danjiangkou Reservoir and its Upper Duhe sub-basin.

Discussion at the Danjiangkou Reservoir on sub basin selection in September 2012.

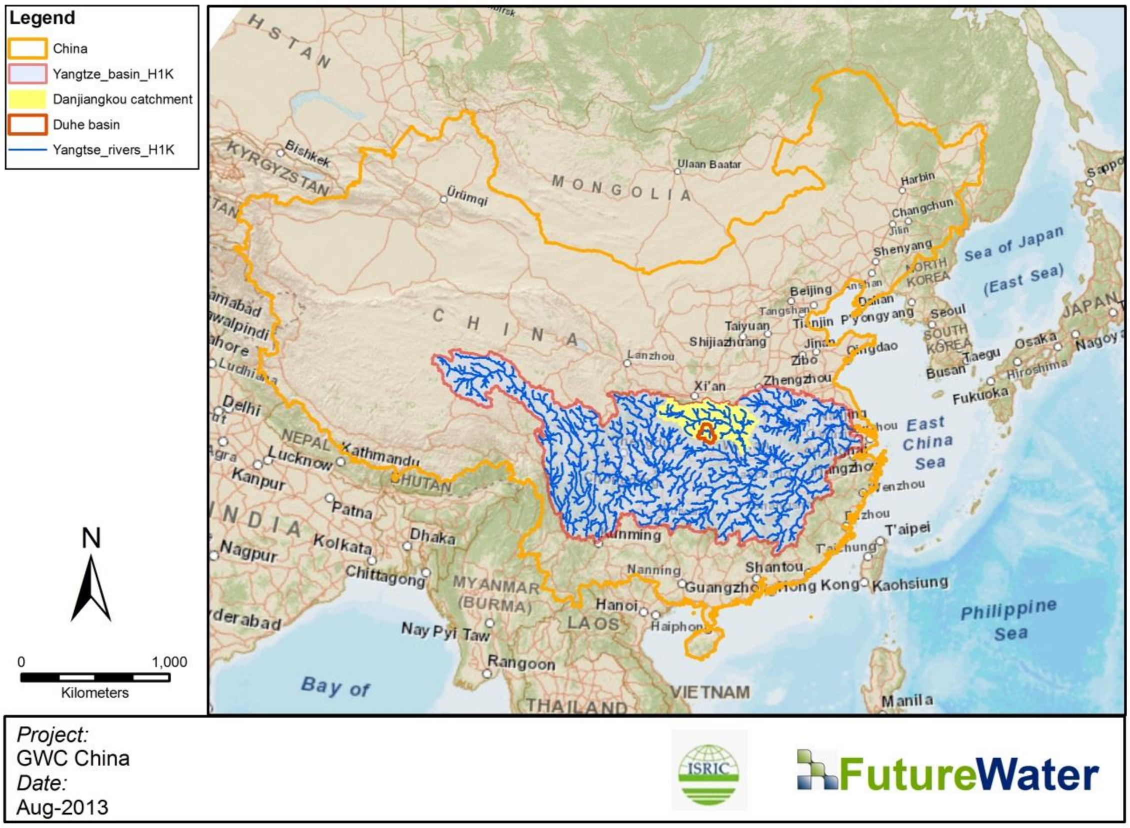

Figure 4: Basin selection for feasibility study.

1.3.3 Upper Duhe basin overview

The Upper Duhe catchment is situated in the upstream part of the Hanjiang basin and covers an area of 9,027 km^2. The most downstream point in the catchment is the Zhushan gauging station. The elevation ranges between over 3000 m in the South and South-West and goes down towards 280 m at Zhushan (see Figure 5). The source of the Duhe is situated in the Daba Mountains and after a 354 km course the river joins the Hanjiang (Yan *et al.,* 2013). The average slope of the Duhe is 4.8%. The topography in the area is undulating, in the Southern part slopes are steepest reaching op to over 80% and in the Northern lower part slopes are more gentile with mostly under 10%. The area has a typical sub-tropical monsoon climate, for which the mean annual temperature over the past 50 years has varied between 12.4 and 18.4ºC. Annual rainfall has varied between 728 and 1480 mm with a mean annual precipitation of 973mm of which over 80% falls in the monsoon (June – October). Soils in the northern part are predominantly classified as Yellow-brown-earths with over 70% of the total area. In the southern part Brown earths are more regular, and limestone soils cover another 5% of the total area. (National Soil Survey Office, 1992) The dominant land use types are forest and shrub land; villages, small towns and agricultural land are concentrated along the river. The major arable crops are corn and wheat (Yan *et al*., 2013).

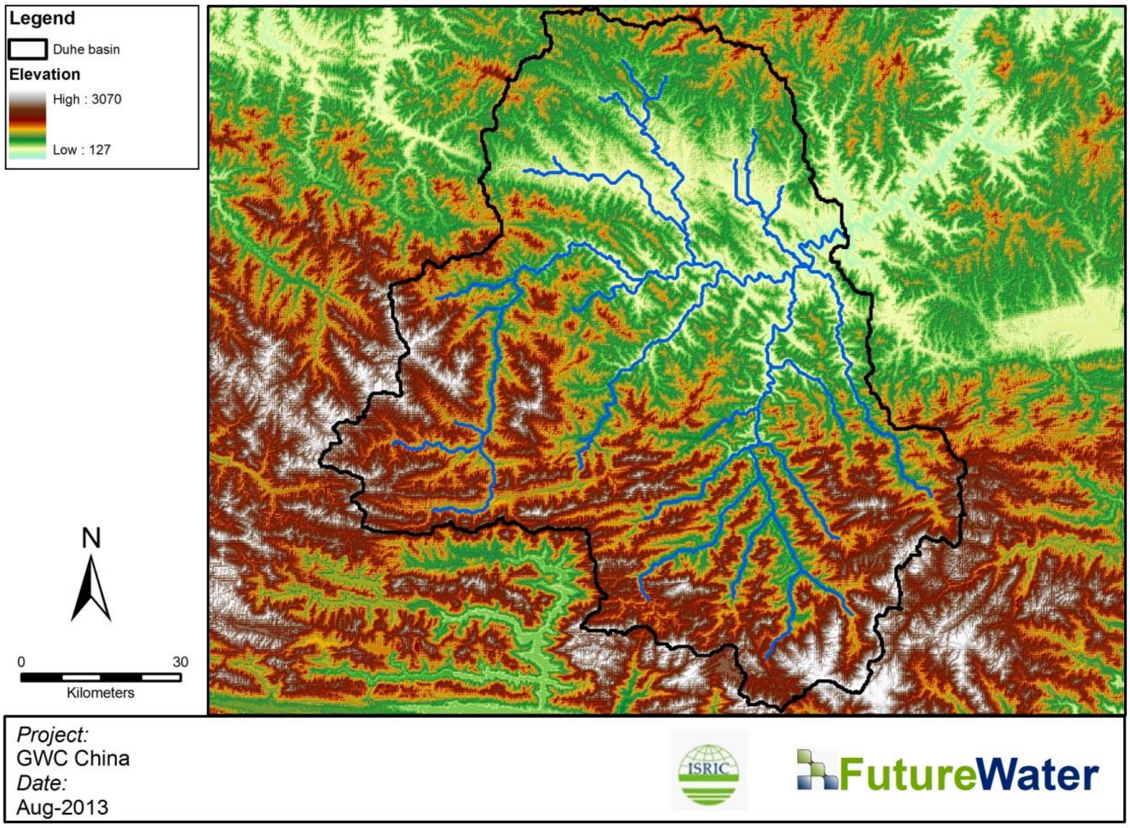

Figure 5: Digital Elevation Model (DEM) at 250m resolution

1.3.4 Overall water balance

Over the last two to three decades measures have been taken within the Duhe basin to improve water availability and water quality, besides soil conservation. However these measures have not resulted in a higher stream flow and water for downstream users became even scarcer. Figure 6 shows a downwards trend of the average flow at Zhushan station over the last 30 years. However, this downward trend is mainly caused by the relatively high discharges from 1980-1985. Meanwhile the average precipitation over the nine gauging stations show a complete flat trend line, so the downwards flow trend cannot be explained by a decrease in precipitation and must be caused by a higher evapotranspiration or storage change. During the GWC project the aim is to find sustainable measures which increases the stream flow and decreases evaporation.

The overall water balance (1980-2010) of the Upper Duhe basin shows that roughly 60% of the total precipitation returns as stream flow (*blue water*), 40% is captured by evapotranspiration (*green water*). The 40% evapotranspiration of water is the so-called working space which determines the limit of how much extra stream flow or *blue water* may be generated with the correct measures. To define measures, splitting of evapotranspiration into soil evaporation and plant transpiration is needed and will gain insight in the water balance terms. This plant transpiration is strongly related to crop production in agriculture.

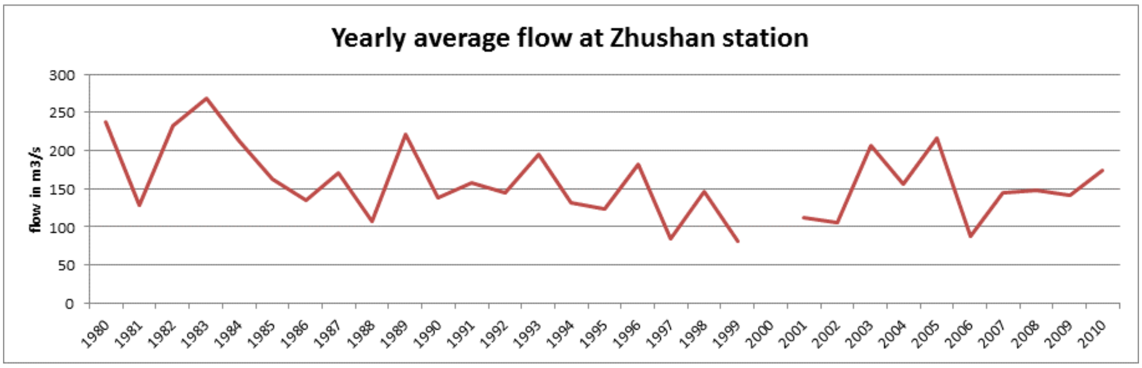

Figure 6: Yearly average measured stream flow at Zhushan gauging station in mm y^{-1}.

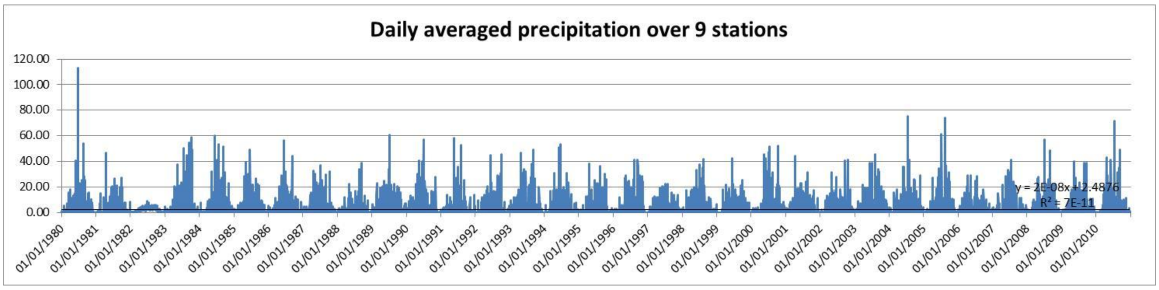

Figure 7: Aerial averaged precipitation in Upper Duhe basin in mm d^{-1}.

1.3.5 Sediment load at Zhushan gauging station – basin outlet

Erosion and sedimentation are important aspects within the GWC concept. By decreasing surface runoff, water can be stored as *green water* source in the soil and the soil can be conserved. The measures which the government has been implementing over the last decades resulted in a reduced sediment load at Zhushan gauging station (see Figure 8). Erosion decreasing measures include the land use change from cultivated land to forest (see Table 1). The downward trend in sediment load shows that achievements has been made so far and that any further GWC measures should aim in continuing this trend.

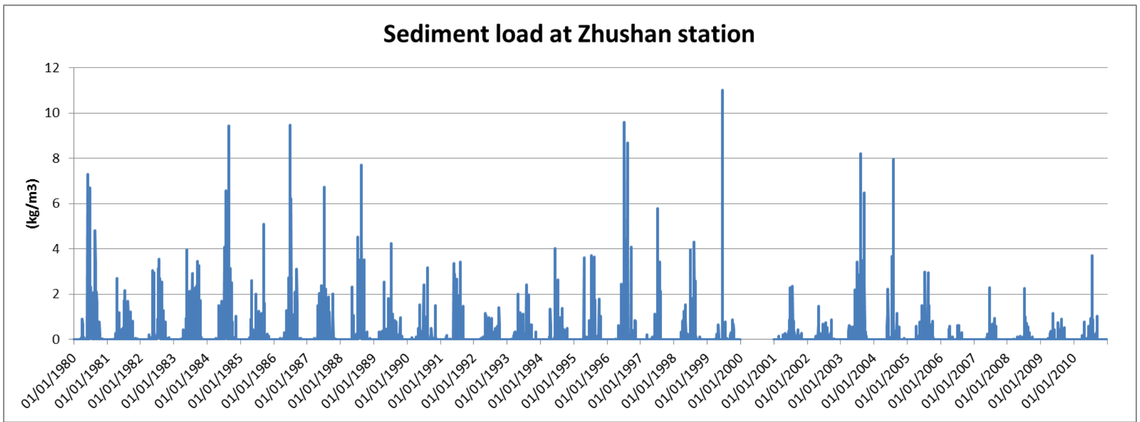

Figure 8: Sediment load at Zhushan gauging station in ton y^{-1}

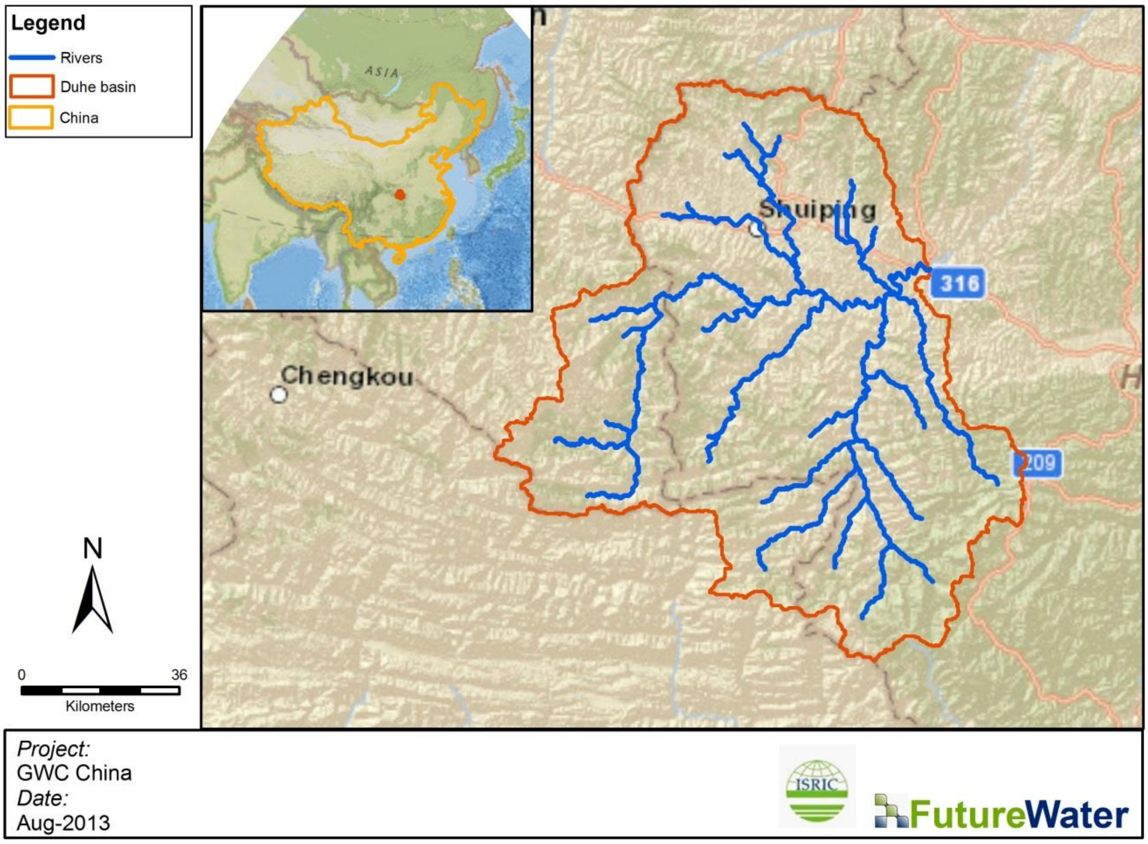

Figure 9: The Upper Duhe basin in China

1.4 The project – a feasibility study

The GWM&C approach is a unique knowledge point of the consortium partners. In order to have concrete outputs and quantified results, as required to implement the GWM&C approach, the GWM&C-Toolkit will be used. The toolkit needs to be refined to the Chinese conditions. It is a combination of three components: (i) data resources, (ii) analytical assessment tools, and (iii) presenting and decision system.

(i) The data resources are inter-linked and include all the GWM&C knowledge that has been obtained by the consortium over the last decades. These knowledge databases are being used for new GWM&C projects and are still expanding. The data in these database can be used freely, however the use of the information stored in these database required advanced knowledge available at the consortium.

(ii) The analytical assessment tools are computer simulation models that provide support to policy and decision makers to support them in their role to make sound decisions in what the impact will be of implementing GWM&C and where the most promising areas are located.

(iii) The presentation and decision part of the GWM&C Toolkit is essential to show and present in a convincing way what the impact of certain decision will be. The Lizard tool is the backbone of this presenting system.

This study has been performed within the Partners for Water project PVWS12001 'Refinement and Capacity Building of Green Water Management & Credits Toolkit for China'. The project has two components, the feasibility study and capacity building. This report is on the feasibility study, and more specific on the analytical / biophysical assessment tool SWAT. This regional-scale simulation model allows us to quantify the effect of separate measures taken or to be taken in basin areas in terms of water flow and erosion and sediment transport.

This report will show the feasibility of the use of the simulation model SWAT to evaluate and predict effects of GWM&C-measures on the water and sediment resources by different water and soil management practices. These models can be applied to several basins, feeding the Danjiangkou Reservoir. For the feasibility study, the Upper Duhe basin was chosen as the study area. In the next chapters, we will present the methodology and the model concept (Chapter 2), data needed (Chapter 3), and the baseline model for the situation at present (Chapter 4). The scenario analysis calculations are based on the baseline model, which will be adapted according to measures proposed (Chapter 5).

2.1 Simulation model selection

The circulation of water within the earth and atmosphere is a complex mechanism of energy exchange and different ways of transportation. A schematisation of the different processes involved in the water cycle is shown in Figure 10. Hydrological models are a tool to simulate these paths of water movement under different conditions. They are used to study, for example, the impact of climate change on water availability, the impact of land use change on river discharges, and the impact of (agricultural) management strategies on water availability and sediment yield.

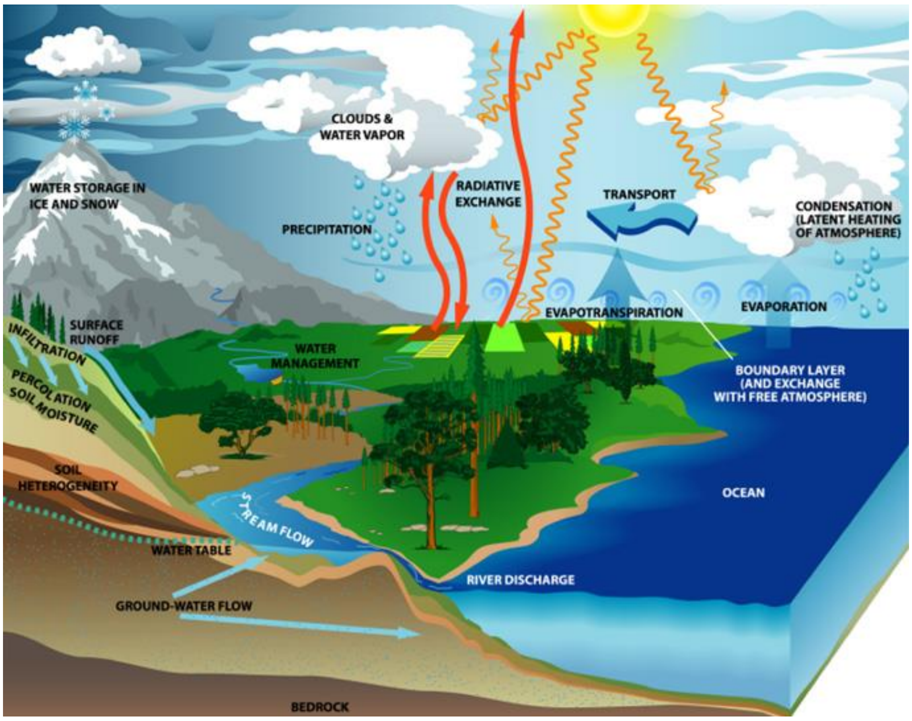

Figure 10: Schematisation of the water cycle.

Currently, a huge number of hydrological models are available to analyse soil-water relationships at the field and catchment/basin level. For the current study, the Soil and Water Assessment Tool (SWAT) (Gassman *et al.* 2007) was chosen to evaluate the impact of crop-land-soil management on downstream water and sediment flows. SWAT (version 2005) was chosen because it is a basin-scale model, which is able to quantify the impact of land management practices in large, complex watersheds.

The main advantage of SWAT for the exploration of GWC in the Duhe basin is that SWAT uses a physical-based rainfall-runoff scheme, instead of a purely data-based statistic or conceptual scheme. This guarantees more reliable scenario simulations and better performance in poorly gauged catchments, which is essential for a study at this scale. Besides, the model is primarily focused on the interaction between land management versus water-and erosion processes. This makes the tool appropriate for this study, as it is able to represent and simulate the impact of land management practices on basin-scale water and sediment yields.

In brief, strong aspects of the SWAT model that make it suitable for the current project can be summarised as:

- Physical-based rather than parametric-based rainfall-runoff scheme to ensure more reliable scenario simulations.
- Focus on water-erosion-land management processes.
- Public domain, including source code.
- User-friendly interface.
- Large user-group worldwide.
- Excellent documentation, including training materials.
- Consortium's extensive experiences in application as well as training.
- Modelling experience with previous Green Water Credits assessments in Kenya Morocco and Algeria. (Kauffman *et al.* 2007; Hunink *et al.* 2009). The relevant components of SWAT for this study will be described in the following paragraphs.

2.2 SWAT

SWAT is a distributed, regional-scale basin model developed originally by the USDA Agricultural Research Service (ARS) and Texas A&M University and is currently one of the world's leading spatially distributed hydrological models. A distributed rainfall-runoff model – such as SWAT – divides a catchment into smaller discrete calculation units for which the spatial variation of the major physical properties are limited and hydrological processes can be treated as being homogeneous. The total catchment behaviour is a net result of manifold small sub-catchments. The soil map and land cover map within sub-catchment boundaries are used to generate unique combinations, and each combination will be considered as a homogeneous physical entity, namely a Hydrological Response Unit (HRU). The water balance for HRUs is computed on a daily time basis. Hence, SWAT disaggregates the river basin into units that have similar characteristics in terms of soil, land cover, and that are located in the same sub-catchment.

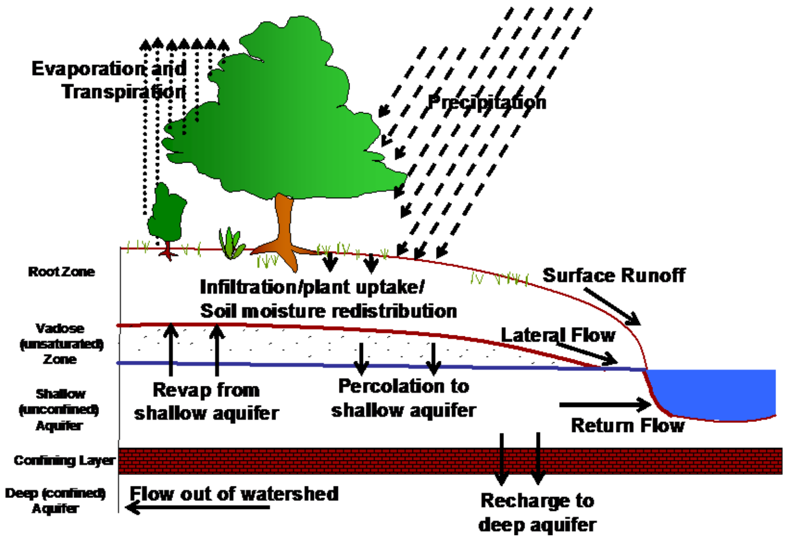

Figure 11: Main hydrological processes implemented in the SWAT model.

Irrigation in SWAT can be scheduled by the user, or automatically determined by the model depending on a set of criteria. In addition to specifying the timing and application amount, the source of irrigation water must be specified, which can be canal water, a reservoir, a shallow aquifer, a deep aquifer, or a source outside the basin.

SWAT can deal with standard groundwater processes (see Figure 11). Water enters groundwater storage primarily by infiltration/percolation, although recharge by seepage from surface water bodies is also included. Water leaves groundwater storage primarily by discharge into rivers or lakes, but it is also possible for water to move upward from the water table into the capillary fringe, i.e. capillary rise. As mentioned before, water can also be extracted for irrigation purposes. SWAT distinguishes recharge and discharge zones.

Recharge to unconfined aquifers occurs via percolation of excessively wet root zones. Recharge to confined aquifers by percolation from the surface occurs only at the upstream end of the confined aquifer. Where the geologic formation containing the aquifer is exposed at the earth's surface, flow is not confined, and a water table is present. Irrigation and link canals can be connected to the groundwater system; this can be an effluent as well as an influent stream.

After water has infiltrated into the soil, it can leave the ground again as lateral flow from the upper soil layer – which mimics a 2D flow domain in the unsaturated zone – or as return flow that leaves the shallow aquifer and drains into a nearby river (see Figure 12). The remaining part of the soil moisture can feed into the deep aquifer, from which it can be pumped back. The total return flow thus consists of surface runoff, lateral outflow from root zone and aquifer drainage to river.

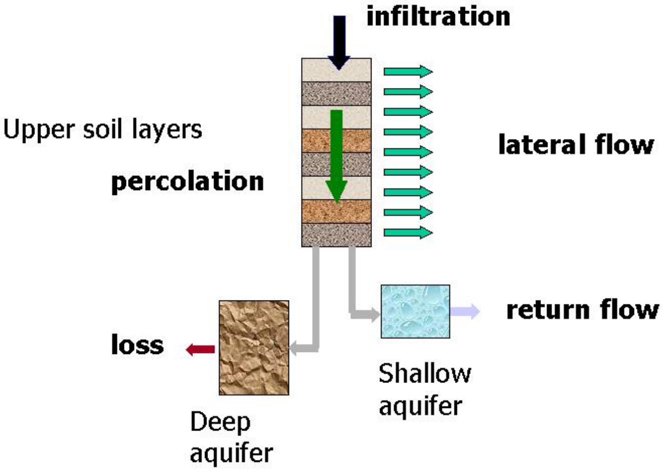

Figure 12: Schematisation of the SWAT sub-surface water fluxes.

For each simulation day, potential plant growth, *i.e.* plant growth under ideal growing conditions, is calculated. Ideal growing conditions require adequate water and nutrient supply and a favourable climate. First the Absorbed Photosynthetical Radiation (APAR) is computed from intercepted solar radiation, followed by a Light Use Efficiency (LUE) that, under SWAT, is essentially a function of carbon dioxide concentrations and vapour pressure deficits. The crop yield is computed as the harvestable fraction of the accumulated biomass production across the growing season (see
Figure 13).

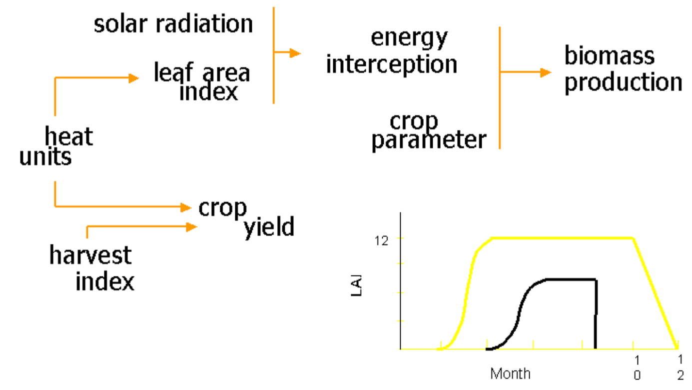

Figure 13: Parameterisation of crop production in SWAT.

2.3 Data needs

An overview of the data required to perform the biophysical assessment is provided for in Figure 14. The datasets were requested and obtained from the Chinese counterparts and evaluated, as described in the following sections. In addition, the remainder of the data necessary for the schematisation of the model was obtained from global public domain datasets.

It was discussed with the local counterparts that the time resolution of the climate-data needs to be daily data. These data need to be from various weather stations, well-distributed throughout the basin, both from mountain areas as well as downstream locations.

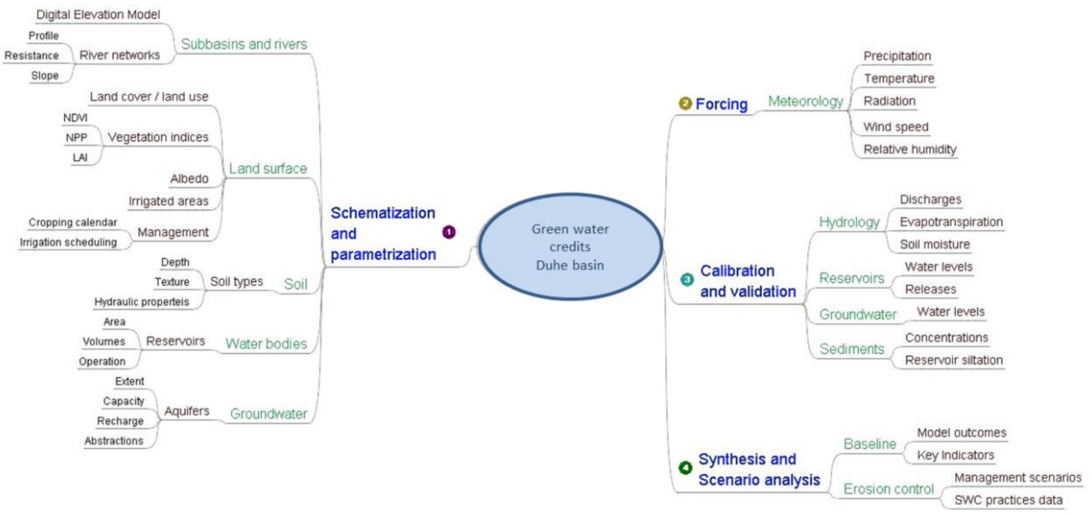

Figure 14: Diagram of required data and modelling components for the GWC bio-physical assessment for the Duhe basin.

The following sections will describe the datasets that have been evaluated and prepared for the assessment. The main datasets that are discussed are:

- Digital Elevation Model (DEM)
- Climate information

- Land use and management
- Soil types and properties
- Streamflow gauging stations
- Reservoir location, volume, management

3 Baseline Datasets

3.1 Introduction

For the Green Water Credits concept it is crucial to fully understand and quantify the up- and downstream interactions in terms of water flows and sediment transport. Consequently good data on the interfering variables of the current situation are needed and must be analysed with the appropriate tool. As was mentioned before, the SWAT model is used in this study to analyse the impacts of land use management strategies on the water and sediment dynamics in the Upper Duhe basin.

The current chapter describes the available datasets which were used to build-up the distributed hydrological model in the Upper Duhe basin. Different datasets are available, which are compared and evaluated in order to make an appropriate dataset selection to obtain optimal accuracy in the quantification of the interactions relevant for the scope of Green Water Credits.

3.2 Digital Elevation Model

Digital elevation data for Duhe watershed were obtained from the Shuttle Radar Data Topography Mission (SRTM) of NASA's Space Shuttle Endeavour flight on 11-22 February 2000 and shown in Figure 15. SRTM data were processed from raw radar echoes into digital elevation models (DEM) at the Jet Propulsion Laboratory2 (JPL) in California.
SRTM data at a spatial resolution of 3 arc-second (90 meters) are available for global coverage between latitude 60 degrees North and 56 degrees South. This product consists of seamless raster data and is available in geographic coordinates (latitude/longitude), and is horizontally and vertically referenced to as the EGM96 Geoid (Lemoine *et al*., 1998). The SRTM-DEM data were obtained using the Data Distribution System of CIAT (http://srtm.csi.cgiar.org/) where the original DEMs were further processed to fill in these no-data voids. This involved the production of vector contours and points, and the re-interpolation of these derived contours back into a raster DEM. These interpolated DEM values are then used to fill in the original no-data holes within the SRTM data. These processes were implemented using Arc/Info and an Arc Macro Language AML script. The DEM was resampled to the Lambert Conformal Conic 3 projection with a resolution of 250 m using a bilinear algorithm. Finally it was clipped to the boundary of the basin, and sink were filled using the method of Tarboton *et al.* (1991) with a threshold of 20 m.

The elevations in the Duhe watershed range between 141 m and 2944 m. Large gradients are found: highest in the Wudang mountains in the south-western, southern and north-eastern part of the watershed. The lowest elevation of the watershed is 141 m, at Zhushan station. The average DEM is about 1145 m (See Figure 15).

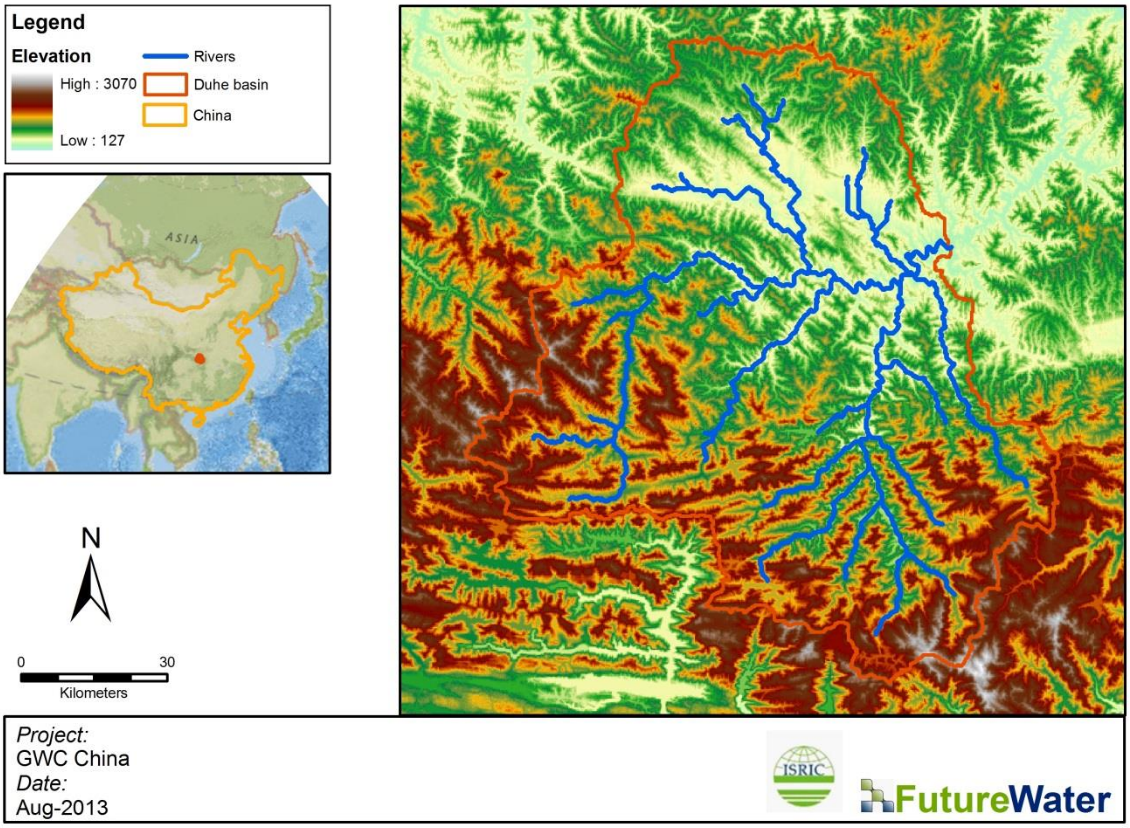

Figure 15: Digital Elevation Model (DEM) of the Duhe basin at 250m spatial resolution.

3.3 Climate information

3.3.1 Data needs

SWAT requires daily rainfall data, as well as other meteorological input data that depend on the evapotranspiration method used. Several methods are available to calculate the potential evapotranspiration. The most advanced method available, the Penman-Monteith method (Monteith *et al.,* 1965), requires data on temperature, solar radiation, wind speed, and humidity for the calculation of the spatially distributed potential evapotranspiration rates. For this phase, the Penman-Monteith method was used for the calculation of the potential evapotranspiration. However, for the temperature, solar radiation, wind speed, and humidity data there are no ground-based measurements available. A Climate Forecast System Reanalysis (CFSR) was used to obtain these data (http://rda.ucar.edu/pub/cfsr.html).

3.3.2 Data sources

The data used for the SWAT model is a combination of locally obtained data and global climate data from a Climate Forecast System Reanalysis. In the following paragraphs both will be discussed.

3.3.2.1 Locally obtained climate data

Daily precipitation data at nine stations, seven (Guandu, Baofeng, Taoyuan, Qingu, Hongmiao, Caijiaba, Huangjiawan) in the upper Duhe area and the another two (Yeda and Damuchang) in the downstream of the Upper Duhe basin (see Figure 16) were provided by the Chinese partners who collected the data from the Water Conservancy Department of Hubei province. These daily data are time-series of precipitation for the period from 1965 to 2010. Precipitation data at two stations (Laohekou and Wanyuan) which are outside the watershed were collected for the period of 1951-2000. The location and elevation of the stations are show in Table 2. In this study the precipitation from 1980-2010 were used.

Table 2: Location and elevation of the precipitation stations.

Precipitation station	Longitude	Latitude	Elevation (m)
Guandu	110°05’E	32°00’N	345
Baofeng	110°00’E	32°19’ N	484
Taoyuan	109°49’ E	31°44’N	894
Qingu	109°50’ E	32°26’ N	570
Hongmiao	109°38’E	32°22’ N	525
Caijiaba	109°51’ E	32°01’N	676
Huangjiawan	110°01’E	31°35’ N	1305
Yeda	110°27’ E	32°33’ N	239
Damuchang	110°33’E	32°23’N	434
Laohekou	111°24’E	32°14’N	900
Wanyuan	108°12’E	32°24’N	674

Meteorological station at the bank of the Danjiangkou Reservoir.

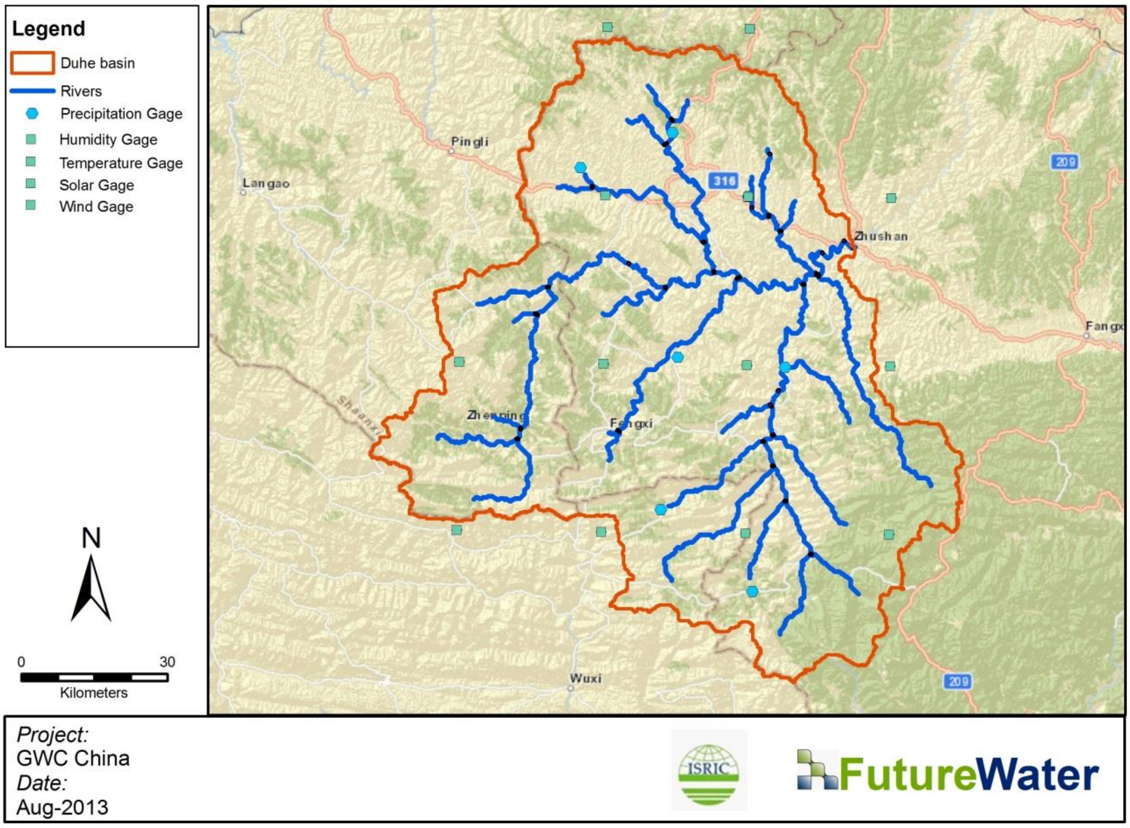

Figure 16: Locations of ground-based precipitation station and CFSR grid locations.

3.3.2.2 CFSR climate data

For the period (1980-2010) daily precipitation, daily minimum and maximum air temperature data, daily humidity data, daily wind speed data and daily solar radiation data are required for the SWAT model. We use gridded air temperature extracted from the PRINCETON Global Meteorological Forcing Dataset for land surface modelling (PRINCETON) (Sheffield *et al.*, 2006]. The PRINCETON dataset is constructed by combining a suite of global observation-based datasets with the National Center for Environmental Prediction – National Center for Atmospheric Research (NCEP– NCAR) reanalysis. The data is available at 0.5° x 0.5° spatial resolution (see also grid in Figure 16).

3.4 Land use

Land use data for the years of 1990, 2000 and 2007 were provided for by the Huazhong Agricultural University (see Figure 17). The land use data of the year 2007 were used as an input data in this study, because our simulation period is 2001-2010.

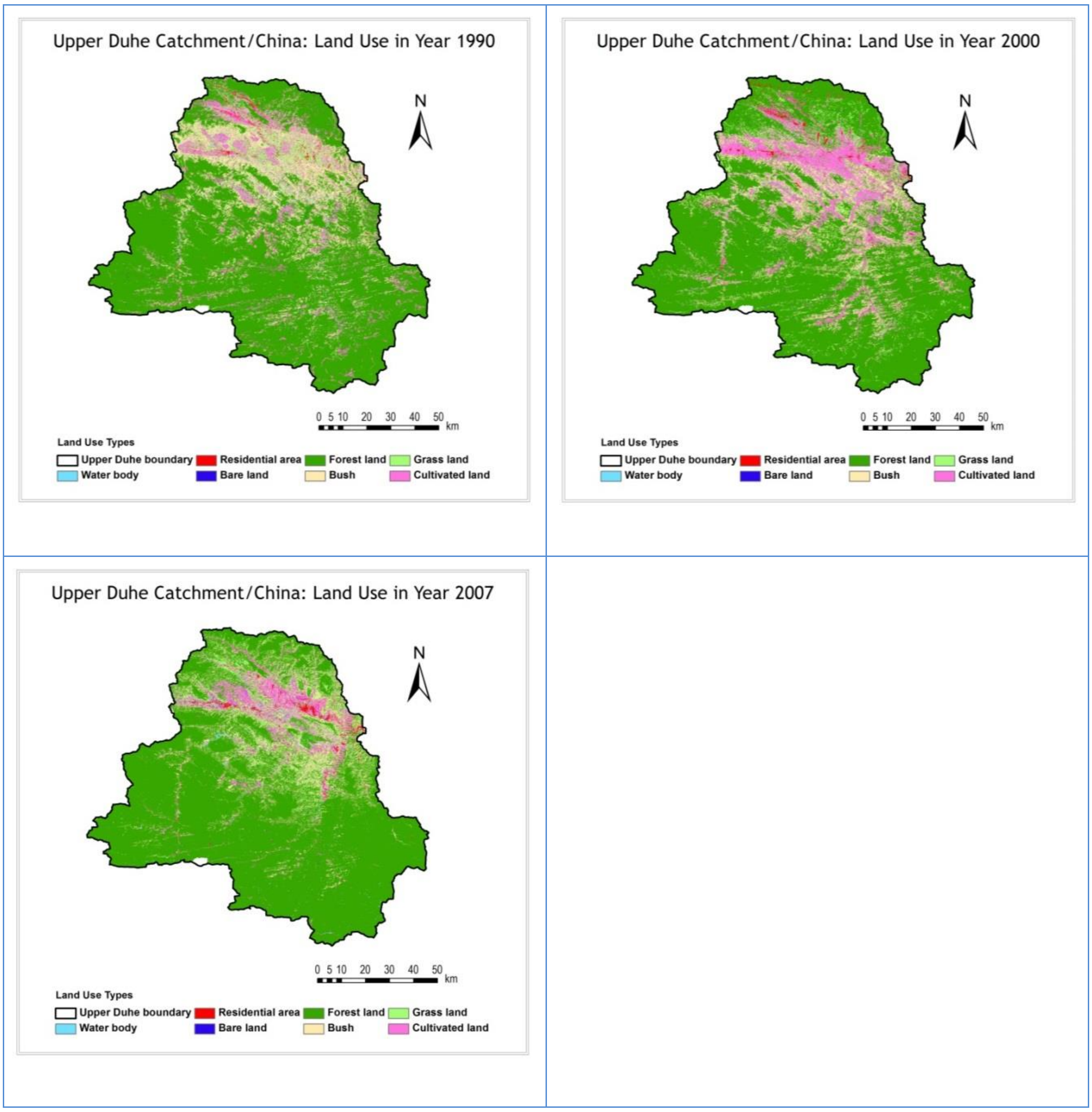

Figure 17: Land use in Upper Duhe basin for year 1990, 2000, and 2007.

The data were produced using the satellite images of Landsat TM 5 and 7 at 30m spatial resolution. Landsat TM 7 was launched on 15th April, 1999, which was operated and managed by NASA in California. The Landsat TM 7 is a sun-synchronous orbit satellite, at altitude of 705 km, which covers the entire globe every 16 days (except for the highest polar latitude). The Inclined is 98.2°. The sensors of Landsat TM 7 are Enhanced Thematic Mapper Plus, which produces satellite images resolution in 30m*30m with eight spectral bands, including a panchromatic and thermal band. The Scene size is 170 km*185 km. These photos are aimed to provide up-to-date and cloud-free image (USGS, 2013).

3.4.1 Processing of land use data

The satellite images were classified in ERDAS Imagine 9.2 according to the Current Land Use Condition Classification for National Standard of the People's Republic of China (China's National Standard (GB/T 21010 -2007) by the following steps:

- All data were re-projected to WGS_1984_UTM_Zone_49N;
- The data were clipped for the Duhe watershed;
- According to the classification system, the data were classified using supervised classification and visual interpretation;
- Draw the boundaries of the land use and added the labels of the polygons to produce digital map;
- Edit and compile the vector digital maps;
- The processed data were converted to 250 m grids using nearest neighbour's resampling.

The error from Landsat TM data interpretation was estimated by sampling frames. For each 7 km, a 200 m width sampling frames was built. Seven land use classes were identified in the study area and shown in Table 3. In the National Standard Land Use Condition Classification, cultivated land is defined as all agricultural lands, including permanently cultivated land, new cultivated land, paddy, grassland-farming rotated land and inter cropping land (crop-fruiter and crop-mulberry). Grasslands include dense, moderate and sparse grass. Water bodies include stream, rivers, reservoir and ponds (Chen and Zhou, 2007). In Duhe watershed, forest lands account for most of the total area, *i.e.*, more than 70% of the total area, followed by bush fallow, grassland, cultivated land; water body, residential area took up only around 2% of the total area.

Table 3: Land use types and areal coverage (%) in the Duhe basin.

Land use class	Area (km^2)	% of total area	SWAT_name	Code
Water body	31	0.35%	WATR	11
Residential area	113	1.26%	PLAN	21
Bare land	61	0.68%	BARE	31
Forest land	6852	76.36%	FRST	41
Bush fallow	845	9.41%	RNGB	51
Grassland	553	6.16%	RNGE	81
Cultivated land	519	5.78%	AGRL	82
Total	**8973**	**100%**		

3.5 Soils

Soil data for Duhe watershed, including soil types and properties, were obtained from the Soil Survey Office of Hubei Province (Figure 18). The data were surveyed during the Second National Soil Survey from 1979 and 1994 (Shi *et al.*, 2004). Soil types in the Duhe watershed are shallow and vary in space due to diverse parent materials. According to the Chinese Soil Classification System (National Soil Survey Office, 1992), the soil types include yellow-brown earths, brown earths, limestone soils, paddy soils, dark-brown earths, purplish soils, fluvo-aquic soils and meadow soils. These soil types were converted to the USA Soil Taxonomy (Shi *et al.*, 2010).

Given the fact that most soils are shallow and based on rocky sediments, a regional-scale aquifer system is assumed to be absent or not relevant enough to play a significant role in the hydrology of the Upper Duhe basin.

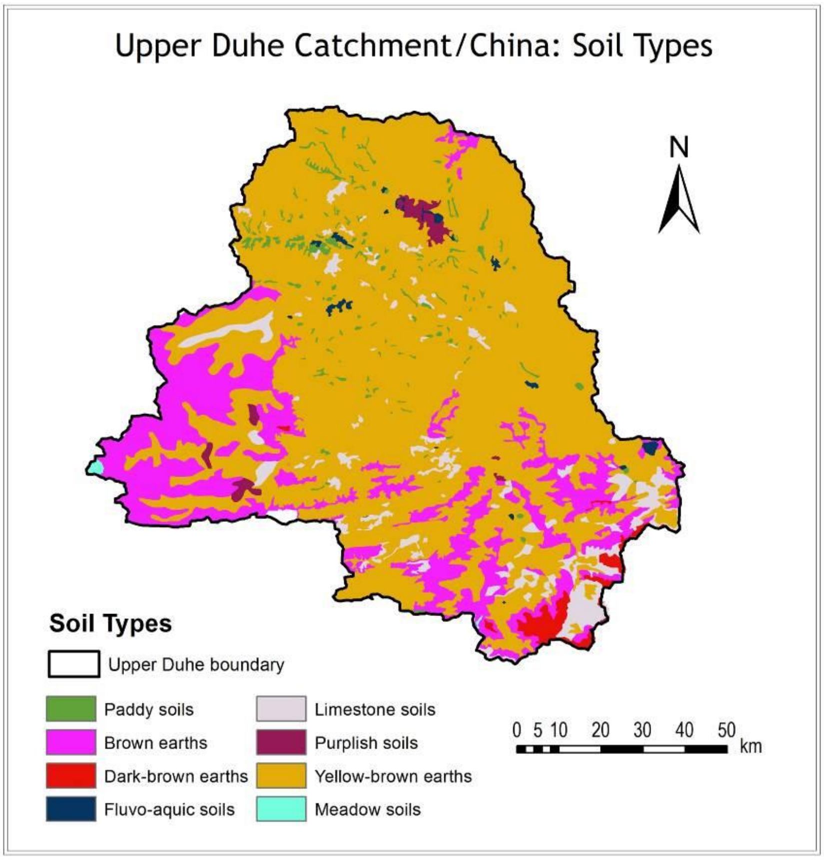

Figure 18: Soil types in the Upper Duhe watershed

The soil chemical properties are relevant to water quality and used in the SWAT model. The soil physical properties affect water cycle in simulation process. They are 1) soil layers (NLAYERS); 2) the maximum root depth in soil profile (SOL_ZMX); 3) the depth between soil surface and soil basement (SOL_Z); 4) soil saturated hydraulic conductivity (SOL_K); 5) soil surface spectral reflectance (SOL_ALB); the factor of soil erosion (SOL_EC); 6) soil bulk density (SOL_BD); 7) soil available water storage (SOL_AWC); 8) soil hydrology groups (HYDGRP); 9) soil organic carbon content (SOL_CBN); 10) soil clay content (CLAY); 11) soil silt content (SILT); 12) soil sand content (SAND); 13) soil rock content (ROCK); 14) soil texture (TEXTURE). The soil properties from 1) to 5) were looked up in the two books << Xun Yang Soil>> (Wang, 1988) and <<Hu Bei Province Soil Outline>> (Wang and Xu, 1997). The other soil physical properties were calculated in the model of Soil Water Characteristics of the software Soil Water Atmosphere Plant (SWAP) according to the percentage of soil particles size. The soil properties are shown in Annex A.

The soil hydrological groups were classified by final constant infiltration rate in terms of similar rainfall and surface runoff (Musgrave, 1955). Four soil hydrological groups are defined, which classification standards are shown in Table 4 (Cronshey, 1986).

Table 4: Soil hydrological groups and some characteristics.

Soil hydrological groups	Soil textures	Infiltration speed	Infiltration rate(mm/h)
A	Mainly with sand	High	7.6 -11.4
B	Silt loam or loam	Medium	3.8-7.6
C	Sandy clay loam	Low	1.3-3.8
D	Mainly with clay	Very low	0-1.3

To distinguish soil data in SWAT model, a soil type index table (Table 5) has been built, where “Value” and “SNAM_CN” stand for the code of soil type in number and words in SWAT model.

Table 5: Statistics of soil type in the Upper Duhe basin.

Soil types	Area (km^2)	Area in total (%)	Value	SNAM_CN
Yellow-brown earths	6415.7	71.5	7	huangzongrang
Brown earths	1660	18.5	2	zongrang
Limestone soils	493.5	5.5	5	shuihuitu
Paddy soils	143.6	1.6	1	shuidaotu
Dark-brown earths	116.6	1.3	3	anzongrang
Purplish soils	89.7	1	6	zisetu
Fluvo-aquic soils	44.9	0.5	4	chaotu
Meadow soils	9	0.1	8	caodiantu

3.6 Discharge – outflow of basin

Daily mean streamflow at five stations (Zhushan, E'Ping, Huangwan, Xinzhou and Yanba) were collected from the Water Conservancy Department of Hubei Province, for the period from 1965 to 2010. Daily sediment load data at two stations (Zhanshan and Xinzhou) were collected for the period of 1965-2010 and 1975-2009, respectively. Zhushan station, built in 1958, is the biggest hydrological gauging station in the basin and the second biggest discharge station in Hubei Province (Wang, 2007; Luo and Chen, 2010).

There is no other water transfer to or from the Upper Duhe basin. All surface water leaves the catchment at the Zhushan gauging station. We have used measured data from this station to check and optimize the SWAT model for the period 2001-2010.

3.7 Reservoirs

The Upper Duhe basin is part of the Danjiangkou Reservoir basin. The Danjiangkou Reservoir, with its dam situated near Danjiangkou City, Hubei Province, is the water source for the Middle Route Project (MRP) for the South-to-North Water Transfer, which will divert water from Danjiangkou reservoir on the Hanjiang (Han River), a tributary of Changjiang (the Yangtze River), to Beijing City through canals along Funiu and Taihang Mountains. The MRP will mitigate the crisis of water resources in Beijing, Tianjin and North China, and increase irrigated area by 0.6 million ha, 6.4 billion m^3 for municipal and industrial water supply, 3.0 billion m^3 for agriculture, for Beijing, Tianjin, Hebei and Henan provinces, and significantly improve the biological environment and investment environment of receiving areas, and boost the economic development in China. Hanjiang, upper Danjiangkou Reservoir, is approximately 925 km in length, the catchment area is 91,388 km^2.

Within the Upper Duhe basin, the five major reservoirs are illustrated in Table 6and Figure 20. Several other small reservoirs were built in this area with a volume below 100km3 and with unsufficient data to include them in the SWAT model. The small reservoirs could serve as sediment traps though, to some extent.

Figure 19: Danjiangkou Reservoir (upper picture) and heightened dam, China, September 2012.

Table 6: Major reservoirs in the Upper Duhe basin.

Name of reservoir	Location (Lat/Lon)	Catchment area (km^2)	Water level (m)	Volume (million m^3)	Inflow (million m^3/year)	multi-year mean Inflow (m^3/s)	Sediment load (Ton/year)	Electricity (*10^6 Watt/year)
Pankou (Du River)	32° 12' 33" N, 110° 09' 10"E	8950	355	2338	5170	164	4790000	1050
Hunaglongtan (Du River)	32° 40' 34.11"N, 110° 31' 22.77" E	11140	247	945.3	5640	179	8580000	759
Xiaoxuan (Du River)	32° 14' 13.37"N, 110° 12' 51.11" E	9040	264	367.4	5112	162	3934000	149.4
Songshuling (Guandu River)	31° 57' 16.74"N, 110° 03' 57.08"E	2447	394	57.48	1827	57.9		153.9
E' Ping (Si River)	32° 12' 19.02"N, 109° 42' 16.44"E	2210	550	296.3	1105	35		270

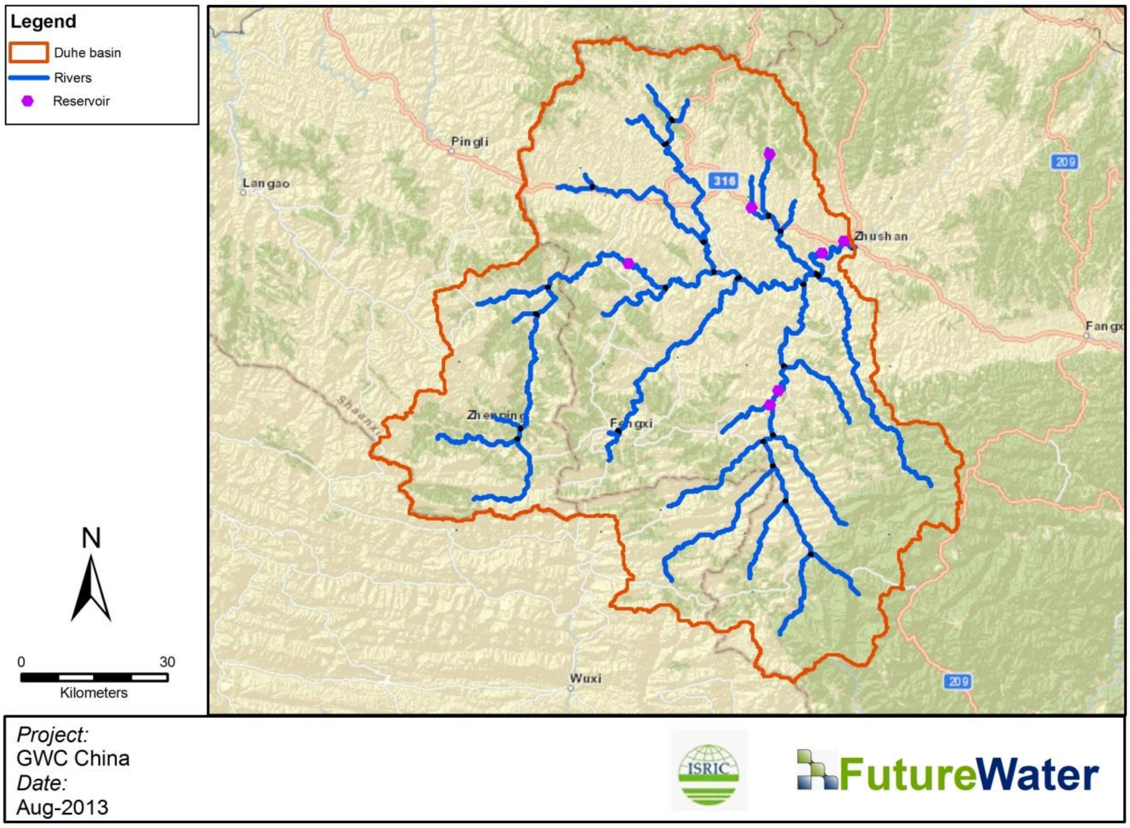

Figure 20: Location of the major reservoirs in the Upper Duhe basin.

4 Baseline modelling assessment

4.1 Introduction

This chapter describes the set-up of the SWAT hydrological basin-scale simulation model to serve as the quantitative tool for exploring the effect of measures within the framework of the 'Green Water Credits' concept (GWC). This technical part of the GWC-Toolbox will enable us to simulate the basin situation in terms of water and sediment at present, to evaluate relevant measures from the past (e.g., see Yan *et al*., 2013), and to assess future water and land management measures as a part of policy programs.

Using the SWAT model, we can quantify the hydrological and erosion-sedimentation processes in the Upper Duhe basin at present. To be able to do this, we have setup a baseline model. Given this model, we will calculate the separate and total effect of future GWC-measures in terms of green water, blue water, and erosion. We will quantify these effects, based on the field measurements and baseline calculation results at Zhushan gauging station in terms of stream flow and sediment load. Steps taken to build and optimize the baseline model will be discussed and model performance will be shown. Furthermore, the spatial distribution of the SWAT model output will be analysed at the spatial level of Hydrological Response Units (HRUs). These spatial units build up to sub-basins, while the sub-basins add up to the total Upper Duhe basin under consideration in this project.

We are not aiming at calculating results on the water and sediment balance of the Upper Duhe catchment to judge or influence policy plans or issues. Our main goal is to show that SWAT is an appropriate tool at the basin-scale, to quantitatively evaluate measures on beforehand, in time and space.

The baseline SWAT model has been set-up for a period of 31 years (1980-2010). Justification of data used to build the model was provided for in the previous section. To summarise:

- DEM: NASA SRTM dataset;
- Climate: for precipitation measurement stations derived from Chinese counterpart (9). For temperature, solar radiation, humidity and wind speed the NCEP Climate Forecast System Reanalysis (CFSR) dataset is used (13 'stations' / grid points);
- Land use: aggregated land use map by Huazhong Agricultural University, based on Landsat TM 5 and 7;
- Soil types were obtained from the Soil Survey Office of Hubei Province;
- Discharge measurements and reservoir characteristics have been obtained from local counterparts in China.

4.2 Baseline model set-up

4.2.1 Basin delineation

Under SWAT, the basin outlet is set to the gauging station at Zhushan, just before the tributary from Huohe/Muyushan reservoir. All upstream tributaries from Zhushan are included in the analysis. This delineation for which the basin outlet is similar as the gauging station is very favourable for optimizing the model as the model can be calibrated for the full study area.

The DEM forms the base to delineate the catchment boundary, stream network and sub-catchments. This is performed by the pre-processing module of SWAT and requires a threshold area. This refers to a critical source defining the minimum drainage area required to form the origin of a stream. The determination of an appropriate threshold area has to be in accordance with the desired level of detail.

In the current study we found an appropriate threshold of 10,000 ha, which provides a good balance between the level of detail and computational constraints. This resulted in a total of 55 sub-catchments. A first trial was performed with a threshold area of 20,000 ha, but this led to a total of 33 sub-catchments, which lacks the desired detail for this study. A threshold of 20,000 ha also results in elongated sub-catchments with large elevation differences within the sub-catchment. This has negative effects on the simulation of the orographic precipitation regimes. The delineation of the 55 sub-catchments is shown in Figure 21. It can be seen that the sub-catchments are more or less equally sized, and that they are not too stretched. The average sub-catchment area with the defined threshold of 10,000 ha is 164 km^2.

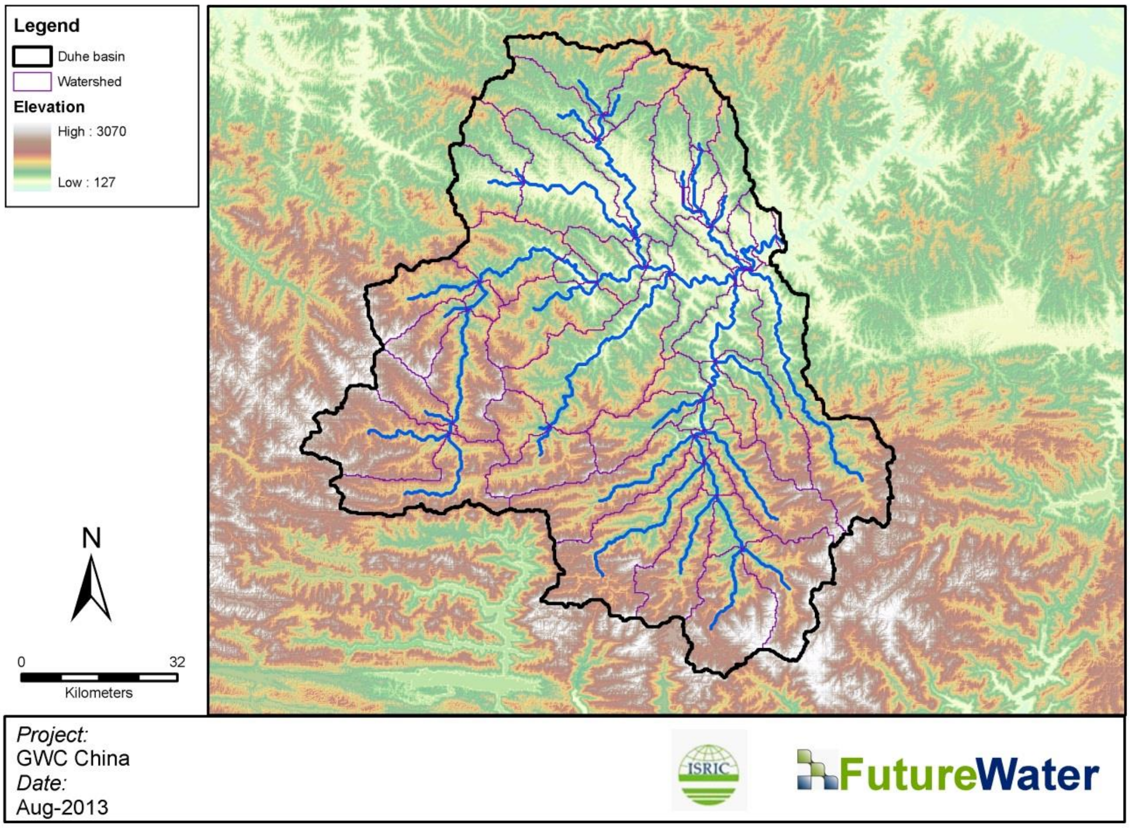

Figure 21: Locations of the 55 delineated sub-basins along with the derived streams. The threshold for delineation was set at 10,000 ha.

4.2.2 Hydrological Response Units

For the spatial disaggregation of the sub-catchments, SWAT uses the concept of Hydrological Response Units (HRUs) (Neitsch *et al.,* 2000). These are portions of a sub-catchment that possess unique land use, management, and soil attributes. In other words, an HRU is the total area within a sub-catchment with a unique land use, management, and soil combination. HRUs are used in SWAT since they simplify a run by lumping all similar soil and land use areas into a single response unit. The size of a HRU depends on the size of the total area under consideration.

Implicit in the concept of the HRU is the assumption that there is no interaction between HRUs within one sub-catchment. Loadings (runoff with sediment, nutrients, etc. transported by the runoff) from each HRU are calculated separately and then summed to determine the total loadings from the sub-catchment. If the interaction of one land use area with another is significant, rather than defining those land use areas as HRUs they should be defined as sub-catchments. It is only at the sub-catchment level that spatial relationships can be defined. The benefit of HRUs is the increase in accuracy this adds to the prediction of loadings from the sub-catchment. The growth and development of plants can differ greatly substantially among species. If the diversity in plant cover within a sub-catchment is accounted for, then the net amount of runoff entering the main channel from the sub-catchment will be much more accurate.

In practice the HRUs are defined by overlaying three data layers:

- Sub-catchments;
- Land use;
- Soils.

Based on these three data layers 829 HRUs (see Figure 22) were determined for the upper Duhe catchment. The land use is most responsible for the spatial differentiation among the HRUs. This results in smaller HRUs in the north of the Upper Duhe basin where land use is more diversified.

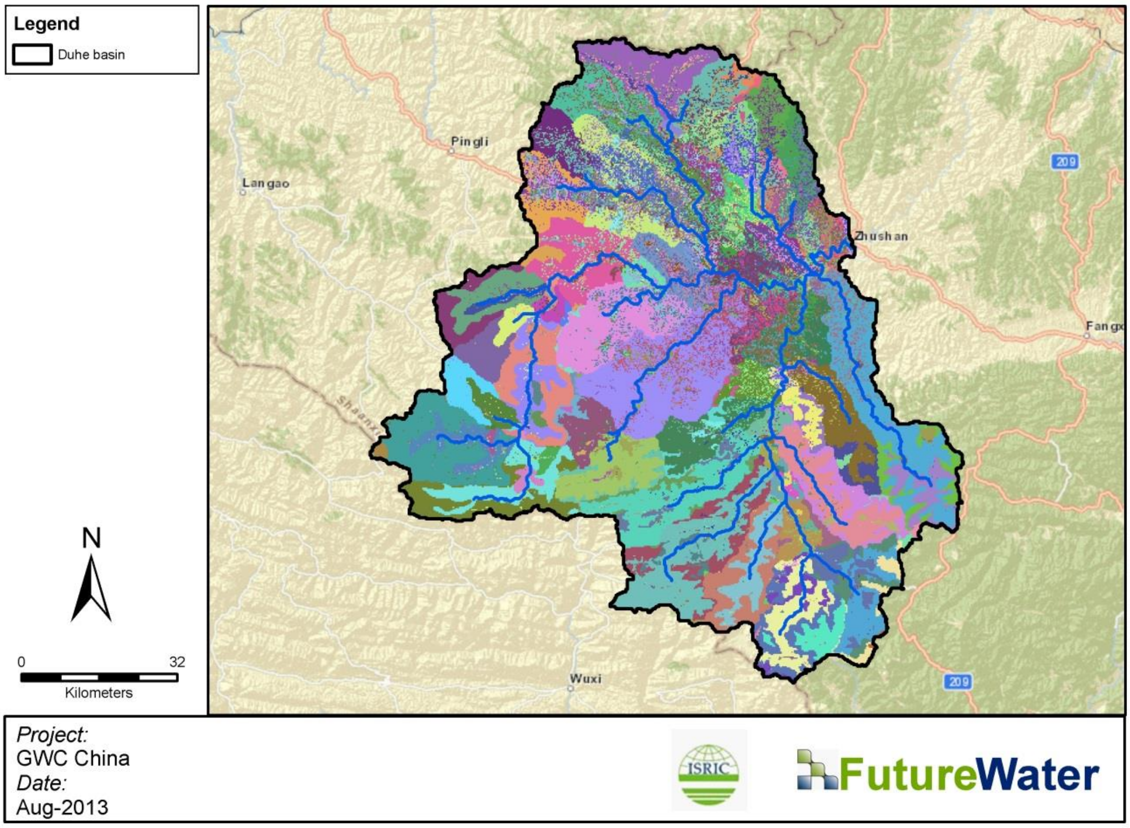

Figure 22: SWAT - hydrological response units (HRUs) in Upper Duhe basin.

4.3 Reservoirs

All five major reservoirs within the Upper Duhe catchment are implemented in the model. During the determination of the sub-basins, additional outlet points are created on the place of the reservoirs. This co-defines the layout of the sub basins as outlet points are seen as the most downstream point within a sub-basin. This additional added outlet points are later on linked to the reservoir data. Missing data concerning reservoir surface area was calculated by dividing the total volume by the water level. For those reservoirs for which the water level was not known a linear regression was made of the surface area and the volume to fill the data gaps. See Figure 23.

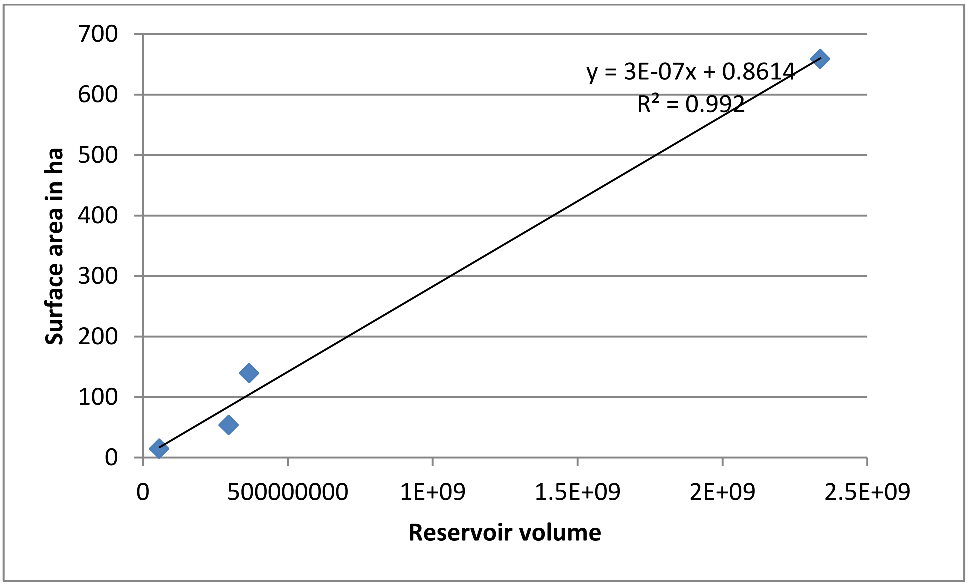

Figure 23: Reservoir volume vs. surface area.

4.4 Climate data in SWAT

The location and elevation of the weather stations and daily time series for precipitation, solar radiation, relative humidity, wind speed and temperature are included in the model. The Penman-Monteith method (Monteith *et al.* 1965) is used for the calculation of the spatially distributed potential evapotranspiration rates. This method requires data on temperature, solar radiation, wind speed, and humidity. See paragraph 4.7 for the spatial results of the climate data.

4.5 Model performance on outflow and sediment loads

The long-term time series of stream flow and sediment load at Zhushan gauging station will be used to optimize the model performance. Since the land use has changed over the last decades, the choice is made to focus on the modelling period 2001-2010. This period is most representative for the land use map used in the model, dated 2007, and it is a good starting period to calculate and evaluate future GWC-measures. The period 1980-2000 is used to initialize the model. For this feasibility study, the key focus is to assess the impact of the *green water* management practices on water and sediment in the basin, quantifying the differences between the studied scenarios and the current management situation, represented in the baseline model. In this sense, it is crucial to note that conclusions drawn from scenario analysis are much more reliable than absolute model predictions (relative vs. absolute model accuracy, e.g. Droogers *et al.,* 2008).

In order to optimize the model, a sensitivity analysis was first carried out using the parameters shown in Table 7. These seven parameters were altered within realistic ranges (Neitsch *et al.,* 2005), showing that the model was most sensitive to parameters CN, LAI_INIT, SOL_AWC, SOL_K, PLAPS and ESCO.

The Curve Number (CN) parameter varies non–linearly with the moisture content of the soil. The curve number drops as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. The LAI_INIT is the initial leaf area index. These numbers are slightly adapted for the land use classes' forest, urban and bare soil, to better fit with the local situation. The PLAPS rate is the precipitation laps rate, which adjusts the precipitation for the elevation bands in the sub basin. SOL_K relates soil water flow rate to the hydraulic gradient and is a measure of the ease of water movement through the soil. SOL_AWC is the available water capacity of the soil layer, which is available for the plants. The ESCO factor varies between 0.01 and 1. A lower value allows the model to extract more of the evaporation demand from lower levels. The USLE_P factor increases with steeper slopes and is a ratio between soil loss and slope.

Table 7: Parameters used for sensitivity analysis and model optimization with respect to stream flow and water balance.

Parameter	Unit	Variable
CN		Initial SCS runoff curve number for moisture condition
LAI_INIT		Initial leaf area index (forest,bare,urban)
PLAPS	mm H2O/km	Precipitation laps rate
SOL_K	mm/hr	Saturated hydraulic conductivity of the soil layer
SOL_AWC	mm H2O/mm soil	Available water holding capacity of the soil layer
ESCO		Soil evaporation compensation factor
USLE_P		USLE equation support practice factor

The model is optimized based on the overall water balance, the outflow at Zhushan gauging station and based on the sediment load at the Zhushan gauging station. The optimization was performed both, on a monthly base and on a yearly base. For a first annual mass balance, the following formula was used: P-ET-Q=ΔS (see Figure 24) in units [mm/y], in which:

- P = Precipitation
- ET = Evapotranspiration
- Q = Discharge/outflow of basin
- ΔS = is the change of storage within the time step.

As mentioned in chapter 1.3, the overall mass balance shows that from all precipitation, about 40% returns as evapotranspiration (green water) into the atmosphere, 58% becomes discharge out of the basin (blue water), which is available for downstream water users. The remaining 2% is net storage change. Note that this storage change is relatively small and could be caused by uncertainties in e.g. precipitation data. Unless the catchment as a whole is becoming significantly wetter with time (trend), the long-term expected storage change should approach zero.

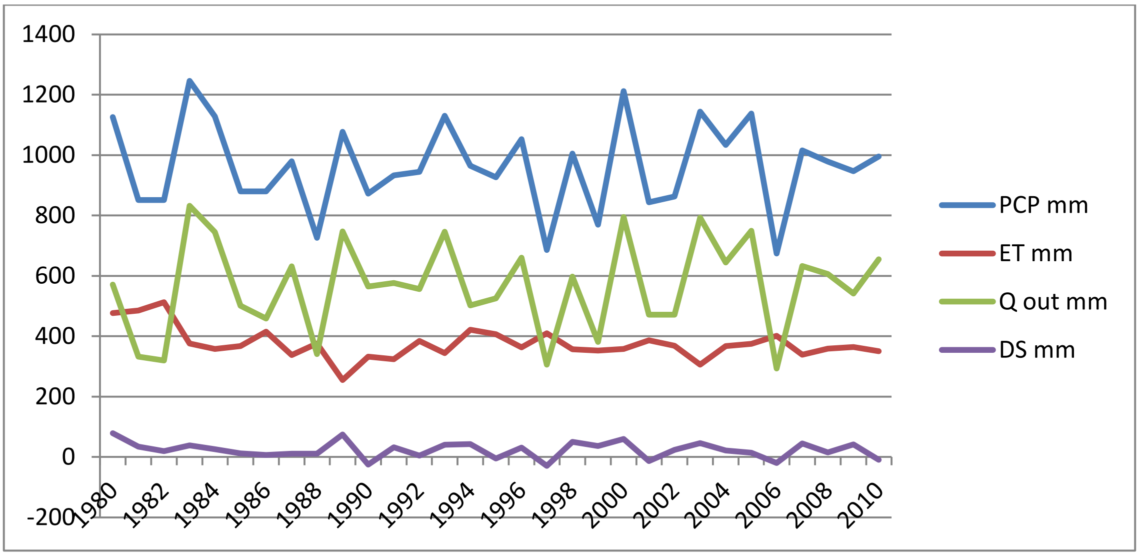

Figure 24: Upper Duhe basin, annual water balance terms in mm y^{-1} (1980-2010). PCP for precipitation, ET for evapotranspiration, Q for outflow, and DS for storage change.

The correlation of the measured and simulated discharge at Zhushan shows that the low discharges and base flow are simulated well, and that the higher discharges are slightly overestimated by the model calculations. However, with an overall correlation coefficient of nearly 0.8, the model is performing well (see Figure 25).

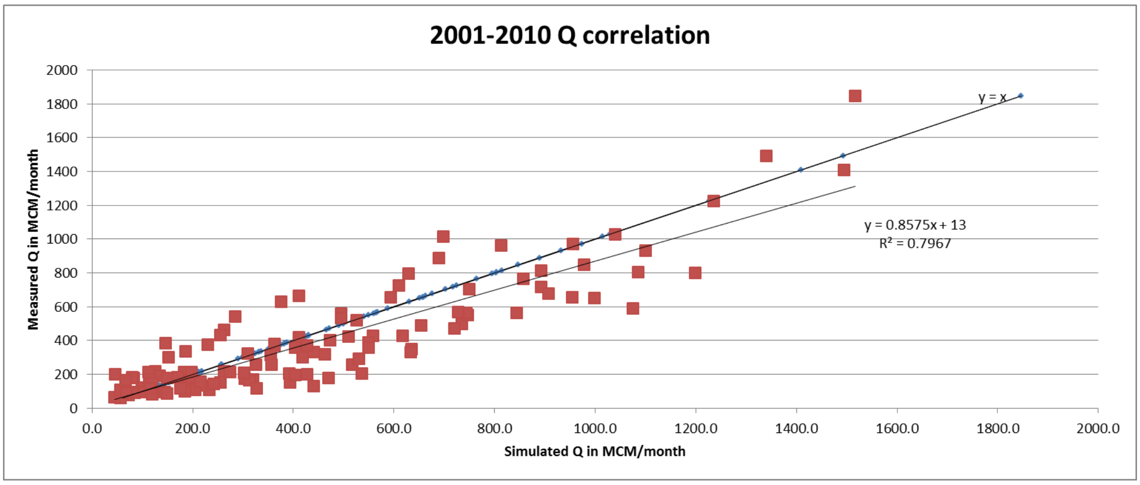

Figure 25: Correlation between simulated (X-axis) and measured discharge (Y-axis) at Zhushan station. Data period 2001-2010, monthly data.

When plotting the measured and simulated discharge at Zhushan station in the time it becomes clear that the measured and calculated time series are quite similar and that both peak flows and base flow are simulated well (see Figure 26). The model seems to have a small time delay in generating the discharge, which may be caused by a slightly higher storage capacity of the soils as compared to the soils in reality. No further analysis was performed on this subject.

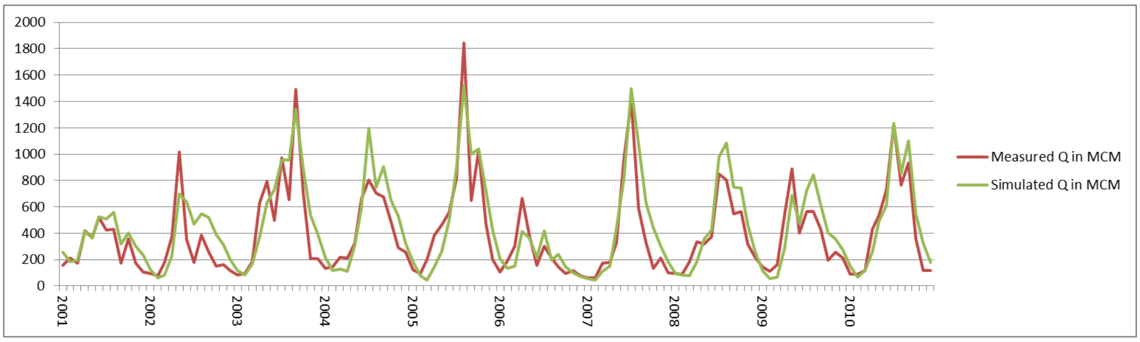

Figure 26: Observed and simulated stream flow at Zhushan station in MCM (10^6 m^3) for the 2001-2010 period.

The sediment load at Zhushan gauging station was initially simulated too low by the non-optimized baseline model at a long-term average of 23% of the measured values (see Figure 27). Several parameters influence the amount of erosion and sediment in the reach (see Table 8). The largest adjustments have been done to the SPCON parameter which was adapted from 0.0001 towards 0.0006, which is still within the allowable range of 0.0001 to 0.01. Improving the model performance for sediment load results in Figure 28, which shows the measured vs. simulated sediment load at Zhushan station. Extreme events are underestimated, especially during the first years of the period. However, the overall mass balance of sediment load is resulting in 105% of the measured sediment load over the 30-year period. This is mainly accountable for the last four years in which the total amount of sediment is overestimated, which may be caused by the two new large reservoirs upstream of Zhushan gauging station.

Table 8: Parameters used for sensitivity analysis and model performance improvement with respect to the calculated sediment load.

Parameter	Unit	Variable
SPEXP		Linear parameter for calculating the maximum amount of sediment that can be reentrained.
SPCON		Exponent parameter for calculating sediment reentrained in channel sediment routing
FILTERW	m	With of edge-of-field filter strip
OV_N		Manning's "n" value for overland flow
USLE_P		USLE equation support practice factor

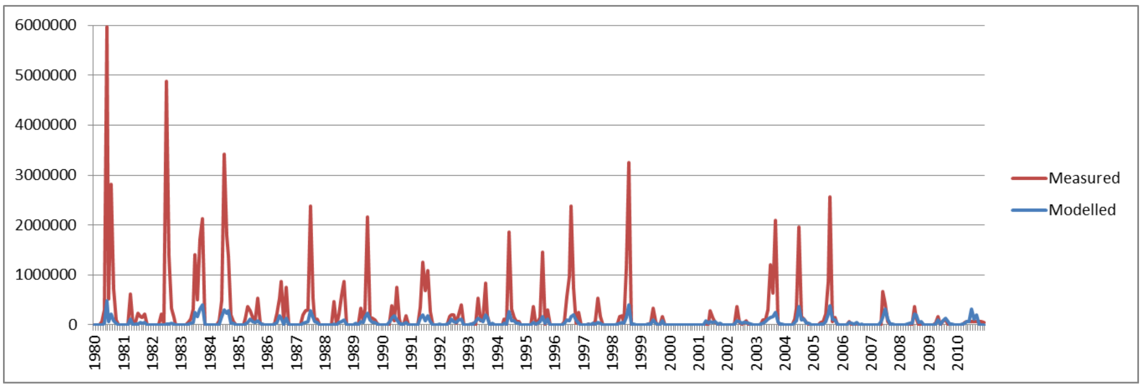

Figure 27: Observed and simulated sediment load (tons/month) at Zhushan station before optimization of baseline model. Data period 1980-2010.

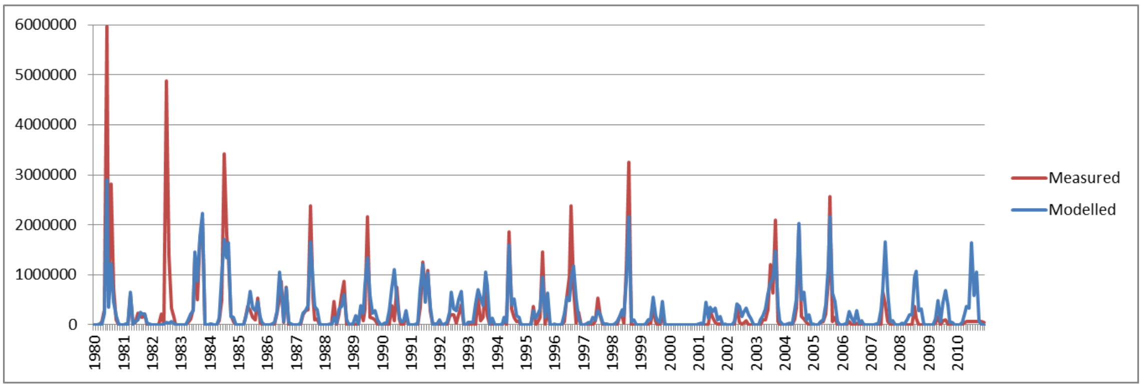

Figure 28: Measured and simulated sediment load in (tons/month) at Zhushan gauging station with optimized baseline model. Data period 1980-2010.

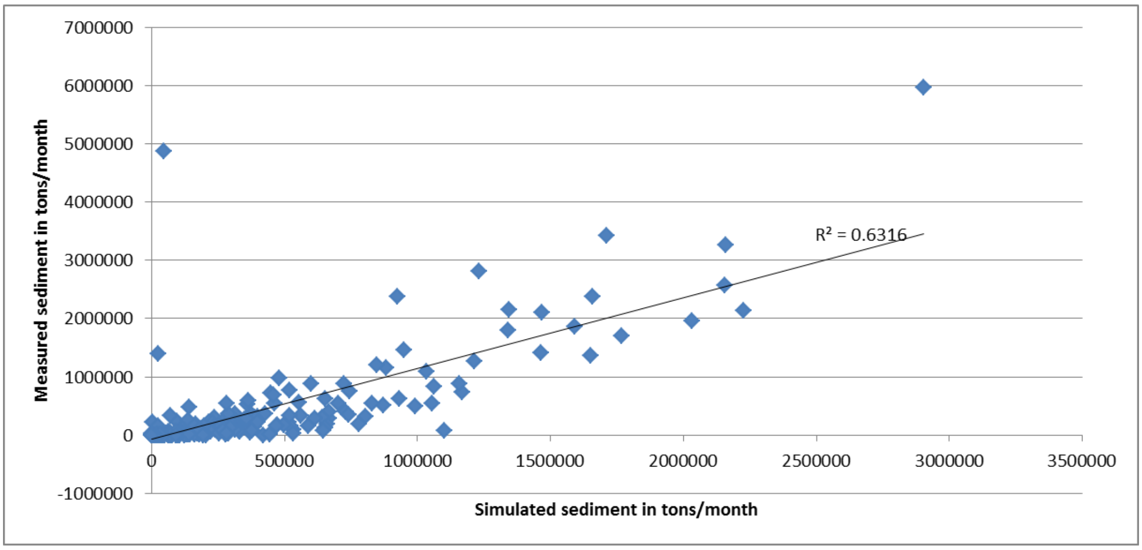

Figure 29: Correlation between simulated (X-axis) and measured sediment load (Y-axis) at Zhushan gauging station. Data period 2001-2010, monthly data.

Example of sediment present in tributary river to Danjiankou Reservoir, September 2012.

4.6 Role of agriculture in GWC practices

To explore the most relevant land use classes regarding Green Water Credits, baseline results were aggregated for each land use class. The following results have been plotted:

- The total amount of water consumed by vegetation through plant transpiration and water lost by soil evaporation (see Figure 30);
- *Blue water*: water entering the streams by surface runoff, lateral drainage, and groundwater discharge (see Figure 31);
- Erosion: gross erosion rates (see Figure 32).

Evapotranspiration is the sum of water consumed by the plants for transpiration and the water lost by soil evaporation. Evaporation also occurs of intercepted rainfall, but this process was not included in the analysis. Soil evaporation can be considered a non-beneficial loss of green water from the soil system. The water gained by reducing soil evaporation can be either used for plant transpiration or can infiltrate and serve as groundwater recharge, in the end becoming blue water downstream.

Figure 33 shows annual evapotranspiration (ET) data for each land cover class, split into plant transpiration (T) and soil evaporation (E). It can be remarked that evaporation from bare soil is somewhat high and possibly overestimated by the model calculations, but the total area of bare soil is fairly small. The calculated evaporation from bare soil has only a small influence on the basin water balance.

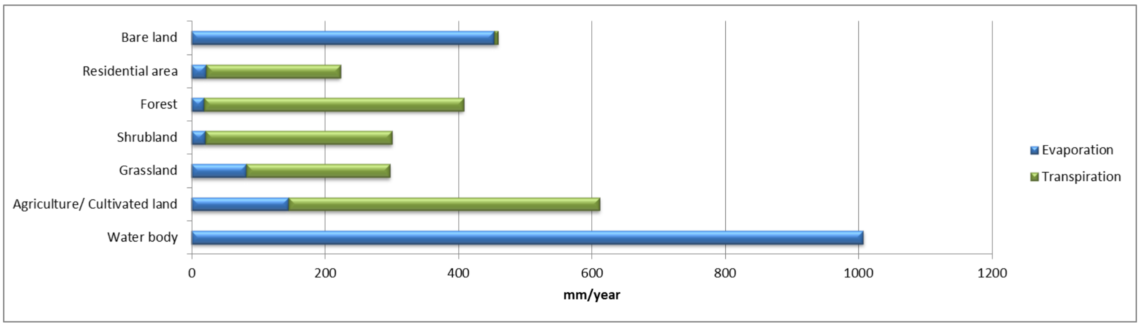

Figure 30: Annual evapotranspiration (ET) in (mm y^{-1}), split into plant transpiration (T) and soil evaporation (E) for each land cover class, average data for 2001-2010 period.

Figure 31 shows the differences between different land covers in terms of the effect of ET on the precipitation excess (P minus ET; see water balance Figure 27). This excess ends up as surface runoff, groundwater recharge, and lateral drainage. All these terms are *blue water* sources.

Part of the water that reaches the ground surface is routed as surface runoff, a fast hydrological process. A second part is routed through sub-surface, lateral drainage flow to the streams. This process generally shows a slower response as compared to surface runoff. The third component is the water that percolates through the soil system and recharges the local groundwater aquifer system. This groundwater in the end will be discharged and serve as 'blue water' base flow for the Duhe basin. Groundwater discharge shows a much slower response due to the longer travel times, but is a secure a more continuous and reliable water source. Enhancement of groundwater recharge is therefore of importance, also for downstream water users.

The variation between the land covers is caused by the different vegetation, soil and topographical characteristics, and conditions at each site. Surface runoff is undesirable, because this often results in land erosion and thus sediments, ending up in the downstream reservoirs. More surface runoff also means less water infiltration, and therefore less groundwater recharge. Areas with a considerable proportion of surface runoff relation to groundwater recharge are also potential areas for effective implementation of GWC-measures.

Figure 31 shows clearly that the agricultural area has the greatest potential for benefits from the implementation of *green water* management practices. Besides this, the residential area and the bare soil classes show potential for reducing surface runoff. However since these areas are very small as compared to the agricultural area, it is expected that GWC practices in the cultivated areas will be most beneficial.

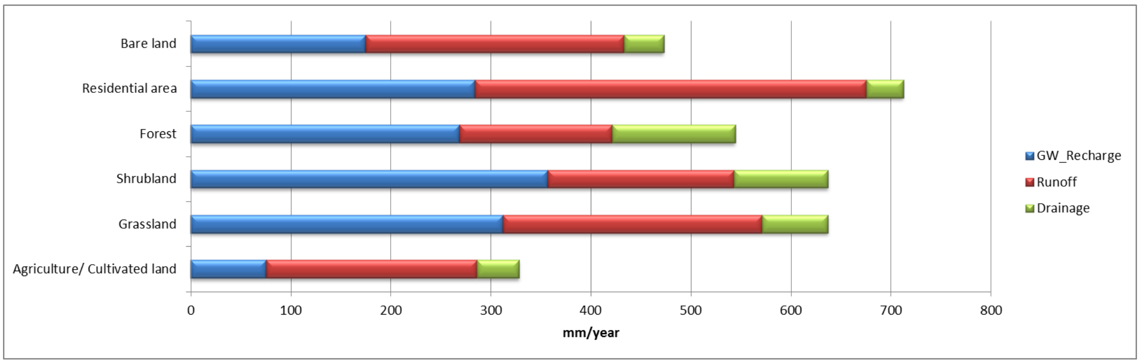

Figure 31: Water entering the drainage network and rivers by groundwater recharge, surface runoff, and lateral drainage. Average calculated data for 2001-2010 period.

Figure 32 shows the sediment yields for the different land covers classes, where it is clear that bare soil shows the highest erosion rate. Considering all land use classes, potential *green water* management practices which reduce soil erosion, will be most effective on the agricultural land and to a lesser extent on grassland. The gross erosion rate for agriculture is roughly 38,000 kg ha^{-1} y^{-1}. If we take the unit weight for soil as 1,600 kg/m^3, then this corresponds to a gross erosion rate of an equivalent 2.4 mm y^{-1} soil depth. These numbers confirm that there is a great potential for *green water* management measures to reduce the erosion rates so as to limit the loss of fertile lands and mitigate the sedimentation of downstream reservoirs. The preliminary scenario analysis done so far within this study confirms that sediment yields can be reduced significantly (see also Yan *et al*., 2013).

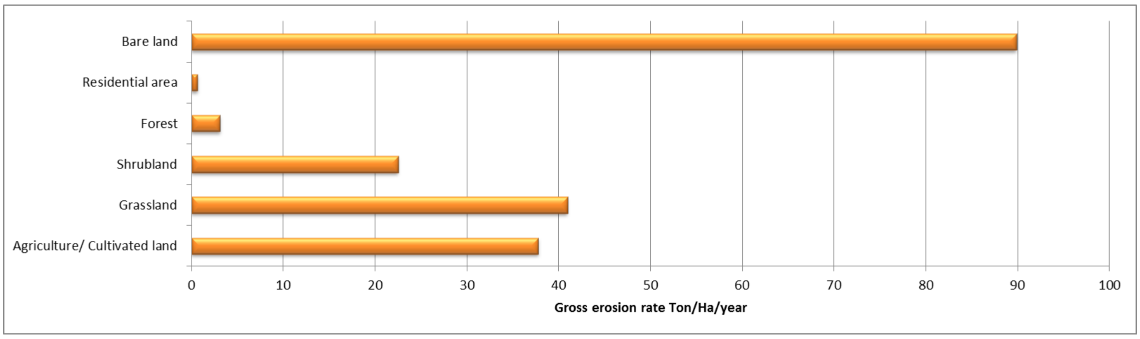

Figure 32: Total calculated sediment loss in terms of gross annual erosion rates per land use class. Average data for 2001-2010 period.

4.7 Spatial analysis of calculation results

The SWAT distributed modelling approach that was chosen for the bio-physical assessment of Green Water Credits in the Upper Duhe basin gives the ability to assess the water and sediment flows at a high spatial detail. For this Proof-of-Concept and feasibility phase, this will give insight into the areas where *green water* management implementation is most significant in terms of benefits. To provide insight into the output that will form the basis for the *green water* management biophysical analysis, the following maps have been plotted, based on averages for the 2001-2010 period:

- Annual precipitation: spatial distribution of the annual precipitation sum;
- Annual evapotranspiration: total amount of water consumed by plant transpiration and water lost by soil evaporation;

- Annual actual transpiration: total amount of water that is used by vegetation (agricultural crops as well as natural plants) to produce biomass with *green water* as its source;
- Annual soil evaporation: total amount of water that is lost by soil evaporation. This includes bare soils, but also areas partly covered by vegetation. This soil evaporation can be considered as a non-beneficial loss of *green water*;
- T-fraction: percentage of total evapotranspiration used for plant transpiration. This factor quantifies the effectiveness of the crop to use the *green water* source;
- Annual water yield: water entering the streams by surface runoff and sub-surface lateral drainage, turning into *blue water* for downstream users;
- Annual groundwater recharge: water that contributes to the groundwater aquifer and eventually becomes base flow and *blue water*;
- Annual erosion rate.

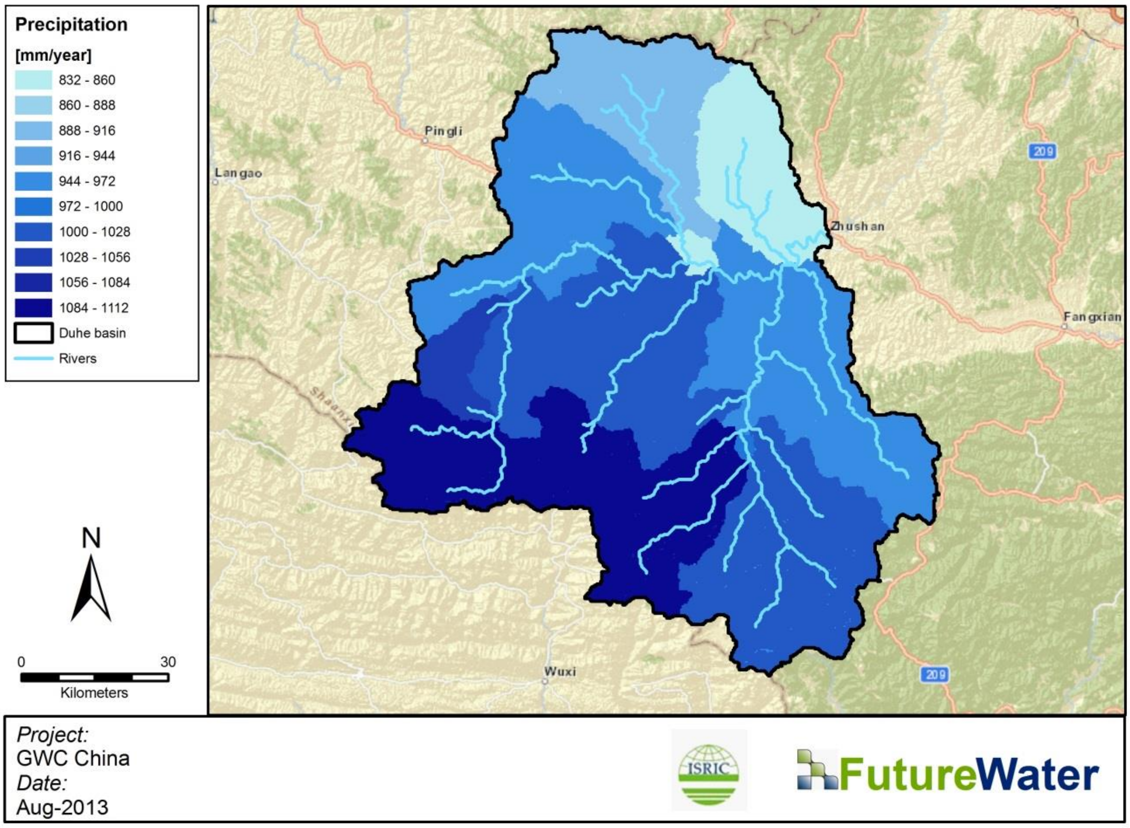

Figure 33: Annual precipitation, averaged over the period 2001-2010.

The spatial pattern of the annual precipitation is shown in Figure 33. The distribution of annual precipitation is based on the 9 measurement stations. It is clear that the largest precipitation rates are found in the South western part of the Duhe catchment where the mountains are highest. Annual precipitation rates in this area can be up to 1100 mm y^{-1}. The annual average precipitation is approximately 850 mm y^{-1} near Zhushan.

The distribution of annual evapotranspiration rates, averaged over the period 2001-2010, is shown in Figure 34. This is the sum of water consumed by vegetation (transpiration) and by soil water evaporation. The largest evapotranspiration rates are found in the Northern, lower part of Duhe, and in the agricultural areas. The main crop type in these regions is winter wheat and maize (Yan *et al*., 2013). It is, however, more interesting to know which part is transpiration and which part is evaporation, because evaporation from the soil surface can be considered as a loss of *green water*. Therefore, the average annual transpiration and evaporation are shown in Figure 35 and Figure 36, respectively. The areas with the largest potential for *green water* management practices are the areas with high evaporation rates. From Figure 36, it is clear that areas with high evaporation rates are located in the Northern, lower parts of the basin which are mainly used for agriculture. These areas were already marked in Section 4.6 as having potential for *green water* management practices. Figure 35 shows that transpiration is highest in the Forest areas in the North and to a lesser extend in the South East. Decreasing transpiration rates from the non-agricultural vegetation, e.g. like the forest, can also contribute to a higher stream flow, without compromising the food security. This is an option that will be explored further in chapter 5.

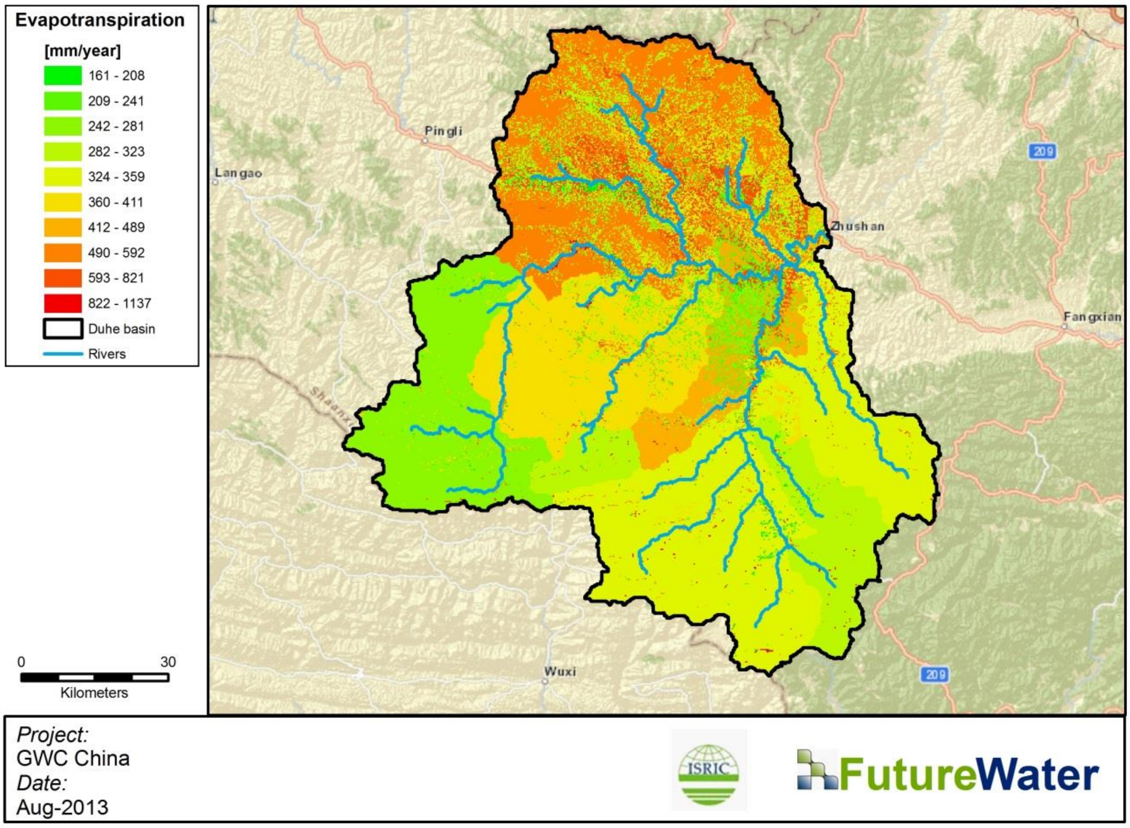

Figure 34: Annual evapotranspiration (ET), averaged over 2001-2010.

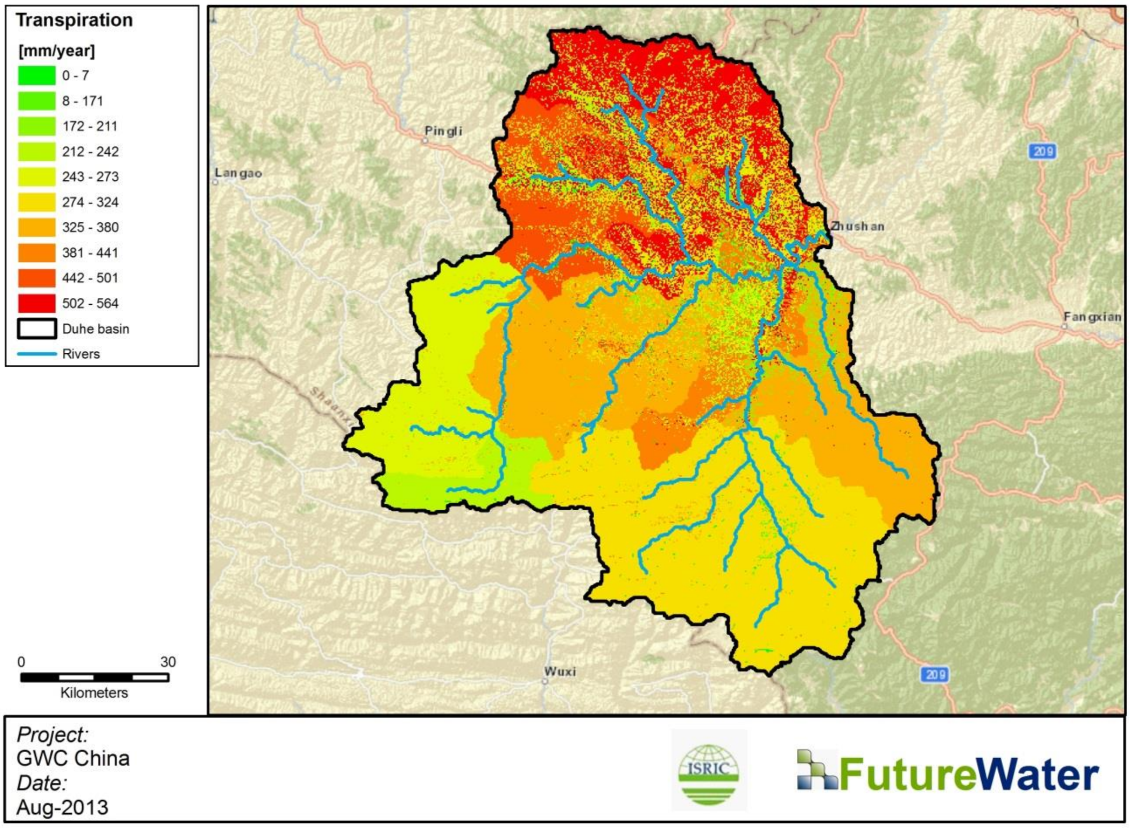

Figure 35: Annual plant transpiration (T), averaged over 2001-2010.

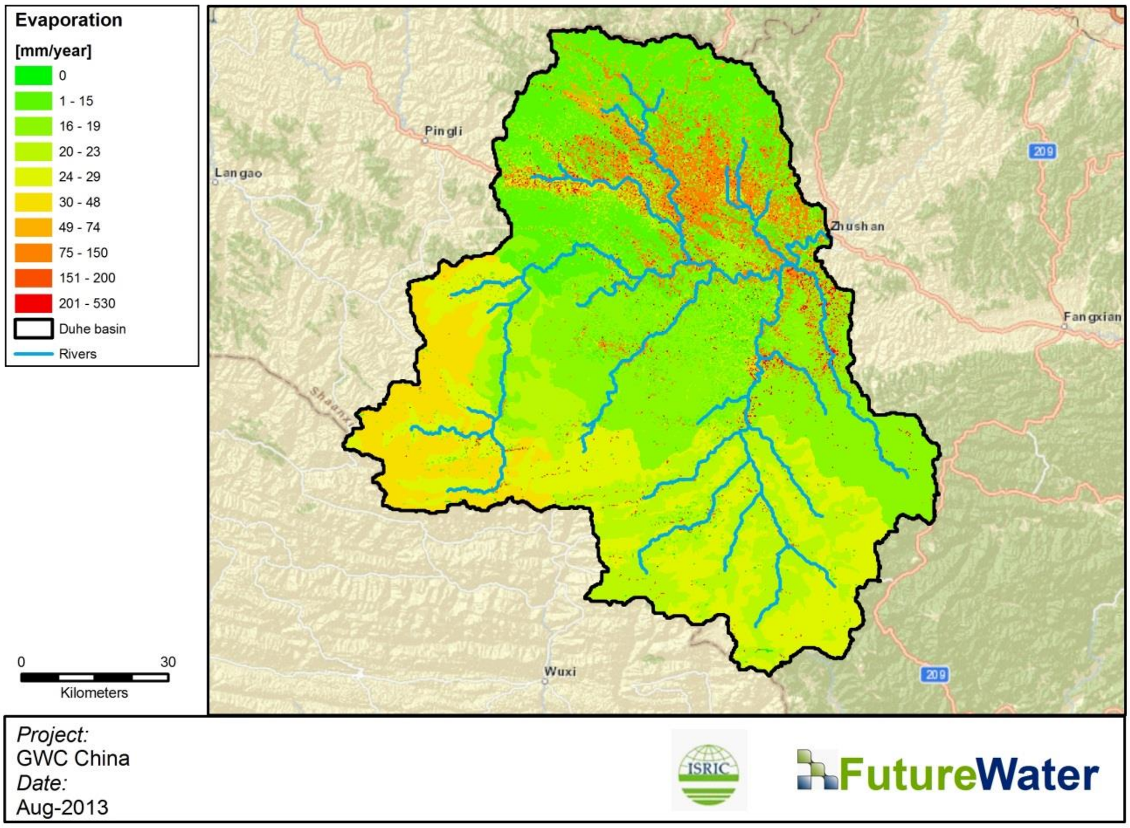

Figure 36: Annual soil evaporation (E), averaged over 2001-2010.

The proportion of transpiration relative to total evapotranspiration is defined here as the T-fraction. The lower this percentage, the more water is lost by evaporation. The average annual T-fraction is shown in Figure 37. Again the Northern flat area stands out as especially the flat lower valleys have a relative low T-fraction. The T-fraction from the forest in the Northern part stands out and is extraordinary high, approaching 100%.

The average annual water yield (sum of runoff, sub-surface flow and base flow) is shown in Figure 38. The largest water yields are found in the Southern mountainous part of the Duhe basin. Water yield is closely correlated with annual precipitation. Figure 33 already showed that the Southern mountains receive the largest amount of annual precipitation. That explains the large water yields in these areas. Besides high water yields can be found on the paddy soils and on the scrublands and grasslands areas. As can be seen from Figure 31, these land use types "generate" more water than the surrounding forest, which can merely be explained from the difference in ET from the land use types.

The average annual groundwater recharge is shown in Figure 39. Again, these are very closely correlated with the rainfall amounts. The groundwater recharge depends on the land use (ET), the soil type (infiltration capacity), and the slope (more or less surface runoff). Soil types with low permeability hardly allow the water to percolate to the saturated zone. After recharge, part of the groundwater will eventually enter the streams and turn into base flow for the Duhe basin.

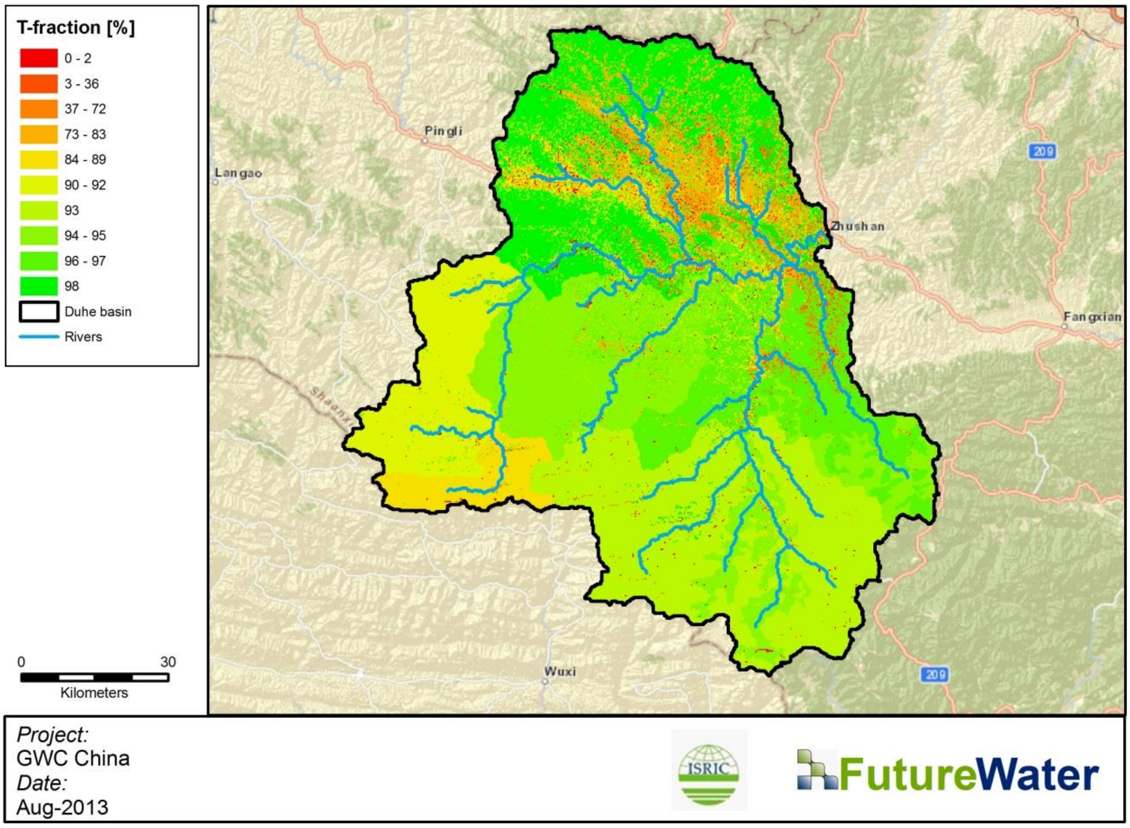

Figure 37: Transpiration (T) as percentage of total evapotranspiration (ET), averaged over the 2001-2010 period.

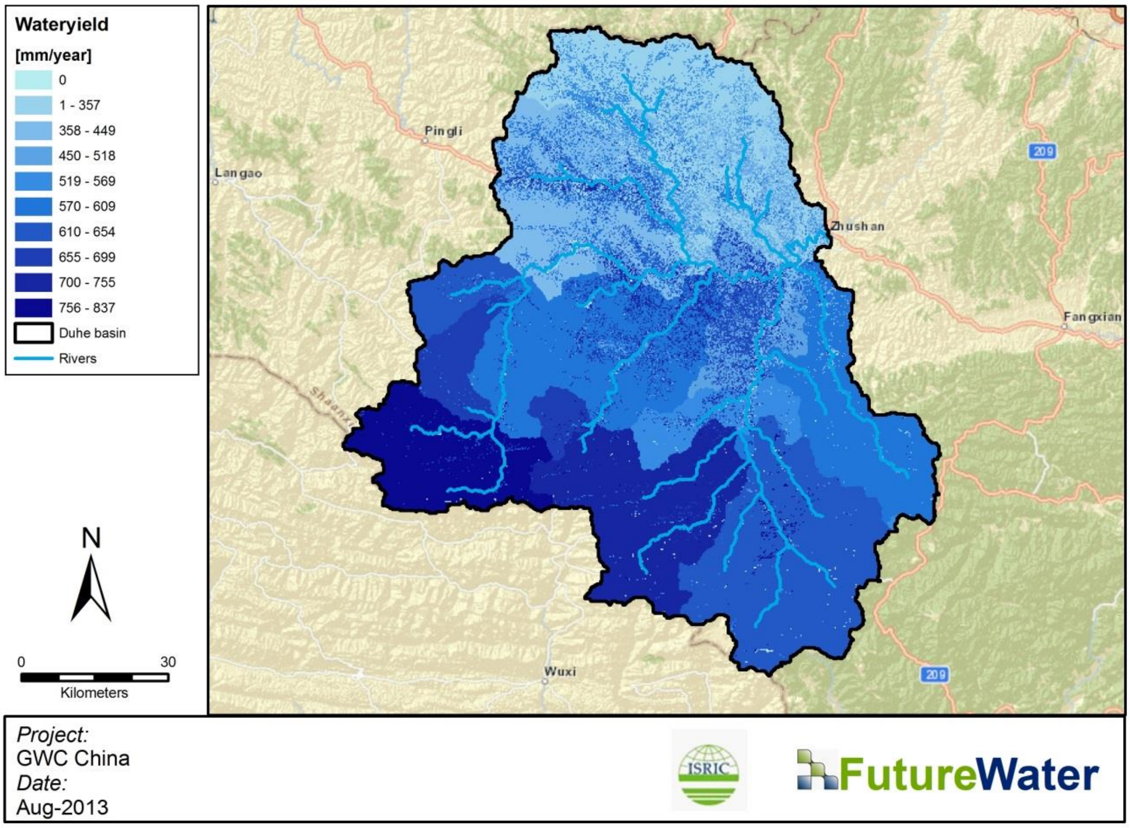

Figure 38: Annual blue water yield as the sum of runoff, sub-surface drainage flow, and base flow, averaged over 2001-2010.

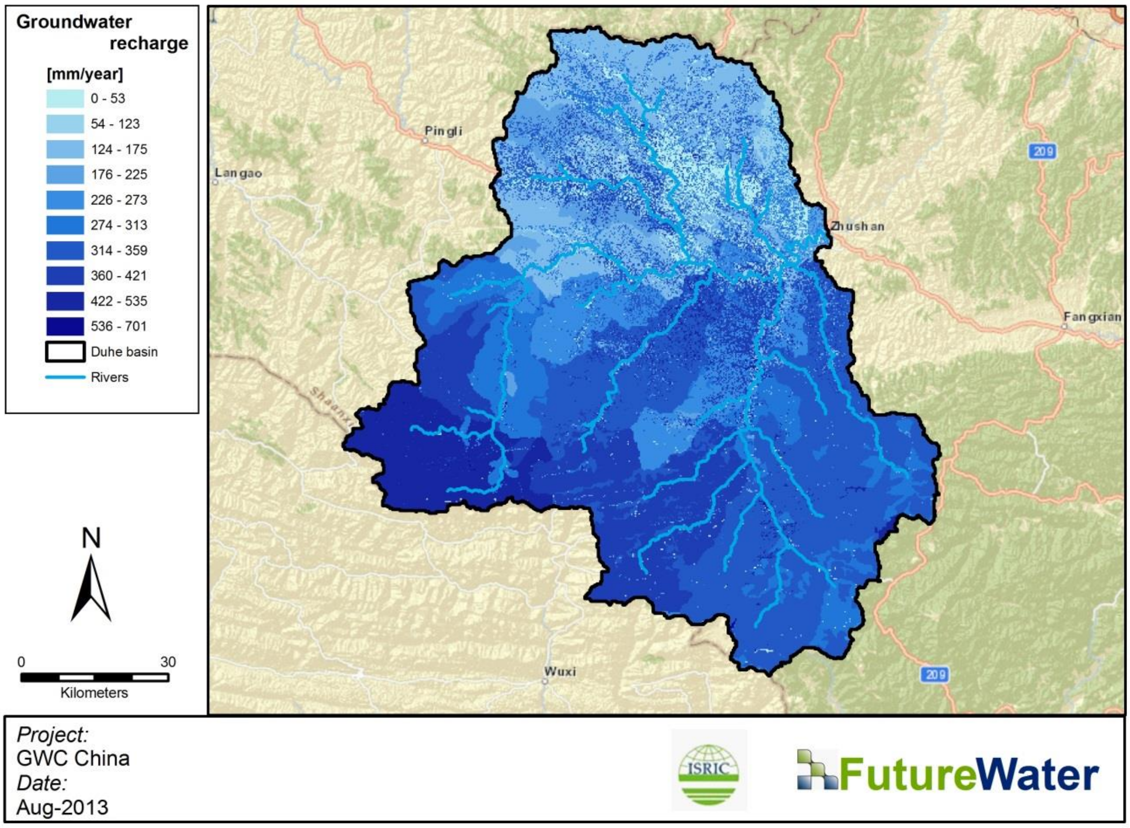

Figure 39: Annual groundwater recharge, averaged over 2001-2010.

The sediment yield in a sub-catchment is mainly dependent on the rainfall intensity, the land use and management, the slope, and soil type. The average annual sediment yield is shown in Figure 40. Sediment yields are largest in the northern area of the basin. This is mainly a result of the land use and erodible soils. Forest is less vulnerable for erosion, which can clearly be seen in Figure 40.

The changes in land use greatly affect stream flow and sediment yield in the Upper Duhe basin. The major land use changes that affected stream flow are changes to farmland, forest, and urban areas. The biggest contribution to the sediment yield is from the farmland, followed by forest (Yan *et al*., 2013). Their results also indicated that changes in grassland did not exert a significant influence on either stream flow or sediment yield.

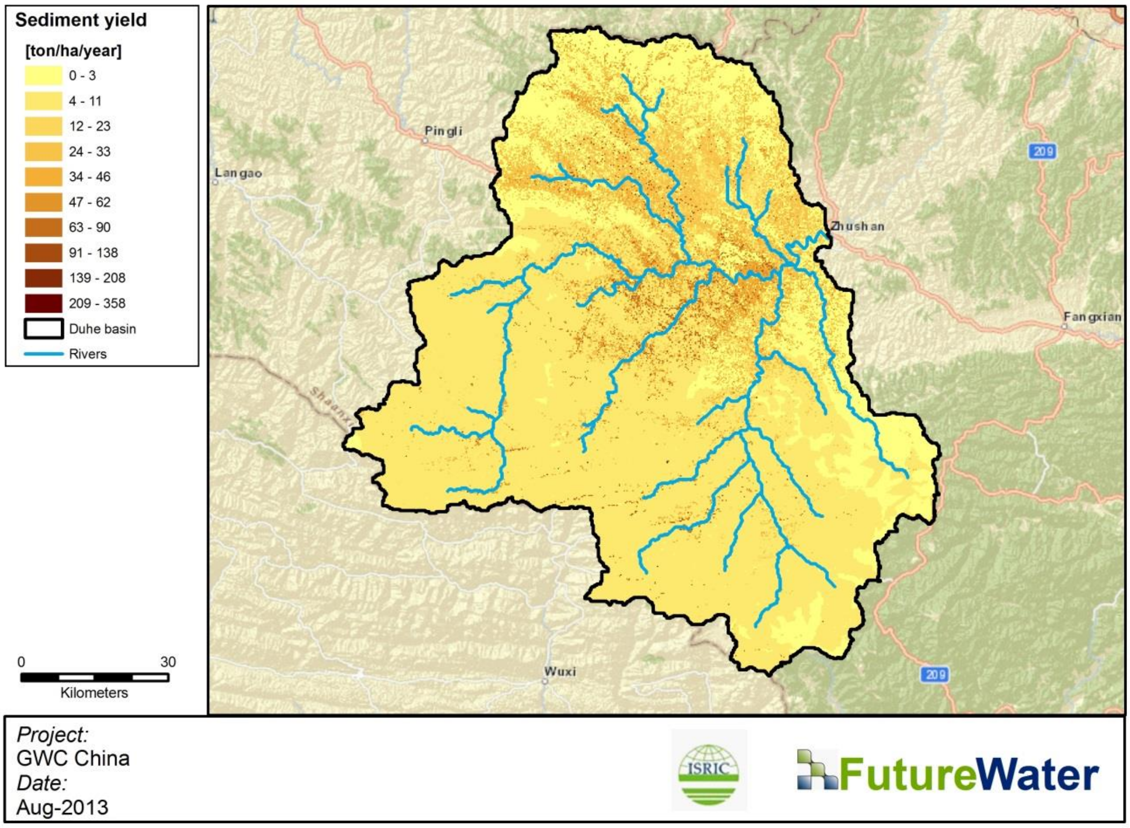

Figure 40: Annual sediment yield by erosion, averaged over 2001-2010.

Based on the model calculations shown in this chapter, GWC measures will need to focus on decrease of soil evaporation (E) and decrease of sediment losses by erosion. The GWC measures could lead to increased agricultural crop production by increased plant transpiration, to enlarge the farmer's income. Finally, if the overall evapotranspiration rates for non-agricultural vegetation could decrease, more blue water could be generated at the Zhushan gauging station, with the Duhe basin finally feeding the Danjiangkou reservoir.

5 Future Management Options for GWC

5.1 Potential benefits upstream and downstream

Green Water Credits is about meeting the interests of upstream land users and downstream water users at the same time. By linking downstream water users and upstream farmers, *green water* management enhances the overall water management of the basin and benefits both parties. These potential benefits need to be quantified in order to transform them to an institutional and financial arrangement that sustains GWC implementation. Within the 'Soil and water management' domain (see Figure 44), different land management options have been studied and evaluated in order to obtain the most optimal implementation scheme.

Figure 41: GWC - The four domains.

The principal potential benefits that need to be quantified for upstream farmers are:

- Increased transpiration rates, determining crop production, and reduction of non-productive soil evaporation;
- Infiltration and retention of water in the soil system;
- Reduction of erosion rates and loss of fertile top soil.

For downstream water users, e.g. irrigators, hydropower, industrial and drinking water supply, the principal potential benefits that have to be assessed can be summarised as follows:

- Total water flowing from the mountainous areas into the reservoirs;
- Enhancement of groundwater discharge or base flow due to increased soil infiltration and increased groundwater recharge;
- Reduction of sediment loads to the drainage network and reservoirs and preserved storage capacity.

These benefits will be quantified by introducing a set of key outcome indicators, as will be explained in the following sections.

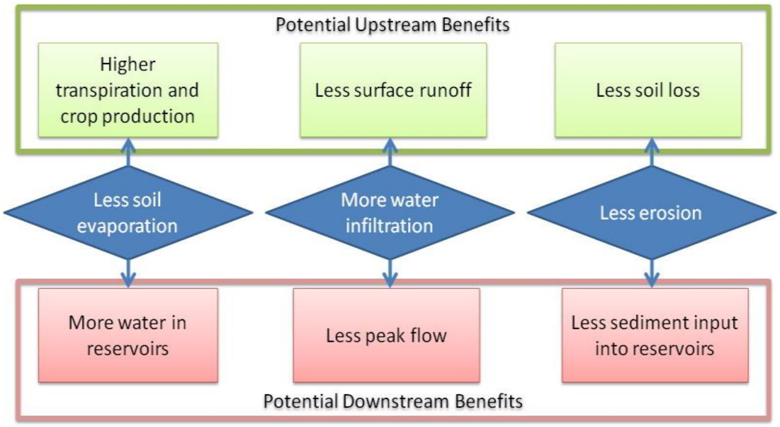

Figure 42: GWC - Examples of potential upstream and downstream benefits.

A major problem in basin-scale water management is to cope with the irregular rainfall and flow regimes that lead to floods in some seasons and to drought in others. Infrastructural solutions such as dams, canals and diversions, are able to hold certain amounts of water temporarily so as to redistribute the water available during the drier seasons and to lessen hazardous peak flows. The soil and groundwater system storages regulate flows and their capacity is, in most basins, much larger than man-made reservoirs. Due to land use change and inappropriate land management, the use of these natural reservoirs is usually not at its full potential. By changing to better land management practices, the use of the soil and groundwater reservoirs can be enhanced.

The main strength of *green water* management is that both upstream as well as downstream stakeholders have profits. Aiming at only one single stakeholder group would lead to other solutions, e.g. fertilizers, sediment traps, artificial groundwater recharge. Green Water Credits (GWC) aims at a sustainable mechanism to be implemented by enabling the interaction between up- and downstream stakeholders.

Different land and water management options are available as possible candidates for incorporation in the Upper Duhe case. These have to be selected, studied and evaluated. A first selection has been conducted in the following section. Also, a first indicative analysis was carried out in order to show the methodology and outcomes of this part of the assessment.

5.2 From baseline model to scenario analysis

The SWAT baseline model has been set up, tested and optimized, as shown in Chapter 4. The model calculation results are plausible and show a good fit between measured and calculated outflow and sediment load data. This all means that the baseline model is capable of simulating hydrological processes at the basin scale at present (2001-2010). If the spatially distributed hydrological model represents the Upper Duhe system well enough, we trust it to be applied to GWC-measures and scenario analysis.

The hydrological processes involved in the Upper Duhe basin have all (sets of) model parameters that control the computed process. We have to make a translation of GWC-measures to processes, and from these processes to specific model parameters involved. Once we know which baseline model parameters are connected to a GWC-measure, we can adjust the parameters to represent the new situation in the Upper Duhe basin, given the measures taken. Because the SWAT model has a spatially distributed setup, we can also choose to put the measures in a spatial context. To give two examples, in sloping areas we can build terraces, and we apply mulching to arable land. In this way, we move from the baseline model to scenario analysis model versions, using adjusted model parameters that fit GWC-measures.

5.3 Selection of management options

The World Overview of Conservation Approaches and Technologies (WOCAT) is a programme whose objective is to use existing knowledge and funds more efficiently to improve decision-making for sustainable land management. It is a framework for collecting databases of successful SWC experiences concerning technologies, approaches and aerial distribution through the use of standardised and simplified questionnaires worldwide. All data are readily analysed, and can be disseminated and prepared for presentation, evaluation and monitoring. WOCAT can be used as a tool in land management for all land users (stakeholders) with benefits that are multiple and mutual through the improved WOCAT decision support system.

A selection was made of management practices from the WOCAT database and from discussion with local experts of measures that have shown large potential in previous GWC assessments. They are presented here and will be projected with the local stakeholders and representatives in order to initiate the quantitative scenario analysis and determine the upstream and downstream benefits. The following GWC-management options were selected by discussions held with our Chinese partners and trainees:

1. Stone lines;
2. Bench terraces;
3. Contour tillage;
4. Mulching;
5. Forest management.

With the SWAT model, the impacts and possible trade-offs of these practices can be studied and quantified. The following paragraphs give a more detailed explanation on these practices.

5.3.1 Stone lines

Stone lines (Figure 43) are small structures (WOCAT: NIG01 and NIG02) of stones, where the stones are placed in a horizontal line across the slope. The distance between the lines is a function of the slope and availability of stone.

Stone lines are intended to slow down runoff. They thereby increase the rate of infiltration, while simultaneously protecting the planting pits from sedimentation. Often grass establishes between the stones, which helps increase infiltration further and accelerates the accumulation of fertile sediment. Wind-blown particles may also build up along the stone lines due to a local reduction in wind velocity. The accumulation of sediment along the stone lines in turn favours water infiltration on the upslope side. This then improves plant growth, which further enhances the effect of the system.

Construction does not require heavy machinery (unless the stones need to be brought from afar by lorry). The technique is therefore favourable to spontaneous adoption. Stone lines may need to be repaired annually, especially if heavy rains have occurred.

Figure 43: GWC - Example of stone lines (source: www.wocat.net).

5.3.2 Bench terraces

This measure (Figure 44) is an embankment constructed along the contour by the use of stone and soil as a construction material (WOCAT: ETH32). The technology is used in areas where there is not sufficient stone and where the soil shallow. Terraces are established by excavating soil, and using this to shape the embankment. Stone is used to face the downslope side (the terrace “riser”) for reinforcement. Vegetation is planted on the upper part of the embankment when there is sufficient soil.

Figure 44: GWC - Example of bench terraces (source: www.wocat.net).

The purpose is to reduce surface runoff, decrease slope length, increase infiltration rate, and consequently minimise soil erosion. The structures require regular maintenance, since the embankments are often made of small stones, which are unstable. In order to properly stabilise the structure livestock should not be allowed to graze where the structures are placed. Checking for breaks after heavy storms is necessary.

In terms of bio-physical processes, this measure will have the following impact:

- Reduction in soil loss by erosion, and
- Reduced overland flow / surface runoff.

5.3.3 Contour tillage

This *green water* management option comprises contour ploughing (WOCAT: HUN2) often combined with soil bunds (WOCAT: ETH43). The basis of the technology is the annual ploughing. The ploughing and all other cultivation is carried out along the contour lines. This can significantly decrease erosion. Rotary cultivation aims to reduce wind and water erosion, to control weed and to develop a good seedbed. On very low slopes contour tillage may be adequate on its own without bunds.

Figure 45: GWC - Example of contour tillage (source: www.wocat.net).

On slopes of more than 3%, soil bunds can be supplemented to the contour cultivation. Stone, and stone faced, bund height depends on the availability of stones. On average the base width is 1.0 -1.2 m and height is 0.6 - 0.7 m. Bunds reduce the velocity of runoff and soil erosion, retain water behind the structure and allow it to infiltrate. This further helps the process of groundwater recharge.

Planning is carried out by initial community/group and individual discussion, and a consensus reached on layout, spacing, implementation modalities and management requirement. The technology is applicable in areas where soil is moderately deep and stones are available.

5.3.4 Mulching

The use of mulches in landscape plantings is increasing. Mulches have been promoted by water conservation, green waste reduction, and other programs primarily to reduce evaporation from soil. In addition, many of the materials used for mulching provide an improved aesthetic appearance for the landscape and provide weed control. Many different materials are available from composted products such as manures, sludge, and green waste to non-composted products such as wood chips and yard waste from landscape maintenance operations, bark products from lumber mills, and rock (CIWMB).

Mulches can benefit landscapes by reducing soil evaporation, cooling the soil, suppressing weed growth, and possibly providing nutrients for plant growth. Several studies have evaluated the moisture retention and cooling of soils under mulch (Bennett, 1982).

Figure 46: GWC - Example of Mulching with rice residues.

5.3.5 Forest management

Forest management or a change of use of natural areas is an often used method in GWC measures. A different land use usually comes with different values for water yield, erosion and infiltration. Also see the figures in Chapter 4. In the Upper Duhe basin, forest can be associated with a very low erosion rate compared to agriculture and grassland and scrubland. However the evapotranspiration of forest is about 100 mm higher per year, which does affect the water yield from the forest areas. In the most ideal case a low erosion rate can be combined with a high value for water yield.

Figure 47: GWC - Example of forest management

5.4 Scenario analysis

A preliminary analysis has been carried out for each of the selected *green water* management options. In order to compare these scenarios with the baseline current situation, a set of indicators is introduced that gives insight into the impact of the practices.

The main challenges which are defined within the Upper Duhe basin and in the greater Danjiangkou catchment are the water efficiency, erosion, and to a lesser extend flooding. In 1998 a large flood occurred in the Duhe catchment. Erosion related problems include loss of fertile topsoil in upstream area, and sedimentation of the canals, reservoirs and the corresponding capacity loss. In the larger Danjiangkou catchment the main aim is to create a higher discharge to have water available for the South-to-North Water Transfer, without compromising downstream water demands. As key indicators the water yield and the erosion rate will be used.

To quantify the effect of the *green water* management scenarios on the reservoirs, the change in surface runoff and sediment loss has been analysed. Besides the effect on the reservoirs, the change in plant transpiration, soil evaporation, and groundwater recharge has also been evaluated. A reduction in soil evaporation and an increase in plant transpiration will result in increased crop growth, and thus higher yields per hectare. Groundwater recharge, which eventually becomes base flow, feeds the streams and reservoirs (See Figure 48). Therefore, an increase in groundwater recharge will by groundwater discharge result in more water in the reservoirs and streams. This means that more *green water* from upstream sources is available as *blue water* to the downstream users, and for the planned water transfer.

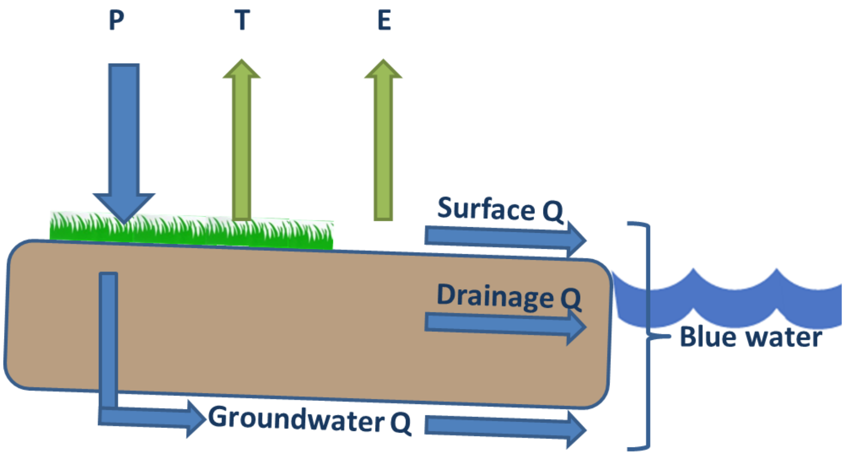

Figure 48: Blue water and SWAT output - sum of surface runoff, lateral drainage, and groundwater discharge.

For the preliminary assessment, it has been assumed that the practices are implemented in the agricultural/cultivated areas, except for the forest management scenario. This area remains part of the natural area in the basin and will replace part the forest area with the smallest slopes, less than 20%. This results in 3.5% of the total forest area of the Upper Duhe catchment. The scenario of forest management is modelled in a way that several options are possible. Model parameters which have been changed compared to forest can be observed in Table 10. In practice this result in a forest which is not so dense, has a smaller leaf area index, a lower canopy height and smaller rooting depth.

The SWAT model parameters, which were used for the scenario analyses, were based on expert knowledge and previous GWC studies (e.g. Hunink *et al.* 2011). The parameters used for the baseline (current situation) scenario, and five selected *green water* management scenarios are shown in Table 9.

Table 9: SWAT – Model parameter values and changes for each of the *green water* management scenarios.

Nr	Scenario	Land use	ESCO	USLE_P	CN2	SLOPE	OV_N	FilterW
0	Baseline	Agricultural	0.9	1	77-89	100%	0.14	0
1	Stone lines	Agricultural	0.96		75-87			0.5
2	Bench terraces	Agricultural		0.8	75-87	80%		
3	Contour tillage	Agricultural		0.9	70-82		0.42	
4	Mulching	Agricultural	0.99	0.9	75-87			
5	Forest management	Forest	0.9	1	77-89	100%	0.14	0

Table 10: SWAT – Adapted model parameters for the scenario forest management.

OBJECTID	ICNUM	CPNM	IDC	CROPNAME	BLAI	CHTMX	RDMX	GSI	ALAI_MIN	BIO_LEAF	MAT_YRS	BMX_TREES
6	6	FRST	7	Forest-Mixed	5	6	3.5	0.002	0.75	0.3	50	1000
114	114	NEW		NEW	3.5	0.8	1	0.005	0.5	0.1	2	50

The description of these parameters is as follows:

- ESCO: soil evaporation compensation coefficient: a higher value results in reduced soil evaporation, making more water available for transpiration or as *blue water*.
- P_USLE: support practice factor for soil loss: a lower value results in reduced soil erosion.
- CN2: runoff curve number: a lower value results in reduced soil erosion and increased groundwater recharge.
- SLOPE: average slope steepness: a lower value will reduce the overland flow and erosion, and will increase the groundwater recharge.
- OV_N: Manning's “n” value for overland flow: a higher value means more resistance to flow, lower flow velocities and less erosion.
- FILTERW: width of edge-of-field filter strip: represents buffer zone around HRU area. Higher values mean less erosion, more infiltration, and less overland flow.
- BLAI: Maximum potential leaf area index.
- CHTMX: Maximum canopy height (m).
- RDMX: Maximum root depth (m).
- GSI: Maximum stomatal conductance at high solar radiation and low vapour pressure deficit (m/s).
- ALAI_MIN: Minimum leaf area index for plant during dormant period (m^2/m^2).
- BIO_LEAF: Fraction of the tree biomass accumulated each year that is converted to residue during dormancy.
- MAT_YRS: Number of year required for tree species to reach full development (years).
- BMX_TREES: Maximum biomass for a forest (metric tons/ha).

5.5 Analysis of *green water* management options

The results of the five selected *green water* management scenarios and the baseline scenario are shown in Table 11. The principal water balance components of the potential *green water* management practices areas are also shown, as well as the entire basin balance.

	Baseline	Stone_lines	Bench_terraces	Countour_tillages	Mulching	Forest management
	Value	% change	% change	% change	% change	% change
Basin balance						
Area (km2)	9,026.723	0.0%	0.0%	0.0%	0.0%	0.0%
Precipitation [MCM]	8,959.712	0.0%	0.0%	0.0%	0.0%	0.0%
Crop transpiration [MCM]	3,078.915	0.2%	0.2%	0.3%	0.2%	-0.8%
Soil evaporation [MCM]	295.016	-1.5%	0.2%	0.4%	-2.5%	0.5%
Groundwater recharge [MCM]	2,630.498	0.3%	0.3%	1.0%	0.4%	0.7%
Surface runoff [MCM]	1,580.956	-0.7%	-0.8%	-2.5%	-0.7%	-45.3%
Drainage [MCM]	1,074.432	0.1%	-0.1%	0.2%	0.1%	81.9%
GW_Q [MCM]	2,491.845	0.3%	0.3%	1.0%	0.4%	198.4%
Sediment loss [Tons/y]	9,557,981.256	-6.3%	-8.6%	-7.2%	-3.1%	0.1%
Blue water [MCM]	5,147.234	0.0%	-0.1%	-0.3%	0.0%	0.4%
Agricultural area						
Area [km2]	519	0.0%	0.0%	0.0%	0.0%	
Crop transpiration [MCM]	265	2.3%	1.9%	3.9%	2.5%	
Soil evaporation [MCM]	65	-6.9%	0.8%	2.0%	-11.1%	
Groundwater recharge [MCM]	23	39.3%	34.9%	108.2%	44.2%	
Surface runoff [MCM]	108	-10.6%	-11.9%	-36.3%	-9.7%	
Drainage [MCM]	8	7.0%	-13.3%	21.6%	7.1%	
GW_Q [MCM]	22	39.3%	34.9%	108.1%	44.2%	
Sediment loss [Tons/y]	1,660,043	-36.6%	-49.8%	-41.7%	-17.8%	
Blue water [MCM]	138	-1.6%	-4.5%	-9.9%	-0.1%	
Forest Area						
Area [km2]	238					0.0%
Crop transpiration [MCM]	121					-20.9%
Soil evaporation [MCM]	3					50.8%
Groundwater recharge [MCM]	42					43.4%
Surface runoff [MCM]	36					14.6%
Drainage [MCM]	7					7.0%
GW_Q [MCM]	39					43.6%
Sediment loss [Tons/y]	42,131					15.4%
Blue water [MCM]	82					28.0%

Table 11: Key outcome indicators for *green water* management scenarios (averages for 2001-2010 period).

The results from the five green water management scenarios show that the measures taken within the cultivated/agricultural land will reduce the sediment loss up to 50%. However, the agricultural land covers just about 6% of the total study area, which reduces the effects of the measures when expressed as percentage of the total basin balance. For the first four scenarios the increased groundwater recharge and the corresponding increased green water results in higher transpiration rates. This is very favorable for the farmers in the area as yields will increase. A change can be observed that surface runoff and the related sediment loss decreases and that the green water contributes more to the streams. However due to the increase in transpiration within these scenarios the total amount of blue water generated will slightly decrease for all these four scenarios. The scenario of the forest management shows that by replacing forest by a relatively low, ground covering crop the high transpiration of the forest can be reduced by over 20%. The lower leaf area index of the new crop results in an increase of soil evaporation and surface runoff. The sediment loss increases by 15% compared to forest. However the reduction of transpiration causes an additional flow towards the blue water of 28%. Whenever combined with erosion reducing measures this scenario may have the potential to increase the downstream water availability without causing additional sediment loss.

5.6 Project targets, further steps, and outlook

The targets of this project were:

- To show the use of the GWC-concept in China.
- To prove the feasibility of using biophysical modelling tools to quantify GWC-measures on a basin scale. We have taken the Upper Duhe basin as an example for sub-basins that count to the Danjiangkou Reservoir catchment.

- To establish a partnership between Chinese parties involved and the Dutch consortium of ISRIC, FutureWater and Nelen&Schuurmans.
- To provide a firm basis for future projects in China within the GWC-framework, opening the Chinese market, based on knowledge, tools, and cooperation.

We have shown useful biophysical modelling results and have started our partnership with the Changjiang Water Resources Commission, CWRPI, and HAU. We will focus on strengthening our partnership and future cooperation within the GWM&C framework by analysing catchment areas and by facilitating possible implementation plans of GWC-measures. The setup and start of follow-up projects should be part of this.

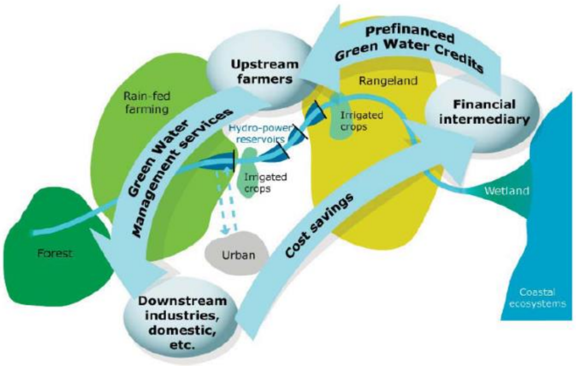

Figure 49: GWC-overview.

We have looked at hydrological features of the Duhe basin and SWAT modelling results on hydrology and erosion. One of the aspects we did not take into account is the quality of groundwater and surface water. Point and non-point sources can pollute the water system, reducing the possibilities of using the blue water downstream. With respect to agriculture, direct spill of agro-chemicals and diffuse sources of nutrients and pesticides can negatively influence the downstream water quality. Nutrients and pesticides are used for crop production and protection to pests. Direct spills should be avoided by using correct management practices at the right time. E.g., just before or during rainfall events, agro-chemicals can be lost to the environment and its water system by surface runoff. Also, nutrients can be transported through the subsoil system into the groundwater aquifer if the crops are not able to uptake all the nutrients applied by the farmer.

Rate and timing of applications of agro-chemicals are both important factors. The soil and hydrological system come in as factors when the flow and transport of water is determined by land surface and subsoil conditions. To give an example, surface runoff as a discharge component serves as a risk of losses of agro-chemicals and acts as a ‘freeway’ of chemicals on their way to the surface water system. Agro-chemicals are applied to the land surface, to the top part of the soil. The shallow flow path of the water can take sediments with adsorbed chemicals directly and/or dissolve chemicals from the soil and transport these towards a ditch or stream.

It is not easy and not directly possible to translate the modelling results we obtained into effects on downstream water quality. What we can say is that any decrease of surface runoff leads to both a *smaller risk* of chemical loads entering the surface water system and probably to a *smaller absolute load* of agro-chemicals. A logical next step in the SWAT modelling could be to follow and calculate the transport of chemicals through the soil and water system the Duhe basin. Also, to model and analyse another sub basin of the Danjiangkou Reservoir with a larger area of agricultural land could be very useful to evaluate the environmental losses of agro-chemicals.

Further steps can be made in analysing other sub basins in terms of hydrology and land and water management. We can also assist in setting up monitoring programs for the situation at present, and for measuring the effect of measures actually taken in the field. Data collection and processing will be part of a follow-up project, feeding the partnership between Chinese and Dutch institutes and companies. Of course, the parallel process that we followed of knowledge transfer and capacity building is also important. We can enlarge the group of Chinese partners if there is more attention from other areas and/or other issues are involved. The most concrete follow-up activity is to define, setup, and fund a project to start during 2014. We then can continue the work from our side and further build our cooperation.

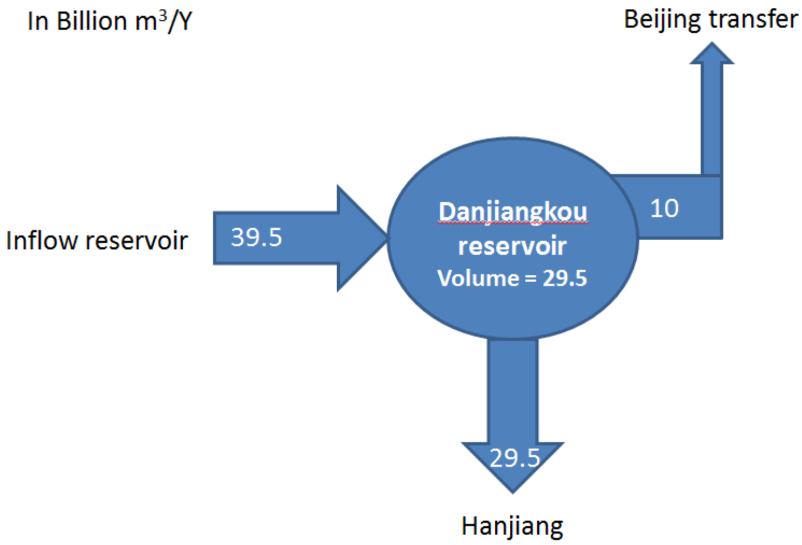

Figure 50: Danjiangkou Reservoir - in and outgoing annual stream flow.

6 Conclusions

GWC concept
Green Water Credits (GWC) is a mechanism for payments to land users in return for specified green water management activities that determine the water supply to stakeholders in the basin. Within the Upper Duhe basin there are various interrelated issues related to water availability, reservoir sedimentation and flooding that offer unique opportunities for implementation of *green water* management measures. The implementation of these management options can enhance the water availability for downstream users and reduce problems related to flooding and erosion. However, farmers need incentives to sustainably implement these measures. At the same time, downstream users may be unaware of the benefits they might gain through farmer implementation of these measures in upstream areas. This feasibility study is meant to demonstrate and quantify the potential benefits to all stakeholders in the basin.

Data
The data available allowed us to carry out the study reported here. However, the study results are always a reflection of the data which are used for building the model. The more detailed the input maps and time series are, the more detailed the outcome will reflect reality. For this study the best available data is used, mainly obtained from the Chinese counterparts. Data which could make the model more detailed include a detailed land use map, which indicated the crops grown in specific areas and whether they are irrigated or not. This would allow for a more in depth analysis per crop, as each crop has different growing seasons, and different parameters concerning soil erodibility, transpiration and evaporation. Precipitation data was available for nice station scattered around the Duhe basin. However these stations unfortunately had no information about solar radiation, wind speed, humidity and temperature and the range of elevation of the stations raises the question whether the data is also realistic on higher elevations. The limited data available did not allow an in depth validation of the data as limited or no documentation was available.

Biophysical assessment using SWAT
We managed to setup and run the SWAT model for the Upper Duhe basin, giving realistic calculation results. The main reason of using the spatially distributed hydrological model was that this tool would enable us to model processes and to quantify beforehand the effect of GWC-measures. The SWAT model performed well, showing quantified fluxes of both water and sediment in time and space. The instrument is complex in its handling, covers many processes at the basin scale, and has many features. If setup and used well, it is a very powerful tool to hydrologically analyse a catchment area and serve as a basis for policy making on water and land management.

Calculation results
The calculation results for the five GWC-scenarios are plausible and mutual consistent. Based on the model calculations for the agricultural area, it can be concluded that for the overall Upper Duhe basin, the proposed GWC-measures will lead to further reduction of soil erosion and sediment loads to the streams. At the basin scale, there is little effect on blue water volumes downstream. The green water that is generated by the scenarios because of reduced surface runoff and increased groundwater recharge leads to increased plant transpiration i.e. crop production. This benefits the local farmer’s income, and does not increase the downstream blue water. The overall influence of measures taken in the agricultural area on the Upper Duhe basin

as a whole is basically a matter of area, with agriculture covering less than 6% of the surface area. On the contrary, the forest land covers about 76%. Any significant measure taken in this area to decrease evapotranspiration and keep the erosion protection of forest land, will lead to increased blue water production for downstream use.

Locally, improved agricultural practices by incorporating GWC-measures will lead to small changes in evaporation and transpiration, but to larger reductions of surface runoff, to less erosion, and to increased groundwater recharge.

Upscaling towards Danijangkou Reservoir catchment
To generate more blue water and to decrease the sediment load to the Danjiangkou Reservoir, each sub-basin within the 91,388 km^2 reservoir area will play its role. It depends on the land use distribution, hydrology, and water and land management which targets can be met. GWC-measures in agricultural areas will probably lead to reduced erosion and smaller sediment loads. The larger these areas are, the more effect will be seen towards the reservoir system. Local measures can lead to higher crop production by increased plant transpiration, supporting the farmer's income. Forest areas show small erosion and high evapotranspiration rates.

The SWAT model, being part of the GWM&C Toolbox, has proven to be a useful instrument in quantification of the effect of past and future land and water management measures. This information is very useful to facilitate policy issues on water and land management. If SWAT models would be available for other sub-basins within the reservoir catchment, a complete overview could be generated on measures and effects.

7 Recommendations

Based on the conclusions and the project experience, the following recommendations can be made:

- The GWC-concept has started working in the Duhe basin and for Chinese partners. Therefore, a follow up will give a push forward to the people and issues involved.
- On-site data: quality control, extension of monitoring with evapotranspiration data, rainfall data at higher altitudes, more information on operational reservoir management.
- Introduction of up to date monitoring and management technologies of Dutch companies, like soil moisture monitoring (www.dacom.com), spectral water quality control (www.waterinsight.nl) and climate adaptive drainage (www.futurewater.nl/kad), can be fitted into a preparation or implementation program of GWC-measures.
- The SWAT model has proved to be a successful tool to apply to hydrology and erosion issues at the basin scale. The quantification of water volumes and sediment loads allowed us to start scenario development for GWC-measures. This can become a structural part of the work involved within the process of policy making on land and water management. Different issues, e.g. water quality can be added, and the modelling exercise can be extended to other (sub) basins.
- Further cooperation between Chinese partners and the project consortium is very fruitful in handling water and sediment challenges.

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