



Zentrum für Entwicklungsforschung  
Center for Development Research  
University of Bonn

# ZEF-Discussion Papers on Development Policy No. 177

Maksud Bekchanov, Anik Bhaduri and Claudia Ringler

## **How market-based water allocation can improve water use efficiency in the Aral Sea basin?**

Bonn, May 2013

The **CENTER FOR DEVELOPMENT RESEARCH (ZEF)** was established in 1995 as an international, interdisciplinary research institute at the University of Bonn. Research and teaching at ZEF addresses political, economic and ecological development problems. ZEF closely cooperates with national and international partners in research and development organizations. For information, see: [www.zef.de](http://www.zef.de).

---

**ZEF – Discussion Papers on Development Policy** are intended to stimulate discussion among researchers, practitioners and policy makers on current and emerging development issues. Each paper has been exposed to an internal discussion within the Center for Development Research (ZEF) and an external review. The papers mostly reflect work in progress. The Editorial Committee of the ZEF – DISCUSSION PAPERS ON DEVELOPMENT POLICY include Joachim von Braun (Chair), Solvey Gerke, and Manfred Denich. Tobias Wünscher is Managing Editor of the series.

**Maksud Bekchanov, Anik Bhaduri and Claudia Ringler, How market-based water allocation can improve water use efficiency in the Aral Sea basin?, ZEF- Discussion Papers on Development Policy No. 177, Center for Development Research, Bonn, May 2013, pp. 22.**

**ISSN: 1436-9931**

**Published by:**

Zentrum für Entwicklungsforschung (ZEF)

Center for Development Research

Walter-Flex-Straße 3

D – 53113 Bonn

Germany

Phone: +49-228-73-1861

Fax: +49-228-73-1869

E-Mail: [zef@uni-bonn.de](mailto:zef@uni-bonn.de)

[www.zef.de](http://www.zef.de)

**The authors:**

**Maksud Bekchanov**, Center for Development Research (ZEF), University of Bonn. Contact: [maksud@uni-bonn.de](mailto:maksud@uni-bonn.de)

**Anik Bhaduri**, GWSP, Center for Development Research (ZEF). Contact: [abhaduri@uni-bonn.de](mailto:abhaduri@uni-bonn.de)

**Claudia Ringler**, International Food and Policy Research Institute (IFPRI). Contact: [c.ringler@cgiar.org](mailto:c.ringler@cgiar.org)

## **Acknowledgments**

The study is prepared on the basis of PhD study supported by the IPSWaT (International Postgraduate Studies in Water Technologies) program of BMBF (German Ministry of Education and Research). The authors thank for Prof. Dr. Joachim von Braun (ZEF, Bonn University) and Dr. Arnim Kuhn (ILR, Bonn University) for constructive comments to improve the paper.

## **ABSTRACT**

Increasing water demand due to population growth, irrigation expansion, industrial development, and the need for ecosystem improvements under mounting investment costs for developing new water sources calls for the efficient, equitable and sustainable management of water resources. This is particularly essential in the Aral Sea Basin (ASB) where ineffective institutions are the primary reason of intersectoral and inter-state water sharing conflicts and lack of sufficient investments for improving water use efficiency. This study examined market-based water allocation as an alternative option to the traditional administrative allocation to deal with water scarcity issues in the ASB. Potential economic gains of tradable water use rights were analyzed based on a newly constructed integrated hydro-economic river basin management model. The analysis differentiates between inter-catchment and intra-catchment water trading. The former does not consider any restrictions on water trading whereas the latter is based on the assumption that water trading is more likely to happen between neighboring water users located within the same catchment area. The analyses show that compared to fixed water allocation, inter-catchment water trading can improve basin-wide benefits by US\$ 373 and US\$ 476 million depending on water availability. Similarly, additional gains of US\$ 259 to US\$ 339 million are estimated under intra-catchment water trading depending on relative water availability. Trading gains are higher under drier conditions. However, water trading carries a series of transaction costs. We find that transaction costs exceeding US\$0.05 per m<sup>3</sup> of water traded wipe out the economic potential for water trading. Enforcement of the rule of law, infrastructural improvements, participation of representatives of all water stakeholders in decision making processes, and friendly relationships among the riparian countries are suggested as means for reducing transaction costs of water trading contracts.

**Keywords:** inter-catchment and intra-catchment water trading, transaction costs, hydro-economic model

## 1 Introduction

The scarcity of water resources in arid and semi-arid regions of the world adds pressure to water needs for direct human consumption, irrigation, industrial processes and environmental systems. Currently more than 20% of the global population lives under water shortage conditions and this share is expected to reach 33% by 2025 (UN WATER 2007). This challenges governments to undertake measures to prevent or lessen potential adverse consequences of water shortages both at national and global levels. Secure water availability for food production, drinking needs, and the environment are essential for achieving the Millennium Development Goals (UN 2000) to decrease malnutrition, to eradicate poverty, to improve sanitary conditions, and to ensure environmental sustainability (von Braun et al. 2003, 2009:23).

Since measures of increasing water supply through the construction of dams, reservoirs, and pumping stations and exploitation of groundwater sources have reached limits in many river basins of the world, water demand management measures such as creating economic incentives for wider implementation of water conservation technologies, transforming economies toward less water intensive production structures, and improving water management institutions and governance have often become the more or even only viable options to deal with water availability issues (Harou et al. 2009). As irrigated agriculture accounts for 70% of global water withdrawals (WRI 2005) and irrigation efficiency is estimated to be less than 40% at a global level (Pimental et al. 1997), the sector has a huge potential for reducing water use.

This study illustrates the case of the Aral Sea Basin (ASB), a dryland area where water is a critical resource for sustainable development. The tremendous expansion of irrigation and cotton production since the 1960s combined with unbalanced water resources management in the ASB led to the destruction of the ecosystems in the delta zone and the gradual desiccation of the Aral Sea, once the fourth largest lake of the world with a surface area of 68,000 km<sup>2</sup> and a total water volume of 1,100 km<sup>3</sup> (Micklin 2007). The shrinkage of the Sea has been acknowledged as one of the worst manmade disasters in the world (UN 2010).

Tensions among up- and downstream users over sharing water resources and over water release regimes of the reservoirs increased after the emergence of five independent Central Asian states following the collapse of the Soviet Union in 1990s (Dukhovny and de Shutter 2011) fuelling inefficient use of water resources. Inefficient water governance and institutions have been the main reasons of insufficient investments in irrigation infrastructure, lack of economic incentives to adopt water-saving approaches, and consequent reduction of water use efficiency in the post-Soviet period. In particular, command-and-control based approaches for water management, inherited from the Soviet system, lingered preventing empowerment of individual water users and local governments to deal with water scarcity issues (Weinthal 2002). Despite the availability of many options to cope with water scarcity in the ASB, which includes not only irrigation technology adoption at field level but also water transfers from neighboring river basins, which could help restore the Sea, inadequate financial capability of the Central Asian states became a key concern for the top-down based (administrative) realization of these projects. Bottom-up approaches, such as adoption of efficient water use technologies by irrigators and cropping less water intensive crops, did not take place because of a lack of

appropriate incentives under the control-and-command management based system as well as inadequate awareness of water users regarding ecosystem values. Each of the Central Asian countries is trying to unilaterally maximize use of common basin water resources while neglecting the interests of the neighboring countries as evidenced by the national perspective plans which include plans for increased irrigation water use by each of the basin states (Dukhovny and de Shutter 2011). Furthermore, interstate agreements on water sharing in the ASB have often been disregarded by the riparian countries, which in turn increased vulnerability of downstream regions and fragile ecosystems to the reduced natural river runoffs (Dukhovny and de Shutter 2011). Considering the interdependence of all users within a single basin, integrated approaches of basin management which considers efficient, equitable, and sustainable use of water resources for the entire basin (Ringler et al 2004) is required to effectively deal with water scarcity issues in the ASB.

Several water allocation approaches were examined to deal with water issues of the ASB. Previous studies (e.g. McKinney and Karimov 1997) aimed, for instance, to minimize the gap between the actual and required water demands by different water users in the basin. Revenue or benefit maximization approaches under the assumption of fixed revenues or benefits and water uses per hectare addressed economic revenues for the entire basin (e.g. Karimov 1997) differing from the previous approach that focused on equitable distribution of the water scarcity burden. An improved benefit maximization approach incorporated the relationships between water uses and benefits (Cai et al. 2002, 2003a, 2003b) into the integrate hydro-economic model rather than assuming fixed water use and revenues per hectare. The latter approach proposes the maximum level of benefits for the entire basin due to the transfer of water from its lower to higher uses. However, the question on why the farmer with lower marginal water use benefit should agree to transfer part of his or her water use right to more productive water users for attaining optimal benefits for the entire basin remained unanswered since optimal basinwide benefit means partial loss of individual benefit to the low productive user due to a reduced water use, unless compensatory mechanisms are officially established. Providing sufficient compensations for the low productive users for its reduced water use and thus creating incentives for this user to cooperate for achieving optimal basinwide benefit can be enhanced by implementation of market-based water allocation mechanism. Market-based water allocation is a proven tool for efficient and equitable allocation of river basin resources not only through promoting water reallocation from its lower to higher use and but also through incentivizing users to reduce water overuse and invest in efficient technologies if market prices are high enough (Dinar et al. 1997). Trading can increase welfare and water productivity for the entire basin because water is generally transferred from lower-valued to higher-valued uses (Howe et al. 1986, Rosegrant and Binswanger 1994, Easter et al. 1998, Ringler 2001). Despite its advantages over administrative based water allocation the potential role of market-based water allocation for water use efficiency improvements in the ASB has not been studied yet. This study aims to assess its scope to cope with growing water scarcity in the basin.

## **2 Study area description**

Most of the area of the ASB coincides with Central Asia and the territory of the ASB is chiefly shared by five Central Asian states – Kyrgyzstan, Kazakhstan, Uzbekistan, Tajikistan and Turkmenistan – and partly by North Afghanistan and Iran. Amu Darya and Syr Darya are the two

main rivers in the basin, and are also lifelines of the irrigated agriculture and thus of the economies in the ASB. Both rivers emerge in the Pamir and Tien Shan mountains and flow to the west crossing numerous valleys as well as the Kyzylkum and Karakum deserts and end in the Aral Sea.

Owing to the isolated location of Central Asia within the Eurasian continent and its remoteness from the world oceans the ASB has a distinct continental climate (UNEP 2005). Seasonal and daily temperatures in the basin are highly variable, with high solar radiation and relatively low humidity. The basin is characterized by an average temperature in July of 26°C in the north and 30°C in the south, with a maximum temperature of 50°C. In January, average temperature varies between 0°C in the south and -8°C in the north with a minimum of -38°C (SANIIRI 2004). Annual precipitation is 1,500-2,500 mm at the glacial belt of Tien Shan and Pamir in the eastern parts of the basin, 500-600 mm at the foothills, and 80-200 mm in the lowlands in the west (UNEP 2005:20). Annual precipitation is less than 200 mm in about 40% of the Central Asian territory, 200-300 mm in 30%, and 300-400 mm in almost 20% of the territory (de Pauw 2007). Precipitation mainly occurs during winter and spring, non-growing season. A rate of evapotranspiration greater than average precipitation during the summer in most parts of the basin requires irrigation for crop cultivation. Although rainfed areas are important at the global level, occupying 80% of crop lands and contributing to 60-70% of the global food basket (Falkenmark and Rockström 2004:67), the shares of “green water use”, e.g. direct use of precipitation by main crops cultivated in the region, e.g. cotton and rice, are less than 7% in Tajikistan, less than 4% in Turkmenistan, and less than 6% in Uzbekistan (Aldaya et al 2010).

Favorable climate and availability of water resources led to the emergence of irrigated agriculture and rural settlements along the rivers over the centuries (Dukhovny and Schutter 2011). Even at present, the majority of the more than 45 million people living in the ASB relies on incomes from agricultural activities (SIC-ICWC 2012). Intensive expansion and excessive diversion of river waters to irrigation needs were observed particularly in the last century due to the cotton self-sufficiency policy in the Soviet Union. Irrigation expansion mainly took place in either mid- or down-stream river reaches with more fertile lands. As a consequence, the area of the irrigated lands increased from 4.8 to 7.5 million ha between 1960 and 2000 (Cai 2003b).

Planners and decision makers neglected environmental consequences of the irrigation expansion plan (Ashirbekov and Zonn 2003) considering any flow to the Aral Sea as water wasted. Under this policy, the river flows to the Aral Sea decreased or were not delivered at all in some water scarce years. As a consequence, the sea shrunk to one tenth of its volume and one fourth of its original surface area between 1960 and 2006 (Micklin 2007). In parallel to the Aral Sea desiccation, fish production and ship navigation ceased in the sea. The wetland areas in the deltaic zone decreased from 550,000 ha to less than 30,000 ha (TEEB 2011). In addition to these benefit losses, spread of toxic salts and dust from the dried bed of the Sea through winds reduced crop and livestock yields damaging soil productivity and led to significant adverse health impacts in the population (INTAS 2004).

In the aftermath of the independencies, the emergence of five independent Central Asian states with contradictory interests led to interstate conflicts over sharing water resources and regulatory water infrastructure (Dukhovny and Shuetter 2011). The conflicts arose as water resources are distributed unevenly and cannot meet present nor future demands in the basin. Despite limited lands and water resources available for irrigation all countries except Kazakhstan also have ambitious plans of extending their irrigated lands. Furthermore, water-

rich but resource-poor Kyrgyzstan and Tajikistan also store water in reservoirs in the summer time to release it to generate hydro-electricity to meet winter energy demands for heating. However, water-dependent but resource-rich countries Uzbekistan, Kazakhstan, and Turkmenistan face peak water demands for irrigation during the summer period. Consequently, in the downstream areas, flooding is frequent in the winter season alleviating irrigated lands and damaging irrigation infrastructure while less water is available for irrigation during summer season (Dukhovny and Schutter 2011).

Water allocation among different irrigation zones within the countries are conducted on the basis of a command-and-control system (Weinthal 2002). Equal distribution of water scarcity burdens among the irrigation zones are considered in water allocation plans (Dukhovny and Schutter 2011:272-273). However, upstream regions take advantage of their geographic position and use more water than agreed. For instance, in 2000, when overall water supply dramatically decreased, it is reported that the water abundance (the ratio of total water withdrawal to the total required amount of water) was 90% in the upstream region of Tajikistan but only 40% and 45% in the downstream regions – of Dashauz (Turkmenistan) and Karakalpakstan (Uzbekistan), respectively (Dukhovny and Schutter 2011:277). The situation requires development and implementation of alternative water allocation concepts to foster cooperation among the water users to attain more efficient and fair water sharing, particularly in the growing season while considering also environmental water use demands. Market-based water allocation can be a suitable option for providing efficient water use in the ASB.

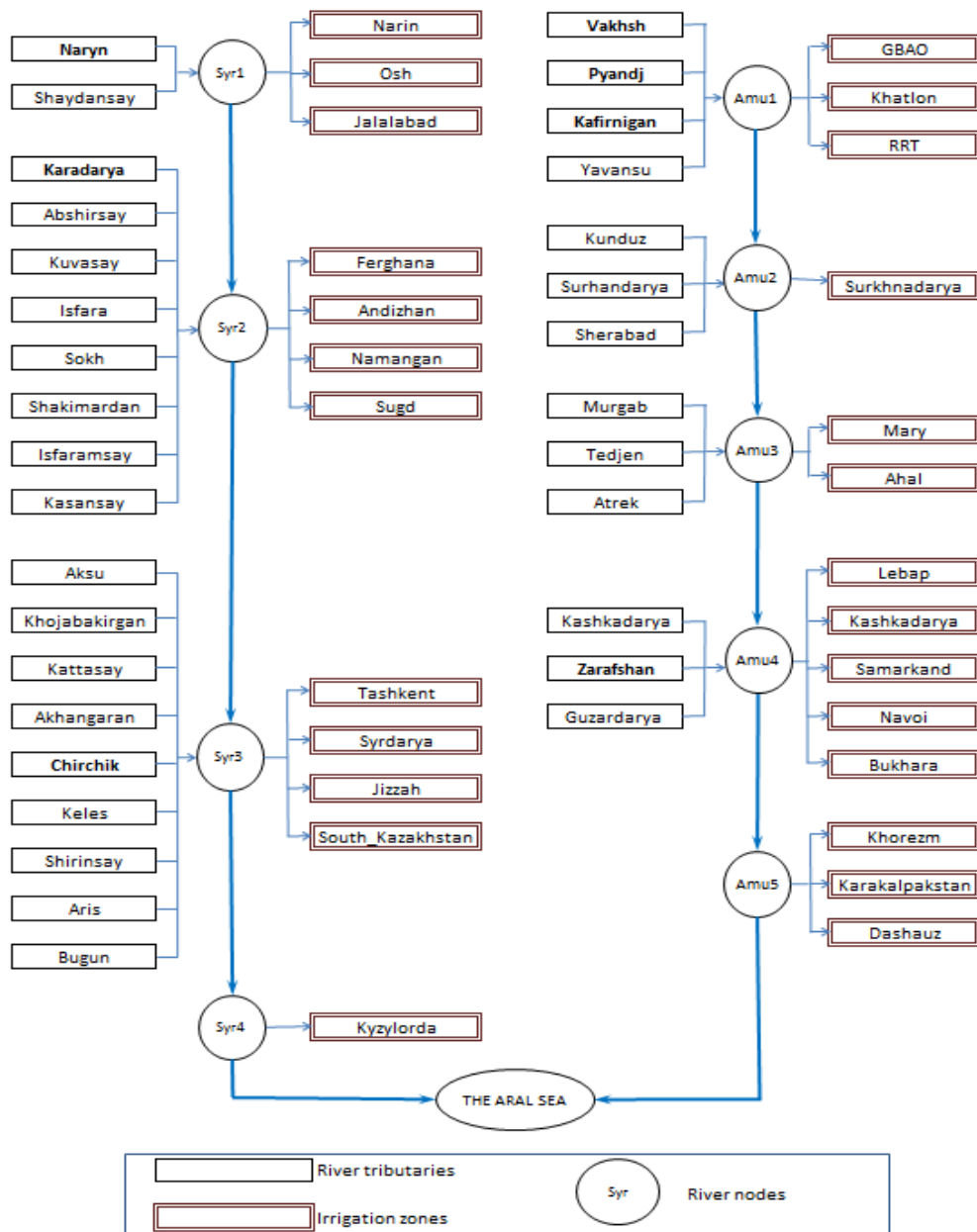
### **3 Analytical framework**

#### **3.1 A river node model**

A river node-link based hydro-economic model was developed to analyze potential benefits from market-based water allocations in the ASB. A river network scheme includes tributaries and irrigation water intake nodes along the two largest rivers (Amu Darya and Syr Darya) which flow from the east to the west towards the Aral Sea (Figure 1). Administrative regions rather than hydrologic irrigation units are used as water using units considering data availability. A total of 12 regions and 19 river tributaries in the Syr Darya Basin and 14 regions and 13 river tributaries in the Amu Darya Basin were incorporated into the model. The regions were grouped into single water catchments (with relevance to the river nodes) according to their proximity to one another.



**Figure 1 The Aral Sea Basin river network scheme**



Due to the priority of the municipal and industrial sectors in water allocation and use, and the fact that agriculture accounts for almost 90% of total water consumption (SANIIRI 2004), water allocation to municipal and industrial use is considered as exogenous and fixed, and water trading is analyzed only among the irrigation zones. Since the model focused on the potentials of water rights trading among the irrigation zones to attain socially optimal benefits and considered only one year without monthly time-steps, reservoir management and electricity production, which require at least monthly time intervals, were not included. Furthermore, water trading is allowed only among irrigation regions within each river basin of the ASB as water uses in the different rivers are not physically connected. It is assumed that there is a basin management organization that organizes water trading (e.g. all water transaction agreements occur through this organization), which buys and sells water use rights after taking into account the willingness of individual water users to pay for or sell water.

### 3.2 Key model equations

Water flow relationships among the tributaries, water withdrawals to the irrigation regions, and flows from one river node to other nodes are modeled as:

$$\begin{aligned} & \sum_{(rn_{up},rn) \in RVLINK} Q_{rn_{up},rn} + Src_{rn} + \sum_{(dm,rn) \in NDLINK} Ret_{dm,rn} \\ = & \sum_{(rn,rn_{lo}) \in RVLINK} Q_{rn,rn_{lo}} + \sum_{(rn,dm) \in NDLINK} (WDR_{rn,dm} + \overline{WID}_{rn,dm}) \end{aligned} \quad (1)$$

where  $Q_{rn_{up},rn}$  is river water flow to the node ( $rn$ ) from the upper node ( $rn_{up}$ ) and  $Q_{rn,rn_{lo}}$  is river flow from the node ( $rn$ ) to the next lower node ( $rn_{lo}$ ) if a link between the nodes ( $RVLINK$ ) exists,  $Src_{rn}$  is the source flow in the tributary node, and  $Ret_{dm,rn}$ ,  $WDR_{rn,dm}$  and  $\overline{WID}_{rn,dm}$  are return flows from irrigation demand sites ( $dm$ ) to the river node ( $rn$ ) and water withdrawal from node ( $rn$ ) to the demand site ( $dm$ ) for irrigation and municipal-domestic needs respectively if a link between the node and the water user site ( $NDLINK$ ) exists.

Quadratic functions were chosen to estimate the empirical relationship between water use and irrigation benefits due to their property of diminishing marginal returns to additional input. Quadratic functions are commonly used to evaluate the relationships between the value of crop production and water use in the literature (Zilberman et al. 1994, Ringler et al. 2006, Qureshi et al. 2007). Water benefit functions were developed for each water user site by regressing the total regional crop production benefits with total water withdrawals between 1980 and 2000 using the Ordinary Least Squares (OLS) method (Greene 2003):

$$Ben_{dm} = a0_{dm} + a1_{dm} w_{dm} + a2_{dm} w_{dm}^2 \quad (2)$$

where  $w_{dm}$  is water use per hectare,  $Ben_{dm}$  is irrigation benefit per hectare, and  $a0$ ,  $a1$ , and  $a2$  are the parameters of the benefit function. Since in most irrigated areas of the ASB, precipitation plays less role since it mainly occurs during the non-vegetation period and much lower than the evaporation rate (de Pauw 2007) its impact on the yields are assumed negligible.

Total water application in the field depends on water withdrawals to the irrigation sites ( $WD_{dm}$ ):

$$WD_{dm} = \sum_{rn} WDR_{rn,dm} = w_{dm} AR_{dm} \quad (3)$$

where  $w_{dm}$  is water use (withdrawal) per hectare and  $AR_{dm}$  is total cultivated area in the region.

A linear relationship between annual environmental flows into the Aral Sea ( $Env_w$ ) and benefits ( $Env_{ben_{dm}}$ ) is elaborated as:

$$Env_{ben} = b0 + b1 Env_w \quad (4)$$

where  $b0$  and  $b1$  are parameters of the regression function and  $Env_w$  is the environmental flow calculated as the sum of the inflows from the Amu Darya and Syr Darya into the Aral Sea.

The objective function is defined as maximizing overall basin-wide benefit:

$$obj = \sum_{dm} (Ben_{dm} AR_{dm} - CC_{dm} WD_{dm} + Env\_Ben + WTP_{dm}(WS_{dm} - WB_{dm}) - tc (WS_{dm} + WB_{dm})) \rightarrow max \quad (5)$$

where  $CC_{dm}$  is conveyance and pumping costs to deliver one cubic meter of water from irrigation node to the irrigation site,  $WTP_{dm}$  is water trading price or shadow price of water across the irrigation regions,  $WS_{dm}$  and  $WB_{dm}$  are the amounts of water sold and bought by irrigation regions respectively, and  $tc$  is transaction costs per unit of water traded which was assumed to be shared equally by both the buyers and sellers of water (Challen 2000).

The shadow price of water was estimated by taking derivatives from the sum of irrigation and trading benefit functions while considering transaction costs ( $tc$ ):

$$WTP_{dm} = \frac{\partial (Ben_{dm} AR_{dm})}{\partial WD_{dm}} - CC_{dm} - tc \frac{\partial (WS_{dm} + WB_{dm})}{\partial WD_{dm}} \quad (6)$$

or

$$WTP_{dm} = a1_{dm} + a2_{dm}w_{dm} - CC_{dm} + tc \frac{WS_{dm} - WB_{dm}}{WS_{dm} + WB_{dm}} \quad (6')$$

Moreover, additional constraints were introduced regarding water trading.

A water user site either buys or sells water use rights:

$$WS_{dm} WB_{dm} = 0 \quad (7)$$

Total water use rights sold are equal to the total water use rights bought for either river system:

$$\sum_{dm} WS_{dm} = \sum_{dm} WB_{dm} \quad (8)$$

Water intake to the water user region should be lower than the sum of its water use rights and the additional water bought if the user buys water whereas total water intake should be lower than the difference between water use rights and the amount of water sold if the user sells water:

$$WDR_{dm} \leq WUR_{dm} - WS_{dm} + WB_{dm} \quad (9)$$

where  $WUR_{dm}$  is the water use right of the demand site ( $dm$ ), which is determined here according to proportional fixed water use shares calculated based on historical water distribution among irrigation water user sites following the method used by Cai et al. (2006).

### 3.3 Data sources

Data on cultivated land area, irrigation water use, and yields are obtained from the CAREWIB database (SIC-ICWC 2011) which is a single source that provides detailed data on crop

production system across all regions of the ASB. Prices of the agricultural commodities and input costs were estimated based on market survey results of the ZEF/Urgench project (2010), data by ObSelVodKhoz (2010) and SIC-ICWC (2010). Cotton prices were based on SIC-ICWC (2010) and Anderson and Swinnen (2008:40). Data on water delivery (conveyance) costs are taken from MAWR (2007). All economic cost and benefits were estimated at the prices of 2006.

Data on water supplies in the source nodes (tributary flows) is from SIC-ICWC (2011) and return flow rates were estimated based on EC-TACIS (1997). Municipal and domestic water uses were assumed as fixed amount equal to 10% of the total withdrawals (FAO 2012). Economic benefit levels and losses of ecosystem services at different levels of the Aral Sea volume and inflows to the Sea were estimated based on INTAS (2001, 2004, 2006) and TEEB (2011).

### 3.4 Scenarios

#### 3.4.1 *Baseline (fixed water use rights) and optimization scenarios under different levels of water availability*

The model was calibrated to the real conditions of land and water use and hydrologic flows in 1999, a year with average water supply. The year was chosen based on the average value of the observed water flows between 1980 and 2000. For analyzing the impact of water availability on water distribution among the water users, two alternative water supply scenarios were assumed equivalent to 90% and 80% of average supply.

The baseline scenario considers water distribution based on fixed water use rights which were derived according to fixed water use shares as of 1999. An optimization scenario without water trading was run to show the ideal water distribution in economic terms as a target for water management:

$$obj' = \sum_{dm} Ben_{dm} AR_{dm} - \sum_{dm} CC_{dm} WD_{dm} + Env\_Ben \rightarrow max \quad (5')$$

#### *Fixed water use rights vs. intra- and inter-catchment water trading*

The water trading scenario allows water users to sell or buy water rights, thus increasing the scope of water withdrawal beyond the fixed water rights and boosting additional benefits in the regions with higher marginal water benefits. Intra-catchment (intra-node) and inter-catchment (inter-node) water trading are differentiated from each other considering that the introduction of water markets is easier between the irrigation sites that are geographically closer to each other. Intra-catchment or restricted (RWT) water trading means that water transfers are allowable only among the water users within a catchment. Inter-catchment or unrestricted (UWT) water trading can occur freely among the water users located in the same and also different catchments. These two main water trading scenarios were compared to the fixed water use rights distribution (baseline scenario) for analyzing the effects of water trading on net benefit levels of different water users. Trading scenarios were also compared to the results of the optimization scenario to show how much they differ from the ideal case.

The impacts of introducing “within catchment” boundaries on full water trading were tested by including additional model restrictions which allow water trading only within the single water catchments. Under this restriction, total water withdrawals should be equal to the total water use rights within the catchment:

$$\sum_{(rn, dm) \in NDLINK} WDR_{dm} = \sum_{(rn, dm) \in NDLINK} WUR_{dm} \quad (12)$$

Moreover the amount of water sold and bought within the catchment are equal to each other:

$$\sum_{(rn, dm) \in NDLINK} WS_{dm} = \sum_{(rn, dm) \in NDLINK} WB_{dm} \quad (13)$$

These water trading scenarios were run assuming zero transaction costs for water market institutions, therefore the objective function did not include a transaction costs component:

$$obj'' = \sum_{dm} (Ben_{dm} AR_{dm} - CC_{dm} WD_{dm} + WTP_{dm}(WS_{dm} - WB_{dm})) + Env\_Ben) \rightarrow max \quad (5'')$$

#### *Transaction costs*

The impact of transaction costs on economic profitability of water trading was assessed based on scenario analysis (Eq. 5). Transaction costs varied between US\$ 0.012 and US\$ 0.125 per cubic meter or alternatively 3% to 30% of the water prices in Australia according to previous studies (Challen 2000). We considered 21 simulations of transaction costs varying costs between US\$ 0.0/m<sup>3</sup> and US\$ 0.1/m<sup>3</sup> per water transaction volume.

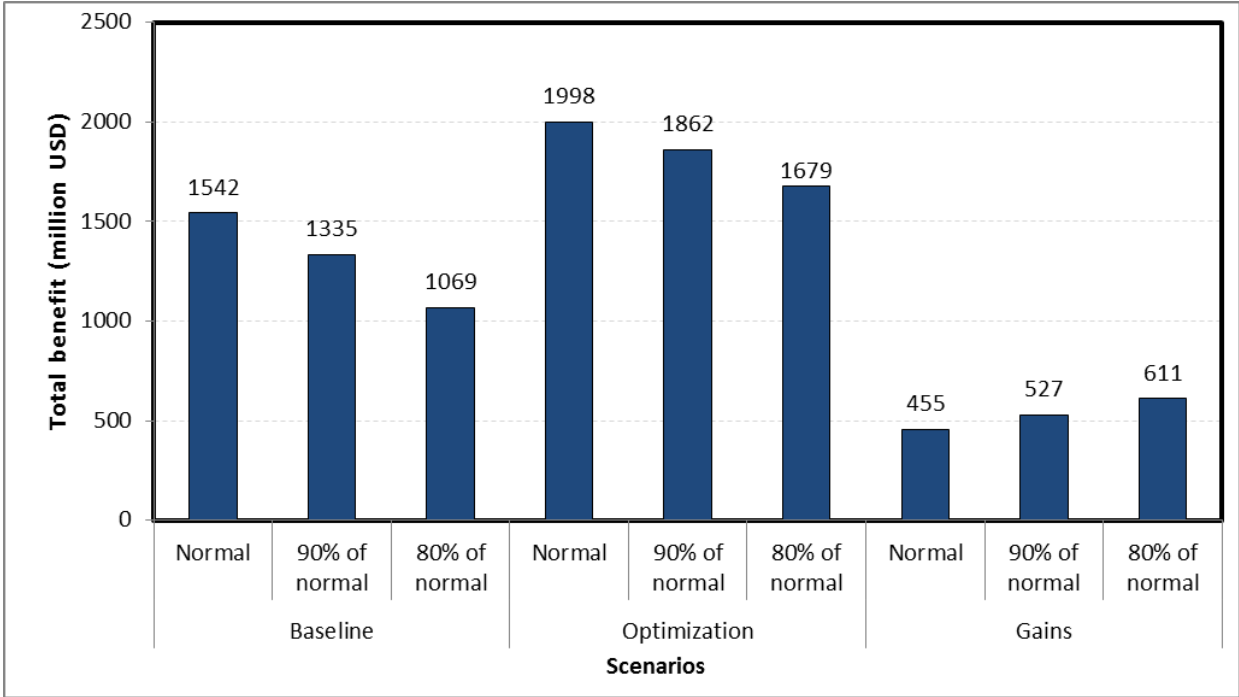
## **4 Optimal water allocation and water trading**

The integrated hydro-economic model that combined benefit functions and the river water balance system was used to evaluate efficiency of different water allocation institutions including fixed water use rights, water trading, and optimization in the ASB. First, the benefits under fixed water rights and optimization scenarios were compared. Next, because of benefit losses to some individual users, particularly upstream ones, despite higher overall economic gains for the basin under the optimization scenario, optimal water allocation allowing for tradable water use rights was examined. In the end the impacts of different levels of transaction costs of establishing water markets on the additional gains from water trading were analyzed.

### **4.1 Baseline (fixed water use rights) vs. optimization**

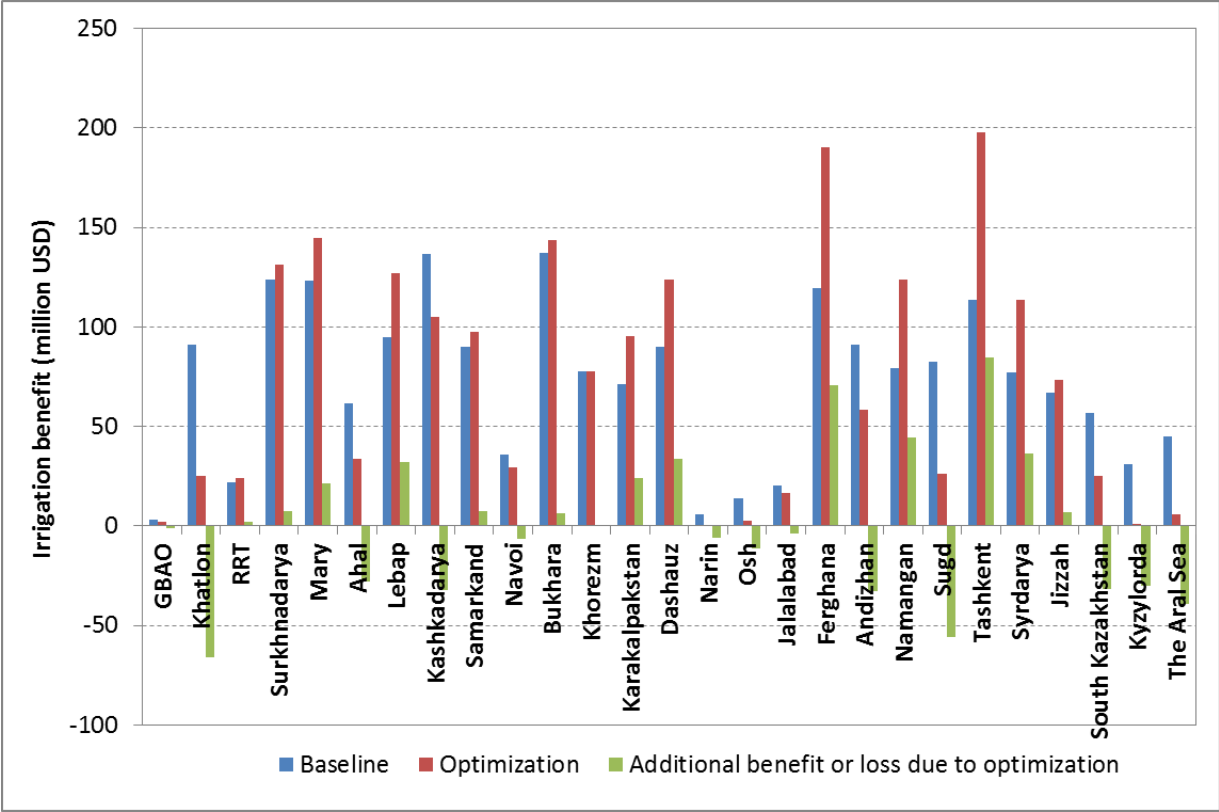
Although the costs of establishing an omniscient and benevolent decision maker who optimizes water use benefits for the entire basin is too high and unrealistic considering the multiple number of independent water users involved, optimization results can still serve as a target point for comparing the benefits from alternative water management institutions (Ringler et al 2004). The results indicate that the potential overall benefits (irrigation and environmental) from optimal water use in the ASB vary between US\$ 1,680 million and US\$ 2,000 million depending on water availability (Figure 2). Thus, between US\$ 450 million and US\$ 610 million of additional economic benefits are feasible for the irrigation sector along, compared to the baseline of fixed water use right benefits.

**Figure 2 Total water use benefit under baseline and optimization scenarios at different levels of water availability**



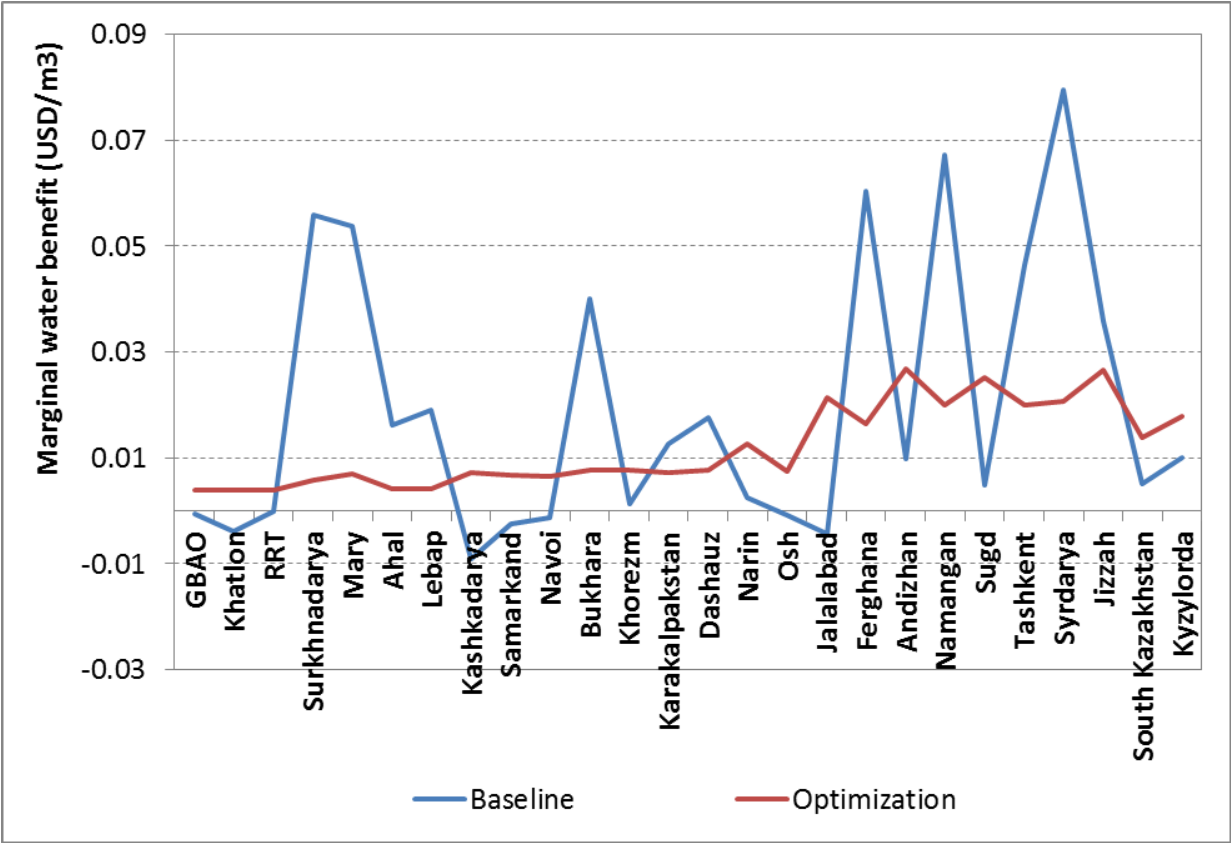
Despite substantial increases in basin-wide water use benefits under the optimization scenario, benefits were not equally distributed for all regions, i.e., while some users got higher benefits from optimization of water allocation, some lost out due to decreased water availability (Figure 3). For instance, optimal water allocation would be reached by diverting more water resources to irrigation in the highly fertile valleys and oases like Tashkent and Ferghana at the same time water consumption and benefits would decline in Khatlon, Ahal, Kashkadarya, Andizhan, Sugd, South Kazakhstan, and Kyzylorda.

**Figure 3 Water use benefits across water user sites of the Aral Sea Basin under normal water supply**



Marginal water benefits across the regions in both the Amu Darya and Syr Darya Basins were highly variable under the fixed rights based water allocation (baseline), but stabilized under optimization (Figure 4). Moreover, marginal benefits were lower in the regions of the Amu Darya Basin, indicating higher water availability compared to the Syr Darya Basin. Theoretically, marginal water use benefits should be equal across the regions in each river basin under optimization if the only restriction is water availability. However, additional restrictions due to differences in hydrological, land use and productivity conditions along the rivers and water catchment zones also had impacts on marginal benefits and prevented equal marginal benefits across all regions. Cai et al. (2008) also noted that the concept of equimarginal benefits may not hold within the hydro-economic modeling framework due to different hydrological and institutional constraints.

Figure 4 Marginal irrigation benefits across the regions of the ASB under normal water supply

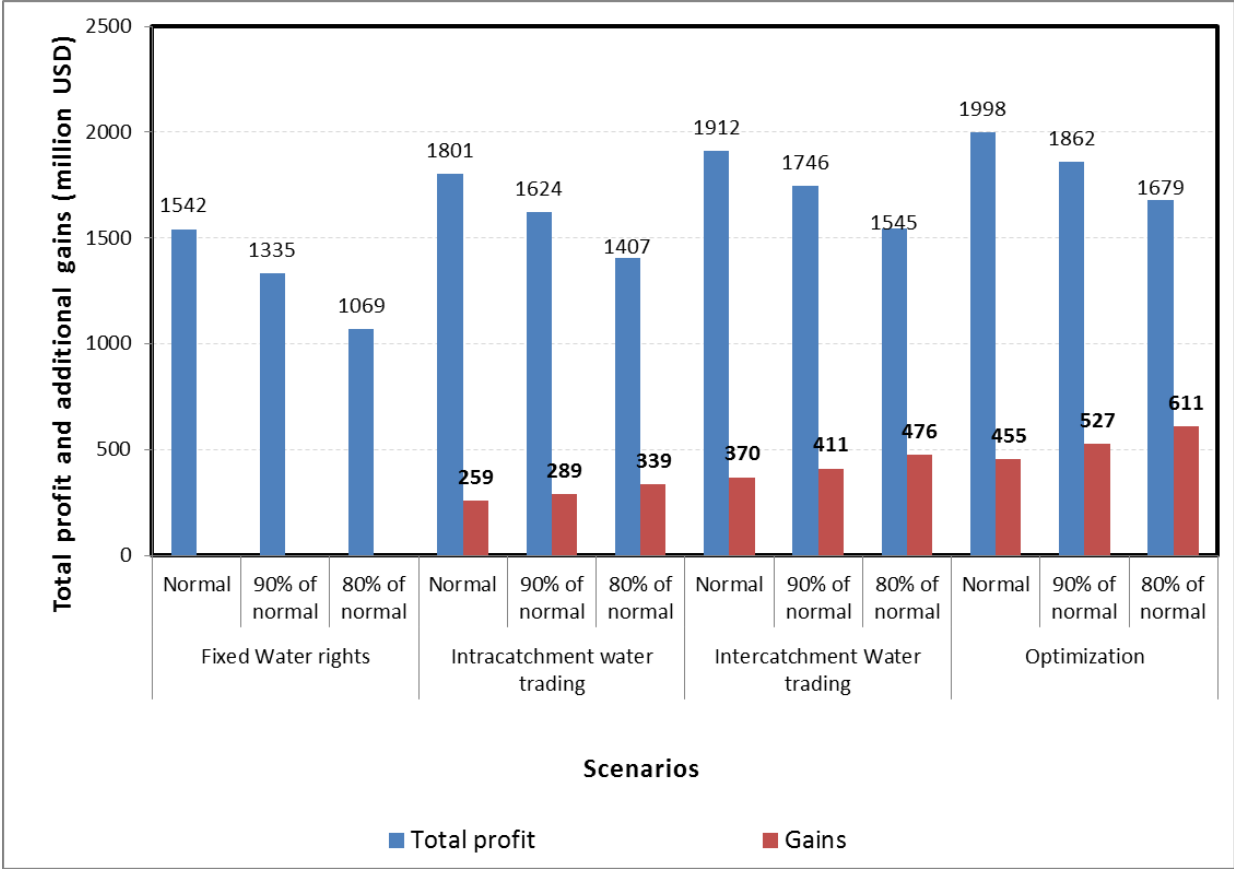


**4.2 Intra-catchment and inter-catchment water trading**

Despite the substantial increase (30%, 39%, and 50% under normal water supply levels, 90% of normal, and 80% of normal respectively) in overall basin benefit under optimal water allocation, the regions with lower marginal water productivity will only cooperate in attaining optimal basin-scale benefit if only they are compensated for lost income due to their reduced water use. Introducing tradable water rights would provide incentives for cooperation by increasing willingness of less water productive regions to transfer part of their water rights for appropriate compensation to more productive regions. Results indicate that although additional gains from introducing water markets were less than those of the pure optimization scenario, economic gains were substantially higher than those under fixed water rights (Figure 5). Additional benefits from inter-catchment water trading vary between US\$ 373 million to US\$ 476 million. Higher than baseline gains were also obtained under intra-catchment water trading. Furthermore, the scarcer water becomes the more beneficial water trading is, as reflected in the increased trend of additional gains in parallel with decreased water availability. These results are in line with the findings of Booker and Young (1994) and Cai et al. (2006).



**Figure 5 Comparing benefits and additional gains from water trading and optimal water allocation**



Irrigation benefits across the regions varied between US\$ 2 million and US\$ 151 million under long-term average water availability (Table 1). Total irrigation benefit was lowest in upstream regions such as Gorno-Badakhshan (GBAO) and RRT of the Amu Darya Basin and Naryn, Osh, and Jalalabad of the Syr Darya Basin, which can be explained by their mountainous landscapes, limited irrigated areas, and the high energy (pumping) costs to deliver water to the fields in mountainous zones.

Additional gains from water trading were achieved in all regions (Table 1). The top gains from trading are expected in Surkhandarya and Mary of the Amu Darya Basin and in Ferghana and Tashkent of the Syr Darya Basin. Additional regional gains under intra-catchment trading (restricted) compared to the benefits under inter-catchment trading (unrestricted) depended on the marginal water benefit of the regions within the catchment.

Analysis of water transfers and willingness to pay illustrates the routes of water trade flows and market prices of water (Table 1). Major water rights buyers are the Mary, Lebap, and Bukhara regions of the Amu Darya Basin and the Ferghana, Namangan, Tashkent and Syrdarya regions of the Syr Darya Basin. Furthermore, allowing tradable rights resulted in smoothed marginal water productivities or water prices across regions. Smoothing of the prices was higher under unrestricted water trading (UWT) than restricted water trading (RWT) as expected. The average water prices were US\$ 0.012/m<sup>3</sup> in the Amu Darya Basin regions and US\$ 0.02/m<sup>3</sup> in the Syr Darya Basin.

**Table 1 Benefits, water use, water transfers, and water prices across the regions and the Aral Sea under fixed water rights (FWR), intra-catchment (UWT) and inter-catchment water trading (UWT) under normal water availability**

Regions	Total irrigation profit, 10 <sup>6</sup> US\$			Water withdrawal (million m <sup>3</sup> )			Water transfer (million m <sup>3</sup> )		Shadow price of water (US\$/m <sup>3</sup> )		
	FWR	RWT	UWT	FWR	RWT	UWT	RWT	UWT	FWR	RWT	UWT
<b><i>Amu Darya Basin:</i></b>											
GBAO	2	2	3	362	335	104	0	-258	-0.001	0.002	0.007
Khatlon	25	26	43	5115	4262	2461	0	-2654	-0.004	0.002	0.010
RRT	20	24	25	660	660	596	0	-64	-0.003	0.004	0.010
Surkhandarya	96	101	120	3075	3075	4131	0	1055	0.056	0.033	0.010
Mary	115	137	134	4423	5415	5358	993	935	0.054	0.008	0.011
Ahal	21	25	29	3346	2353	1918	-993	-1428	0.016	0.008	0.011
Lebap	89	93	100	3151	4034	5040	883	1889	0.019	0.015	0.010
Kashkadarya	90	116	111	3747	2663	2973	-1083	-774	-0.009	0.017	0.012
Samarkand	81	99	97	2802	2372	2638	-429	-164	-0.002	0.016	0.011
Navoi	29	34	32	1390	864	1016	-526	-374	-0.001	0.016	0.012
Bukhara	104	119	126	2735	3891	4145	1156	1411	0.040	0.017	0.011
Khorezm	71	81	81	3408	2749	2805	-659	-603	0.001	0.012	0.012
Karakalpakstan	64	66	65	5956	4654	4824	-1302	-1132	0.013	0.012	0.012
Dashauz	80	85	87	5203	7164	7364	1961	2161	0.018	0.012	0.012
<b><i>Syr Darya Basin:</i></b>											
Naryn	3	3	5	646	646	247	0	-399	0.003	0.005	0.013
Osh	7	10	12	1539	1328	318	0	-1221	-0.001	0.005	0.007
Jalalabad	16	19	22	585	585	330	0	-255	-0.004	0.006	0.029
Ferghana	109	129	151	2461	3858	4478	1397	2017	0.060	0.032	0.019
Andizhan	73	91	86	2490	1133	1385	-1357	-1105	0.010	0.032	0.029
Namangan	55	75	96	1837	3019	3502	1182	1664	0.067	0.033	0.018
Sugd	41	60	60	3185	1963	1943	-1222	-1241	0.005	0.032	0.032
Tashkent	109	115	140	2708	3840	5229	1132	2520	0.046	0.036	0.022
Syrdarya	72	108	101	2123	3154	3063	1031	940	0.080	0.008	0.015
Jizzah	57	62	62	1765	1264	2371	-500	607	0.036	0.050	0.023
South Kazakhstan	42	48	48	2813	1150	1150	-1663	-1663	0.005	0.014	0.014
Kyzylorda	27	27	34	3133	3133	1268	0	-1865	0.010	0.010	0.018
The Aral Sea	45	46	42	15947	16242	15041	0	0	0.003	0.003	0.003
<b>Total profit</b>	<b>1542</b>	<b>1801</b>	<b>1912</b>	<b>86603</b>	<b>85808</b>	<b>85697</b>	<b>0</b>	<b>0</b>			

Additional gains from water trading across all regions were also achieved under drier year conditions (90% of normal water supply) (Table 2). Average water prices under inter-catchment water trading were US\$ 0.014/m<sup>3</sup> and US\$ 0.023/m<sup>3</sup> in the Amu and the Syr Darya Basin regions, respectively. Similarly, average marginal water use benefits under 80% of the normal water supply were US\$ 0.016/m<sup>3</sup> and US\$ 0.025/m<sup>3</sup> in the Amu and Syr Darya Basins, respectively (Table 3). Comparison of marginal benefits under different levels of water

availability showed that marginal water use benefits increased and that water trading was more beneficial in parallel with decreased water availability.

**Table 2 Benefits, water use, water transfers, and water prices across the regions and the Aral Sea under fixed water rights (FWR), intra-catchment (UWT) and inter-catchment water trading (UWT) under 90% of normal water availability**

Regions	Total irrigation profit, 10 <sup>6</sup> US\$			Water withdrawal (million m <sup>3</sup> )			Water transfer (million m <sup>3</sup> )		Shadow price of water (US\$/m <sup>3</sup> )		
	FWR	RWT	UWT	FWR	RWT	UWT	RWT	UWT	FWR	RWT	UWT
<b><i>Amu Darya Basin:</i></b>											
GBAO	2	2	2	319	254	104	0	-215	0.001	0.004	0.007
Khatlon	26	26	43	4512	4110	2018	0	-2494	0.000	0.003	0.013
RRT	20	24	24	582	582	559	0	-23	0.000	0.011	0.014
Surkhandarya	73	89	112	2713	2713	4058	0	1345	0.073	0.041	0.013
Mary	80	120	124	3902	5235	5298	1333	1396	0.082	0.017	0.014
Ahal	14	33	29	2952	1619	1749	-1333	-1203	0.021	0.017	0.014
Lebap	81	85	89	2780	3597	4342	817	1562	0.021	0.018	0.014
Kashkadarya	92	113	108	3306	2272	2731	-1033	-574	-0.001	0.022	0.015
Samarkand	81	95	93	2472	2073	2441	-398	-30	0.005	0.022	0.015
Navoi	29	34	31	1227	702	897	-525	-330	0.004	0.021	0.015
Bukhara	89	103	117	2413	3553	3993	1140	1580	0.048	0.025	0.015
Khorezm	70	77	78	3007	2453	2435	-554	-571	0.006	0.015	0.016
Karakalpakstan	54	59	61	5255	3938	3732	-1250	-1522	0.015	0.015	0.015
Dashauz	68	72	71	4590	6395	5670	1805	1080	0.020	0.015	0.015
<b><i>Syr Darya Basin:</i></b>											
Naryn	3	3	4	568	567	247	0	-321	0.005	0.005	0.013
Osh	7	8	11	1353	1052	318	0	-1035	0.000	0.006	0.007
Jalalabad	16	18	21	514	514	301	0	-213	0.003	0.012	0.032
Ferghana	90	112	131	2164	3655	4165	1492	2001	0.067	0.036	0.025
Andizhan	69	81	81	2189	1133	1133	-1056	-1056	0.014	0.032	0.032
Namangan	40	61	82	1615	2269	3331	654	1716	0.074	0.037	0.023
Sugd	37	55	66	2800	1710	1433	-1089	-1367	0.016	0.040	0.049
Tashkent	93	97	109	2381	2629	4196	248	1815	0.050	0.040	0.032
Syrdarya	49	100	100	1867	3094	3093	1227	1227	0.100	0.012	0.012
Jizzah	49	50	50	1551	1399	1594	-152	43	0.044	0.045	0.037
South Kazakhstan	40	43	43	2473	1150	1150	-1323	-1323	0.007	0.014	0.014
Kyzylorda	23	23	28	2755	2755	1268	0	-1487	0.012	0.012	0.018
The Aral Sea	40	40	38	14658	14658	14071	0	0	0.003	0.003	0.003
Total profit	1335	1624	1746	76917	76081	76330	0	0			

**Table 3 Benefits, water use, water transfers, and water prices across the regions and the Aral Sea under fixed water rights (FWR), intra-catchment (UWT) and inter-catchment water trading (UWT) under 80% of normal water availability**

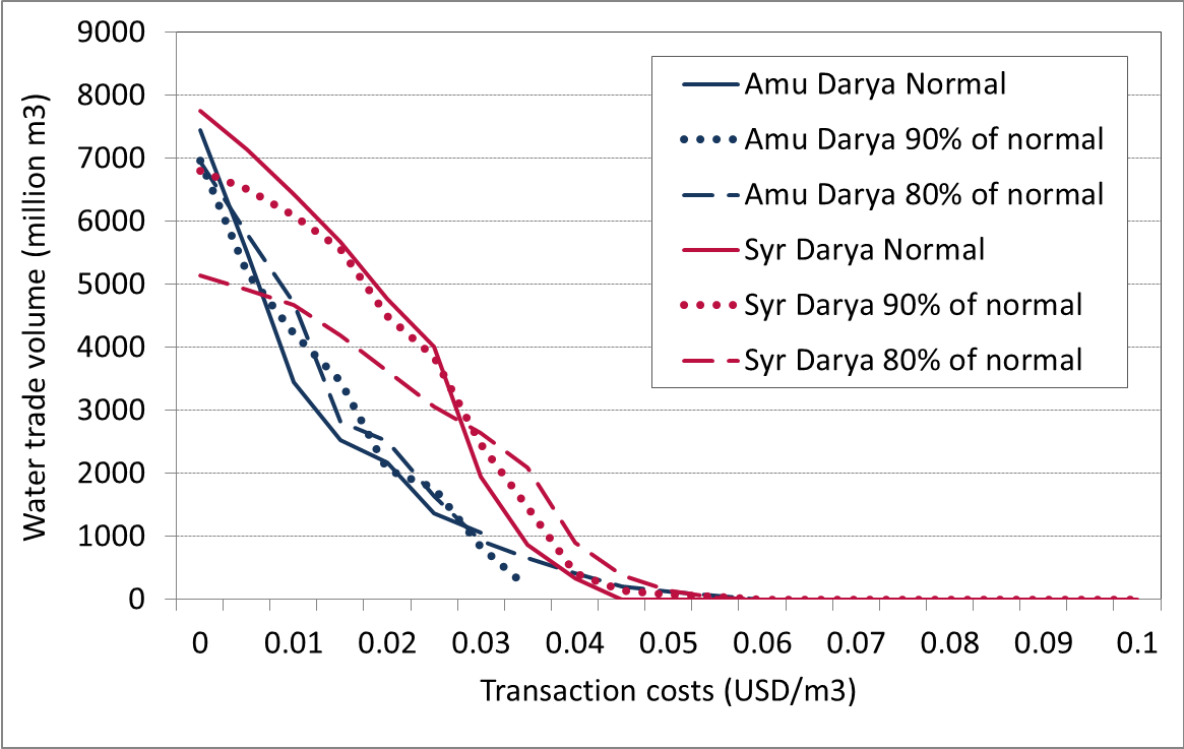
Regions	Total irrigation profit, 10 <sup>6</sup> US\$			Water withdrawal (million m <sup>3</sup> )			Water transfer (million m <sup>3</sup> )		Shadow price of water (US\$/m <sup>3</sup> )		
	FWR	RWT	UWT	FWR	RWT	UWT	RWT	UWT	FWR	RWT	UWT
<b><i>Amu Darya Basin:</i></b>											
GBAO	2	2	2	277	239	104	0	-173	0.002	0.005	0.007
Khatlon	25	25	35	3910	3848	2018	0	-1892	0.003	0.004	0.013
RRT	20	23	23	504	504	534	0	29	0.009	0.019	0.016
Surkhandarya	43	70	103	2351	2351	4008	0	1657	0.090	0.062	0.016
Mary	30	98	113	3381	4597	5258	1216	1877	0.110	0.023	0.016
Ahal	5	32	26	2558	1342	1631	-1216	-927	0.025	0.023	0.017
Lebap	73	75	80	2409	2858	3842	449	1433	0.023	0.022	0.016
Kashkadarya	91	107	101	2865	1945	2561	-920	-303	0.007	0.027	0.018
Samarkand	78	88	87	2142	1824	2302	-318	161	0.012	0.027	0.018
Navoi	28	33	29	1063	543	812	-520	-251	0.009	0.026	0.018
Bukhara	73	90	107	2091	3400	3885	1309	1795	0.056	0.029	0.017
Khorezm	67	71	72	2606	2422	2172	-183	-433	0.010	0.016	0.018
Karakalpakstan	43	45	53	4554	3873	2952	-348	-1601	0.016	0.015	0.018
Dashauz	56	62	65	3978	4508	2607	531	-1371	0.022	0.015	0.018
<b><i>Syr Darya Basin:</i></b>											
Naryn	2	2	3	490	486	247	0	-243	0.007	0.006	0.013
Osh	7	8	9	1167	956	318	0	-849	0.002	0.006	0.007
Jalalabad	16	17	18	443	443	301	0	-143	0.011	0.019	0.032
Ferghana	69	94	117	1866	3430	4025	1564	2159	0.073	0.041	0.028
Andizhan	64	69	71	1888	864	1133	-1024	-755	0.019	0.032	0.032
Namangan	23	50	56	1393	1866	2101	473	708	0.081	0.043	0.033
Sugd	29	49	50	2415	1402	1349	-1013	-1066	0.027	0.050	0.052
Tashkent	76	82	84	2054	2118	2627	64	573	0.053	0.046	0.039
Syrdarya	21	84	103	1610	2579	3139	969	1529	0.121	0.013	0.009
Jizzah	39	41	41	1338	1288	1516	-50	178	0.052	0.050	0.040
South Kazakhstan	37	38	38	2133	1150	1150	-983	-983	0.009	0.014	0.014
Kyzylorda	18	18	21	2376	2376	1268	0	-1108	0.013	0.013	0.018
The Aral Sea	36	36	35	13368	13368	13180	0	0	0.003	0.003	0.003
<b>Total profit</b>	<b>1069</b>	<b>1407</b>	<b>1545</b>	<b>67231</b>	<b>66583</b>	<b>67042</b>	<b>0</b>	<b>0</b>			

As can be seen from Tables 1-3, additional inflows to the Aral Sea are negligible under the intra-catchment (restricted) water trading or even slightly decreased compared to the baseline scenario under inter-catchment (unrestricted) trading. This is mainly because of low marginal productivities of the environmental flows since the non-use values of the ecosystem services, such as option, existence, and bequest values, which can be four or five times higher than the direct water use values (Dziegielewska et al. 2009), were not considered in the calculations in this study based on lack of necessary data.

### 4.3 Water trading benefits considering transaction costs

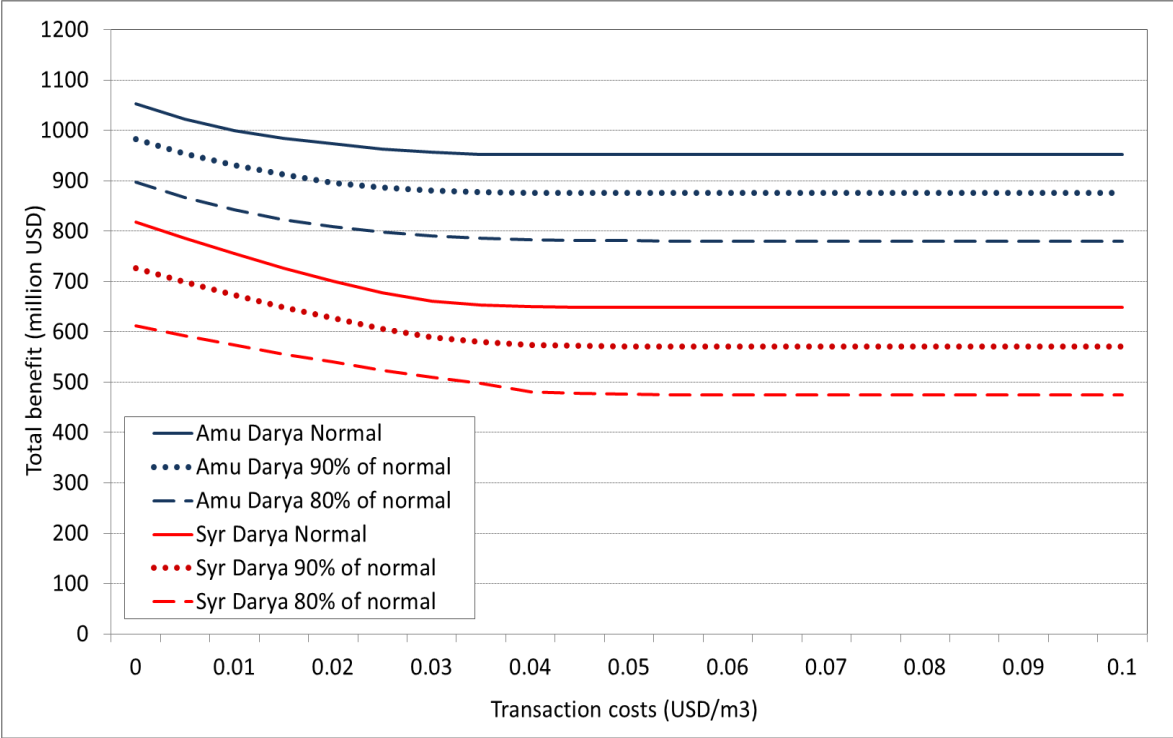
Consideration of the transaction costs of establishing tradable water use rights slightly decreased overall irrigation water use while substantially decreasing water trade volume (Figure 6) and benefits from water trading (Figure 7) in both the Amu Darya and Syr Darya Basins. When transaction costs were not considered, the optimal volume of water trade under normal water availability was more than 7.5 km<sup>3</sup> in each basin. Increase in transaction costs up to US\$ 0.05 per m<sup>3</sup> of traded irrigation water volume practically nullified the potential additional economic gains of water rights trading (Figure 6). Since there are only five regions whose marginal productivity was higher than US\$ 0.05 per m<sup>3</sup> and values varied between US\$ 0.05 and US\$ 0.08 per m<sup>3</sup> in the baseline scenario (Figure 4), water rights trading among the remaining regions were obviously not beneficial while among these five areas was mainly constrained by other land and water use capacity as well as other hydrological and water trading limitations.

**Figure 6 Change in water trade volume due to increases in transaction costs in the Amu Darya and Syr Darya Basins under different levels of water availability**



According to the comparison of total benefits under different levels of transaction costs and different levels of water availability, overall benefits without considering transaction costs of water trading were more than US\$ 1,050 million and US\$ 800 million in the Amu Darya and Syr Darya basins, respectively, under average water supply (Figure 7). However, once transaction costs per cubic meter of water exceeded US\$ 0.05/m<sup>3</sup>, total benefits fell to US\$ 950 million and US\$ 650 million in these two river basins, respectively. Reduced water transfers, decreased net benefits, and lowered water trading gains due to increased costs were also found by Cai et al. (2006) in the case of the Maipo Basin in Chile.

**Figure 7 Change in total water use benefits due to increases in transaction costs in the Amu Darya and Syr Darya Basins under different levels of water availability**



**5 Conclusions**

Efficient allocation of water among different irrigation sites and to the environment while also providing equal access and rights to all water users is a global issue as food, fiber, environmental and health security directly depend on limited water resources in many developing areas, and particularly in Central Asia. Water is a critical resource for sustaining livelihoods and ecosystems in the ASB of Central Asia due to the dominance of irrigated agriculture and rural employment as well as aggravated environmental problems related to water overuse and ineffective water allocation institutions. The bureaucratic approach in water management inherited from the Soviet period did not provide sufficient incentives for improving water use efficiency. After the emergence of several independent riparian state actors in the ASB in 1991 the centralized system of water allocation in the ASB ceased to function, intensifying conflicts over sharing water resources and decreasing water use efficiency. Inadequacy of governmental funds to improve irrigation infrastructure and low profitability of the emerging private sector due to high governmental intervention has worsened the situation.

The analysis showed that, as an alternative to the command-and-control based water management system, market-based water allocation institutions could incentivize the riparian irrigation sites to voluntarily cooperate in order to obtain additional gains through reallocating water from lower to higher-valued uses in the ASB. Given the heterogeneous distribution of water productivity across the irrigation zones, re-allocation of water from less to more productive water users would result in increased economic gains and improved water productivity throughout the basin. Under improved institutions, more productive users, who obtain additional water and consequently additional economic gains, would pay part of these

gains as compensation for unused water use rights by less productive water users, consequently maintaining equal distribution of additional gains. The analysis also indicates that additional economic gains from water rights trading and thus importance of market-based institutions increases along with growing water scarcity.

The results of the current study do not indicate a considerable amount of additional flow to serve environmental needs in maximizing basinwide benefits due to the likely underestimation of the environmental benefits in this study. Overall environmental flow benefit would be much higher when option, existence, and bequest values are additionally considered. Full consideration of environmental benefits would likely make the environmental sector competitive vis-à-vis irrigation. Separation of the benefits from the deltaic zone and the Sea itself may also increase rational environmental flows since the water value for deltaic ecosystems is higher than for the Sea itself.

Furthermore, although tradable water rights promise substantial economic gains transaction costs, that can be incurred while establishing water trading, can be hardly ignored. Additional gains from water trading inversely related to the level of transaction costs as already theoretically proven by several existing studies (Coase 1960, North 1989, North 1990, Colby 1990b, Challen 2000, Saleth and Dinar 2004). Yet, increasing volume of water trading over time in the river basins of United States and Australia where water market is officially introduced (Garrick et al. 2011) indicates achievability of sufficiently low transaction costs for effective performance of water markets. Improved irrigation infrastructure and proper legal and governance settings also lower the amount of transaction costs (McCann et al. 2005). Although the existing water management system with dependence on authorities in all decision making processes perhaps can enhance economic or social stability in the short-run, however, empowering water stakeholders to manage their own land and water resources is essential for social and economic sustainability in the long-run. In the latter case, the government retains important roles, such as setting and enforcing necessary institutional and legal frameworks and supporting research and development, and mediation and compensation roles.

The state organizations also should fasten regional cooperation in managing common resources. Controversially, unwillingness of the current governments to collaborate with each other for achieving mutual benefits from common resources use increase the transaction costs of establishing market-based water allocation. Nationalistic ideologies, which were developed during the early period of independence in order to reduce the pressure of the federalism of the Soviet epoch and emphasized individualistic interests and the historical uniqueness of each nation, led to the gradual separation of the Central Asian countries from each other (Dukhovny and Schutter 2011). In the water sphere, sharing water resources and related infrastructure among these countries is getting more complicated over time as the governments might act egotistically to divert more resources for their own needs without considering the irrigation and drinking needs of neighboring countries and environmental requirements. To avoid potential damage to common resources and regional security under such circumstances as illustrated through iterated Prisoner's Dilemma (Axelrod 1984), what is essential is to seek ways for partnership for using common resources optimally and sharing benefits fairly. Cooperation among the riparian countries and providing the rule of law in common resources sharing are central and unavoidable tasks for establishing the foundations for long-term economic prosperity in the region.

## 6 REFERENCES

- Aldaya, M.M., Muñoz, G. and Hoekstra, A.Y., 2010. Water footprint of cotton, wheat and rice production in Central Asia, Value of Water Research Report Series No.41, UNESCO-IHE.
- Anderson K., and J. Swinnen, 2008. Distortions to Agricultural Incentives in Europe's Transition Economies. World Bank, Washington D.C.
- Ashirbekov U.A. and I.S. Zonn. 2003. Aral: The history of disappearing Sea. Dushanbe (in Russian)
- Axelrod, R., 1984. The Evolution of Cooperation. New York: Basic Books.
- Booker, J.F. and R.A. Young, 1994. Modeling intrastate and interstate markets for Colorado river water resources. *Journal of Environmental Economics and Management* 26(1): 66-87.
- von Braun, J., M. S. Swaminathan, and M.W. Rosegrant, 2003. Agriculture, Food Security, Nutrition and the Millennium Development Goals. New York: International Food Policy Research Institute (IFPRI).
- von Braun J, R.V. Hill, and R. Pandya-Lorch, 2009. The poorest and hungry: a synthesis of analyses and actions. In J. von Braun, R.V. Hill, R. Pandya Lorch (eds.). *The Poorest and Hungry: Assessments, Analyses and Actions*, Washington, D.C.: International Food Policy Research Institute, pp. 1-61.
- Cai, X., D. C. McKinney, and L. S. Lasdon (2002), A framework for sustainability analysis in water resources management and application to the Syr Darya Basin. *Water Resources Research*, 38 , 6 , doi:10.1029/2001WR000214.
- Cai, X., McKinney, D., and Lasdon, L. (2003a). Integrated hydrologic-agronomic-economic model for river basin management. *Journal of Water Resources Planning and Management* 129 (1), pp. 4–17.
- Cai, X., D.C. McKinney, and M.W. Rosegrant (2003b). Sustainability analysis for irrigation water management in the Aral Sea region. *Agricultural Systems*, 76, 1043–1066
- Cai, X., C. Ringler, M.W. Rosegrant, (2006). Modeling water resources management at the basin level: methodology and application to the Maipo River Basin. Research Report, No. 149. International Food Policy Research Institute (IFPRI), Washington DC.
- Cai X., 2008. Implementation of Holistic Water Resources-Economic Optimization Models for River Basin Management – Reflective experiences, , Vol. 23, 1, 2-18. doi:10.1016/j.envsoft.2007.03.005
- Challen R., 2000. *Institutions, Transaction Costs and Environmental Policy: Institutional Reform for Water Resources*. Aldershot, UK: Edward Elgar, 233 pp.
- Coase R.H., 1960. The Problem of Social Cost. *Journal of Law and Economics*, 3, 1-44.
- Colby B.G., 1990. Transaction costs and efficiency in western water allocation. *American Journal of Agricultural Economics*, 72, 1184-1192.
- Dinar, A., M. W. Rosegrant, and R. Meinzen-Dick, 1997. Water allocation mechanisms. World Bank: Policy Research Working Paper No. 1779, Washington, DC.
- Dukhovny V.A. and J.L.G. de Schutter , 2011. *Water in Central Asia: Past, Present, Future*. Taylor and Francis, London.
- Dziegielewska D., T. Tietenberg, S.S. Niggol , 2009. Total economic value. In: *Encyclopedia of Earth*. Eds. C.J. Cleveland. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Available online at: January 7, 2013 (Last visited on 07.01.2013)
- Easter, K. W., Rosegrant, M. W., & Dinar, A. (Eds.), 1998. *Markets for water: Potential and performance*. Boston: Kluwer.
- European Commission (TACIS), 1997. WARMAP Project: Formulation & Analysis of Regional Strategies on Land and Water Resources. Tashkent, Uzbekistan.
- Falkenmark, M. and Rockström, J., 2004. *Balancing water for humans and nature: The new approach in ecohydrology*, Earthscan, London, UK.
- FAO, 2012. AQUASTAT. Online database on irrigation and agriculture. Available online at: <http://www.fao.org/nr/water/aquastat/data/query/results.html> (Accessed 20.11.2012)



- Garrick D., Lane-Miller C. and McCoy A.L., 2011, Institutional Innovations for Governing Environmental Water in the Western U.S., *Economic Papers*, 30 (2), 167–84.
- Greene W.H., 2003. *Econometric Analysis*, fifth edition. New York.
- Harou, J. J., M. Pulido-Velazquez, D.E. Rosenberg, J. Medellín-Azuara, J.R. Lund, and R.E. Howitt, 2009. Hydro-Economic Models: Concepts, Design, Applications, and Future Prospects. *Journal of Hydrology* 375 (2009) 627–643.
- Hartman, L.M., and D. Seastone. 1970. *Water Transfers: Economic Efficiency and Alternative Institutions*. Baltimore, Maryland: Resources for the Future, Johns Hopkins Press.
- Hearne R. and K.W. Easter, 1995. *Water Allocation and Water Markets: An Analysis of Gains-From-Trade in Chile*. Technical Paper No. 315, World Bank, Washington, DC.
- Heidecke C., A. Kuhn, S. Klose, 2008. Water pricing options for the Middle Drâa River Basin in Morocco. *African Journal of Agricultural and Resource Economics* 2(2): 170-187.
- Heidecke C. and T. Heckelej, 2010. The impact of water pricing in an arid river basin in Morocco considering the conjunctive use of ground- and surface water, water quality aspects and climate change. Paper presented at the Conference of the Global Catchment Initiative (GCI) on the Global Dimensions of Change in River Basins, 6-8 December 2010, Bonn, Germany. 85-89.
- Howe, C.W., Schurmeier, D.R., and Shaw, W.D., 1986. Innovative Approaches to Water Allocation: The Potential for Water Markets. *Water Resources Research*, 22(4), p. 439-445. Available at: <http://www.agu.org/pubs/crossref/1986/WR022i004p00439.shtml>.
- INTAS, 2006. Final report: The rehabilitation of the ecosystem and bioproductivity of the Aral Sea under conditions of water scarcity. Tashkent, INTAS Project-0511 REBASOWS.
- INTAS, 2001. Assessment of the Social-Economic Damage under the Influence of the Aral Sea Level Lowering for South Aral Sea Coast. INTAS Project-1733, Tashkent.
- INTAS, 2004. Economical assessment of joint and local measures for the reduction of socio-economic damage in the coastal zone of Aral Sea. INTAS 1059, Tashkent.
- McCann L., B. Colby, K.W. Easter, A. Kasterine, and K.V. Kuperan, 2005. Transaction cost measurement for evaluating environmental policies. *Ecological Economics*, 52(4), 527-542, doi: 10.1016/j.ecolecon.2004.08.002.
- McKinney, D.C., and A. Karimov, 1997. Report on Model Development: Aral Sea Regional Allocation Model for the Amudarya. USAID.
- McKinney, D. C., 2004. Cooperative management of transboundary water resources in Central Asia. In: D. Burghart and T. Sabonis-Helf (eds), *In the Tracks of Tamerlane: Central Asia's Path to the 21st Century*. Washington, DC: National Defense University, 187–220.
- Micklin P., 2007. The Aral Sea Disaster. *Annu. Rev. Earth Planet. Sci.*, 35, 47-72. Available online at: (last visited on 28.07.2011)
- Ministry of Agriculture and Water Resources of Uzbekistan (MAWR), 2007. Conveyance costs of delivering water to the irrigation regions in 2006. Unpublished report. Tashkent, Uzbekistan.
- North D.C., 1989. Institutions and economic growth: An historical introduction, *World Development*, 17(9), 1319-1332.
- North D.C., 1990. *Institutions, institutional change and economic performance*. Cambridge University Press, New York, U.S.A., 159 p.
- ObiSelVodKhoz (Khorezm region branch of the Ministry of Water Resources and Agriculture), 2010. Revenues, costs, and profits of growing different agricultural commodities. Urgench.
- Pauw, E. de (2007). Principal biomes of Central Asia. p.3-24 In *Climate change and terrestrial carbon sequestration in Central Asia* (R. Lal, M.Suleimenov, B.A Stewart, D.O. Hansen and P. Doraiswamy. eds). Taylor and Francis Group, New York, NY, USA.
- Pimental D., J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, T. Barsky, S. Tariche, J. Schreck, S. Alpert, 1997. Water resources: Agriculture, the environment, and society, *BioScience* 47(2), 97-106.

- Qureshi ME, Connor J, Kirby M, Mainuddin M. 2007. Economic assessment of environmental flows in the Murray Basin, *Australian Journal of Agricultural and Resource Economics*. 513: 283-303
- Ringler, C., 2001. Optimal Allocation and Use of Water Resources in the Mekong River Basin: Multi-country and Intersectoral Analyses. PhD Thesis. Frankfurt, Germany, Peter Lang.
- Ringler, C., J. von Braun, and M.W. Rosegrant, 2004. Water Policy Analysis for the Mekong River Basin, *Water International*, 29(1), 30-42.
- Ringler, C., N.V. Huy, and S. Msangi, 2006. Water Allocation Policy Modeling for the Dong Nai River Basin: an Integrated Perspective. *JAWRA Journal of the American Water Resources Association*, 42, 1465–1482. doi: 10.1111/j.1752-1688.2006.tb06014.x
- Rosegrant M.W. and Binswanger H.P., 1994. Markets in tradable water rights: Potential for efficiency gains in developing country water resource allocation. *World development*, 22 (11), 1613-1625.
- Saleth, R.M., and Dinar, A., 2004. Water Institutions and Sector Performance: A Quantitative Analysis with Cross-Country Data. World Bank, Washington, DC.
- SANIRI, 2004. Problems of integrated management, rational use, and protection of water resources in the Aral Sea basin. Project report. Tashkent, Uzbekistan, SANIRI (in Russian).
- SIC-ICWC, 2010. Crop input use costs and output prices across the regions of Uzbekistan in 2006. Unpublished database. Tashkent, Uzbekistan.
- SIC-ICWC, 2011. CAREWIB (Central Asian Regional Water Information Base) database. Tashkent, Uzbekistan.
- SIC-ICWC, 2012. Key socio-economic development indicators in the Aral Sea basin. Available online at: [www.cis-icwc.uz](http://www.cis-icwc.uz) (accessed on 12.01.2012)
- TEEB in Business, 2011. The Economics of Ecosystems and Biodiversity in Business. Edited by Joshua Bishop. Earthscan, London.
- United Nations General Assembly (UN), 2000. Resolution 2, Session 55, United Nations Millennium Declaration, on 18 September 2000.
- UN WATER, 2007. World Water Day 2007: Coping With Water Scarcity.
- UN, 2010. Shrinking Aral Sea underscores need for urgent action on environment – Ban. News report on visit of UN Secretary-General Ban Ki-moon to the Aral Sea. Available online at: [www.un.org/apps/news/story.asp?NewsID=34276](http://www.un.org/apps/news/story.asp?NewsID=34276) (accessed on 10.09.2012)
- UNEP, 2005. Severskiy, I., Chervanyov, I., Ponomarenko, Y., Novikova, N.M., Miagkov, S.V., Rautalahti, E. and D. Daler. Aral Sea, GIWA Regional assessment 24. University of Kalmar, Kalmar, Sweden.
- Weinthal E., 2002. State Making and Environmental Cooperation: Linking Domestic and International Politics in Central Asia. Cambridge, MA: MIT Press, 2002. pp. 274.
- World Resources Institute (WRI), 2005. World resources 2005: the wealth of the poor-managing ecosystems to fight poverty. World Resources Institute, Washington D.C.
- ZEF/Urgench project (2010). Weekly prices of meat, egg, rice, wheat, onion, potato, apple, carrot, tomato and the processed sour cream in 2000-2009. Market survey data. Urgench, Uzbekistan.
- Zilberman D., N. Macdougall, and F. Shah, 1994. Changes In Water Allocation Mechanisms For California Agriculture. *Contemporary Economic Policy*, Western Economic Association International, 12(1), 122-133.