Green Water Management & Credits Toolbox China

Benefit-Cost Analysis Based on Supply-Demand Modeling by WEAP for the Upper Duhe Basin, China – Feasibility Study

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Abbreviations and Acronyms

CWRC	Changjiang Water Resources Commission (CWRC)
GWM&C	Green Water Management & Credits
HZAU	Huazhong Agricultural University
MCM	Million Cubic Meter
MPR	Middle Route Project (MRP) for South-to-North Water Transfer
MWR	Ministry of Water Resources, P.R. of China
SRTM	Shuttle Radar Data Topography
SWAT	Soil and Water Assessment Tool
WEAP	Water Evaluation And Planning system
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.

The Green Water Management & Credits concept (GWM&C) aims at linking upstream to downstream activities in water and soil management. Green water management upstream benefits to both upstream and downstream land and water users, and a compensation scheme from downstream beneficiaries to upstream practitioners is needed. To demonstrate the GWM&C concept to China, a feasibility study has been undertaken in the Changjiang Basin, the largest river basin in China. Within the Changjiang Basin, for this demonstration project, the focus was on the area around the Danjiangkou Reservoir, *i.e*. the Upper Duhe Basin, a tributary to the Danjiangkou Reservoir, from which water is transferred to the North. An important component of this demonstration project was to quantify the potentials of GWM&C by using the so-called GWM&C Toolkit. This Toolkit is a combination of three components: (i) data resources, (ii) analytical assessment tools, and (iii) presenting and decision system. This report focuses on part of the second component: analytical assessment tools. The quantification of hydrological and erosion processes and costs and benefits of measures is undertaken by two modeling tools: SWAT and WEAP. SWAT (Soil Water Assessment Tool) is specifically developed to explore the impact of changes in green water management on runoff, groundwater recharge and erosion. The WEAP (Water Evaluation And Planning) system links the upstream and downstream interactions and is particularly strong to evaluate and compare different scenarios, *e.g*. in terms of costs and benefits. This report describes the application of the WEAP model to evaluate potential benefits from applying GWM&C in the Upper Duhe basin.

The WEAP system was applied to analyse costs and benefits of Green Water Credits interventions in the Upper Duhe Basin. Data needed for this model were the output results of the SWAT model, costs of interventions, and water pricing. The WEAP model was tested, optimized, and proven reliable in discussion with our Chinese project partners. The quantification of costs and benefits leads to selection of effective GWM&C-measures. For the Upper Duhe Basin, the WEAP model calculations result in a positive balance of cost and benefits for three GWM&C-interventions: stone lines, bench terraces, and contour tillage. Mulching almost reaches a break-even point at the moment. This means that the GWM&C-interventions that we analyzed not only have a positive effect on green and blue water and erosion, but also gain positive financial effects. The return of investments on measures in the Upper Duhe Basin can be processed, based on these results.

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 Relevance

China's water resources are threatened and policy makers and decisions makers at all levels are looking for solutions. So far, these solutions have been mainly focused on the so-called structural measures like dams, reservoirs, dikes, pumping etc. A main pillar of solving the uneven water distribution in the country is massive trans-basin water re-allocations, such as the Middle Route Project (MRP) for South-to-North Water Transfer. However decision makers are more and more convinced that these structural measures alone are not sufficient and alternatives has to be explored. One of the options needed to be further investigated is the so-called Green Water Management and Credits approach.

Green Water Management & Credits[1] (GWM&C) is a concept based on: (i) linking upstream to downstream activities, (ii) Soil Water Conservations upstream to the benefit of both upstream and downstream land and water users, and (iii) a compensation scheme from downstream beneficiaries to upstream practitioners. GWM&C has been developed in countries as Kenya Morocco and Algeria. More details regarding GWM&C can be find in many reports and literature as well as the website www.greenwatercredits.org.

To demonstrate the GWM&C concepts to China a feasibility study has been undertaken in the Changjiang Basin, the largest basin in China. Within the Changjiang Basin focus will be on the area around the Danjiangkou Reservoir. The reservoir 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 , to Beijing City through canals along Funiu and Taihang Mountains. The MRP will mitigate the crisis of water resources in Beijing, Tianjin municipalities, and Hebei and Henan provinces.

An important component of this demonstration project is to quantify the potentials of GWM&C by using the so-called GWM&C Toolkit. This Toolkit is a combination of three components: (i) data resources, (ii) analytical assessment tools, and (iii) presenting and decision system. This report will put focus on the second component: analytical assessment tools. Based on computer simulation models the present situation is compared to situations where GWM&C would have been implemented. This quantification is undertaken by two modeling tools: SWAT and WEAP. SWAT (Soil Water Assessment Tool) is specifically developed to explore the impact of changes in soil and water management on runoff, groundwater recharge and erosion. The WEAP (Water Evaluation And Planning tool) links the upstream and downstream interactions and is particularly strong to evaluate and compare different scenarios.

This report describes the application of the WEAP model to evaluate potential benefits from applying GWM&C in the Duhe basin, a tributary to the Danjiangkou Reservoir from which water is transferred to the North.

[1] In the international literature debates are ongoing whether terms as "green-water" and "blue-water" should be used. These debates argue that (i) these terms are not clearly defined, and (ii) well-accepted hydrological definitions exist and should be used. For consistency with previous similar activities we will stick to these terms in this report.

2 Methods and Tools

2.1 Green and Blue Water

Green water is water held in the soil as soil moisture. It is returned as vapor to the atmosphere by plants (transpiration) and by the soil (evaporation). Green water is the largest fresh water resource, but can only be used in situ. Green water is managed by the land users - farmers, forest and rangeland users.

Blue water is all liquid water. It includes surface runoff, groundwater and stream flow that can be used elsewhere - for domestic and stock water, irrigation, industrial and urban use - and which supports aquatic and wetland ecosystems. The blue water resources, in quantity and quality, are strongly determined by the upstream land users.

The concept of green water addresses the sustainable management of the water resources in a river basin at source. It links the rain water that falls on rain fed land to the (blue) water resources of rivers, lakes and groundwater. The importance of proper management of soil water to the provision of the blue water resources is often overlooked. The emphasis on and labeling of green water was introduced by Falckenmark in 1995.

In the international literature debates are ongoing whether terms as “green-water” and “blue-water” should be used. These debates argue that: (i) these terms are not clearly defined, and (ii) well-accepted hydrological definitions exist and should be used. For consistency with previous similar activities we will stick to these terms in this report.

2.2 Study Area

2.2.1 Changjiang Basin

Danjiangkou Reservoir 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 River, a tributary of Changjiang, 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 municipalities, and 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 Reservoir 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 (62,263 km^2 in Shaanxi Province, 7,911 km^2 in Henan Province and 21,214 km^2 in Hubei Province). It covers three provinces, 6 cities and 33 counties (Fig 3).

There are various issues on the protection and management of eco-environment of the water source 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 Hanjiang, catchments of Xunhe and Jinqianhe, valley of Hanjiang, the peripheral area of Hanzhong Basin and the area of Hanjiang head. With increasing population and mankind 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 source. 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 unacclimatization. The geological disaster is increasing.
- Serious 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.

2.2.2 Current situation on GWM&C options and policies

Some relevant policies are currently developed or under development relevant for GWM&C in the region. The most relevant are:

- Planning on Water Pollution Prevention and Soil & Water Conservation for the Danjiangkou Reservoir Areas and Its Upstream: In 2006, the State Council approved the planning: by the end of 2010, 92 projects have been planned and have been implemented for remediation and prevention of water pollution (19 sewage treatment plants, 8 garbage disposal fields, 53 projects on the treatments of industrial pollution, 5 trash cleaning projects, 7 eco-agricultural demonstration projects, 5 monitoring sites), total investment is about US$ 500 million which has been included in the overall planning of the Middle Route Project (MRP) for South-to-North Water Transfer.

- Soil and water conservation and small watershed management: According to the Planning, prior to end of year 2010, about US$ 500 million has been investing in soil and water conservation (SWC) through 793 projects; among them, 690 small watersheds in 24 counties has been implemented for SWC. To fully control the soil and water loss, involved local governments have been asked to raise fund up to for following up SWC after year 2010, *i.e.,* some US$ 800 million is expected for some 1000 SWC projects.
- National Natural Forest Protection Program
- National Grain for Green Program: Since 1999, China has pursued one of the most ambitious conservation set-aside programs, known as Grain for Green. While the program has made a clear attempt to retire land that has the highest potential of contributing to soil erosion, cost-effectiveness can be improved by targeting plots with highest environmental benefits and allowing payments to reflect heterogeneous opportunity costs. Preventing farmers from reconverting plots to cultivation will be critical to sustain environmental benefits of the program.
- National Countryside Eco-energy Utilization Program
- State Subsidy on the Water Resources for Middle Route Project for South-to-North Water Transfer: The central government has agreed with a trial on mechanism of ecosystem compensation in the water resources protection for the Middle Route Project, and included it as central government’s Fiscal budget: US$ 220 million for year 2008 and US$ 250 million for year 2009 have been paid.

2.2.3 Institutional framework

The institutional structure for water resource management in China includes

- Ministry of Water Resources (MWR),
- Watershed Management Organizations,
- Regional/Local Water Management Organizations.

The Ministry of Water Resources is the national government's authority for water affairs. Watershed Management Organizations are the water resources commissions under the MWR: these are authorities in the larger watersheds or water systems that span more than on province and districts, established under the Water Act and other related law, regulations and authorization of the MWR. Local Water Management Organizations are the water authorities of the provinces; city and county governments are in charge of the sub-watersheds in their respective districts.

Changjiang Water Resources Commission (CWRC) is one of the Seven Watershed Management organizations in China, directly under the Ministry. The Commission is located in Wuhan, Hubei province, and is responsible for the Changjiang Basin and the southwest river valleys of China. It is authorized by the State to exercise administrative water management in its region: to provide overall management of water resources in the valley in accordance with the Water Law of the People's Republic of China; to take charge of the comprehensive, planning, harnessing, development, management and protection of the water resources in the entire valley; to give instructions to conduct examination, coordination and supervision on, and to perform services for the regional water resources facilities.

Also located in the Changjiang Basin is the Nanjing Hydraulic Research Institute (Nanjing, Jiangsu province) which is also a famous research institute in the water sector, but not institutionally under the CWRC.

The Changjiang Water Resources Commission, through its vice president, has expressed its great interests in the GWM&C-concept, because now they lack such an integrative tool that allows to link upstream supply (of water services) to downstream demand. They asked ISRIC/FW to develop and provide an education & training program to their relevant staff and allow ISRIC/FW and HZAU staff to do a feasibility study for a sub-catchment area of the Danjiangkou Reservoir with local institutions. It is this proof that is needed in the Chinese situation to convince local and national authorities to upscale the methodology.

2.3 WEAP

2.3.1 Model overview

An easy-to-use tool is needed to match water supplies and competing demands, and to assess the upstream–downstream links for different management options in terms of their resulting water sufficiency or un-met demands, costs, and benefits. The Water Evaluation And Planning system (WEAP) has been developed to meet this need. It uses the basic principle of water balance accounting: total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and soil). WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Delphi Studio® programming language and MapObjects® software are employed to spatially reference catchment attributes such as river and groundwater systems, demand sites, wastewater treatment plants, catchment and administrative political boundaries (Yates *et al.* 2005).

Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are mutable, both in space and time. WEAP then employs a priority-based optimization algorithm and the concept of “equity groups” to allocate water in times of shortage.

The simplicity of representation means that different scenarios can be quickly set up and compared, and it can be operated after a brief training period. WEAP is being developed as a standard tool in strategic planning and scenario assessment for GWM&C. This approach has been tested in Kenya, Morocco and Algeria so far.

In order to undertake these assessments the following operational steps can be distinguished:

- The study definition sets up the time frame, spatial boundary, system components and configuration. The model can be run over any time span where routing is not a consideration, a monthly period is used quite commonly.
- System management is represented in terms of supply sources (surface water, groundwater, inter-basin transfer, and water re-use elements); withdrawal, transmission and wastewater treatment facilities; water demands; and pollution generated by these activities. The baseline dataset summarizes actual water demand, pollution loads, resources and supplies for the system during the current year, or for another baseline year.

- Scenarios are developed, based on assumptions about climate change, demography, development policies, costs and other factors that affect demand, supply and hydrology. The drivers may change at varying rates over the planning horizon. The time horizon for these scenarios can be set by the user.
- Scenarios are then evaluated in respect of desired outcomes such as water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

Water supply: Using the hydrological function within WEAP, the water supply from rainfall is depleted according to the water demands of the vegetation, or transmitted as runoff and infiltration to soil water reserves, the river network and aquifers, following a semi-distributed, parsimonious hydrologic model. These elements are linked by the user-defined water allocation components inserted into the model through the WEAP interface.

Water allocation: The challenge is to distribute the supply remaining after satisfaction of catchment demand the objective of maximizing water delivered to various demand elements, and in-stream flow requirements - according to their ranked priority. This is accomplished using an iterative, linear programming algorithm. The demands of the same priority are referred to as “equity groups”. These equity groups are indicated in the interface by a number in parentheses (from 1, having the highest priority, to 99, the lowest). WEAP is formulated to allocate equal percentages of water to the members of the same equity group when the system is supply-limited.

2.3.2 Application of WEAP in Green Water Management & Credits

Green water management can increase water productivity by reducing unproductive evaporation losses, storm runoff and soil erosion, and by increasing water storage in soils and aquifers; for instance, soil erosion and the consequent siltation of reservoirs can be reduced by 50-100%. In terms of *blue water* resources, there is a trade-off between runoff, which travels directly overland to streams, and infiltration into the soil - but this may be compensated for by groundwater recharge (as a result of the latter process) which feeds river base flow.

WEAP integrates this information on water supply and water quality with the demands from irrigation, household supply, industry, hydropower generation and environmental flows. By integrating supply and demand with costs of different interventions, WEAP enables the analysis of the costs and benefits of different water allocation and development options. Vulnerabilities in the system, mitigation options and coping capacity may be assessed by using data from extreme years. This, in turn, can be used for cost-benefit analysis of mitigation options.

3 Building WEAP for Upper Duhe Basin

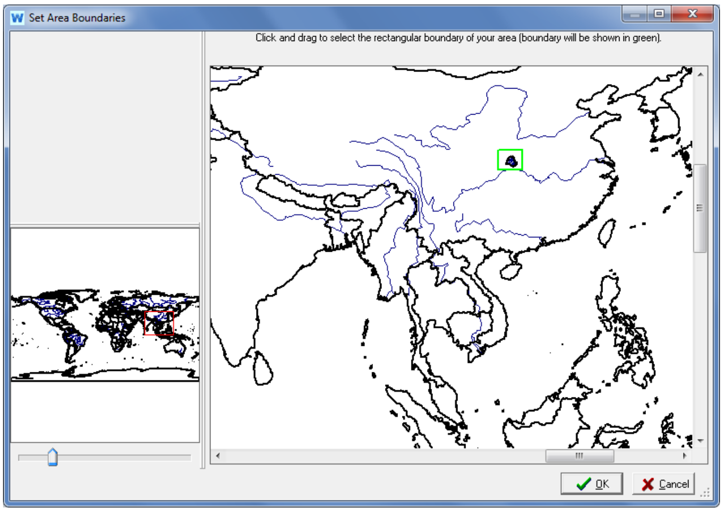
3.1 Introduction

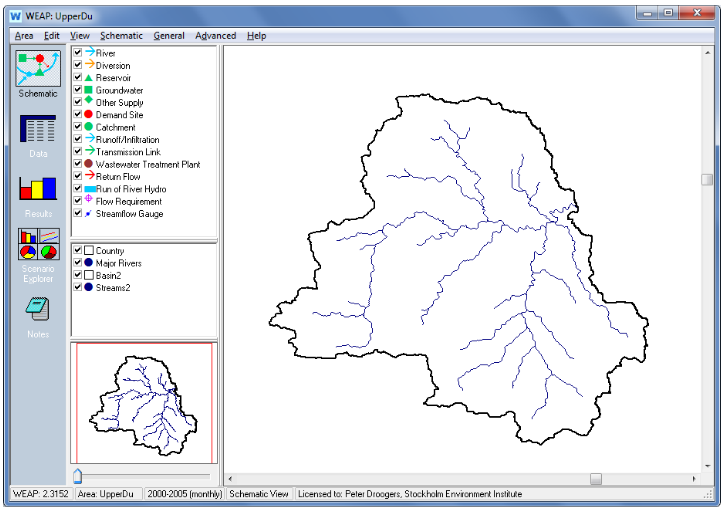
The WEAP model as described in the previous sections has been used widely in the context of GWM&C. For the Upper Duhe Basin, a WEAP model was built with the intention to demonstrate the capacity of such an approach rather than to be inclusive. Results and recommendations should therefore be considered in this respect. If GWM&C will be actually implemented, additional fine tuning of the model is necessary.

3.2 Model Components

3.2.1 Boundary and area extent

Within WEAP shape files were added that identify the exact area and the main streams in the Duhe basin. The exact area boundaries were derived from the SRTM data set and by using the SWAT watershed delineation tool exact physical boundaries were obtained. The total area of the basin is 902,675 ha (Figure 1).





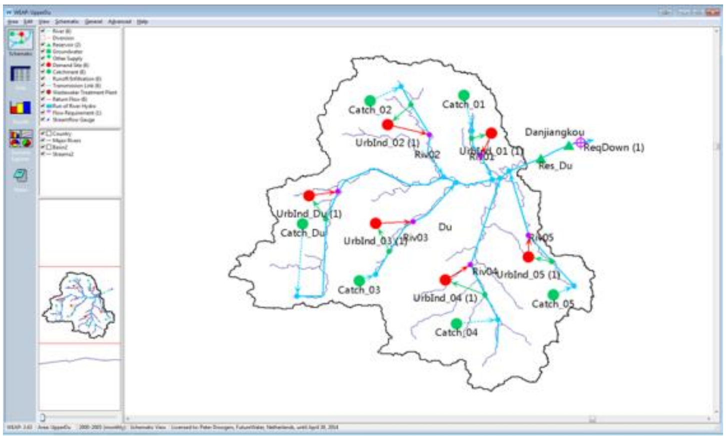


Figure 1. Location, area boundaries, and WEAP scheme of Upper Duhe Basin

3.2.2 Sub-catchments

Based on the overall stream flow network the Upper Duhe Basin is divided into six sub-catchments: the main stream of the Duhe and five tributaries. The area and estimated population of each of these sub catchments is presented in Table 1.

Table 1. Main characteristics of the six catchments as applied in WEAP

Catchment	Area (ha)	Population[1]
Duhe	225,669	250,000
01	45,134	50,000
02	90,268	100,000
03	225,669	250,000
04	225,669	250,000
05	90,268	100,000

[1] *Note: population numbers are based on first order estimate.*

3.2.3 Land cover

Based on the SWAT dataset aggregated land data statistics has been derived for the six catchments (Table 2). Further refinement in terms of area as well as number of land classes can be implemented rather easily within WEAP in case more detailed information will be available.

For each of these land classes characteristics are needed to ensure that WEAP can simulate the present situation as well potential GWM&C interventions. The most relevant characteristics are the so-called K_c factor and the erosion rate.

The K_c factor (referred to as crop factor) is used to convert the ET_{ref} (reference evapotranspiration) to the ET_{pot} (potential evapotranspiration). This ET_{pot} is subsequently used by WEAP to calculate the ET_{act} (actual evapotranspiration) based on the availability of water. So as equation:

$$ET_{act} = K_s \cdot ET_{pot}$$
$$ET_{pot} = K_c \cdot ET_{ref}$$

with

ET_{act} : actual evapotranspiration (mm/d)
ET_{pot} : potential evapotranspiration (mm/d)
ET_{ref} : reference evapotranspiration (mm/d)
K_s : reduction by water deficit (-)
K_c : crop factor (-)

Values for K_c factors are shown in Figure 2 as monthly specific input. K_s is usually calculated by WEAP as function of water availability. Here, we used ET-data as calculated by the SWAT model (Brandsma *et al.,* 2013), and K_s was set to 1.0.

Erosion with as consequence sedimentation and reservoir siltation will finally result in loss of reservoir storage capacity. Moreover, hydropower stations' lifespans will be subsequently shorter and reductions in efficiency will happen by gradually damaging the turbines. Although exact figures of erosion will be calculated by SWAT a first order estimate will be calculated by the WEAP model. WEAP has no sophisticated erosion modeling, but for each land class the sediment concentration, expressed in mg/L, should be provided.

Table 2. Aggregated land classes of the six catchments as applied in WEAP

Catchment	Forest (%)	Rangeland (%)	Corn (%)	Wheat (%)
Duhe	70	20	5	5
01	60	20	10	10
02	60	20	10	10
03	70	20	5	5
04	70	20	5	5
05	80	10	5	5

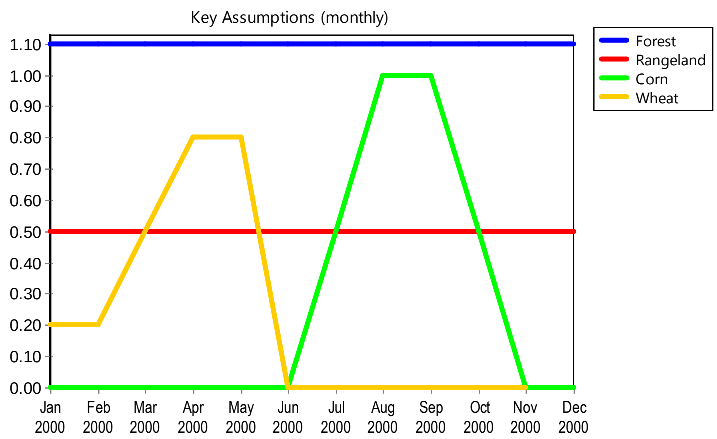


Figure 2. Crop factors (K_c) for the four aggregated land use classes.

3.2.4 Domestic demand

A first estimate of the amount of water extracted for domestic, being urban and industrial demand has been included in the model. It was assumed that per person a total of 45 m^3 per year was extracted for urban and industrial needs. Of this 45 m^3 40% was assumed to be actually used, so that 60% would flow back in the system. Obviously, if more detailed information is available this can be included in an updated version of the model.

3.2.5 Transboundary demand

In order to mimic the downstream water requirements for transfer to Beijing and other users, it was assumed that at least 100 $m^3 s^{-1}$ should be flowing out of the basin.

3.2.6 Hydropower

Two representative hydropower nodes were assumed. The first one represents the reservoirs that were inside of the Upper Duhe Basin. Instead of simulating the five main reservoirs (Pankou, Huanglongtan, Xiaoxuan, Songshuling, E'ping) in the basin separately, one representative reservoir was used. The capacity of this representative reservoir is the sum of the five individual ones, being 4,003 MCM (million cubic meters). The average water level is 362 m.

For the largest reservoir in the basin (Pankou) it is reported that the expected annual average hydropower production will be around 1,000,000 MWh, and the installed capacity is 513 MW. (https://cdm.unfccc.int/filestorage/o/_/MHVNGBS8PD2Q1FK6AWTCE5R3LY7JUX.pdf/Validation%20Report_Hubei%20Pankou%20HP.pdf?t=TWN8bXV2YTIzfDCc4bhvBX4mJAnwEoUxLcxL)

The Danjiangkou Reservoir is located outside the study area. The Reservoir receives also water from other sources. It was therefore decided to create a representative Danjiangkou Reservoir that will reflect the impact of changes that might happen in the Upper Duhe. In order to represent that the reservoir will be partly fed by the Upper Duhe we assumed that the characteristic volume is 25% of the total 29,000 MCM.

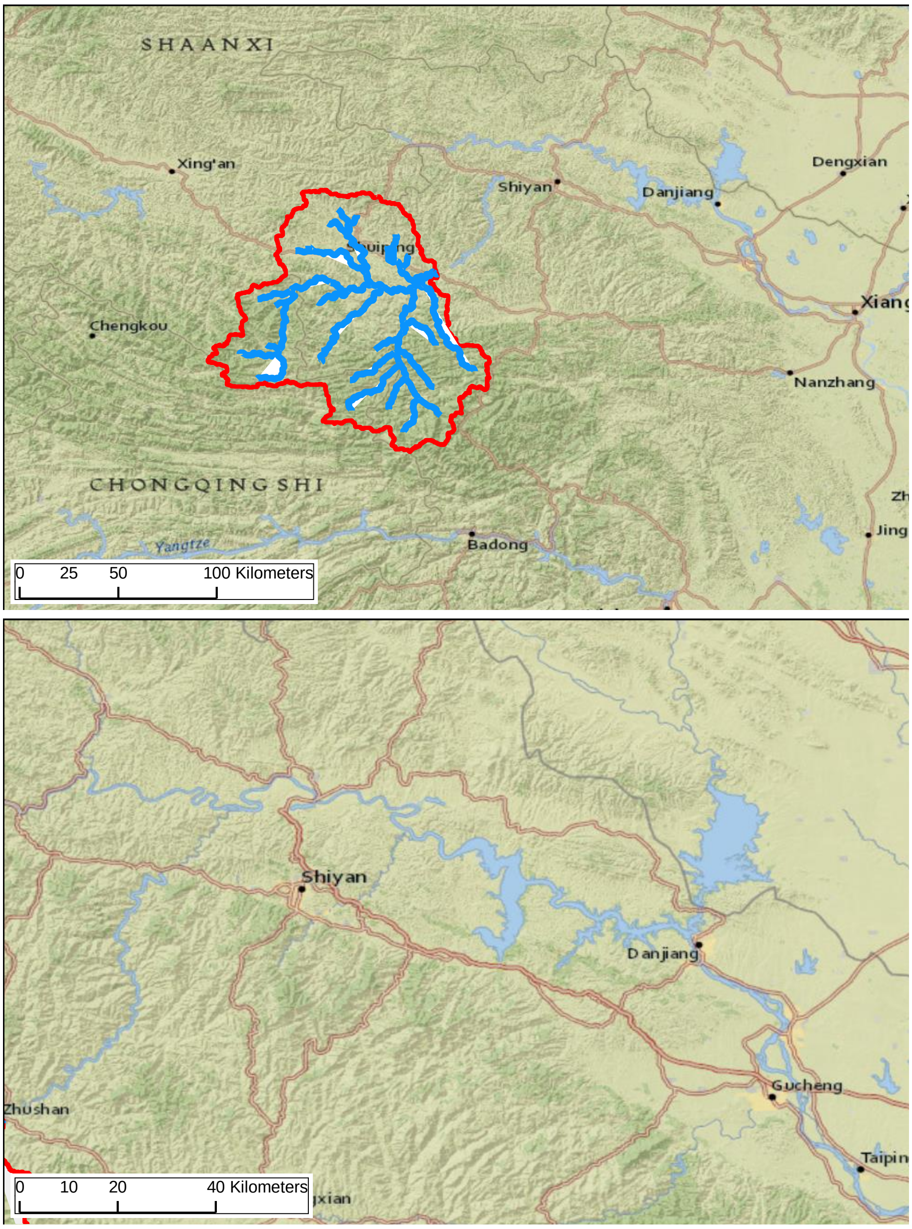


Figure 3. Location of Danjiangkou Reservoir outside the Upper Duhe Basin.

3.3 Validation and calibration

Since the WEAP model is based on the calibrated and validated SWAT model, a detailed validation and calibration was considered not necessary. Also, WEAP will be mainly used for comparing base-line to interventions and model inaccuracy will be therefore largely being ineffective on final output (Droogers *et al*., 2008). However, to provide trust in the final result, observed and simulated outflow has been compared for gauging station at Zhushan.

We looked at mean measured (2001-2010 period), as well as estimated wet and dry climate conditions. For wet conditions, we took 50% more precipitation and 25% less ET_{ref} as compared to mean conditions. For dry conditions, we took 50% less precipitation and 25% more ET_{ref} as compared to mean conditions.

Error! Reference source not found. (top) indicates that the observed mean outflow and the simulated one match quite well. Annul totals are 4,711 MCM per year and simulated ones 4,223 MCM per year, a difference of about 10%. By using the monthly effective precipitation as calibration factor the mean observed and simulated flow at Zhushan are almost identical, indicating that the WEAP model can be used for scenario analysis.

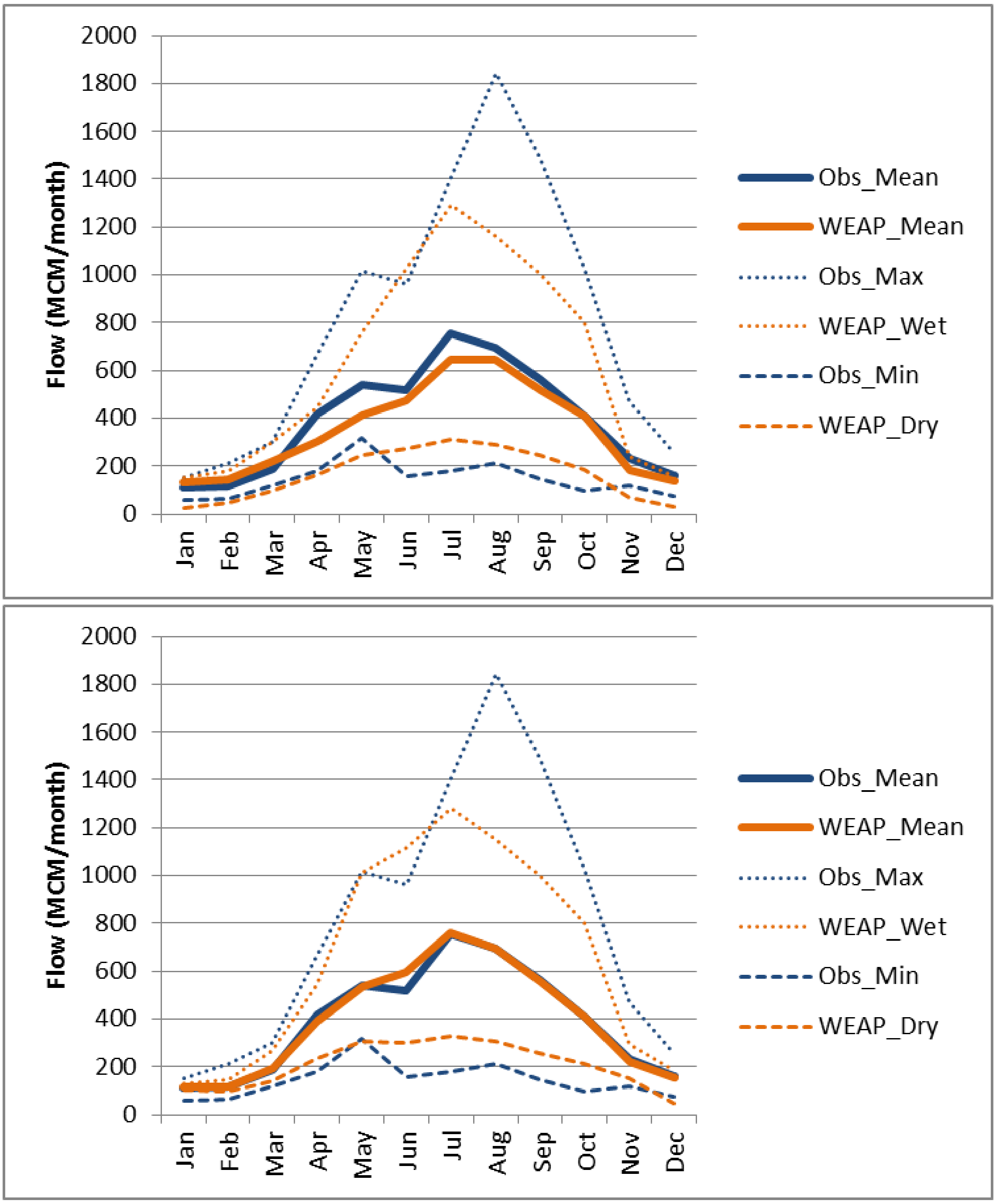


Figure 4: Observed and simulated flows at Zhushan gauging station.

→ Observed mean, maximum and minimum are based on 2001-2010 period. Simulated are based on mean, dry and wet climate conditions. Top: before calibration. Bottom: after calibration.

4 Green Water Credits interventions

4.1 Background

Five green water management interventions were proposed and analyzed. These are (see photographs):

- Stone lines,
- Bench terraces,
- Contour tillage,
- Mulching
- Forest management: slightly changing the forest area land use.

Average costs of these interventions are based on Bai (2013) and are presented in the following sections.

Figure 5. Green Water Credit intervention: Stone lines (source: www.wocat.net).

Figure 6. Green Water Credit intervention: Bench terraces.

Figure 7. Green Water Credit intervention: Contour tillage (source: www.wocat.net).

Figure 8. Green Water Credit intervention: Mulching.

Figure 9. Green Water Credit intervention: Forest management (natural area).

The following assumptions based on earlier Green Water Credits work in Kenya and Morocco has been used:

- Reduction of erosion rates has been taken from the SWAT analysis.
- Erosion will have a major impact on crop production. Fertile soil will be lost and will reduce crop production. Since exact numbers on the impact are highly dependent on many factors (crop, soil, fertilizer, management), the assumption has been made that for every ton of sediment load, crop yields will be reduced by 2%. Again a period of 30 years is considered. This is implemented in WEAP by reducing the Water Productivity value, assuming that the agricultural value of 1 m^3 of water for crop production equals US$ 0.10.
- Irrigation in the Duhe basin is not largely spread. We assume agriculture to be rainfed only. Note that the price for irrigation water is Chinese ¥ 60/m^3 (Bai, 2013).
- Purification plants for drinking water spent considerable amount of money to remove sediments from water, especially costs of chemicals (e.g. aluminum sulfate) for the flocculation process. It is assumed that the costs of water purification increases by US$ 0.02 per m^3 of water for each 1,000 mg/L sediment. Real costs for each mg/L are higher, but not all water will originate from the agricultural fields.
- Sediment flow through hydropower will increase wear of turbines. Exact numbers are not available and it was therefore assumed that for each 1,000 mg/L sediment benefits of hydropower will reduce by US$ 1,000 per GWh.
- Sediment inflow will reduce the capacity of the reservoirs. It was assumed that in 50 years reservoir capacity would be reduced by 50% under the current conditions. Using the SWAT output, this will be reduced by (Brandsma *et al*., 2013):

    - 6%: Stone lines
    - 9%: Bench terraces
    - 7%: Contour tillage
    - 3%: Mulching
    - 0%: Forest management

4.2 Typical output

The WEAP model provides a lot of output related to water resources. Some typical output is shown in the following Figures (10, 11, and 12).

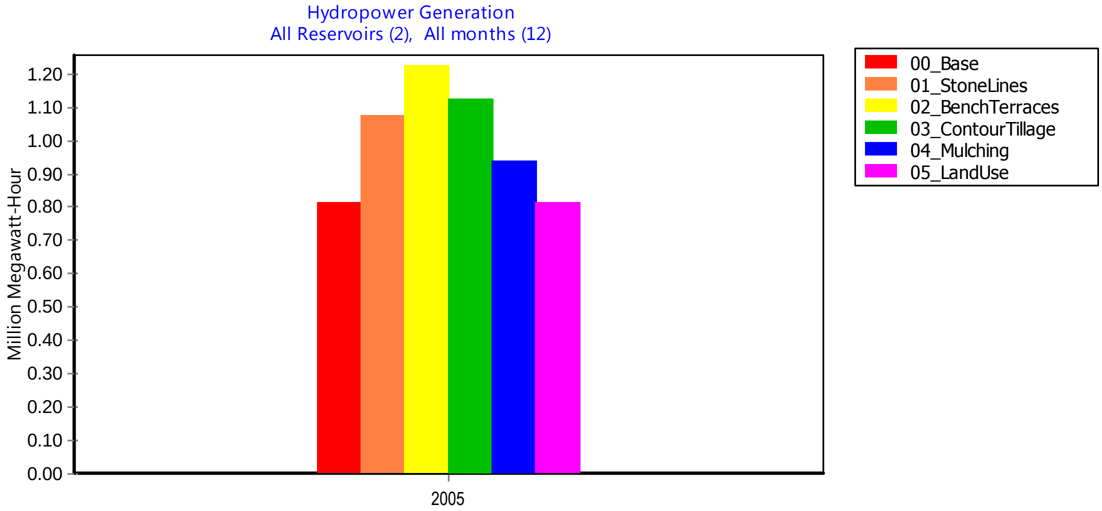


Figure 10. WEAP output: hydropower generation for the five interventions and the base line. Year 2005 stands for average year for 2001-2010 period. Note: 05_Landuse is forest management intervention.

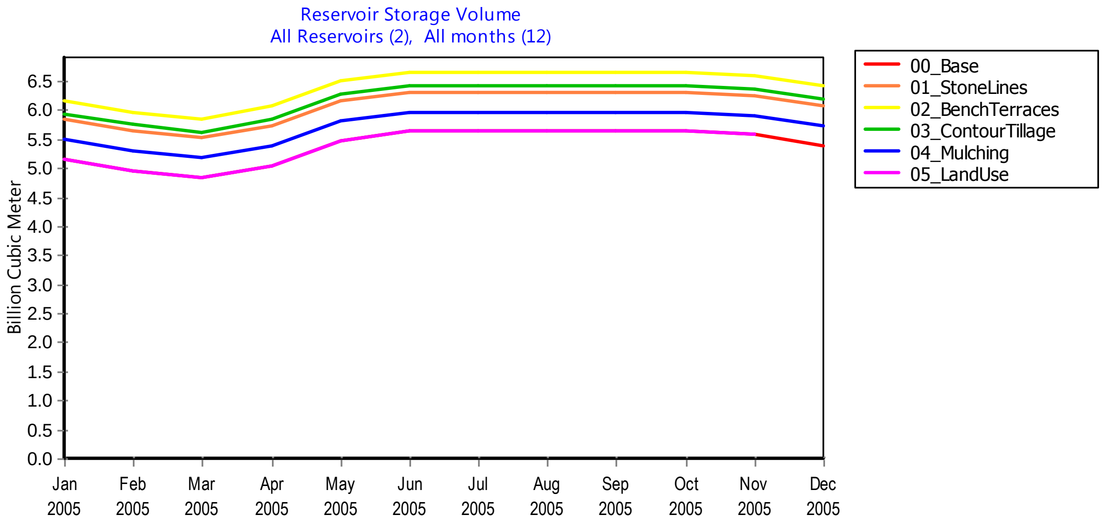


Figure 11. WEAP output: monthly reservoir volume for the five interventions and the base line. Year 2005 stands for average year for 2001-2010 period.

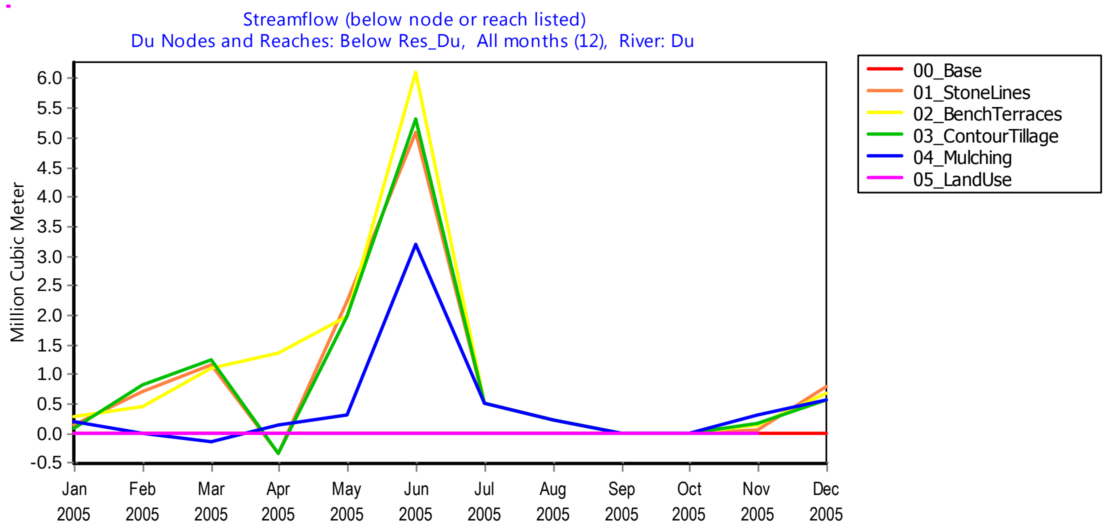


Figure 12. WEAP output: difference in stream flow compared to base line for the five interventions. Year 2005 stands for average year for 2001-2010 period.

4.3 Benefit-cost analysis

4.3.1 Returns on water consumption

Based on the WEAP results a benefit-cost analysis has been undertaken for the five interventions. The annual returns from water consumption are shown in Table 3. In the current situation (00_Base) without GWC interventions the three main sectors produce a total value of US$ 32 million per year. Depending on the intervention that will be implemented at full scale (51,000 ha agricultural area), these benefits can increase to over US$ 60 million per year for the Bench Terraces. The same results are also presented in Figure 13.

Table 3. Annual returns from water from the three main sectors for the entire Upper Duhe Basin. Mean measured conditions for the 2001-2010 period. Note: 05_Landuse is forest management intervention.

	Rainfed Agr.		Domestic		Hydropower		TOTAL
	mm/y	MUS$	MCM/y	MUS$	GWh	MUS$	MUS$
00_Base	511	9.5	45.0	4.9	814	17.9	32.4
01_StoneLines	522	16.1	45.0	8.9	1,075	28.4	53.4
02_BenchTerraces	520	18.3	45.0	10.3	1,223	34.1	62.7
03_ContourTillage	531	17.3	45.0	9.4	1,123	30.3	57.0
04_Mulching	523	12.9	45.0	6.9	940	22.7	42.4
05_LandUse	0	0.0	45.0	10.3	814	22.7	33.0

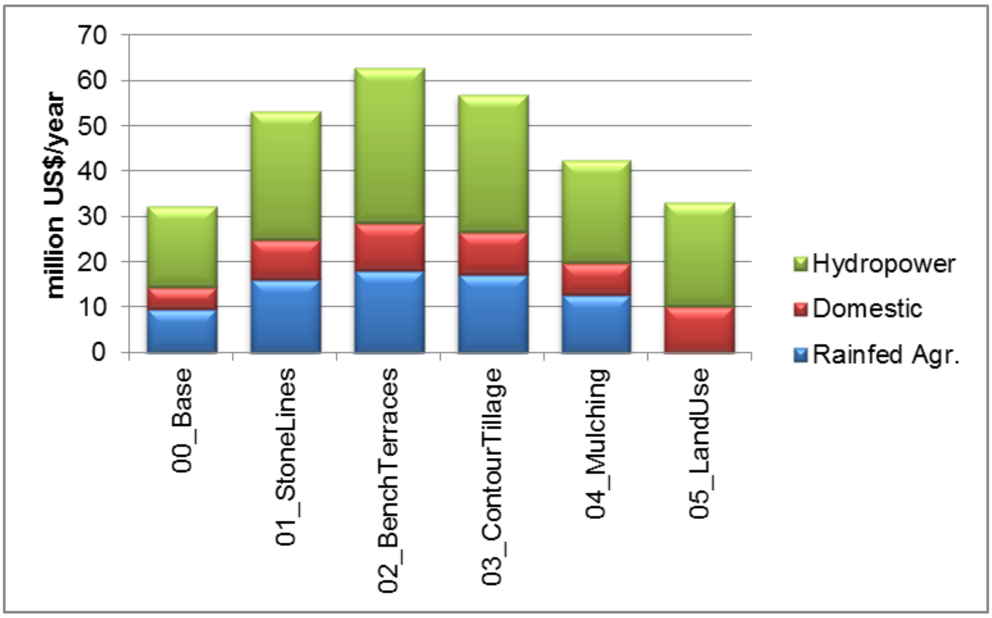


Figure 13. Annual return from water for the three main sectors of the five interventions and the base line for Upper Duhe Basin. Average data for 2001-2010 period.

4.3.2 Cost of GWC interventions

Obviously in order to implement these GWC interventions investments and/or annual costs have to been made. Those costs are presented per hectare as well as for the entire Upper Duhe in Table 4.

Table 4. Annual cost of GWC interventions for the Upper Duhe Basin.

	¥/mu Costs	$/ha Costs	mUS$ Costs
Stone lines	1000	2400	4.2
Bench terraces	1750	4200	7.3
Contour tillage	100	240	12.5
Mulching	100	240	12.5
Land use change	500	1200	2.1

*¥ or RMB; 1 ¥ = 0,16 US$; 1 ha = 15 mu.

4.3.3 Benefit-cost analysis

The net return of GWC interventions are based on taking the difference of the returns of current water use and the returns if interventions are taken. Obviously, the difference between these returns should be higher than the costs that have to been made for the interventions. In Figure 14 it is clear that for three interventions (stone lines, bench terraces and contour tillage) the benefits are higher than the costs. For mulching are benefits and costs somewhat balanced, while the last intervention (land use change) costs are low but benefits are also very low.

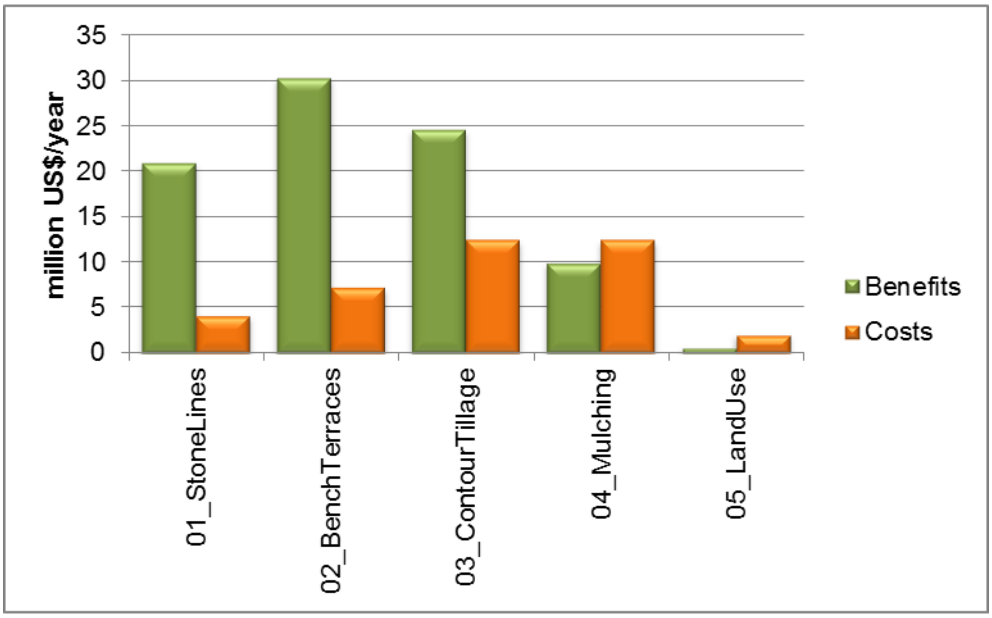


Figure 14. Annual benefits of GWC interventions compared to base line (no interventions) and the annual costs of the five interventions.

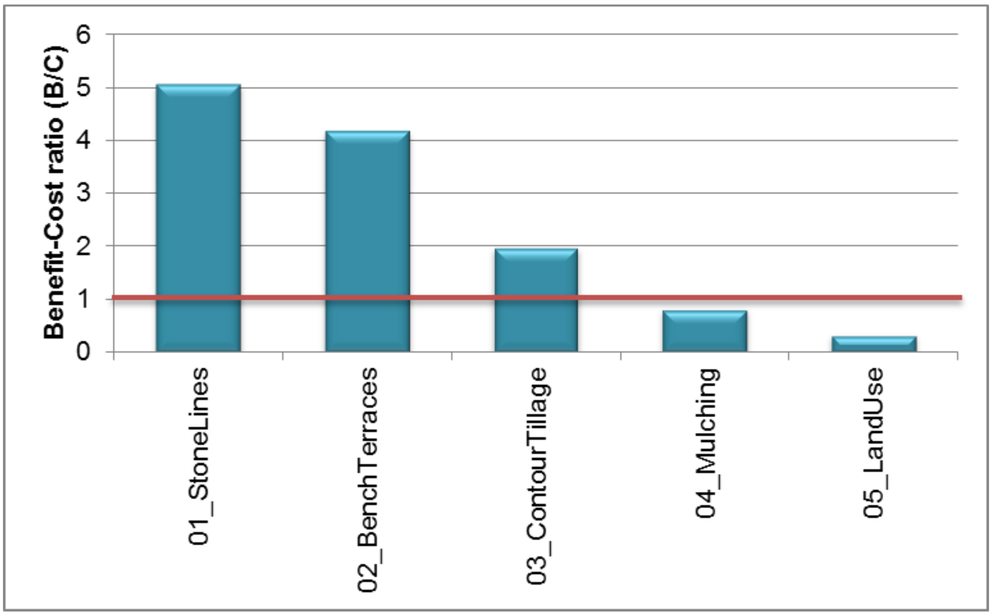


Figure 15: Benefit – cost ratio defined as the total benefits divided by total costs. A value higher than 1 indicates that benefits are higher than costs.

4.3.4 Sensitivity analysis on prices

In the current study, the water resources and the hydrology is well validated by looking at observed and simulated flows. However, for costs of interventions some variation might occur, based on local specific conditions. Therefore is a sensitivity analysis on those costs performed. Four different cost scenarios have been analyzed and can be found in Table 5. The results of these scenarios on benefit and cost are shown in Table 6.

Table 5. Parameters for the sensitivity analysis of benefit-cost values.

	A	B	C	D
Depreciation GWC interventions (year)	30	20	30	30
De-silting costs urban for each 1000 mg/L (US$ per m3)	0.02	0.02	0.04	0.01
Turbine wear for each 1000 mg/L (US$ per GWh)	1000	1000	2000	500

A = most realistic
B = depreciation of GWC interventions shorter
C = de-silting more expensive
D = de-silting less expensive

Table 6. Results of the benefit-cost sensitivity analysis. B-C numbers are the Benefits minus the Costs.

	===== A =====			===== B =====			===== C =====			===== D =====		
	Ben.	Costs	B-C	Ben.	Costs	B-C	Ben.	Costs	B-C	Ben.	Costs	B-C
Stone lines	21	4 ⇧	**17**	21	6 ⇧	**15**	27	4 ⇧	**22**	18	4 ⇧	**14**
Bench terraces	30	7 ⇧	**23**	30	11 ⇧	**19**	38	7 ⇧	**31**	26	7 ⇧	**19**
Contour tillage	25	12 ⇧	**12**	25	19 ⇧	**6**	31	12 ⇧	**19**	21	12 ⇧	**9**
Mulching	10	12 ○	**-2**	10	19 ⇩	**-9**	12	12 ○	**0**	9	12 ○	**-4**
Land use change	1	2 ○	**-1**	1	3 ○	**-2**	11	2 ⇧	**9**	-4	2 ⇩	**-7**

5 Conclusions and Recommendations

Data
The application of WEAP for this feasibility study was based on general data, on-site data of the Upper Duhe Basin from Chinese partners, and SWAT model calculations. The quantity and quality of the data determine the final outcome of this study. For WEAP, we have used estimates on *e.g*. cost issues. Refinement and improvement of these data will lead to better and more accurate results. However, the headline of this study will provide a sound basis for discussion, planning, and follow-up.

Methodology
The GWC-concept uses computer models to analyze the biophysical situation in a basin and to evaluate water demand and supply, including the cost-benefit analysis of GWC-interventions. The data and tools used are important, because their suitability to analyze hydrology and erosion processes on the catchment scale is the basis for quantification of effects of past and future measures. The combination of SWAT and WEAP models is feasible, powerful and potential benefits of GWC-interventions can be assessed.

Calculation results
The WEAP model calculations result in a positive balance of cost and benefits for at least three GWC-interventions, stone lines, bench terraces, and contour tillage. Mulching almost reaches a break-even point at the moment. This means that the GWC-interventions that we analyzed not only have a positive effect on green and blue water and erosion, but also gain positive financial effects. The return of investments on measures in the Upper Duhe Basin can be processed, based on these results.

Recommendations
At this stage, discussion on the results with Chinese partners can lead to different follow-ups for the Upper Duhe Basin:

- Data improvement
- Model refinement
- Climate change effects
- Planning of effective measures

Also, first order WEAP models could be setup for other sub basins feeding the Danjiangkou Reservoir, in case information on hydrology and erosion is provided for.

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