Sustainable Management of River Oases along the Tarim River – SuMaRiO

Urumqi Charta - Stakeholder Recommendations to Combat Desertification


Content

Preface

The long-term cooperation on environmental issues in China between the German Federal Ministry of Education and Research and the Chinese Ministry of Science and Technology has brought up the project “Sustainable Management of River Oases along the Tarim River – SuMaRiO” in the German funding program “Sustainable Landmanagement”. The project consortium consisted of eleven German and nine Chinese universities and research institutions and stakeholders and worked together for five years from 2011 to 2016. As a transdisciplinary project SuMaRiO integrated the stakeholders from the beginning in the project work. Stakeholders helped us to give us suggestions for the right project course. Their valuable comments were included in the main outcome of the project – the SuMaRiO decision support system (SuMaRiO-DSS). In the SuMaRiO-DSS all the results of the project are integrated, including results of regional climate change, cryosphere, water management of the Tarim River and its tributaries, ecosystem and agricultural analyses, socio-economic assessment and the stakeholder analysis. The SuMaRiO project is unique, as it considers various angles of the Tarim River Basin and combines them to form a holistic overview.

Stakeholder Recommendations to combat desertification

From 2011 to 2015, transdisciplinary research on land and water management in the Tarim basin was done collaboratively by Germans and Chinese. Based on this research experience, SuMaRiO researchers have formulated the following recommendations for policy makers in Xinjiang and for research funding agencies.

1. For policy makers

We recommend that

- comprehensive assessment of ecosystem services is promoted and that the ecosystem services concept is more widely integrated into regional planning and environmental management. This enables to generate rational development strategies that maximize the benefits humans derive from ecosystems, safeguarding the natural capital. In SuMaRiO we found that it is beneficial to increase understanding for the diverse ecosystem services beyond provisioning services while monetary valuation remains difficult.
- for regional planning and environmental management, Xinjiang administration sets up well-designed participatory strategy development processes that enable free exchange and successful integration of knowledge from multi-sectoral administrative bodies. In SuMaRiO we developed a range of knowledge integration methods that are suitable for application in Xinjiang.


- policy makers continue to base their decisions on scientific evidence as provided by research institutes, and to extend and utilize the Tarim River Decision Support System (DSS) developed within SuMaRiO. The DSS quantifies ecosystem system services and helps to consider ecological, social and economic aspects of land and water resources management in a holistic manner.

1.1 Urban and peri-urban vegetation

We recommend that

- the share of urban and peri-urban green in city structures is increased as part of efforts to make cities more resilient against climate change. Many co-benefits related to health, well-being and recreation are obvious; urban forests contribute to cleaning the air from dust particles, they provide space for physical exercise and serve as natural laboratories for environmental education.
- local ecological and cultural dimensions are taken more strongly into account in planning and managing of urban and peri-urban green. In SuMaRiO we found that there are large differences in water consumption levels among plant species. Generally, locally adapted species provide the highest key ecosystem services (like dust retention, mitigating heat island effect) while using relatively small amounts of water. Regarding cultural dimensions, planners may mimic and further develop locally adapted traditional ways of city development.
- diverse stakeholders and local citizens are more strongly involved into planning and management of urban and peri-urban green. We found that many participatory methods are applicable in the Chinese context (surveys, interviews, group methods, etc.). Institutional arrangements that can complement publicly managed green elements include neighborhood gardens and small plots for agriculture that are leased to urban dwellers. Participatory and community-based approaches are likely to increase social capital in cities by promoting a sense of belonging, ownership and responsibility.

1.2 Agriculture

We recommend that

- agricultural production technologies that save water and control salinity are promoted. In SuMaRiO we could show that water use efficiency can be significantly increased with adapted irrigation. The saved water should be used to increase biodiversity.
- production of crops that are adapted to salinity and have low water requirements is promoted. Studies in SuMaRiO showed that mono-cropping of cotton bears many risks and does not feed the population.
- the price for agricultural water is increased significantly, and that farmers are compensated for income losses by targeted subsidization of water-efficient production (i.e. drip irrigation). Research in SuMaRiO has shown that 1) water pricing only improves water productivity if the water price is significantly increased and 2) subsidization is required to maintain agricultural productivity and achieve increased water use efficiency.
- agricultural extension is improved as this is necessary to enable farmers to efficiently react to increased water prices.
- expansion of agricultural area and consequently water use is stopped by 1) promoting off-farm income alternatives and 2) by shifting towards labor-intensive high-value commodities (e.g. vegetables). According to SuMaRiO research, reducing the agricultural area in all three headwater regions (Aksu, Hotan, Yarkand) to the 1998 value (i.e. reducing the agricultural area in 2010 by 50%) would allow to achieve the streamflow objectives outlined in the “Planning Report for Immediate Comprehensive Improvement to the Tarim River basin” (GXUAR and MWRC 2002, China Water Power Press, Beijing) even without water management changes. If agricultural

area is maintained at the 2010 level, strong water saving measures are required to increase river discharge downstream of Alar under all climate change scenarios considered until the end of this century.

1.3 Tugai forests and Tarim river ecosystem

We recommend that

- the amount of drift wood and leaves in the Tarim river is increased by maintaining or restoring riparian strips of *Populus euphratica* of 20-50 m width. In SuMaRiO we found low aquatic biodiversity and small abundance of aquatic animals due to the lack of drift wood that serves as habitat and food for macroinvertebrates and fish but also due to low water quality including salinity.
- a moderate extent of wood harvesting by pollarding (cutting twigs and branches from trees) is allowed in case of *Populus euphratica* growing at a short distance to the groundwater (up to 2 m). Stakeholders have agreed to such a measure in discussions on this subject. We found that *Populus euphratica* has a high regeneration potential after moderate pollarding and would severely suffer only from frequent and intense pollarding.
- a continuous and sufficient water supply to *Populus euphratica* forests growing at short distances to the groundwater (up to 5-6 m) is ensured instead of diverting water to stands located at large distances to the groundwater. Generative reproduction necessary for long-term sustainability of forests stands is only possible in case of regular flooding and a high water table. Poplar stands growing at large distances to the groundwater cannot reproduce generatively at all, lose their capability to reproduce vegetatively with increasing age and distance to the water table, and are foredoomed to die off.
- a continuous flow of water in the Tarim River down to its terminal lake Taitema is re-established to maintain and restore the Tugai forests along in the lower reaches of the Tarim River. If continuous flow is not possible over the entire non-frozen season, “ecological water conveyance” with flooding should occur during the phenological phase of seed maturity of *Populus euphratica* in July/August.
- controlled flooding behind embankments is either optimized with respect to the health of the riparian ecosystem or embankments are removed; there should be no additional embankment or straightening neither at the middle nor the lower reaches of Tarim River. Free-flowing conditions have been shown to be essential for ecosystem functioning and ecosystem services.

1.4 Water resources

We recommend that

- precipitation in all headwater areas of the Tarim is more intensively monitored in order to confirm the trend of increasing precipitation. Glaciohydrological modeling in SuMaRiO indicates that precipitation increases projected by climate models as well as melt water may increase streamflow particularly in the upstream parts of Hotan and Yarkand rivers. However, streamflow decreases upstream of the oases cannot be precluded after 2050, in particular in case of the Aksu River.
- that the following activities are performed for understanding, monitoring and projecting glacier development, possibly applying methods and models developed within SuMaRiO:
  - Perform integrated studies at selected benchmark catchments with intensive climatological, hydrological (esp. discharge measurements) and glaciological (in-situ mass balance complemented by remote-sensing derived geodetic mass balance) measurements.
  - In these catchment, measure ice thickness for calibrating physically-based models.
  - Establish a remote sensing-based snow and glacier monitoring for the entire Tarim basin. This should include the generation of a complete glacier inventory, geodetic mass balance assessments as well as velocity measurements at an interval of about five years. Snow should be monitored on weekly basis with adjusted snow cover products.

- Set up a fully coupled physically-based glacio-hydrological model for the benchmark catchments and calibrate it using measured data; set up and regularly improve a simplified glacio-hydrological model of the whole Tarim basin.

Research results of SuMaRiO confirm the high importance of glacier melt for Tarim streamflow. It is likely that the measured increase of streamflow in the upstream Aksu River, the most important tributary of the Tarim River, is mainly due to increased glacier melt driven by temperature increase. Model-based scenarios indicate that streamflow in the upstream Aksu River may decrease after approximately 2050 due to significantly decreased glacier volumes if not compensated by increased precipitation.

2 For research funding agencies

We recommend that

- transdisciplinary social-ecological research in support of sustainable development is funded in the form of research projects in which natural and social scientists cooperate in a structured form and knowledge of multi-sectoral stakeholders is integrated. Both Chinese scientists and stakeholders appreciated the transdisciplinary research and the integrative dialogues done within SuMaRiO and agreed that increased application of this research mode would support a sustainable land and water management in Xinjiang.
- research cooperation among ecosystem ecologists, foresters and remote-sensing specialists is strengthened to intensify the development of sound and reliable methods for determining the amount of standing tree biomass and tree biomass increment of riparian poplar forests at the landscape level. We found statistically significant relationships between tree crown morphology and biomass increment in riparian forests that could be used to assess the health status of the stands and to predict their future performance using remote-sensing technologies.
- interdisciplinary research on agricultural water saving techniques and on methods controlling salinity and groundwater level is funded. The effect of more trees on reduction of dust and wind influence should also be a research focus. In SuMaRiO we found that cooperation of engineers, soil scientists and agronomists is appropriate for optimizing crop production.
- sustainability-oriented projects are evaluated with respect to both scientific excellence and quality of implementation strategies.
- training and knowledge transfer to university students and researchers on interdisciplinary and transdisciplinary research design and implementation is funded.

Introduction to the region

The Tarim River Basin is a large, unique and arid region of extreme vulnerability in northwestern China (Xinjiang Province) (see figure 1). The climate is continental with large temperature amplitude, annually and daily. It is, globally, the most remote area from oceans; hence rainfall is extremely rare and low and does not exceed 50 mm per year. Thus, all kind of economic activities, especially agriculture and urban life, as well as the natural ecosystems depend on the river water as major water source. The Tarim River, which is the largest river of the Tarim Basin, is fed from snowmelt and glacier-melt in the mountains. The water discharge into the Tarim River has been increasing over the last decade. However, global climate change prognoses forecast a shrinking

water supply within this century. Due to strong expansion of irrigated agriculture in oases along the rivers since the 1950s river flows have strongly decreased, leading to a degradation of floodplain vegetation, while agricultural soils have become unusable due to salinization (see figure 2). There is a clear trade-off between generating income from irrigation agriculture, mainly cotton, at the cost of Ecosystem Functions (ESF) and Ecosystem Services (ESS) provided by the natural ecosystems.

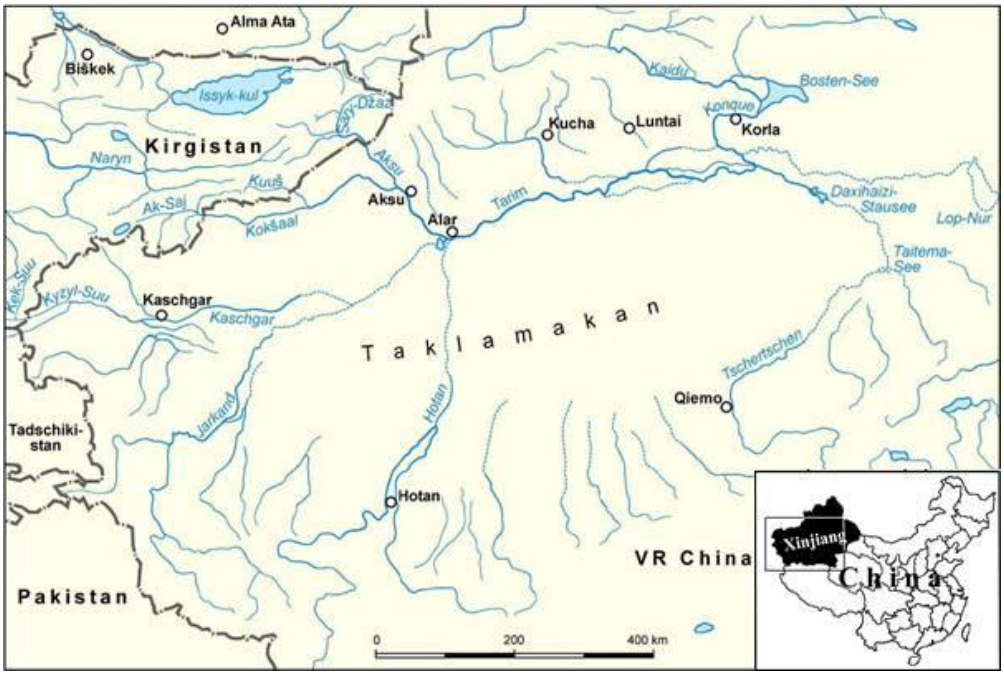


Figure 1: *Map of study region in northwestern China, Xinjiang province.*

The central question is how to manage land use, i.e. irrigation agriculture and utilization of the natural ecosystems, and water use in a very water-scarce region, with changing water availability due to climate change, such that ecosystem services and economic benefits are maintained in the best balance for a sustainable development.

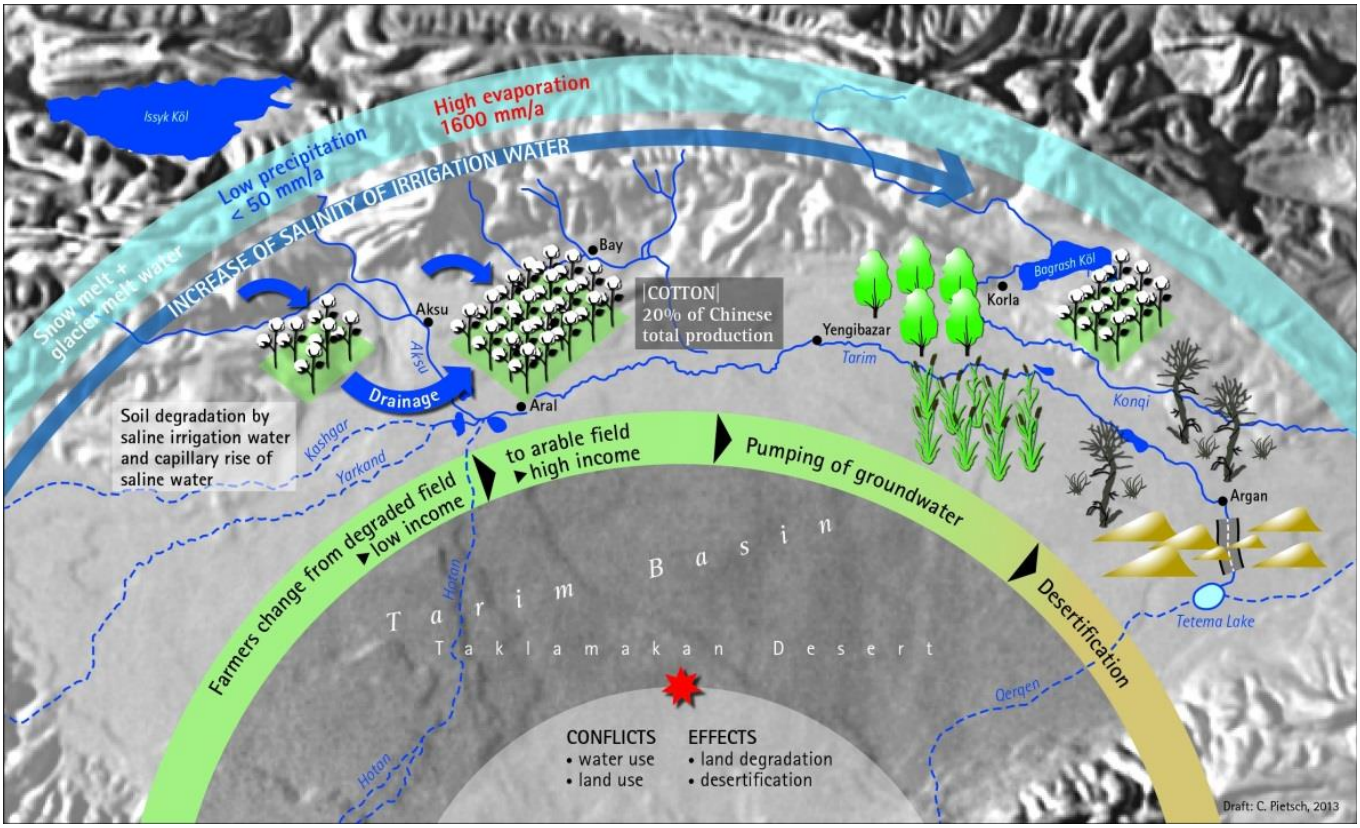


Figure 2: *Sketch of the regional issues on land and water management*

Sustainability

Sustainable Development should meet the needs of the present generation without compromising the ability of future generations to meet their own needs. This was the general thinking behind the research in the Tarim Basin. Chinese and German scientist from different scientific fields had recognized that the carrying capacity of the region has gone beyond and the use of natural resources in the river oases was not sustainable. Especially in case of river and ground water there was an overexploitation of enormous dimension. This had already led to a severe damage in the riparian forests, the more or less only 'green nature' in the Tarim Basin, and also agriculture and settlements were suffering by the non-sustainable use of water.

Sustainable development is a principle including the preservation of finite resources and by analyzing all components of sustainability in the Tarim Basin – ecological, societal as well as economical – the scientific consortium consisting from leading Chinese and German scientists was formed to make suggestions for the remediation of the non-sustainable situation. The suggestions should comprise a desirable future state for human societies in which living conditions and the use of resources will meet integrity, stability and beauty of natural systems.

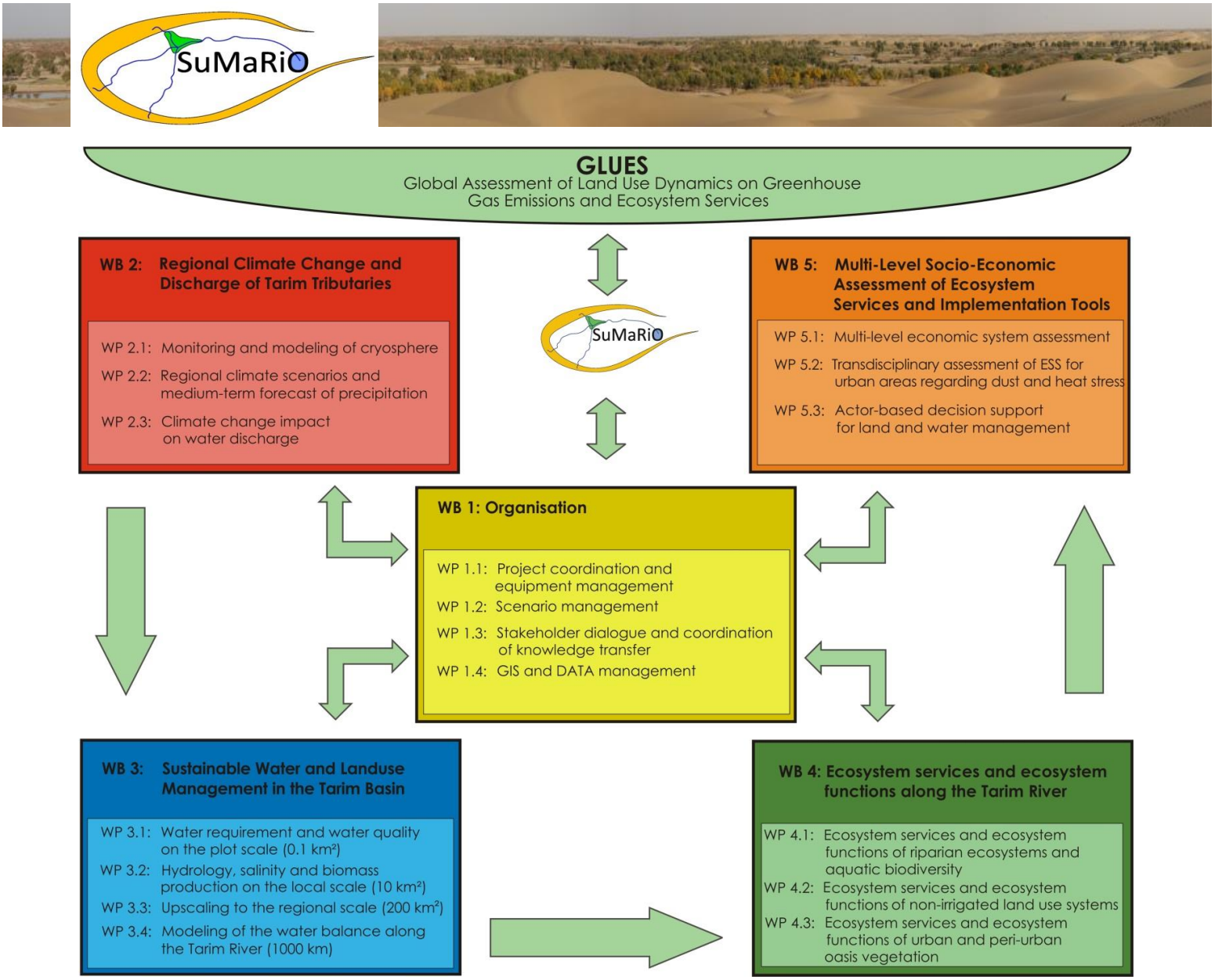


Figure 3: *SuMaRiO project structure*

This question is dealt with in the **SuMaRiO project** subdivided in work blocks being each of them pieces of a puzzle (see figure 3 and figure 4).

The SuMaRiO project was designed to

- identify existing structures of sustainable management as well as the natural and societal basis for sustainable development in the fields of ecology, sociology and economy;
- assess the possibilities of sustainable development in the river oasis and along the Tarim River;
- develop recommendations for sustainable development including structure for a respective management under consideration of the carrying capacity of the region.

SuMaRiO Project Highlights

- Four **climate change** scenarios were simulated for three headwater catchments and the lowland (oases) part. Both temperature and precipitation are increasing for all scenarios and periods.
- A precise **glacier** inventory for the entire Hotan and Yarkant catchments for the period 2010 was generated.
- The **discharge** from the **Tarim tributaries** Hotan, Yarkant and Aksu Rivers were modeled. There is an increase in discharge of the Aksu River in the near future (2030s) and a discharge decrease in the far future (2050s).

- There is a negative impact on plant growth during the early stages of plant development under **drip irrigation under plastic mulch** with drip lines for four plants. Irrigation with a drip line for two plant rows shows a better wetting of the root zone.
- Results from a hydraulic model show that **the source of irrigation water** is the decisive aspect for the process of salinization and soil degradation.
- The **groundwater recharge** volume is directly linked to the intensity of the yearly floods of the Tarim River.
- The **reduction of farmland area** in the upper reaches will significantly benefit middle and lower reaches for water availability. Increasing the farmland area in the lower reaches will enhance water deficit and should be avoided. With a reduction of total available water in the soil to 40%, the cotton yield decreased by 6% compared to the yields of a total available soil water of 70%.
- The set-up of a groundwater model leads to the recommendation to preserve the current practice of groundwater recharge through the natural flooding of the Tarim floodplain for the purpose of the **revitalization of the Tugai forests**.
- The decrease in **groundwater level** can result in a distinct decrease in productivity of Euphrates Poplar (Populus euphratica) trees not only at sites with large distances to the groundwater, but also at sites that are relatively close to the groundwater.
- Because of rising labor prices and other production costs, **cotton** is expected to be the least profitable crop in the years to come.
- Locally adapted, typical **indigenous species** should be given the priority in urban greening.
- For successful implementation of volumetric water pricing and subsidization, an improved **cooperation of water authorities** (water pricing policy) and agricultural authorities (subsidies) is required.
- An **integrated approach**, which combines mechanisms for controlling water use with technical consulting, enhancement of environmental awareness and subsidized water saving irrigation technologies, is preferable instead of focusing only on regulations.
- The **SuMaRiO decision support system (DSS)** is designed to support stakeholders to assess possible consequences of their actions in the Tarim River Basin.

SuMaRiO project findings

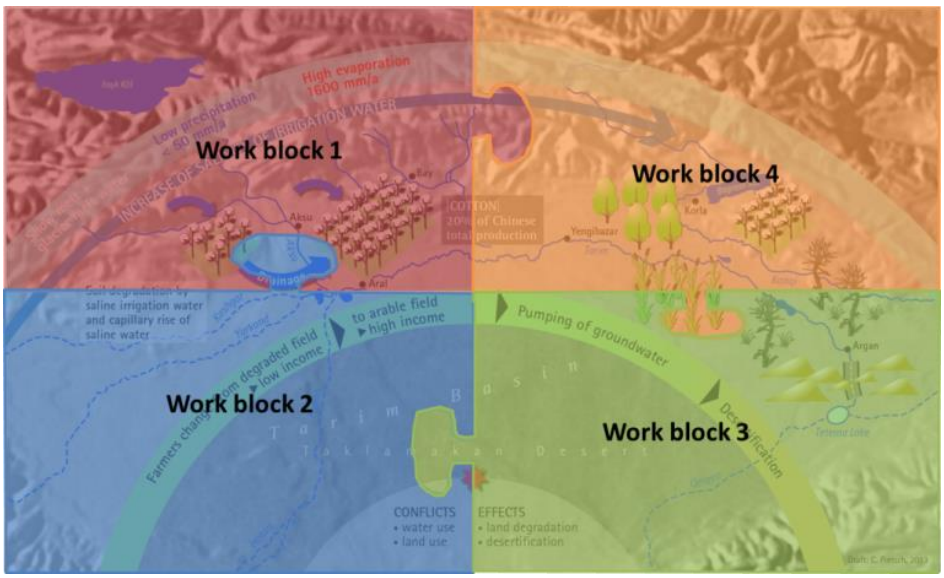


Figure 4: *The pieces of the puzzle of the SuMaRiO project dealing with the issues in the region*

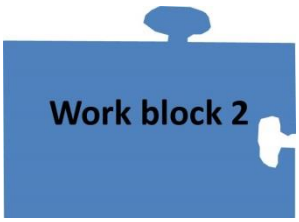
Work block 1 is dealing with the regional climate (change) prediction, the cryosphere and the modeling of the tributaries of the Tarim River. This work block delivers the data of the future regional climate scenarios, the mass and volumes of the glaciers and snow cover in the surrounding mountains (the volume of frozen water) and the volumes of the discharges of the tributaries to the Tarim River, Aksu River, Yarkant River and Hotan River.

The **climate change** signals for COSMO-ClimateLimited-areaModelling (CCLM) and Regional Model (REMO) were analyzed separately for three headwater catchments and the lowland (oases) part. Four climate scenarios from the regional climate models CCLM (IPCC AR5 RCP 2.6, 4.5 and 8.5) and REMO (IPCC SRES A1B) were analyzed and applied for impact assessment. Both temperature and precipitation are increasing for all scenarios and periods. While the temperature increase is uniform over all areas (from 1–4°C), the precipitation increase is more pronounced in the Hotan and Yarkant catchments of 10-50% in contrast to up to 10% in the Aksu headwaters.

A precise **glacier** inventory for the entire Hotan and Yarkant catchments for the period 2010 was generated based on Landsat scenes (mapped glacier area: 12,300 km²); the inventory for the entire Aksu catchment for the period of 1975 based on Hexagon and Landsat MSS data was finalized (mapped glacier area: 4,100 km²) in addition to the one of 2010. The overall mapped glacier area is 14% of the glacier cover of entire High Mountains in Asia. Glacier ice thickness and volume were calculated for entire Aksu, Hotan, and Yarkant catchments. The glacierized area of the entire catchment changed from 6607 km² in 1975 to 6,362 km² in 2008. Hence, 3.7% of the ice-covered area was lost. The volume changes could be assessed for an ice covered area of about 5,000 km². The results revealed a mass loss of -0.35±0.34 m water equivalent/year.

Using data on the observed glacier areas and modelled glacier thickness as input for the hydrological model Soil and Water Integrated Model (SWIM) to **model the discharge caused by glacier melt**. The model was calibrated and validated to match the observed catchment-wide glacier area and thickness distribution with elevation (hypsometry) along with the measured river discharge. The flow changes were attributed to increases in temperature (and related glacier melt) and precipitation. First results indicate a further discharge increase of the Aksu River in the near future (2030s), and a discharge decrease in the far future (2050s). The discharge increase in the near future is probably due to increases in precipitation and increases in glacier melt due to higher temperatures, which compensate decreasing glacier melt due to decreasing glacier areas. In contrast, in the far future, the effect of decreasing glacier melt caused by decreasing glacier areas dominates. In the Hotan and Yarkant river basins, the available water for irrigation is highly restricted by the water resources coming from the mountainous areas. As a result, there is a significant correlation between the headwater inflow amount and the abstraction amount in the oases of these two basins. This indicates that people in these two river basins simply abstract as much water as available in the river, without optimal planning. In the Aksu basin, such relationship between the inflow and the abstraction could not be found in the period 1984 - 2004, as water was not the limiting factor for agricultural development during this period. Under both scenario conditions, the discharge in the downstream Aksu River increases in the near future (approx. until the year 2030), then drops down approaching the current conditions in the middle future (approx. until the year 2070), and then decreases further to lower level than in the current conditions in the far future (approx. until the year 2100).

Such changes indicate that water shortage may become a serious problem in the Aksu oasis by the end of 21st century, when the glaciers in the mountains would retreat under higher temperature.



Work block 2 is assessing the water demand, water quality and the biomass production on different scales of the Tarim River Basin. **On the field scale** this work block delivers the data of the water demand of cotton plants contributing to both the basic data for small-scale modeling, and also provides practical relevance results for cotton production under irrigation. **On a farm scale** the influence of different irrigation water sources, groundwater or river water, on the salt fluxes was simulated with a hydraulic model (MIKE SHE). The Environment Policy Impact Calculator Model (EPIC) is used for simulating the agricultural potentials of biomass production in the relation to soil salinity, management and to the water demand of cotton. **On the regional scale** the MIKE SHE model is used for the modeling of the groundwater recharge. Furthermore, Leaf Area Index (LAI) measurements, a SOil and TERrain (SOTER) digital database to model cotton yields with EPIC, soil and land use maps are used to regionalize the collected data. **On the river scale** the water allocation and water saving scenarios for the region is simulated with the water management model MIKE HYDRO and is, besides the groundwater model (MODFLOW), one basis of the Decision Support System (DSS).

On the field scale drip lines for four plant rows emitters with high flow were selected, it is clearly shown that the topsoil in the zone of plant roots strongly dries out partly; while the soil moisture in the upper 30 cm remains generally low. This has a negative impact on plant growth during the early stages of plant development. In contrast, irrigation with a drip line for two plant rows shows a better wetting of the root zone when a dripper with a lower discharge flow is used (1.8 L/h). In this irrigation system the upper 30 cm, in which most roots are found, is best supplied with water. The salinity increases significantly in the soil during the irrigation. As a very low rate of evaporation is achieved through the plastic covers over the drip lines, it may be assumed that the salinity is promoted primarily by the low water quality. The salinization problem is the reason for the common practice of leaching before sowing. In this case, a large amount of water is used to dissolve the salts present in the soil and to transport it under the root zone. This method does help to reduce salinization; however this also requires large amounts of water. At the regional level, this practice leads to more evaporation and a balance of more salt brought into the water body. At a small scale, it is observed that water does not infiltrate evenly on the field. Thus, puddles are formed, which dry out more slowly and produce a locally higher salt content. This effect can lead to yield losses.

On a farm scale it could be shown that the ecological flooding has a flushing effect of salt to the region. The ecological flooding is a water diversion measure to artificially ensure the water supply for the riparian forests along the diked Tarim River via locks. Model results from the hydraulic model (MIKE SHE) show that the salt in the fields irrigated with river water is transported to deeper soil layers. Fields irrigated with pumped groundwater show an increase of accumulations of salts in the fields. An increasing gradient of salt concentration from fields irrigated with river water to fields irrigated with groundwater is modeled. The added river water is leading to a flow away from fields. The pumping process attracts the water and the salt loads so that pumped groundwater has a higher salinity than river water. Salt is accumulating on the fields due to evapotranspiration and the lack of a drainage system, especially on the fields irrigated with groundwater. Accordingly, the source of irrigation water is the decisive aspect for the process of salinization and soil degradation. For the analyses of the soil salinity and its effect on the cotton yield, the soil water balance was measured with specific equipment and soil samples were taken. Several soil profiles

were studied and the results are displayed in a soil map. These soil data were the input for the SOTER database and the EPIC model, which is used for modeling of agricultural potentials of biomass production in the relation to soil salinity, management and to the water demand of cotton. The simulation results show that the cotton yield is decreasing with the increase of soil salinity. On high saline soils no cotton can be grown. The best field management for agricultural sustainability should be bound to different soil types and salinity, find the best irrigation and fertilization amount for different salinity levels and inform the local farmers to use reduced amounts of fertilizers and water.

On the regional scale the water balance could be computed for the region of Yingbazar. In the area the mean annual volume of groundwater recharge is about 12 Mio. m^3 of water. This corresponds to a rate of 4.5 $l/(s*km^2)$ or in other terms 139 mm/year. Considering the study region of Yingbazar, a proportion of four fifths of the total recharge is originating in these areas of flooding. Hence, the recharge volume is directly linked to the intensity of the yearly floods. A SOTER digital database is set up for the Aksu-Alar and for the Yingbazar region. This digital database forms the input and output data of the EPIC model for estimating the various land use scenarios along the Tarim River. The scenarios show a total decrease in cotton yield for the whole area by 11% under the conditions of scenario I - increase of temperature by +2°C - and 27% under the conditions of scenario II - reduction of irrigation water by 40% - compared to the estimated cotton yield under current conditions. In both scenarios the soil salinity was the main limiting factor.

On the river scale water allocation along the whole Tarim River is simulated with the water management model MIKE HYDRO. Three scenarios for the water allocation were developed: (i) Agricultural land use reduction scenario in the upper and middle reaches of the Tarim River, (ii) Agricultural land use increase scenario in the lower reaches of the Tarim River, (iii) crop type change scenario is considered for the purpose of using less irrigation water by substituting cotton with Apocynum.

The reduction of farmland area in the upper reaches will significantly benefit middle and lower reaches for water availability. Increasing the farmland area in the lower reaches will enhance water deficit and should be avoided. The scenarios show that substitution of Apocynum with cotton is a good method to reduce water stress in the Tarim River Basin. Additionally, the MIKE HYDRO model was used to simulate the effects of a reduction of the total available water in the soil as a target for the irrigation water amount. With a reduction of total available water in the soil to 40%, the cotton yield decreased by 6% compared to the yields of a total available soil water of 70%. Whereas the yields of tomato or melon decreased by 50% reducing the total available water in the soil from 70% to 40%. In the study area, the implementation of the water-saving irrigation method “drip irrigation under plastic mulch” is developing fast. This technology is mainly applied in the cotton fields in which the ground surface is covered by approximately 80% with transparent polyethylene film as mulch. Along the Tarim River five scenarios with different percentages of application of that irrigation method (10%, 30%, 50% and 100% of the agricultural area) was simulated. Spray loss and wetting fraction dropped down to 10% when drip irrigation under plastic mulch was applied instead of sprinkler irrigation, it did not matter if the application area was 10%, 30%, 50% or 100%. This result represents the advantage of this technology to save irrigation water. The simulation results for the year 2006

showed that the water saving potential reaches up to 25% and 40% with drip irrigation under plastic mulch at levels of 50% and 100% application rate in the whole region (along the Tarim River), respectively.

Work block 3

Work block 3 is dedicated to Ecosystem Functions (ESF) and Ecosystem Services (ESS). Special focus is on the riparian ecosystems (Tugai), but also the Tarim ecosystem, non-irrigated land-use systems, and groundwater are observed as well as oasis vegetation.

An **ecosystem analysis** of the riparian forests is done by satellite imagery and regional water balance models deliver the state of the groundwater body and groundwater salinity. Important knowledge is gained on productivity, water use and dynamics of riparian forests as well as on protective functions and sustainable use of riparian forests. Also the fish diversity and macro invertebrates of the Tarim ecosystem are examined. Very new are investigations on the water balance of extensive land use systems which are non-irrigated and dependent on the ground. Along with this, knowledge is gained on ecology, productivity, and ecosystem services of Apocynum pictum (Kendir). All this is done in the riparian areas, but work block 3 also examines the ESS and ESF of the oasis vegetation in the urban and peri-urban vicinity. In the following, selected results are presented.

Two very high resolution satellite images, Quick Bird of 2005 and WorldView2 of 2011, have been used to quantify tree crown diameter changes in a degraded riparian Tugai forest. Our results suggest a positive tree crown growth. The object based image analysis method proved to be applicable in sparse riparian Tugai forests and showed great suitability to evaluate ecological restoration efforts in an endangered ecosystem.

To understand the annual fluctuations of the groundwater a groundwater model has been set up. This model leads to the recommendation to preserve the current practice of groundwater recharge through the natural flooding of the Tarim floodplain for the purpose of the revitalization of the Tugai forests. It may be reasonable to limit the amount of the annual discharge at around 200,000,000 cubic meters of water.

In the middle reaches of the Tarim River, at the Xayar and Yingbazar study sites, the influence of growth behavior of pollarded **Euphrates Poplar (Populus euphratica)** trees and the influence of the groundwater level on tree growth is assessed. At the Xayar study site, a detailed analysis of stem increment data confirmed the finding of a significantly larger growth increment of the not pollarded Euphrates Poplars compared to their congeners that are subjected to intermediate or severe use. The pollarded trees produce a larger number of secondary shoots. Obviously, this is a response to the higher pollarding intensity. At the Yingbazar study site, relationships can be established between the annual amounts of river run-off and the radial stem increment of the Euphrates Poplars. On the plot with the lowest distance to the groundwater (about 2 m), the tree-ring widths are significantly and positively correlated with the run-off of the preceding year. No such relationship was found on the plots with larger distances to the groundwater (up to 12 m). During the past five decades, the poplars growing on the plot with a low groundwater distance have had a larger increase in the stem diameter than their congeners at plots with larger groundwater distances. A tentative conclusion from these results can be that the decrease in groundwater level can result in a distinct decrease in productivity not only at sites with large distances to the groundwater, but also at sites that are relatively close to the groundwater.

The **riparian vegetation** at the lower reaches of Tarim River provides various ESS. Specifically two ESS were examined:

- the protection of Highway N 218 from sand drift and
- the carbon storage within the Tugai vegetation, especially in poplar trees.

Results show that 81 km of the examined 141 km road section are protected from sand drift by natural vegetation. Authorities would have to spend 972,000 Yuan /year to create this protection artificially by reed checkboards. The value of the stored carbon in the poplar trees sums up to 109,650,000 Yuan/year by avoiding costs for climate change adaptation and damage control. Furthermore, results indicate that these values could easily be increased by higher water releases down the lower reaches of Tarim River for ecological reasons.

Apocynum pictum (Kendir) is compared with *Ziziphus jujuba* (Hongzao/Chinese Red Date) and *Gossypium hirsutum* (cotton) to find out whether it is possible to partly substitute the water demanding cotton production in Xinjiang. The above ground biomass of Kendir is relatively moderate when compared to other steppe and desert plants. Among the three plants tested in this study, Kendir required the least amount of water during the vegetation season of about 220 mm a year while the Hongzao came close second requiring about 340 mm. Cotton was least water-efficient cash crop using about 520 mm, thus demonstrating the viability of Kendir as an alternative with significant water-saving potential. As far as economic issues are concerned, Kendir farming can effectively deal with issues inherent to open access and may prevent the depletion of the resource in the wild. It is the most systematic and sustainable way to utilize Kendir as a natural resource. In this study, Kendir regenerated the highest profit with about 3,276 Yuan/ha compared with Hongzao with ca. 1,275 Yuan/ha and Cotton with roughly 825 Yuan/ha. Cotton is the least profitable of all major cash crops and fruits compared in the study.

Because of rising labor prices and other production costs, cotton is expected to be the least **profitable crop** in the years to come. The government subsidies in Xinjiang to help farmers to grow cotton are not sustainable in terms of market demand and thus cannot be a long-term strategy. Hongzao is one of the most popular fruit trees and has been replacing croplands in the Tarim Basin in recent years. Although Hongzao is a leading alternative to cotton for the moment, Kendir could also be a strong alternative with its low cost and high profitability if sufficient government support is granted. High quality fibers extracted from Kendir could also become valuable textile material for its hygienic features. Besides, Hongzao prices are in decline because of oversupply, costs are rising as labor prices increase, and diversifying the region's agricultural sector is the key to a long-term sustainable development.

Urban greening delivers ESS like dust storm prevention and a cooling climate effect in and outside of cities. In terms of plant species selection, most of the tree and flower species along the roads and on productive green spaces are imported from Eastern China. The total number of alien species is higher than the number of local species. Thus, the urban landscape does not fully reflect the local characteristics and cultural background. Management and maintenance of current urban tree species is not appropriate, trees in different parts of cities are infested with parasites and infected with diseases. Therefore, locally adapted, typical indigenous species should be given the priority in urban greening. Furthermore, urban greening mostly relies on irrigation and exacerbates the problem of water shortage. Water for urban greening of Aksu mainly comes from groundwater and tap water. For the irrigation of urban green space, water saving methods like drip irrigation will be predominantly used and irrigation quota will be controlled at below 6,750 m^3/ha*year. However, poor artificial irrigation facilities cannot fully meet the requirements for water-saving irrigation. Thus, in order to ease the irrigation problems in urban greening, on one

hand, irrigation infrastructure should be improved and the management of urban green space water supply should be strengthened. On the other hand, drought-resistant, deep-rooted tree species should primarily be considered in the selection of urban tree species.

Work block 4 is assessing socio-economic ESS and is the work block in which the DSS is being programmed. This work block delivers the data for water pricing, the cost-benefit analysis of drip irrigation in cotton production. For alternative plants, like Apocynum, their utilization potential as alternative land use was analyzed. Bayesian networks, created together with various stakeholders, helped to analyze the suitable plant species for to prevent dust weather.

Based on the analyses of three **water policy instruments** (tax, water quota, water pricing) on aggregated marginal cost curves for the conservation of water, volumetric water pricing turned out to be more efficient than a water quota. Subsidized drip irrigation and wheat production can lead to water conservation without significantly reduce of farmers' income from wheat and cotton production. For successful implementation of volumetric water pricing and subsidization, an improved cooperation of water authorities (water pricing policy) and agricultural authorities (subsidies) is required.

For the estimation of the benefit of a more sustainable oasis management in the Tarim Basin for the Chinese society, the determination of the water prices for optimizing water allocation and socio-economic analysis of agricultural production systems was carried out.

Income alternatives aside from agriculture and a shift to a more productive **agricultural production** with a) increased yields, b) the shift to more labor intensive high value crops are necessary to ensure sustainable land and water use in the Tarim basin. An increase in farm production with lower yields is necessary with regard to an area-wide change from flood to drip irrigation in order to improve water use efficiency. The change to drip irrigation should however be implemented within the framework of an integrated approach that aims at optimizing crop production. The integrated approach, which combines mechanisms for controlling water use with technical consulting, enhancement of environmental awareness and subsidized water saving irrigation technologies, is preferable instead of focusing only on regulations.

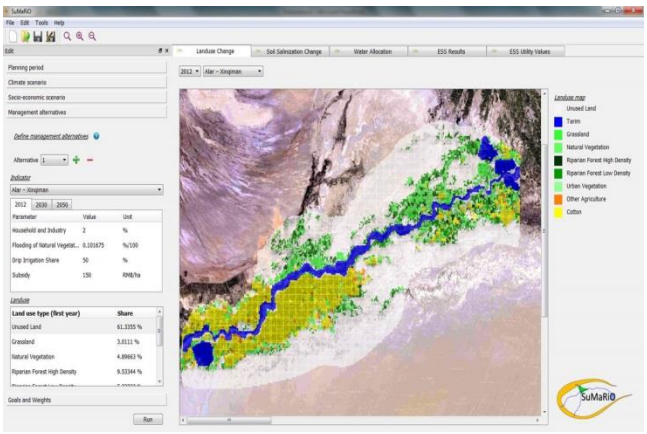
The results of the **contingent valuation** of a more sustainable oasis management in the Tarim basin show that not only local households would benefit from a more sustainable water and land management in the Tarim Basin, but people living far away from the project site would also appreciate such a policy change. It is recommended that local policy makers should take into account the 'long-distance' benefit (or costs) of their decisions.

The use of **Bayesian Networks** (BN) gave a broad overview of the complex management of preventing dust weather. The final Bayesian Network shows which plant species are especially suitable to prevent dust weather and provide shade with little irrigation needs. This information is highly relevant to local vegetation planers. The Bayesian Networks were created together with several stakeholders during stakeholder dialogues and workshops. The stakeholder evaluated the applicability of BN as a benefit for their local vegetation planning and improved their system understanding. The results of the BN will complement the results of the SuMaRiO decision support system. In our transdisciplinary research process, BN model functions were acting as a communication and learning tool.

The **decision support system (DSS)** is an indicator-based tool designed to support stakeholders and to train Chinese students to assess possible consequences of their actions. Under climatic scenarios assumptions for 2013, 2030 and 2050, the consequent inflow into the Tarim and socio-economic scenario assumptions, impacts of planned possible management measures will be calculated in a quantitative and semi-quantitative way and will be evaluated with the help of sustainable ecosystem services indicators. All indicators have been elaborated in SuMaRiO Workshops and stakeholder dialogues.

In the DSS four different kinds of indicators are distinguished:

Input indicators	Output indicators
Climate indicators Socio-economic indicators Management indicators	ESS indicators



On the basis of the climate scenarios the potential inflows from the tributaries into the Tarim were calculated with the models WASA and SWIM. Then the user can choose between eight possible inflows to the Tarim River, depending on the four climate scenarios. The inflow into the Tarim represents the basis for the calculations in the DSS. The possible development of socio-economic indicators can be entered for the planning years. As default values developments in prices for the years 2013, 2030 and 2050 are set, which have been analyzed in SuMaRiO. In the next step of the input section up to ten management measures for the Tarim River Basin can be planned (e.g. 5-year plan management measures, measures recommended by SuMaRiO) and adjusted directly on the integrated grid based land use map. Each cell can be changed to any kind of land use, e.g. cotton production, forest, waste land etc. In a final step of the input section objectives and weights can be entered by the user. For this purpose, the DSS provides a list of the ESS indicators for each sub-region on which the evaluation of the management measures is based.

For each management measure the impact on the ESS indicators for each year between the 1st and 3rd planning year are calculated with the help of multivariate functions or fuzzy logic and are illustrated in the output section in tabular form, graphically and with the help of maps. Based on these results and the objectives assigned to the ESS indicators by the user, an achievement level respectively an utility value between 0 and 1 is calculated, indicating to what extent the objectives have been achieved with the respective measure.

SuMaRiO

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