

Bekchanov, Maksud; Bhaduri, Anik; Ringler, Claudia

**Working Paper**

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

ZEF Discussion Papers on Development Policy, No. 177

**Provided in Cooperation with:**

Zentrum für Entwicklungsforschung / Center for Development Research (ZEF), University of Bonn

*Suggested Citation:* Bekchanov, Maksud; Bhaduri, Anik; Ringler, Claudia (2013) : How market-based water allocation can improve water use efficiency in the Aral Sea basin?, ZEF Discussion Papers on Development Policy, No. 177, University of Bonn, Center for Development Research (ZEF), Bonn, <https://doi.org/10.22004/ag.econ.155504>

This Version is available at:

<https://hdl.handle.net/10419/84792>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*



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, April 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, April 2013, pp. 47.**

**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) scholarship program of BMBF (German Ministry of Education and Research). The authors thank for Dr. Arnim Kuhn (ILR, Bonn University) for constructive comments to improve the paper.

## **ABSTRACT**

Increasing water demand due to population growth and economic development under the mounted investment costs for developing new water sources calls for efficient, equitable and sustainable management of water resources in many developing countries. This is more essential in the Aral Sea basin where the tremendous development in irrigation since the 1960s combined with unbalanced water resources management led to the destruction of the ecosystems in the delta zone and the gradual desiccation of the Aral Sea, once the fourth biggest lake of the world with a surface area of 68,000 km<sup>2</sup> and total water volume of 1,100 km<sup>3</sup>. Disintegration of the Central Asian states after the collapse of the Soviet Union also increased the tensions among up- and downstream users over sharing water resources. Insufficient investments in irrigation infrastructure, lack of economic incentives to adopt water-wise approaches, and inefficient water governance and institutions have been the main reasons of decreased water use efficiency in the post-Soviet period.

Market-based water allocation is tested to deal with aggravating water conflicts in the Aral Sea basin. Aggregated integrated hydro-economic model is constructed to analyze the water market mechanism as an alternative option to the traditional administrative water allocation. Water users are allowed to trading their water use rights and increasing their benefits under this decentralized water management system. The analyses show the availability of additional gains amounted to US\$ 373 to 476 million under inter-catchment water trading depending on the level of water availability. Similarly, additional gains of US\$ 259 to 339 million are estimated under intra-catchment water trading. Furthermore, increased trend of additional gains from water trading along with decreased water availability are found. However, transaction costs of introducing tradable water rights are essential to judge the effectiveness of water market reforms and initiate appropriate institutional changes. According to our estimations, transaction costs of more than 5 ¢/m<sup>3</sup> of traded water use rights eliminate the potential benefits of the water trading option. Friendly relationships among the riparian countries and infrastructural improvements are suggested as a means of developing low cost enforcement of water trading contracts.

**Keywords:** water trading, transaction costs, environmental flow, 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 national and global governments to undertake measures to prevent or lessen potential consequences of water shortages. 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 almost reached their limits in most of the river basins of the world, water demand management measures such as creating economic incentives of wider implementation of water conservation technologies, transforming economies towards less water intensive production structures, and improving water management institutions and governance remain the only viable option to deal with water availability issues (Harou et al. 2009). As irrigated agriculture demands for more than 70% of global water withdrawals (WRI 2005) and irrigation efficiency is estimated to be less than 40% at global level (Pimental et al. 1997), the sector has a huge potential for reducing water use which can be reached by adopting high efficiency water conservation technologies like sprinkler irrigation, drip irrigation, laser guided land leveling, impermeable lining of water conveyance systems, or by introducing less water consumptive but higher yield crop varieties (Bekchanov et al. 2010). Under conditions of water scarcity, economic incentives, such as water pricing, or institutional arrangements such as allocation of the water use rights which permits legal access for a specific amount of water withdrawal for each user and the introduction of water rights trading can also increase water use efficiency. Water reallocation through water rights trading allows additional water transfers to users with higher water productivity while providing compensation to users that voluntarily relinquish water rights (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 use (Howe et al. 1986, Rosegrant and Binswanger 1994, Easter et al. 1998, Ringler 2001). Moreover tradable water rights incentivize users to reduce water overuse and invest in efficient technologies if market prices are high enough.

While emphasizing the essential need for water to sustain life, the Dublin Conference (1992) also recommended treating water as an economic good, given the conditions of current and expected shortages. In addition to considering water as an economic resource, efficient water management should adopt holistic approaches such as the implementation of the Integrated Water Resources Management (IWRM) paradigm that combines social and economic development with ecosystems protection through the coordinated management of land and water resources over the entire river basin. River basins are generally accepted as an appropriate unit of water management analysis as they consider interdependence of all water users and the complexity of hydrologic systems within the basin (Keller and Keller 1995, Keller et al. 1996, Rosegrant 1997, Ringler et al. 2004). Moreover increased

competition for water among different users and anthropogenic environmental interventions can be traced only along the entire basin (Ringler 2001).

Despite the fact that potential benefits of introducing water markets at the basin level have been comprehensively analyzed in the case of some areas in developed countries such as the United States and Australia, there are few studies on their potential role in efficient water use in the context of developing countries. Better-designed and functioning water markets can be currently found in these two countries, but they are still in their early stages or continue to be unavailable in many developing countries (Grafton et al. 2010) where “*water is the defining line between poverty or prosperity*” (Saleth and Dinar 2004:4). While formal water markets are absent in developing countries, the demand for such institutions is apparent in the variety of informal water markets that can be found across South Asia, for example. Since poor water management and governance in developing countries are principal causes of water waste and conflicts (Dinar 2003, UNESCO 2006, Aldaya and Llamas 2008), there is a strong need to examine the potential role of water markets for maintaining cooperation and incentivizing efficient water use in developing countries.

To analyze the potential economic gains of introducing water markets we considered the case of the Aral Sea basin (ASB) in Central Asia. The ASB includes the territories of Uzbekistan, Turkmenistan, Tajikistan, Kyrgyzstan, the southern parts of Kazakhstan, the northern parts of Afghanistan and Iran. The region is representative of river basins in many developing countries where water sources have been depleted because of inefficient institutions. The expansion of irrigation under the administrative-bureaucratic system since the 1960s combined with high water losses in conveyance and field application and the dominance of water intensive crops such as cotton, rice, and fodder crops led to the desiccation of the Aral Sea, once the fourth largest lake in the world. The four regions [Karakalpakstan (Uzbekistan), Khorezm (Uzbekistan), Kyzylorda (Kazakhstan), Dashauz (Turkmenistan)] located in the surroundings of the sea were officially declared as an environmental catastrophe zone<sup>1</sup> during the Soviet period, and the Aral Sea desiccation is recognized as one of the worst artificial environmental disasters in the world (UN 2010). To restore the sea and reduce the water supply and demand gap many measures have been suggested so far, including the technical improvement of irrigation system efficiency in the basin and the diversion of water from other basins. However, the enormous costs of the proposed options, the limited financial capability of the riparian states involved, the lack of incentives for efficient water use, the lack of cooperation among the riparian countries and unilateral approach towards the use of common-pool resources have prevented wide-scale implementation of most of the measures (World Bank 1992).

Furthermore the dissolution of the single administrative unit that controlled water distribution in the basin and the emergence of five independent countries with competing interests after the collapse of the Soviet Union have complicated cooperation and coordination over water resource sharing and management (Mirzaev 2000). Water distribution in the basin has become dependent on the individualistic perceptions of benefits to each of the five riparian countries. The upstream countries (Kyrgyzstan and Tajikistan) where most of the water resources are initially formed have abandoned the previous system of water allocation developed by the SU because it did not favor their interests. Instead, they assumed sovereignty over water resources originated in their respective territories. On the

---

<sup>1</sup> Decree of the Supreme Court of the USSR issued on 27 October 1989.

other hand, the midstream and downstream countries of the basin (Uzbekistan, Kazakhstan, and Turkmenistan), where most of the productive irrigated lands are located, were benefited more by the traditional allocation system. Consequently these three countries are emphasizing that water resources should be allocated based on population size or irrigated land area rather than the individualistic will of particular states that neglect the interdependence of water use among riparian countries. Therefore preventing potential conflicts over water resources through efficient and consensual allocation of these resources among multiple sectors and users, including the irrigation water users and natural ecosystems is urgently needed in the basin.

The remainder of the paper starts with the review of hydro-economic modeling studies on market-based water allocation worldwide and water management in the ASB. Then, we demonstrate a detailed description of water scarcity as a result of water sharing conflicts and environmental issues in the ASB. Next we present the comparisons of different water management institutions and justifications for water markets as the most appropriate available tool for efficient water allocation. This is followed by a description of the analytical hydro-economic model of market-based water allocation in the ASB. Further, in the sections 6-8, irrigation benefit functions, environmental benefit function, and the potential gains from market-based water allocations are presented. The last section includes concluding remarks and discussion of the options for accelerating the transformation towards market-based water allocation institutions.



## 2 Literature review

Integration of economic and engineering sciences can enhance the decisions on efficient use of scarce water resources. Differing from other types of water management models hydro-economic models offer options for efficient water allocation while considering economic value of each additional unit of water use in different economic activities and demand sites (Harou et al 2009). When mentioned about early water management studies that combined both engineering and economic aspects of water use it is generally referenced to the works of Jules Dupuit (1844), a French engineer from 19<sup>th</sup> century, who introduced the concept of “consumer surplus” and analyzed both costs and benefits of hydro-infrastructural facilities (Harou et al. 2009). Throughout the 19<sup>th</sup> and 20<sup>th</sup> centuries hydro-economic modeling has gradually developed by including economic concepts in water systems’ analysis. The most visible study which integrated the engineering practices with economic theory was by the Harvard Water Program that included a group of several professors with the backgrounds of hydrology, law, economics, and political science (Maass et al. 1962). This study demonstrated how to model water resource systems as a river node scheme which combines storage and junction nodes connected by conveyance links and represents reservoirs, water diversion points, and river flow (Harou et al 2009). The early applications of economic water demand curves to optimize water allocation were made by Jacob-Bear and colleagues (1964, 1966, 1967, 1970), Rogers and Smith (1970), and Gisser and Mercado (1972) while analyzing water issues in arid regions such as Israel and the south-western United States (Harou et al. 2009). The potential benefits of introducing water markets or charging for water use have also been investigated by several studies. For instance, Hartman and Seastone (1970) theoretically demonstrated the potential economic gains of introducing water markets. Howe and Orr (1974) analyzed tradable water rights taking water quality into account. Vaux and Howitt (1984), Becker (1995), and Easter et al. (1998) found substantial welfare gains from water rights trading. Booker and Young (1994) compared benefits under inter- and intra-state water trading. Rosegrant et al. (2000) developed an integrated hydro-economic modeling framework to analyze interactions between water rights trading and technology adoption in the Maipo river basin of Chile. Ringler et al. (2004) investigated the impacts of upstream hydroelectric power development and inter-basin water transfers on the economies of upstream and downstream water users in the Mekong river basin. Heidecke et al. (2008) and Heidecke and Heckeley (2010) assessed the impacts of water payments on groundwater use, water distribution, and agricultural income in the Middle Draa river basin of Morocco, concurrently considering inter-relationships between surface and groundwater use, water quality, and climate change. Green and O’Connor (2001) analyzed the role of water banking policies to restore endangered species habitat. Bhaduri and Barbier (2008) demonstrated possibilities for beneficial cooperation between India and Bangladesh over sharing water resources of the Ganges and Brahmaputra rivers and protecting environmental systems through benefit sharing based water allocation. While considering the role of geographic dimensions and associated political sovereignties, White et al. (2008) analyzed the institutional structures and implementation mechanisms for water trading and benefit sharing based water transfers. Colby (1990b) emphasized the need to consider transaction costs in evaluating the efficiency of water markets. Differing from the mainstream approach of basin scale water use optimization based on the assumption of a single decision-making organization, a recent study by Cai et al. (2011) presented a multi-agent system modeling framework to analyze water trading in decentralized river basin

management systems. The study by Kuhn and Britz (2012) is noteworthy in this field as the authors developed a theoretical multi-agent model to distribute basin water resources under asymmetric access through transforming multiple optimization problem into mixed complementarity programming format. However, since the model is developed to the case of hypothetical river basin assuming extremely simplified functional relationships for hydrological and economic production processes it is not clear yet how the transformation of modeling format can be done for large and complex hydro-economic models. Despite the fact that substantial potential and real gains from water markets were found in the hydro-economic modeling studies, there is still no common consensus on the inclusion and measurement of environmental benefits and the transaction costs of trading in hydro-economic modeling analyses (Harou et al. 2009).

In the case of the ASB, several studies have addressed the possibilities for efficient and sustainable water use through the application of optimization and simulation (forecasting) models. Modern water allocation issues in the ASB were first addressed in the general water use schemes for the Amu Darya and Syr Darya River basins in the 1960s (UzSredAzGiproVodKhlopok 1983, 1984) and have been revised regularly since then. These schemes were not only based on research results, but also provided a practical guide for the expansion of irrigation, dam construction, and irrigation technology implementation. These models lost their value, however, after the emergence of independent riparian states in the territory of the ASB. Raskin et al. (1992) developed a hydrological model for water supply-demand simulation and water allocation in the basin and studied possibilities of sustainable inflows to the Aral Sea under different water availability levels. McKinney and Karimov (1997) offered a hydrological optimization model with a multi-criteria objective function which aims to reduce water scarcity impacts on irrigation and the environment based on reservoir management strategies. This was the basis for the EPIC (Environmental Policy and Institutions for Central Asia) modeling interface on water allocation. Schlüter et al. (2005) spatially extended the EPIC model and analyzed optimal water use in the deltaic zones of the Amu Darya River. Future water demand and water availability, as well as gross national incomes under different scenarios of climate change ([WEAP21] Savoskul et al. 2003), market liberalization ([WATERSIM] Abdullaev et al. 2009), population growth ([Globesight] UNESCO 2000, [ASBMM] SIC-ICWC 2002, Schutter 2008), income change ([IMPACT] Pandya-Lorch and Rosegrant 2000), and dietary change ([PODIUMSIM] Yakubov et al. 2009) were analyzed using simulation (forecasting) models.

The river basin management was comprehensively analyzed by Cai et al. (2002, 2003a, 2003b) in the case of the Syr Darya River by employing short- and long-term integrated hydrologic-agronomic-economic models. Optimal water allocation was estimated by maximizing the combined benefit of water use in irrigation, hydroelectric power generation, and ecosystems in the short-term model (Cai et al. 2003a). Average fixed benefit per unit of environmental water use was assumed in the model. Because the short-term multi-dimensional model did not capture long-term environmental consequences such as groundwater quality degradation, soil salinization, and consequent yield reductions, a dynamic water resources management model was developed to analyze long-term irrigation sustainability (Cai et al. 2002, 2003b). This model sought to maximize the long-term objective function, which is a linear combination of sustainability criteria that included risk (agricultural and water supply), environmental integrity, equity (temporal and spatial), and economic acceptability. The studies' findings confirmed the necessity for investment in infrastructural improvement and changes in cropping patterns to improve the sustainability

of agricultural production in the basin. Despite the many innovative modeling techniques demonstrated in these studies (Cai et al. 2002, 2003a, 2003b), the results were based on several assumptions and unverified data (Cai 1999:113) and should therefore be interpreted with caution.

Most of the ASB water management models mentioned assume a bureaucratic water allocation system with single decision maker for the entire basin, which optimizes overall basin benefits. However, because river basins are often shared by several countries and provinces water management based on the interests of multiple users is more relevant than assuming management by a single administrative unit (Bhaduri and Barbier 2008). Despite suggestions for developing water markets as tools for efficient water use in decentralized systems, possible gains from introducing tradable water rights in the ASB have not yet been studied.

Our study contributes to the existing research by examining the potential role of tradable water rights for improving water allocation efficiency and ecosystem security in the ASB. Recently developed concepts in international hydro-economic modeling practices such as water markets, inter- and intra-catchment water trading, decentralized water management, and transaction costs are adapted to the case of the ASB. In addition we estimated and incorporated benefits of environmental flow into the Aral Sea and its deltaic zone. To analyze potential economic and environmental impacts of introducing water trading, we developed a hydro-economic model that combines regional and environmental benefit functions with a river node scheme of the ASB.

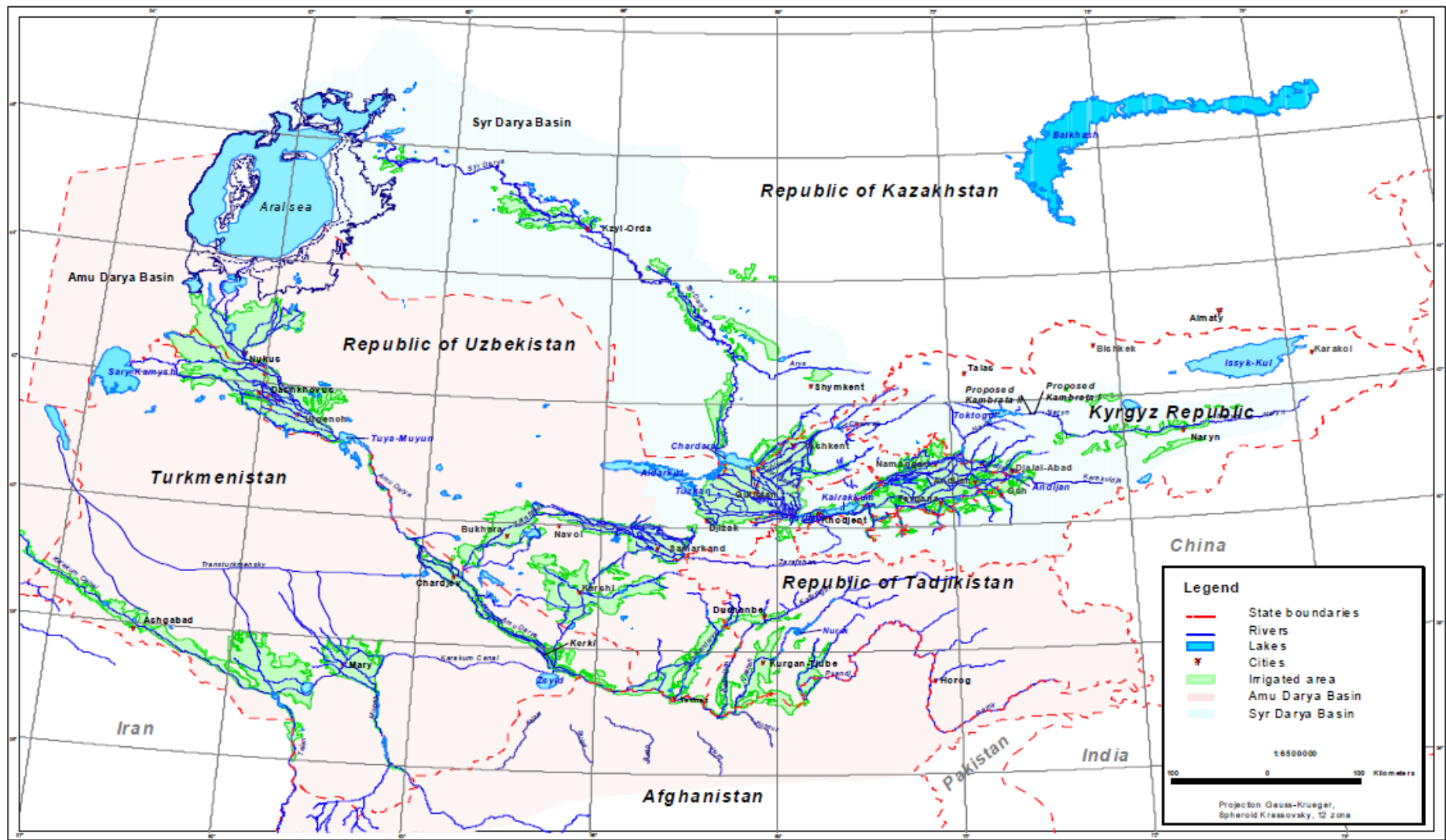
### **3 Water use and scarcity in the Aral Sea basin**

Amu Darya and Syr Darya are two main rivers which are lifeline of the irrigated agriculture and thus lifeline of the economies in the ASB (Fig. 1). Both rivers are started from the tributaries in the Pamir and Tien Shan mountains and flows to the west crossing numerous valleys and Kyzylkum and Karakum deserts finally feeding 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 distinctly 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 of 45° to 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 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% (de Pauw 2007). Precipitation mainly occurs during winter and spring, non-vegetation period. A rate of evapotranspiration greater than average precipitation in summer in most parts of the basin makes crop cultivation possible mainly with the aid of irrigation. Although rainfed areas are important at global level, occupying 80% of crop lands and contributing to 60-70% of the global food basket (Falkenmark and Rockström 2004:67), it is not the case in the ASB. The shares of “green water use”, e.g. direct use of precipitation by crops, in cotton and rice production 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 allowed to the emergence of irrigated agriculture and rural settlements along the rivers over the centuries (Dukhovny and Schutter 2011). Even at present, majority of over 45 million people living in the ASB relies on the incomes from the 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).

**Figure 1** Map of the Aral Sea basin



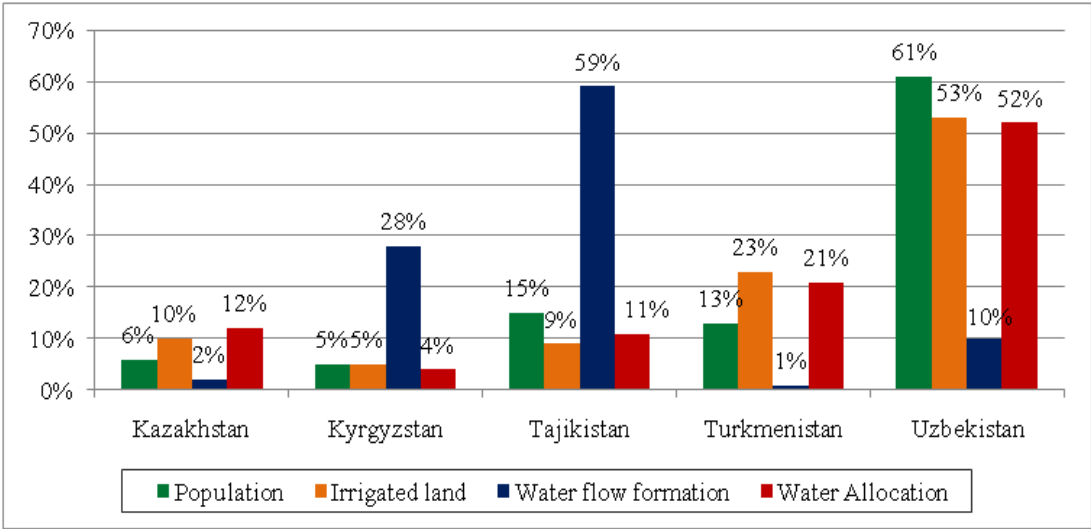
Source: PA Consortium Group and PA Consulting (2002)

Planners and decision makers fully neglected environmental consequences of the irrigation expansion plan (Ashirbekov and Zonn 2003). Even, they stated that any amount of drop to the Aral Sea is nothing than wasting water. Under this policy, the river flows to the Aral Sea decreased or not delivered at all in some water scarce years. In consequence, the sea resized to its one tenth volume and one fourth surface area between 1960 and 2006 (Micklin 2007). In parallel to the Aral Sea desiccation, fish production and ship navigation is also ceased in the sea. The area of wetlands in deltaic zone, which is valuable not only because of fish production ponds and wood resources but also because of being habitat for many types of animals, birds, and plants, thus supporting biodiversity, is decreased from 550,000 to less than 30,000 hectares (TEEB 2011). In addition to these benefit losses spread of toxic salts from the dried bed of the Sea through the winds reduced crop and livestock yields damaging soil productivity and degraded the health of population (INTAS 2004).

Aftermath of the independencies, the emergence of five independent Central Asian states with contradictory interests led to the interstate conflicts over sharing water resources and regulatory water infrastructure. The conflicts were arisen as water resources are distributed unevenly across the nations. Almost 90% of the basin water resources are formed in the mountains of Kyrgyzstan and Tajikistan whereas 10% comes from Uzbekistan and only 1% from each of Kazakhstan and Turkmenistan (Fig. 2). However, favorable soil-climate conditions and availability of lands and labor force in the mid- and down-stream river reaches of Uzbekistan and Turkmenistan allowed the development of irrigated agriculture in these zones. Consequently more than the half of total water resources were consumed in Uzbekistan and one fifth in Turkmenistan during the Soviet period. However, aftermath of the independence, upper-stream water-rich countries claimed for more water use rights while down-stream countries wished for fair water allocation based on either population size or irrigated area share.

Resource-poor but water-rich Kyrgyzstan and Tajikistan have also ambitious plans of extending their irrigated lands despite the limitedness of lands available for irrigation while neglecting down-stream livelihoods and ecosystems. Moreover, these countries attempt to reserve water in summer time to release it to generate hydro-energy to satisfy increased energy demands for heating during winter period. However, water-dependent but resource-rich countries Uzbekistan, Kazakhstan, and Turkmenistan have a pick water demand for irrigation during the summer period. Consequently, in the downstream areas, less water is available for irrigation in summer season while flooding is frequent in winter season alleviating irrigated lands and damaging irrigation infrastructure (Dukhovny and Schutter 2011). 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 upstream regions of Tajikistan but only 40% and 45% in downstream regions – Dashauz (Turkmenistan) and Karakalpakstan (Uzbekistan) respectively (Dukhovny and Schutter 2011:277). The situation requires a clear concept that allows more efficient and fair water sharing among the water users particularly in the vegetation season considering also environmental water demands.

**Figure 2** Distribution of water flows, water use, land, and population in the ASB



Source: McKinney 2004, author’s presentation

## **4 Market-based water allocation as an alternative to other water allocation mechanisms**

### **4.1 Water allocation institutions**

The existence of multiple water users sharing the river basin water resources necessitates setting rules of water allocation among these users to avoid conflict between users. This task is particularly challenging under conditions of water scarcity and should consider social and environmental impacts of water allocation decisions. Water allocation options can be grouped as centralized (top-down) and decentralized (bottom-up) approaches according to the type of governance. In centralized water allocation a single administrative unit (usually a government) takes control over water resources use and allocation. In contrast the decentralized approach provides more opportunities to water users to participate in decision making processes and to cooperate with each other. However, this is not the only way of classifying water allocation options. Dinar et al. (1997) distinguished four types of water allocation mechanisms and described their advantages and disadvantages (Table 1):

- 1) Marginal cost pricing;
- 2) Public (administrative) water distribution;
- 3) Water markets;
- 4) User-based allocation.



**Table 1 Water allocation mechanisms**

<b>Water allocation mechanism</b>	<b>Description</b>	<b>Centralized (CD) or Decentralized (DCD)?</b>	<b>Advantages</b>	<b>Disadvantages</b>
Marginal cost pricing	Targets a price for water equal to the marginal cost of water supply	CD	Theoretically efficient; prevents water overuse under conditions of drought	Difficult to estimate correct marginal cost; neglects equity; requires volumetric monitoring (which is very costly)
Public (administrative) water allocation	State decides what water resources should be used and allocates and distributes water among users	CD	Can promote equity; can protect the poor; can consider environmental needs	Does not take into account the value of water in time and space and generally fails to allocate water to the highest value
Water markets	Referred to as a trade of water (use) rights	DCD	Induces efficient water management; empowers water users	Difficulties in measuring water, defining water rights when flows are variable, and investing in conveyance system; third party effects; need for and difficulty of considering transaction costs
User-based allocation	Based on collective action institutions with authority to make decisions on water rights	DCD	Flexible to adapt water delivery patterns to meet local needs; administratively feasible and sustainable; politically acceptable	Requires a very transparent institutional structure; effectiveness for inter-sectoral water allocation is limited

Source: Adapted from Dinar et al. (1997)

Marginal cost pricing is characterized by charging for water use based on the marginal cost of each additional unit of water supply. Since this option equates the marginal value of water with its marginal cost, it is considered an economically efficient way of determining water allocation. Marginal cost pricing can be applied to develop differential prices based on water quality and reliability (i.e., higher prices for water supply of higher-quality or higher reliability). Advantages of this approach are its theoretical efficiency, its ability to reflect the scarcity of water and to prevent water overuse, and its implementability and compatibility with efforts to collect pollution and tax charges. Disadvantages include the difficulty of estimating marginal cost values, the neglect of equity issues, and implementation difficulty due to the requirement for volumetric monitoring; and in the case of canal irrigation systems, general lack of reliability of water supplies.

Public water allocation is characterized by the dominant role of government intervention in granting permits to use different sources of water, and allocating and distributing water. Public distribution is usually associated with physical water use norms and political influence. Public intervention in water resources development and management is justified since water is common resource belong to an entire community and the investment costs of water development are usually beyond the capacity of private sector actors. Advantages of this approach are that public water allocation can promote equity objectives, can help protect the poor, and can help to ensure water supply for environmental needs. Disadvantages of public options are that water prices, if charged, do not reflect the real value of water, leading to water overuse or misallocation, and the option, unless linked with economic objectives, does not create incentives for users to use resources efficiently.

Market based water allocation relates to introducing tradable water use rights. Water markets can provide additional water supply for high value uses without developing new sources and create incentives for more efficient water use by compensating for sales of water normally used for less valued uses. The necessary conditions for establishing formal water markets generally require government intervention, including: (1) defining initial water use rights for each user, (2) organizing the institutional and legal framework for trading, (3) and building necessary basic infrastructure for water transfers (Holden and Thobani 1995). Rosegrant and Binswanger (1994) enumerated several advantages of market based water allocations, such as: (1) empowering water users by considering their interests in water reallocation and compensating for sales, (2) increasing water rights tenure security, which incentivizes investment in water-saving technologies, (3) providing opportunities to gain additional benefits through the sale of water saved through increased efficiency, (4) providing incentives for water users to consider external costs caused by their water use, and (5) greater acceptability among water users relative to volumetric pricing, which is generally seen as expropriation of traditional water use rights. Water trading can occur among the users at the scale of the small sub-catchment as well as at the entire river basin scale. Additionally market based water allocation is more responsive to climate, crop price and water supply changes than centralized water allocation (Dinar et al. 1997). Disadvantages of market based systems are derived from difficulty of measuring water volume, difficulty of defining initial water use rights when water flows are variable, necessity to invest in water delivery infrastructure, and third party effects of changes in return flows.

User-based allocation of water resources requires collective action institutions with the authority to regulate water use rights as evidenced by farmer-managed irrigation systems (Dinar et al. 1997). A wide variety of rules for water distribution exists within such systems

such as rules based on timed rotation, water depth, land area, or flow share restrictions (Yoder 1994). The effectiveness of the system largely depends on social norms and the power of local institutions (Dinar et al. 1997). The advantages of the system are its adaptability for meeting local needs, feasibility of administrative regulation, and acceptability to government. Disadvantages include the size limitation of farmer-based systems, usually restricted to local communities, the challenge to deal with inter-sectoral water allocations, and the need for very transparent institutions. Elite capture is also possible in such systems.

Summing up, although all water allocation institutions have advantages and disadvantages while being relevant at different scales (local, national, basin), water markets have the potential to improve allocation efficiency, and are particularly relevant for basin water management.

#### **4.2 Conceptual framework: water market mechanism, initial water rights, and transaction costs**

Increased competition among water users for limited water supply in river basins necessitates effective water allocation institutions that provide efficient, equitable, and sustainable distribution of water resources. Traditional administrative methods of water allocation have been based on the consideration of water as a public good. However, water overuse and misallocation, increased costs of developing new sources, and poor quality of public agency services point the need for alternative ways of efficient water allocation and management. Water markets offer a very suitable mechanism for incentivizing water users to increase water use efficiency.

Additional gains from water trading are feasible because of the heterogeneity of the economic value of water and the variation of marginal water profitability across the water user sites, and the differential water needs by sector across space and time. In addition to economic efficiency, equity in water distribution can also be addressed through compensation for low efficiency or low-value users who voluntarily transferred their water (use) rights to more productive users. In river basins shared by several states such as the ASB, upstream users generally tend to divert abundant water to meet their internal demands, releasing less water than the required amount to downstream users and environmental systems in dry years (Sokolov and Dukhovny 2002, Müller 2006). Tradable water use rights under these conditions may lessen the burden of scarcity by compensating less productive water users through sales and benefiting more productive water users through increased water availability. As a result the overall benefit to water use in the basin can be increased without making any user worse off.

While water markets have strong advantages for incentivizing the most productive water uses under scarcity conditions, their establishment requires clear, secure, and transferable water use rights. Despite several attempts to develop general rules for sharing river basin resources based on principles of equity, reasonability, sustainability, and optimality (ILA 1966, UNECE 1992, UN 1997), there is no universal guideline or legal treatment for establishing initial water use rights. The following major principles of water use rights are practiced in different river basins (Wolf 1999):

- 1) *The doctrine of absolute territorial sovereignty (or the Harmon Doctrine)*: often claimed by upstream regions and reserves states' rights to control water resources within national territory without regard to effects on other regions/users;
- 2) *The doctrine of natural water flow (or absolute riverine integrity)*: bases access rights on natural river flow crossing users territory;
- 3) *The principle of prior appropriation (First come, first serve)*: bases water use rights on historical use;
- 4) *The principle of community of interests* treats a river basin as a unified economic system and implies allocation of water to maximize benefits of all riparian regions in an integrated manner;
- 5) *The principle of equitable utilization of river waters* bases water access rights on the equitable allocation through mutual agreements, usually with regards to the size of user populations.

The selection and implementation of these rules depend on basin hydrography, historical water use patterns, social values, and the political authority of the distinct users.

The transaction costs of establishing and maintaining water markets are also essential for evaluating overall economic gains from trading and choosing policy instruments. Transaction costs occur due to conducting research, seeking information on potential buyers and sellers, designing and implementing water trading rules, coordinating and administering water transfers, monitoring water use and distribution, and enforcing agreements (McCann and Easter 2004). The level of transaction costs varies depending on physical attributes of water use, water related institutions, and the general institutional environment (McCann and Easter 2004). Physical attributes include the availability and conditions of irrigation infrastructure, reliability of the water supply, the size of transfers, effects on third parties, and water attributes (quality, quantity, temporal, and spatial). Water related institutions that impact transaction costs include: existing (initial) water rights regimes, the power and rent seeking behavior of participating parties, and the existence of conflict resolution and contract enforcement mechanisms. Transaction costs are also influenced by the factors of institutional environment such as the governance system, the legal system, social norms and social capital.

Due to heterogeneous physical and institutional conditions and due to including different elements into the calculation of such costs, transaction costs vary by country and study. For example transaction costs in the western United States averaged 6% of the price paid for water transfers (Colby 1990b). The overhead costs paid by the State Department of Water Resources for the California Water Bank were nearly 8% of the total costs of purchasing water (Howitt 1994). Water transaction costs incurred by farmers in Chile were 7-23% of the price of water transfers (Hearne and Easter 1995). In Australia expenditures on water transfers varied from 3% to 12% of the price of water entitlements (Challen 2000, ACG 2006). Water trading is only justifiable if its transaction costs are lower than the additional gains by water market participants. Once transaction costs are low enough and the initial water rights are established consensually, water markets can provide mutually beneficial water transfers.

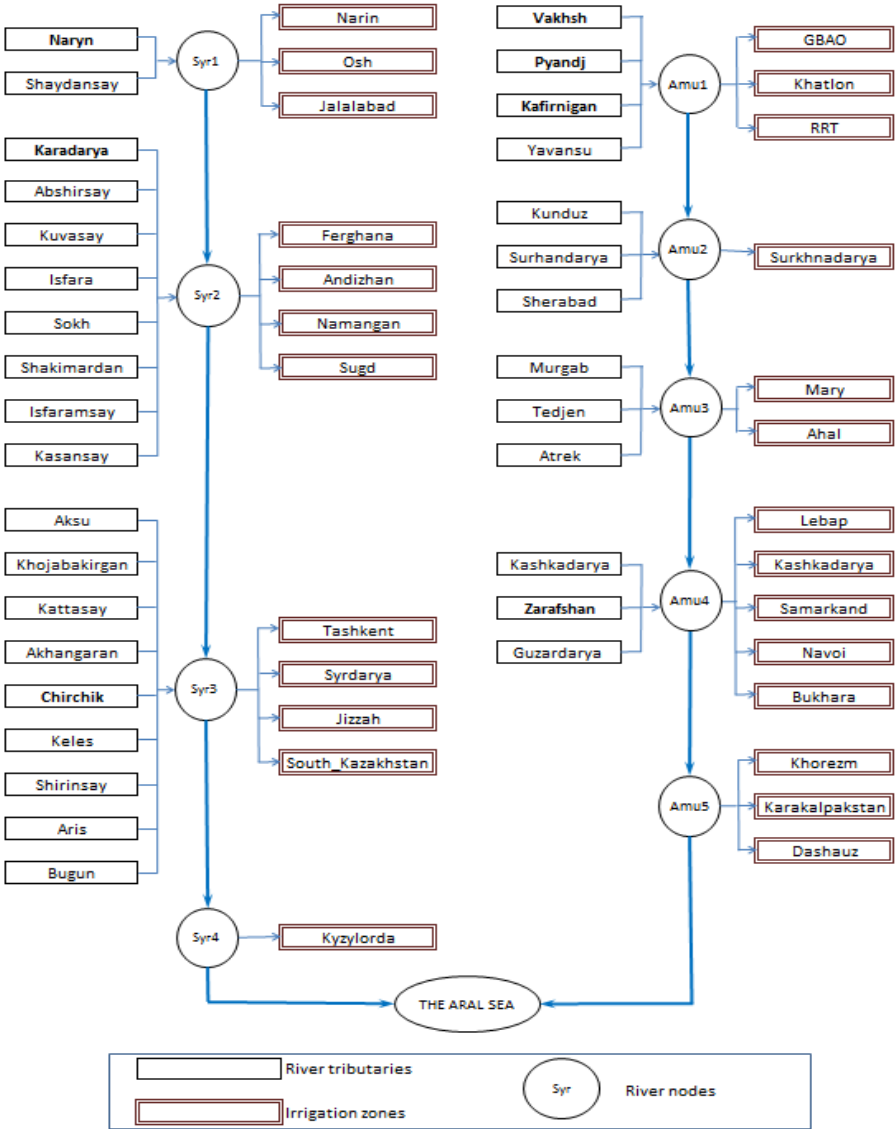
# 5 Analytical framework

## 5.1 River network scheme

Potential benefits from water market based water allocations in the ASB were analyzed using a hydro-economic model. To model river flow and off-takes along the river system, a river network scheme is developed. 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 are delineated in the ASB river network scheme (Figure 3).

Administrative regions rather than hydrologic irrigation units are used as water using units based on 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 scheme. These regions were grouped into single water catchments (river nodes; *Syr1...Syr4*; *Amu1...Amu5*) according to their proximity to one another.

Figure 3 The Aral Sea basin river network scheme



Due to the priorities of municipal and industrial sectors in water use and allocation, and the fact that agriculture accounts almost 90% of total water consumption (SANIIRI 2004), water allocation to municipal and industrial use is considered as exogenous and fixed, and water trading are analyzed only among the irrigation zones. Since model focused on the potentials of water rights trading among the irrigation zones to attain socially optimal benefit and considered only one vegetation period (the period from April to September) without monthly time-steps, reservoir management and electricity production which requires at least monthly time interval 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 interrelated. 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. Alternatively a model that considers direct water trading and implies face to face water trading agreements among the users was also developed, but the results were not reported here since they were only slightly different from the results of the model with a basin unit that organizes water trading. This kind of model allows analyzing also water trading under asymmetric power through availability of higher than-free market prices for water selling agents in which case water buyers accept the price offered by the sellers. However, since we have multiple water users, the results of the decentralized trading with asymmetric power did not differ much from the results of centrally organized water trading assuming a single basin management organization that buys and sells water use rights.

## 5.2 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:

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

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 irrigation water user site ( $dm$ ) and municipal-domestic water use 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 regions ( $WD_{dm}$ ):

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

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

Economic values of the inflows into the Aral Sea and deltaic zones are estimated based on the literature (see section 5.3 for more details). A linear relationship between the environmental flow ( $Env_w$ ) and benefit ( $Env_{ben_{dm}}$ ) is elaborated as:

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

where  $b0$  and  $b1$  are parameters of the regression function and the environmental flow ( $Env_w$ ) is the sum of the inflows from the Amu Darya (the node link "Amu5 → THE ARAL SEA") and Syr Darya (the node link "Amu5 → THE ARAL SEA") rivers into the Aral Sea.

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

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

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 paid by both the buyers and sellers of water.

The shadow price of water was derived directly from the water benefit function considering transaction costs ( $tc$ ) of water trading:

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

or

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

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 or 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 water distribution in the baseline year (Cai et al. 2006).

### 5.3 Estimation of the economic value of inflows to the Aral Sea and deltaic watersheds (environmental benefit)

An approximate general environmental benefit function was estimated by combining the benefit functions of different ecosystem services such as wetlands, recreation, agriculture, health, fishing, and shipping (navigation). The area of wetlands is assumed to be dependent on river flows, while the benefits from the remaining ecosystem services are dependent on the volume of the Aral Sea. The benefit functions of separate ecosystem services were estimated by regressing the literature-survey based benefits with the inflows to the Aral Sea. In order to find relationships between river flow and the benefits of volume-dependent ecosystem services, the relationship between the sea volume and the inflow amount required to stabilize this volume was initially estimated. Due to the data limitations only linear relationships for the environmental benefit functions were assumed. Therefore, environmental flow estimations are just rough estimates based on the available limited dataset and thus requires a further improvement. As the environmental benefit estimates were available at the price levels of different years they were converted to the prices of 2006 considering annual inflation rates.



### *Stabilizing environmental flow*

The water balance in the Aral Sea stipulates that the annual change in volume ( $V$ ) is the difference between the sum of environmental inflow and rainfall ( $RF$ ) and evaporation ( $EP$ ) in year  $t$ :

$$\frac{dV}{dt} = Env\_w + RF - EP \quad (10)$$

We assumed that rainfall over the sea does not depend on the Aral Sea volume and inflows, evaporation is a function of sea volume. Considering the stability of the Aral Sea volume over the long term ( $\frac{dV}{dt} = 0$ ), the relationship between volume and stabilizing inflow ( $Env\_w^*$ ) is as follows:

$$Env\_w^* + RF - EP(V) = 0 \quad \Rightarrow \quad Env\_w^* = RF - EP(V) \quad (11)$$

### *Wetlands*

The area of wetlands decreased from 550,000 ha to 27,500 ha during the period between 1960 and 1990 (TEEB 2011). According to a meta-analytic value function analysis (Brander et al. 2006), the estimated annual economic loss due to the decreased size of wetlands was around US\$ 190 per hectare or US\$ 100 million in total (TEEB 2011). The meta-analytic function analysis is based on the comparability of ecosystem values in the regions with similar wetland types and sizes, GDP per capita, and population density. Estimated ecosystem values across different project sites over the globe are regressed on physical and socio-economic parameters of the wetlands and this model is used to extrapolate unknown wetland values in the non-investigated sites. Based on this meta-analytic function from the literature and wetland area data, wetland economic values over the years in the ASB were first assessed. Then these values were regressed with annual environmental flows in order to estimate the relationship between environmental flow and wetland economic values. Maximum wetlands areas in 1960s were a basis for estimating potential wetland benefits and thus build a piecewise linear function.

### *Tourism*

Tourism was well developed on the shores of the Aral Sea in the 1960s. About 50,000 people were visiting the site with an average stay of five days, during which they spent around US\$ 45 per day in 1960 (INTAS 2004). These numbers were a basis to calculate potential income from tourism in the surroundings of the Aral Sea. Substantial losses in tourism income occurred due to the desiccation of the Sea. By 1990 the number of tourists had decreased to about 5,000 people yet their expenses had doubled. Based on tourism incomes in 1960 and 1990, a piecewise linear touristic benefit function that depends on environmental inflow.

### *Health*

Health benefits were assessed based on benefit losses because of health degradation due to the desiccation of the Aral Sea. Health benefits were assumed to be zero in 1999, and equal to the average annual benefit losses due to the health degradation between 1960 and 1999 in 1960. It was assumed also that health levels in 1960 cannot be influenced by further increase in the Aral Sea volume. Annual benefit losses due to health degradation amounted to US\$ 5.2 million, of which US\$ 1.7 million were due to increased frequency of illness and US\$ 3.5 million were due to reductions in life expectancy (INTAS 2001, 2004). The benefit losses due to increased illnesses were estimated based on the loss of working days and associated income, while the benefit losses due to reduced life expectancy were quantified based on per capita GDP losses and shortened life duration (INTAS 2001, 2004).

### *Agriculture*

The spread of toxic salts from the dried bottom of the Aral Sea is one of the main causes of reduced yields, degraded lands, and decreased crop production in the surrounding regions. An estimated total of US\$ 22 million per year in average in agricultural benefit losses occurred between 1970 and 1997 according to INTAS (2001, 2004). As in the case of the health benefit assessment, agricultural impact benefits were evaluated on the basis of benefit losses due to yield reduction. No benefits were assumed in 1997 and the benefits in 1970 were equal to the amount of annual average benefit losses. A piecewise linear relationship between stabilizing inflow and agricultural benefits were estimated.

### *Fishery*

The Aral Sea's commercial fishery was a backbone of the regional economies in the Amu Darya and Syr Darya deltas in the past, employing about 40,000 people and producing more than 15% of the SU's seafood catch. The average annual harvest was up to 50,000 tons before the 1960s. However, the fishery collapsed in the Southern Aral Sea by the mid-1980s and decreased to 2,000 tons in the Northern Aral Sea due to the shrinkage of the Sea (UNEP and ENVSEC 2011). Fishery benefit functions were built by regressing annual stabilizing inflow and total fish harvest benefits while considering average profits of 264 US\$ per ton in the fishing sector, which was estimated based on fish production cost-benefit data (Timirkhanov et al. 2010).

### *Shipping (Navigation)*

Marine transportation was well developed branch in the deltaic regions of the ASB. Annual cargo traffic between the ports of Aralsk and Muynak was about 2.5 million ton/km in the 1960s (Zonn 2010). The value added per ton of transportation was around US\$ 0.5 (INTAS 2005). Due to the desiccation of the sea, marine transportation decreased by a factors of eight by 1978, and the ports were closed in 1979 (INTAS 2004). Approximate navigation benefits were calculated based on the cargo traffic volume and value added per unit of transportation. A piecewise linear relationship between shipping benefits and environmental inflow was estimated.

### *Limitations*

It is important to note here that the estimations here addressed primarily the direct use values of the inflows to the Aral Sea and its delta. In addition to the direct use values of environmental flows such as fishery and shipping, indirect use values such as providing habitat for wild life is also important for sustainability (Dziegielewska et al. 2009). Overall environmental benefits also include the non-use values of water (Dziegielewska et al. 2009) such as option values, existence values, and bequest values. Option values which can be grouped also as direct use values reflect the potential use of the environmental resources in future which can be exemplified by the will to have the goods in the future for the biodiversity preservation. Existence value is existent as many people want and ready to pay for the protection of habitats of the endangered species which are under the threat of extinction. Bequest value related to the will of preserving the certain environmental goods for future generations at the same quality as we are using them. The share of the non-use values of the ecosystem services in total environmental benefit usually are over 50% but in some cases even reaching 80-98% (Dziegielewska et al. 2009). Therefore, the limitation of this study by underestimating the real values of the environmental flows neglecting non-use values should not be forgotten.

### **5.4 Data sources**

Data on cultivated land area, irrigation water use, and yields are obtained from the CAREWIB database (SIC-ICWC 2011) which is 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 ObIselVodKhoz (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).

Data on rainfall, evaporation, and environmental flows to the Aral Sea from the Amu Darya and Syr Darya are obtained from INTAS project reports (2001, 2004, 2006). Economic benefit levels and losses of the 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).

### **5.5 Scenarios**

*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 flow in 1999, a year with normal water supply. The year was chosen based on the average value of the observed water supplies 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 the normal supply.

Baseline scenario is based on water distribution on fixed water use rights which were derived according to fixed water use shares as of 1999. Optimization scenario was run to show the ideal water distribution case in economic terms as a target for water users. The latter scenario did not consider water trading possibilities thus the objective function (5.33) was changed properly:

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

#### *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. 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 income levels of different water users. Trading scenarios were also compared to the results of the optimization scenario to show how much they distort from the ideal case. Intra-catchment or restricted (RWT) water trading means that water transfers are allowable only among the water users within a catchment (a node, see Figure 3). Inter-catchment or unrestricted (UWT) water trading can occur freely among the water users located in different catchments.

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 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 the scenario analysis. 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 between US\$ 0 and US\$ 0.1/m<sup>3</sup> per water transaction volume. Similar to the case in the theoretical model of Challen (2000), transaction costs were assumed to be paid at equal amounts by both the sellers and buyers.

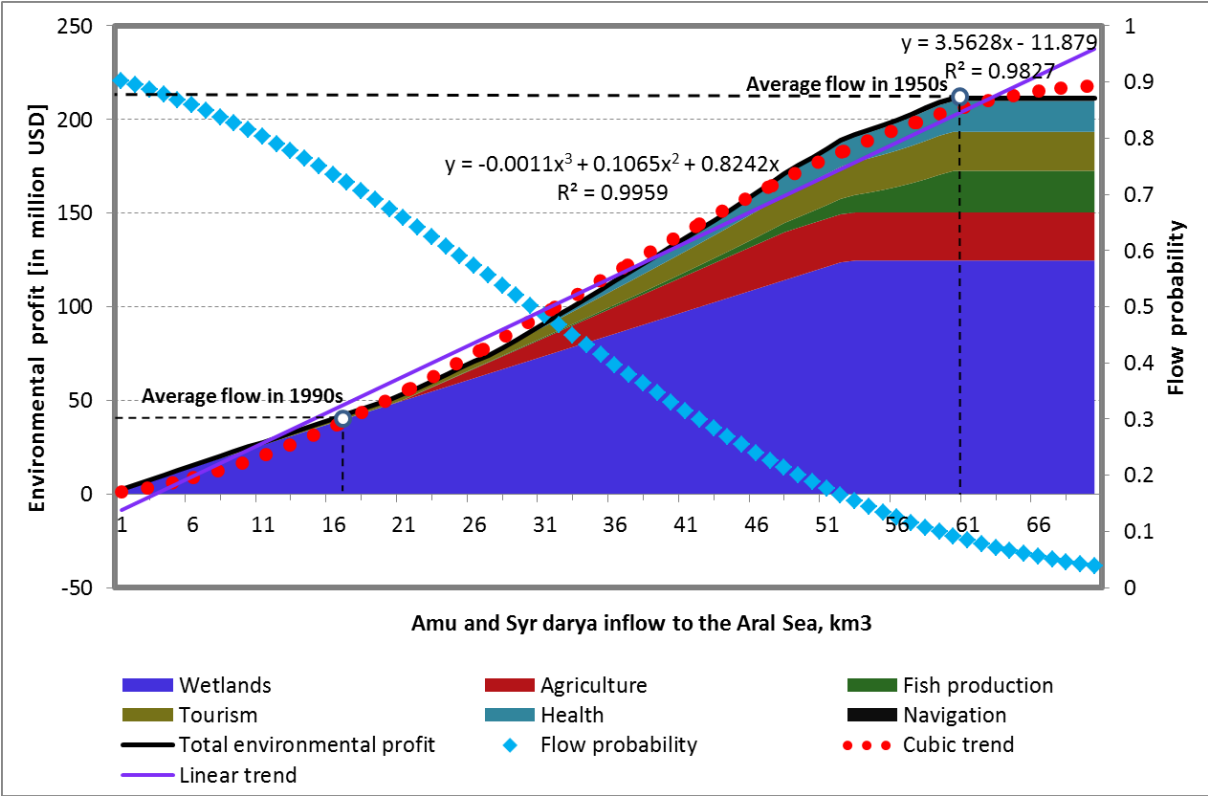
## 6 Benefits from inflows to the Aral Sea and deltaic zones (environmental flow)

Several studies discussed the benefits from the Aral Sea while emphasizing the importance of fish production, shipping (navigation), biodiversity, wetlands, and public health (Micklin 1988, 2007, 2010, Mirzaev 2000). However, only a few studies (INTAS 2001, 2004, TEEB 2011) quantified approximate economic losses due to the degradation of ecosystems. Estimation of an environmental benefit function for the Aral Sea based on the results of the latter studies showed a substantial contribution of wetlands to total environmental benefits (Figure 4). Profits from navigation in the sea were negligible. Crop yield improvement due to decreased land salinization and the revival of tourism can provide annual revenues of US\$ 26 million and US\$ 21 million respectively if average annual inflows to the Aral Sea are at least 50 km<sup>3</sup>.

The average flow into the Aral Sea decreased from 61 km<sup>3</sup> to about 17 km<sup>3</sup> during the period between the 1950s and 1990s. As a result the annual benefits from activities linked to the level of the Aral Sea decreased from US\$ 211.4 million to US\$ 42.8 million, consequently causing annual economic losses of almost US\$ 170 million (at 2006 prices). This estimation is comparable with the previous estimation of US\$ 144 million (at 2000 prices) by INTAS (2001).

The average economic benefit from each additional m<sup>3</sup> of water (marginal water productivity) to the Aral Sea is about US\$ 0.0036 as derived from a linear environmental benefit function. The cubic function fits better than the linear function to reflect the relationship between environmental flow and benefits. However, the R<sup>2</sup> values of fit only slightly differ between R<sup>2</sup>=0.996 for the cubic function and R<sup>2</sup>=0.983 for the linear function. The linear functional form was chosen for further modeling calculations due to its simplicity and sufficiently high R<sup>2</sup> value. Alternatively, choosing a cubic function for representing the environmental benefit function has less practical value since it has negligible influence on the model results if environmental flow varies between 0 and 60 km<sup>3</sup>. The probability of more than 60 km<sup>3</sup> of water inflow to the Aral Sea is negligible according to the observations between 1960 and 2000 (Figure 2.19). The latter boundaries for the environmental flow were considered in the integrated hydro-economic model.

Figure 4 Environmental benefit function



## 7 Benefits from irrigated agriculture

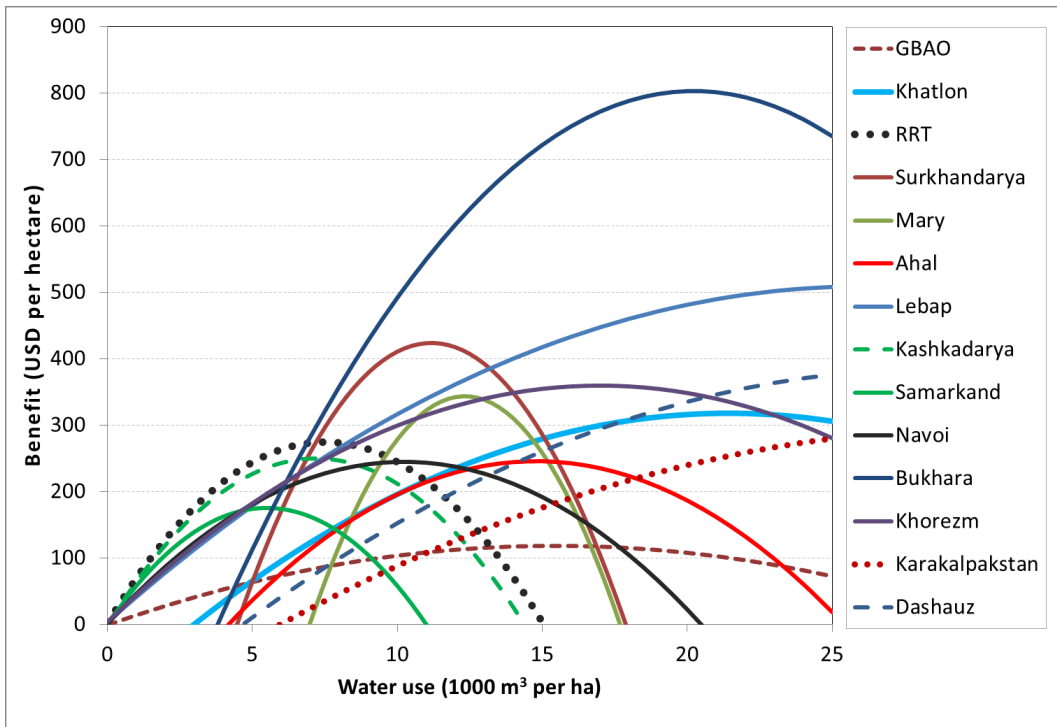
Regression functions for the relationship between per hectare average profit and per hectare water use were used to estimate aggregated irrigation benefit functions for each region (Table 2; Figure 5 and Figure 6). Irrigation benefits vary across the regions of the ASB due to differences in yields, crop patterns, per ha water use, and land availability. Highly productive but more water consumptive zones are located in the midstream and downstream reaches. In contrast, although high water productivity lands are also available in upstream regions, the potential for irrigation in these areas are very limited.

**Table 2 Irrigation benefit function parameters**

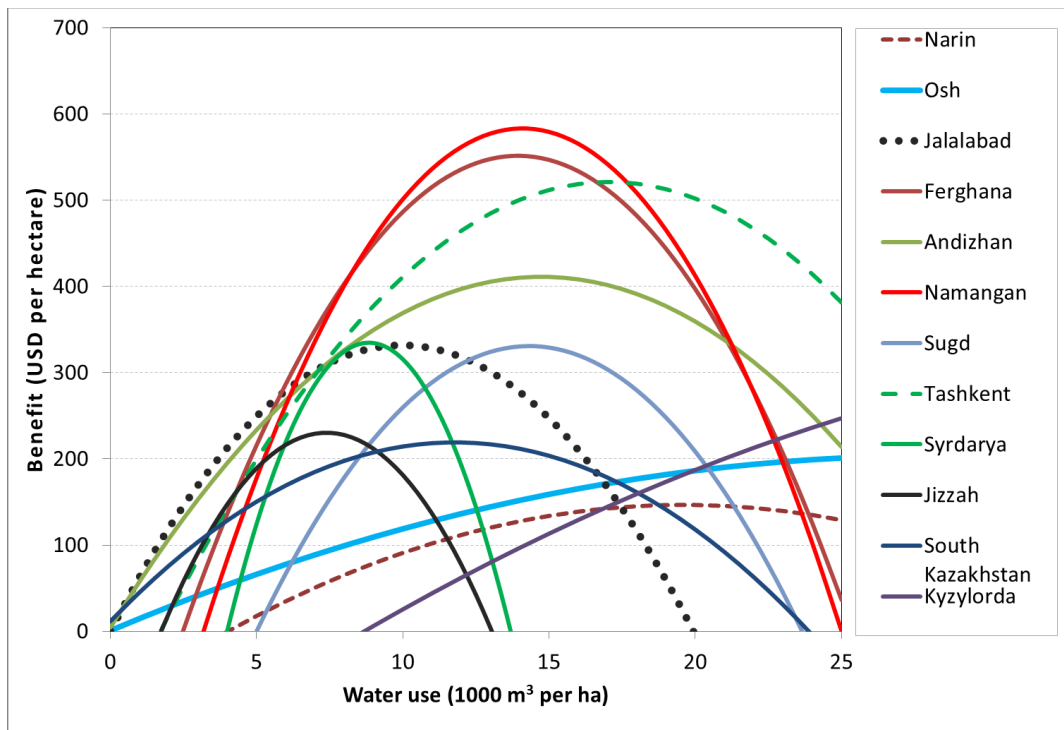
Regions	River node (catchment)	Constant - a0	Linear coefficient - a1	Quadratic coefficient - a2	Coefficient of determination - R <sup>2</sup>
GBAO	Amu1	-1.16	15.47	-0.50	0.71
Khatlon	Amu1	-111.44	40.08	-0.94	0.93
RRT	Amu1	2.23	72.53	-4.83	0.87
Surkhnadarya	Amu2	-752.80	210.58	-9.42	0.75
Mary	Amu3	-1477.07	295.37	-11.98	0.79
Ahal	Amu3	-231.51	64.52	-2.18	0.84
Lebap	Amu4	3.56	38.70	-0.74	0.74
Kashkadarya	Amu4	-0.27	69.55	-4.84	0.85
Samarkand	Amu4	0.40	63.63	-5.79	0.93
Navoi	Amu4	1.02	47.65	-2.33	0.92
Bukhara	Amu4	-414.72	120.45	-2.98	0.69
Khorezm	Amu5	3.79	41.87	-1.23	0.83
Karakalpakstan	Amu5	-158.66	29.43	-0.48	0.86
Dashauz	Amu5	-164.97	38.47	-0.67	0.85
Naryn	Syr1	-85.47	23.69	-0.60	0.77
Osh	Syr1	0.79	14.34	-0.25	0.86
Jalalabad	Syr1	0.07	66.56	-3.34	0.99
Ferghana	Syr2	-264.68	117.17	-4.21	0.90
Andizhan	Syr2	4.59	55.19	-1.87	0.96
Namangan	Syr2	-390.02	138.13	-4.90	0.84
Sugd	Syr2	-449.61	108.96	-3.80	0.97
Tashkent	Syr3	-122.78	75.53	-2.21	0.91
Syrdarya	Syr3	-778.24	251.84	-14.25	0.74
Jizzah	Syr3	-162.92	106.44	-7.20	0.52
South Kazakhstan	Syr3	16.70	25.77	-0.91	0.63
Kyzylorda	Syr4	-191.91	24.53	-0.28	0.75



**Figure 5 Estimated irrigation benefit functions across the regions of the Amu Darya basin**



**Figure 6 Estimated irrigation benefit functions across the regions of the Syr Darya basin**



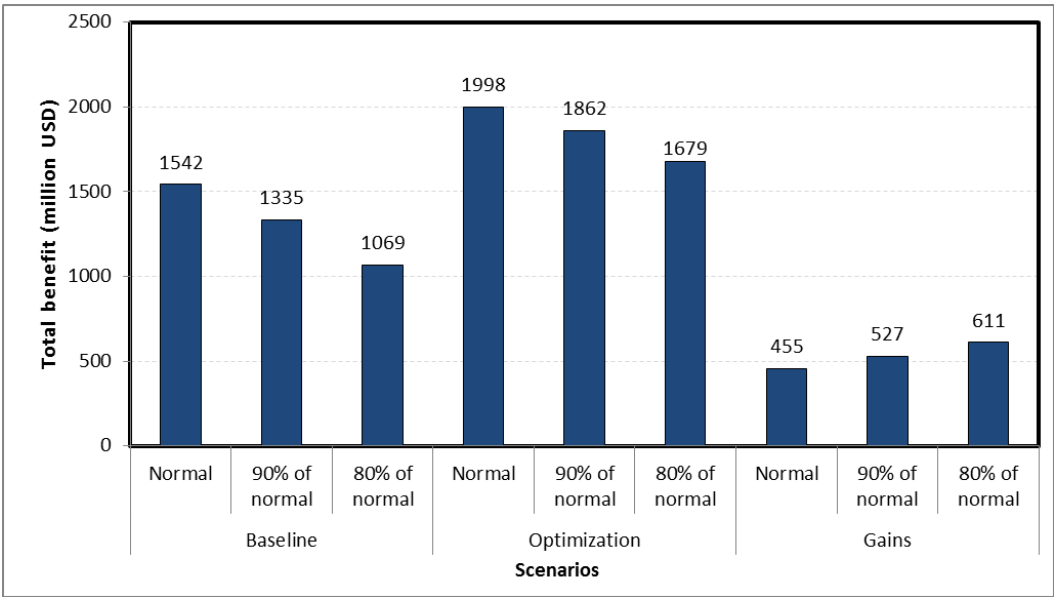
## 8 Optimal water allocation and water trading

The benefit functions developed and the hydrological river basin model were combined into a single modeling framework to evaluate economically optimal water allocation in the ASB. First, the benefits under fixed water rights and optimization scenarios were compared. Next, because optimization is not favorable to some water users, particularly upstream ones, optimal water allocation was estimated when water trading is allowable among the users and the ecosystem. Considering that water trading is more feasible among neighboring regions that share a single water catchment, the benefits from intra-catchment water trading were also assessed. In the end the impacts of different transaction cost scenarios on the gains from water market were analyzed.

### 8.1 Baseline (fixed water use rights) vs. optimization

Although the costs of establishing an omniscient 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. The results indicated 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 7). This signifies additional economic benefits of US\$ 450 million to US\$ 610 million compared to the baseline (fixed water use rights) benefits.

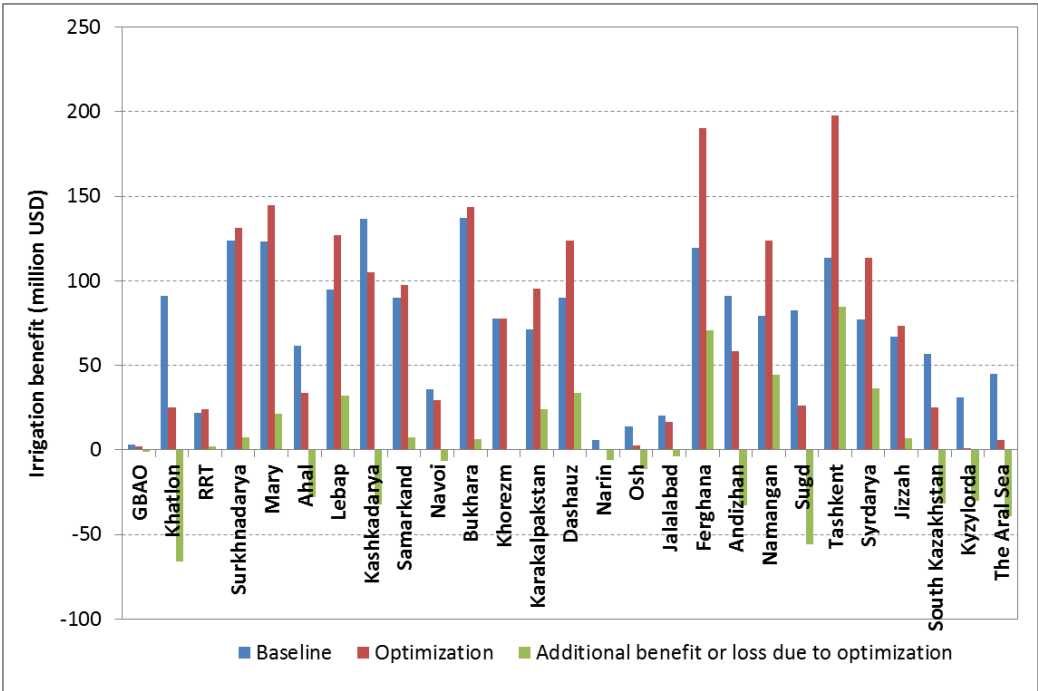
**Figure 7 Total water use benefit under baseline and optimization scenarios at different levels of water availability**



Despite substantial increases in basin-wide water use benefit under optimization benefits were not equally distributed for all regions, i.e., while some users got higher benefits from

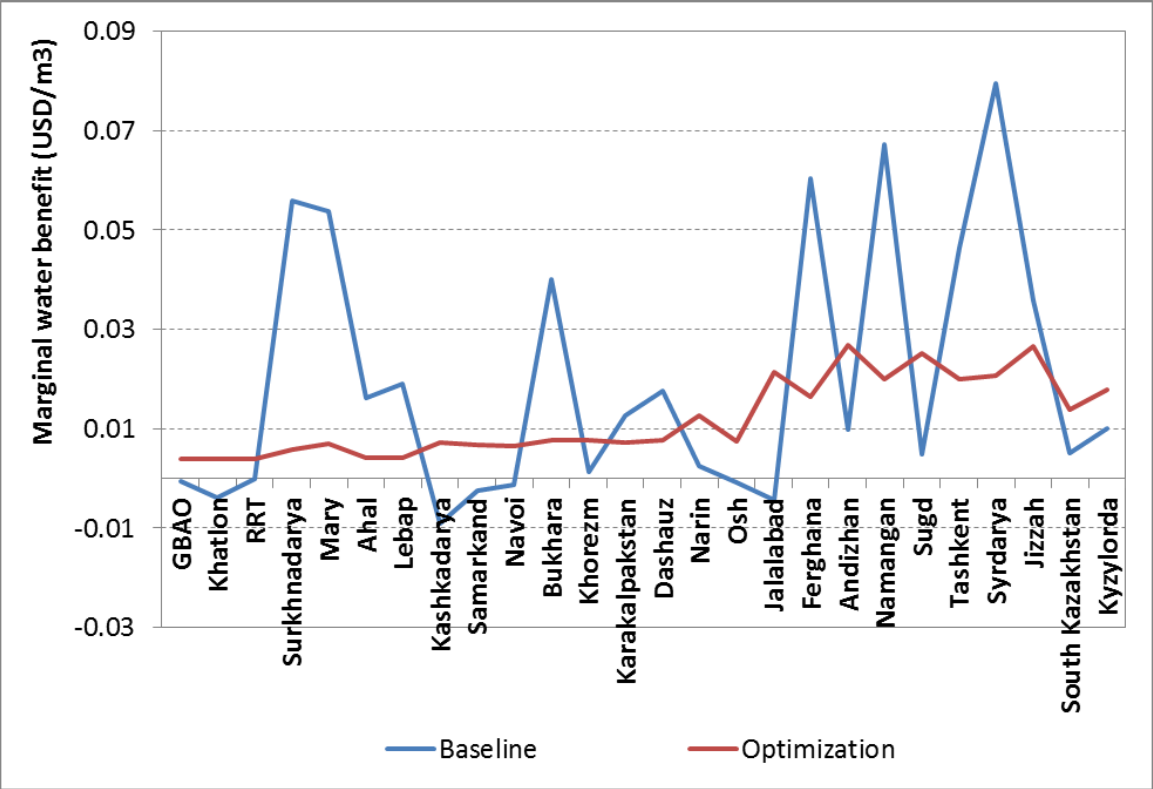
optimization of water allocation, some lost benefits due to decreased water use (Figure 8). For instance, optimal water allocation would be reached by diverting more water resources to irrigation in high fertile valleys and oases like Tashkent and Ferghana at the same time water consumption and benefits would decline in Khatlon, Ahal, Kashkadarya, Andizhan, Sugd, South Kazakhstan, and Kyzylorda.

**Figure 8 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 9). Moreover marginal benefit was lower in the regions of the Amu Darya basin, indicating higher water availability in the basin than in the Syr Darya basin. Higher water scarcity conditions in the Syr Darya basin than in the Amu Darya basin were also previously shown by Raskin et al. (1992). 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 (Cai 2008) and prevented equal marginal benefits across all regions.

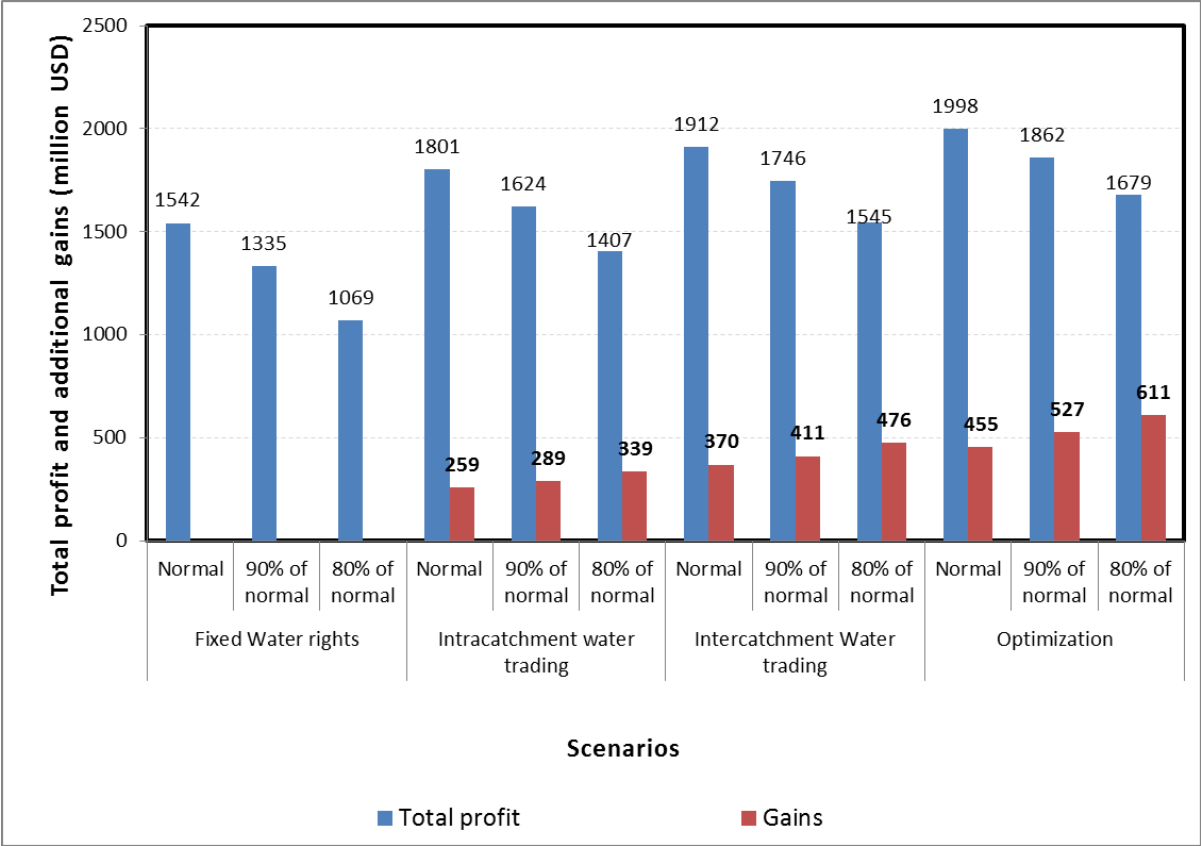
**Figure 9 Marginal irrigation benefits across the regions of the ASB under normal water supply**



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

Despite substantial increase (30%, 39%, and 50% under normal water supply levels, 90% of normal, and 80% of normal respectively) in overall basin profits under optimal water allocation, the regions with lower marginal water productivity will only cooperate in optimal basin-scale profits if they are compensated for lost income due to 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 indicated 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 10). Additional benefits from inter-catchment water trading vary between US\$ 373 million to US\$ 476 million and increased in parallel with the level of water scarcity. Less than that but still higher than baseline gains were available 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. Those results are in line with the findings of Booker and Young (1994) and Cai et al. (2006).

**Figure 10 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 normal water availability (Table 3). Total irrigation benefit was the lowest in upstream regions such as Gorno-Badakhshan (GBO) and RRT of the Amu Darya basin and Naryn, Osh, and Jalalabad of the Syr Darya basin due to their mountainous landscapes, limited irrigated areas, and the high energy (pumping) costs to deliver water to the fields.

Additional gains from water trading were achieved in all regions (Table 3). 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 profitability 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 3). 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 regions.

**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 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 achieved under drier year conditions (90% of normal water supply) (Table 4). 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 5). Comparison of marginal benefits under different levels of water

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

**Table 4 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 5 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>			

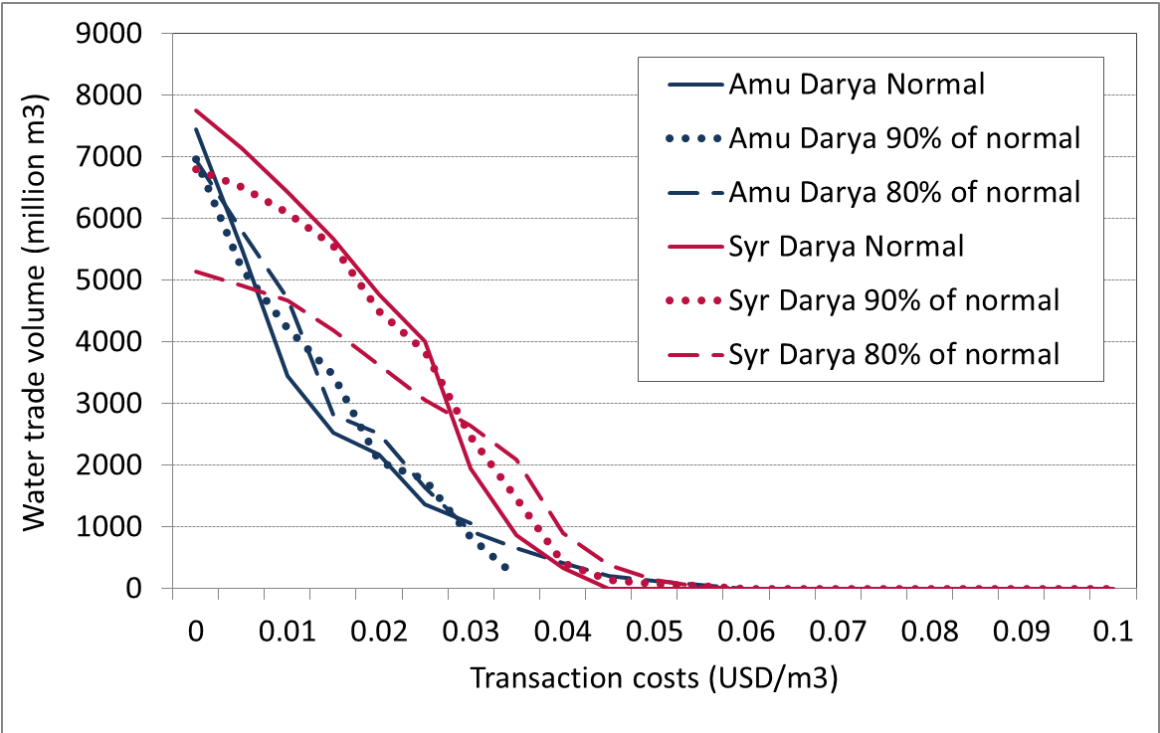
As it can be seen from Tables 3-5, additional inflows to the Aral Sea are negligible under the intra-catchment (restricted) water trading or even slightly decreased compared to the baseline scenario under inter-catchment (unrestricted) trading. It is mainly because of low marginal productivities of the environmental flow due to the rejection of the non-use values of the ecosystem services in the calculations as already explained above.



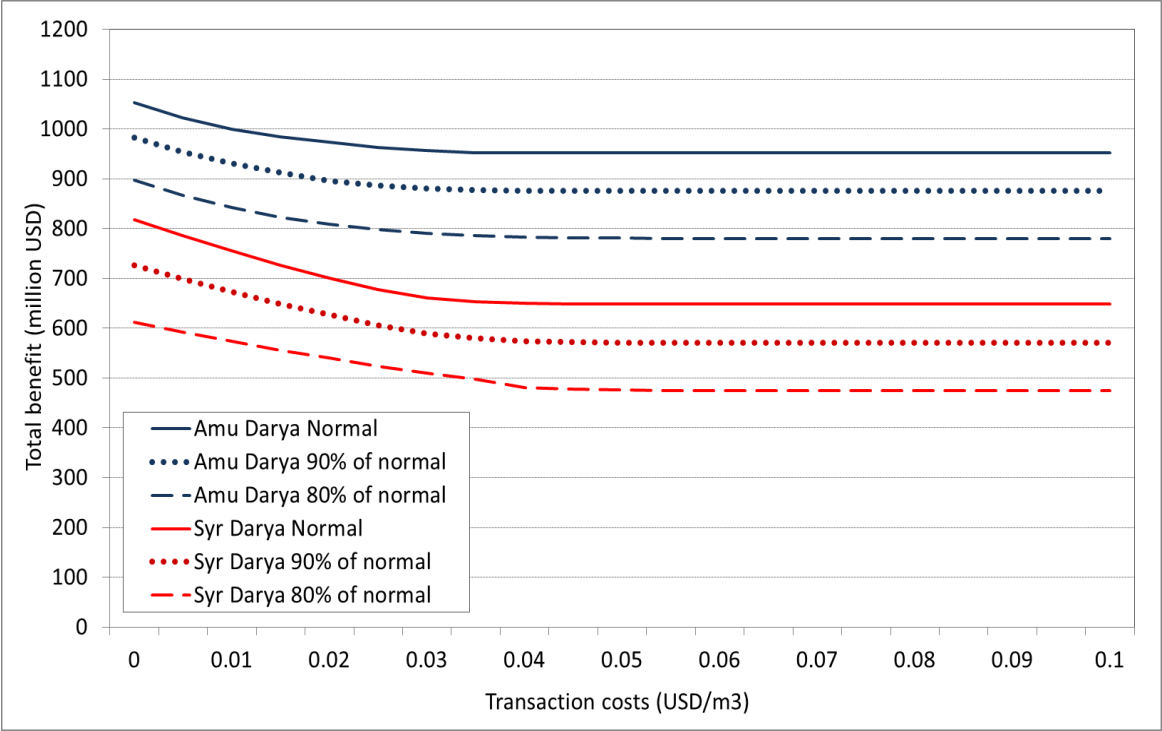
### 8.3 Water trading benefits considering transaction costs

Consideration of the transaction costs of establishing tradable water use rights slightly decreased overall irrigation water use while substantially decreasing water trade volume (Figure 11) and benefits from water trading (Figure 12) in both the Amu Darya and Syr Darya River 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 11). Since there only five regions whose marginal productivity was higher than US\$ 0.05 per m<sup>3</sup> and varied between US\$ 0.05 and US\$ 0.08 per m<sup>3</sup> in the baseline scenario (Figure 9), water rights trading among the remaining regions were obviously not beneficial while among these five sectors was mainly constrained by other land and water use capacity as well as other hydrological and water trading limitations. 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 if water trading is allowed were more than US\$ 1,050 million and US\$ 800 million in the Amu Darya and Syr Darya basins respectively (Figure 12). 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 11 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**



**Figure 12 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**



## 9 Discussion and conclusions

Efficient allocation of water among different irrigation sites and environmental systems while providing equal access and rights to all water users and ensuring sustainable development of socio-economic processes is a global issue as food, fiber, environmental and health security directly depend on limited water resources in many developing areas, including 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 of 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 no longer functions, intensifying conflicts over sharing water resources and decreasing water use efficiency. Inadequacy of governmental funds to improve irrigation infrastructure and low profitability of newly emerged private sector due to high governmental intervention worsens the situation.

The analysis showed that, as an alternative to the command-and-control based centralized system, market based water allocation institutions could incentivize the riparian irrigation sites to voluntarily cooperate in order to obtain additional gains from efficient water use through reallocation in the ASB. Given the heterogeneous distribution of water productivity across the irrigation zones, reallocation of water from less productive water users to the more productive users would result in increased economic gains and improved water productivity over the basin. Under improved institutions, more productive users who obtained additional water and consequently additional economic gains would pay the 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 indicated that additional economic gains from water rights trading thus its importance gets higher in parallel with growing water scarcity. Under market-based water allocation, the state organizations also should play an active role in water trading agreements by maintaining the rule of law and guarantying the realization of the agreed amount of the compensations and water transfers.

Although tradable water rights promise substantial economic gains under zero transaction costs, the establishment of water trading will not be without cost. Additional gains from markets including water trading depend on 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). It was also shown in this study that there is an opposite relationship between the transaction costs of establishing water markets and the additional benefits from water rights trading. Maintenance of sufficiently low transaction costs for effective performance of water markets are possible as evidenced by increasing trade of water use rights in the USA and Australia (Garrick et al. 2011). Low transaction costs can be achieved by improved irrigation infrastructure and improved legal and governance settings (McCann et al. 2005). The successful performance of relatively productive institutions (water market in this study) somewhere in the world (in the USA and Australia in this study) can provide a strong incentive to make relevant institutional changes in poorly performing economies (North 1990:137), including the Central Asian ones. The emergence

of the middle income class with greater power and knowledge would contribute to better governance and thus the stability of the institutional changes (Easterly 2001). Although the system based on the supremacy and dominance of the government and dependence on authorities in all decision making processes perhaps can enhance economic or social stability in short-run, empowering the ordinary people to make decisions over their own fate can effectively work for long-term social and economic sustainability. In the latter case, government must participate actively in development programs but indirectly through maintaining research and education capacity, establishing necessary institutional and legal framework and enforcing the rule of law.

In the case of the ASB, transaction costs of establishing tradable water use rights could be relatively high, considering that the Central Asian economies were under the rule of centralized Soviet governance for more than seventy years. Although a market based economy and governance through gradual reforms is the selected path for the future in all of these countries the evolution of market based management systems and their performance cannot be fully separate from the early course of institutional development processes (North 1990). Furthermore, the necessary institutional changes through the separation of water and land use rights and permission of water rights trading cannot happen overnight, but will require time to realize. Institutional changes occur not only through formal changes in laws and organizational structures, but also due to changes in the informal rules, behavioral codes and the collective mental construct of water users and decision makers (North 1990). For instance, Williamson (2000:597) showed that changes in the property rights regimes and their potential economic performance may require 10 to 100 years to undergo, involving substantial changes in the way of thinking of stakeholders and decision makers. Alteration of norms, ideologies, and mental constructs can be accelerated through greater transparency and the sequential lowered costs of information (North 1990:138).

Except long time needed to institutional change due to its path dependence, the antagonistic attitudes of current governments towards to each other also increase transaction costs of the change. 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 historical uniqueness of each nation led to gradual separation of the Central Asian countries from each other (Dukhovny and Schutter 2011). In 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. Axelrod (1984) compared the situation of independent and selfish nations interacting with each other in a state of near anarchy to the situation in an iterated Prisoner's Dilemma. Eliciting cooperation from others rather than exploiting their weaknesses is a key for better performance under such circumstances. Therefore cooperation among the riparian countries and the rule of law in water resources sharing are central and unavoidable tasks for establishing the foundations for long-term economic growth in the region.

## 10 REFERENCES

- Abdullaev, I., C. de Fraiture, M. Giordano, M. Yakubov, and A. Rasulov, 2008. Agricultural Water Use and Trade in Uzbekistan: Situation and Potential Impacts of Market Liberalization. *Water Resources Development*, 25(1), 47–63.
- Aldaya, M.M. and M.R. Llamas, 2008. Water Footprint Analysis for the Guadiana River Basin. Research Report No. 35. Delft, the Netherlands: UNESCO-IHE Inst. for Water Education.
- Aldaya, M.M., G. Muñoz, and A.Y. Hoekstra, 2010. Water footprint of cotton, wheat and rice production in Central Asia, Value of Water Research Report Series No.41, UNESCO-IHE.
- Allen Consulting Group (ACG), 2006. Transaction Costs of Water Markets and Environmental Policy Instruments. Final Report to the Productivity Commission. Melbourne, Australia: Allen Consulting Group.
- 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.
- Bear J. and O. Levin, 1966. Optimal utilization of an aquifer as an element of a water resources system. P.N. 5/66, Hydraulic Lab., Technion – Israel Inst. Of Technology, Haifa.
- Bear J. and O. Levin, 1967. The Optimal Yield of an Aquifer, Haifa Symposium. International Association of Hydrological Sciences, Haifa, pp. 401–412.
- Bear J. and O. Levin, 1970. Optimal utilization of an aquifer as an element of a water resource system: research period 1967–68. In: Levin, O. (Ed.), *Selected Works in Operations Research and Hydraulics*. Israel Institute of Technology, Haifa, pp. 64–279.
- Bear J., O. Levin and N. Buras, 1964. Optimal utilization of aquifers as elements of water-resources systems. Progress Report No. 1: Basic Concepts and Program of Research, Technion – Israel Institute of Technology, Hydraulic Laboratory, Haifa.
- Becker N., 1995. Value of moving from central planning to a market system: lessons from the Israeli water sector. *Agricultural Economics* 12 (1), 11-21.
- Bekchanov, M., J.P.A. Lamers, and C. Martius, 2010. Pros and cons of adopting water-wise approaches in the lower reaches of the Amu Darya: A socio-economic view. *Water* 2010, 2, 200-216; Available online: <http://www.mdpi.com/2073-4441/2/2/200/pdf>
- Brander L.M., R.J.G. Florax, and J.E. Vermaat, 2006. The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature. *Environmental & Resource Economics*, 33, 223–250. DOI 10.1007/s10640-005-3104-4

- 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.
- 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.
- Bhaduri, A. and E. B. Barbier, 2008. Linking Rivers in the Ganges-Brahmaputra River Basin Exploring the Transboundary Effects. In: Amarasinghe, U.A., Sharma, B.R. (eds.): *Strategic analyses of the National River Linking Project Series 2*. International Water Management Institute, 373-395.
- Cai, X. 1999. Modeling framework for sustainable water resources management. Unpublished Ph.D. dissertation, University of Texas at Austin.
- 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., D. McKinney, and L. Lasdon, 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., Y.E. Yang, J. Zhao, and C. Ringler, 2011. Can water allocation in the Yellow River basin be improved?: Insights from a multi-agent system model, No 1117, IFPRI discussion papers, International Food Policy Research Institute (IFPRI).
- Cai X., 2008. Implementation of Holistic Water Resources-Economic Optimization Models for River Basin Management – Reflective experiences, *Environmental Modelling & Software*, 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.
- De Schutter, J., 2008. Communicating the Issues of the Aral Sea Basin: Long-term Vision for the Aral Sea Basin, *The Aral Sea Basin Management Model (ASB-MM)*; in Moerlins J.E., Khankhasayev M.K., Leitman S.F., Makhmudov E.J. (Eds.), *Transboundary Water*

- Resources: A Foundation for Regional Stability in Central Asia; NATO Security through Science Series, Springer, 2008, 29-42, DOI: 10.1007/978-1-4020-6736-5\_2
- Dinar A., 2003. The Political Economy Context of Water Pricing Reforms. In: P. Koundouri, P. Pashardes, T.M. Swanson, A. Xepapadeas (eds.), *The Economics of Water Management in Developing Countries*. UK: Edward Elgar Publishing, Inc., pp. 15- 40.
- Dinar A., M. W. Rosegrant, and R. Meinzen-Dick, 1997. Water allocation mechanisms. World Bank: Policy Research Working Paper No. 1779, Washington, DC.
- Dublin Conference (DC), 1992. Dublin Statement on water and sustainable development. International conference on water and the Environment, Dublin.
- Dukhovny V.A. and J.L.G. de Schutter , 2011. *Water in Central Asia: Past, Present, Future*. Taylor and Francis, London.
- Dupuit J., 1844. De la mesure de l'utilité des travaux publics. *Annales des Ponts et Chaussées, Memoirs et Documents* 8 (2), 332–375.
- Dziegielewska D., T. Tietenberg, and 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 [http://www.eoearth.org/article/Total\\_economic\\_value](http://www.eoearth.org/article/Total_economic_value) (Last visited on 07.01.2013)
- Easter K. W., M.W. Rosegrant, and A. Dinar, 1998. *Markets for water: Potential and performance*. Boston: Kluwer.
- Easterly W., 2001. *The Elusive Quest for Growth: Economists Adventures and Misadventures in the Tropics*. Cambridge: MIT Press.
- European Commission (TACIS), 1997. *WARMAP Project: Formulation & Analysis of Regional Strategies on Land and Water Resources*. Tashkent, Uzbekistan.
- Falkenmark M. and J. Rockström, 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 November 2012)
- Garrick D., C. Lane-Miller and A.L. McCoy, 2011, Institutional Innovations for Governing Environmental Water in the Western U.S., *Economic Papers*, 30 (2), 167–84.
- Gisser M. and A. Mercado, 1972. Integration of the agricultural demand function for water and the hydrologic model of the Pecos basin. *Water Resources Research* 8 (6), 1373–1384.
- Grafton Q., C. Landry, G. Libecap, S. McGlennon, and B. O'Brien, 2010. *An Integrated Assessment of Water Markets: Australia, Chile, China, South Africa and the USA*. CWEEP Research Paper 10-09.
- Green G.P. and J.P. O'Connor, 2001. Water Banking and Restoration of Endangered Species Habitat: An Application to the Snake River. *Contemporary Economic Policy*, 19(2), 225-237.
- 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, and 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. Heckeley, 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. and D. V. Orr. 1974. Effects of agricultural acreage reallocation on water availability and salinity in the upper Colorado river. *Water Resources Research*, 10(5):893–897.
- Howe C.W., D.R. Schurmeier D.R., and W.D. Shaw, 1986. Innovative Approaches to Water Allocation: The Potential for Water Markets. *Water Resources Research*, 22(4), p. 439-445. Available online at: <http://www.agu.org/pubs/crossref/1986/WR022i004p00439.shtml>.
- Howitt R.E., 1994. Empirical Analysis of Water Market Institutions: The 1991 California Water Market. *Resource and Energy Economics*, 16, 357-371.
- ILA (International Law Association), 1966. *The Helsinki Rules on the Uses of the Waters of International Rivers [Helsinki Rules]*, International Law Association.
- 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.
- Keller A., J. Keller, D. Seckler, 1996. *Integrated Water Resource Systems: Theory and Policy Implications*. Research Report 3. Colombo, Sri Lanka: IIMI.
- Keller A. and J. Keller, 1995. *Effective Efficiency: A Water Use Efficiency Concept for Allocating Freshwater Resources*. Water Resources and Irrigation Division (Discussion Paper 22). Arlington, Virginia, USA: Winrock International.
- Kuhn A. and T. Britz (2012): Can hydro-economic river basin models simulate water shadow prices under asymmetric access? *Water Science & Technology* 66(4): 879-886. doi:10.2166/wst.2012.251
- Maass A., M. Hufschmidt, R. Dorfman, H. Thomas, S. Marglin, and G. Fair, 1962. *Design of Water-Resources Systems*, Harvard University Press: Cambridge, Massachusetts.



- McCann L. and K. W. Easter, 2004. A framework for estimating the transaction costs of alternative mechanisms for water exchange and allocation. *Water Resources Research*, 40, W09S09. doi:10.1029/2003WR002830
- 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., 1988. Desiccation of the Aral Sea: A water management disaster in the Soviet Union. *Science*, vol. 241, 1170-1176.
- Micklin P., 2007. The Aral Sea Disaster. *Annu. Rev. Earth Planet. Sci.*, 35, 47-72. Available online at: (last visited on 28.07.2011)
- Micklin P., 2010. The past, present, and future of the Aral Sea. *Lakes & Reservoirs: Research & Management*. 15(3), 193–213, Available online at: <http://onlinelibrary.wiley.com/doi/10.1111/j.1440-1770.2010.00437.x/abstract> (last visited on 29.07.2011)
- 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.
- Mirzaev S.Sh., 2000. Main institutions of managing water resources in the Aral Sea Basin (ASB). In: Umarov U. and Karimov A.H. (eds.), *Water Resources, Problems of the Aral Sea and Environment*. Tashkent, Universitet, 308-331 (in Russian).
- Mirzaev S.Sh. and H.I. Valiev, 2000. Main principles of saving the Aral Sea and restoring ecological balance in its basin. In: Umarov U. and Karimov A.H. (eds.), *Water Resources, Problems of the Aral Sea and Environment*. Tashkent, Universitet, 99-120 (in Russian).
- Müller M., 2006. A General Equilibrium Analysis of Water and Land Use in Uzbekistan. PhD Dissertation, Bonn University. Bonn, Germany.
- 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.
- ObSelVodKhoz (Khorezm region branch of the Ministry of Water Resources and Agriculture), 2010. Revenues, costs, and profits of growing different agricultural commodities. Urgench.
- PA Consortiom Group and PA Consulting, 2002. *Transboundary water and related energy cooperation for the Aral Sea basin region of Central Asia*. Washington, DC: USAID Regional mission for Central Asia Office of Energy and Water.
- Pandya-Lorch R. and M.W. Rosegrant, 2000. Prospects for food demand and supply in Central Asia. *Food Policy*, vol. 25, 6, 637-646. Available from:

<http://www.sciencedirect.com/science/article/B6VCB-41S4ST1-2/2/ab5e057d4f2d9f0240cec8db59759869>

- Pauw E. de, 2007. Principal biomes of Central Asia. In: R. Lal, M.Suleimenov, B.A Stewart, D.O. Hansen and P. Doraiswamy. (eds), *Climate change and terrestrial carbon sequestration in Central Asia*. Taylor and Francis Group, New York, NY, USA, p.3-24.
- 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 M.E., J. Connor, M. Kirby, M. Mainuddin, 2007. Economic assessment of environmental flows in the Murray Basin, *Australian Journal of Agricultural and Resource Economics*. 513: 283-303
- Raskin P. , E. Hansen, Z. Zhu, and D. Stavisky, 1992, *Simulation of Water Supply and Demand in the Aral Sea Basin*, *Water International*, 17, 55-67.
- 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
- Rogers P., Smith, D.V., 1970. *Integrated use of ground and surface water in irrigation project planning*. *American Journal of Agricultural Economics* 52 (1), 13.
- Rosegrant M. W., C. Ringler, D.C. McKinney, X. Cai, A. Keller, and G. Donoso, 2000. *Integrated economic-hydrologic water modeling at the basin scale: the Maipo river basin*, *Agricultural Economics*, Blackwell, vol. 24(1), pages 33-46
- Rosegrant M.W., 1997. *Water Resources in the Twenty-First Century: Challenges and Implications for Action*. Food, Agriculture, and the Environment Discussion Paper 20. International Food Policy Research Institute, Washington, D.C.
- 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 A. Dinar, 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, SANIIRI (in Russian).
- Savoskul, O.S., E.V. Chevnina, F.I. Perziger, L.Yu. Vasilina, V.L. Baburin, A.I. Danshin, B. Matyakubov, R.R. Murakaev. 2003. *Water, Climate, Food, and Environment in the Syr Darya Basin*. Contribution to the project ADAPT - Adaptation strategies to changing environments.

- Schlüter M., A.G. Savitsky, D.C. McKinney, and H. Lieth, 2005. Optimizing long-term water allocation in the Amudarya River delta: a water management model for ecological impact assessment. *Environmental Modelling & Software*, 20, 529-545.
- SIC-ICWC, 2002. The Aral Sea Basin Management Model (ASBmm) for awareness raising and strategic decision support: final report and integrated river basin model, Tashkent–Delft.
- 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)
- Sokolov V. and V. Dukhovny, 2002. Lessons On Co-Operation Building To Manage Water Conflicts in The Aral Sea Basin. Paper submitted for the PC-CP Project report: Case Studies, UNESCO.
- TEEB in Business, 2011. The Economics of Ecosystems and Biodiversity in Business. Edited by Joshua Bishop. Earthscan, London.
- Timirkhanov S., B. Chaikin, Z. Makhambetova, A. Thorpe, R. van Anrooy, 2010. Fisheries and aquaculture in the Republic of Kazakhstan: a review. *FAO Fisheries and Aquaculture Circular*. No. 1030/2. FAO, Rome, 76 pp.
- United Nations General Assembly (UN), 2000. Resolution 2, Session 55, United Nations Millenium Declaration, on 18 September 2000.
- UN Convention. 1997. United Nations Convention on the Law of the Non-navigational Uses of International Watercourses. UN General Assembly in Resolution 51/229.
- 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. Online at: <http://www.un.org/apps/news/story.asp?NewsID=34276>
- UNECE, 1992. UN Economic Commission for Europe (UNECE) Convention on the Protection and Use of Transboundary Watercourses and International Lakes [Helsinki Convention]. United National Economic Commission for Europe.
- 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.
- UNEP and ENVSEC, 2011. Environment and security in the Amu Darya basin. UNEP, Bresson, France.
- UNESCO, 2000. Water related vision for the Aral Sea Basin. For the year 2025. Paris, France.
- UNESCO, 2006. Water - a shared responsibility. The United Nations World Water Development Report 2 (WWDR 2). Available online at <http://unesdoc.unesco.org/images/0014/001444/144409E.pdf> (last visited in 16.06.2011)

- UzSredAzGiproVodKhlopok, 1984. Correcting the scheme of complex use and protection of water resources in Amu Darya basin (KIOVR Amu). Tashkent, Uzbekistan.
- UzSredAzGiproVodKhlopok, 1983. Correcting the scheme of complex use and protection of water resources Syr Darya basin (KIOVR Syr). Tashkent, Uzbekistan.
- Varis O. and M.M. Rhamanan, 2008. The Aral Sea keeps Drying Out but is Central Asia Short of Water? In *Central Asian Waters*; Rahaman, M.M., Varis, O., Eds.; Helsinki University of Technology: Helsinki, Finland.
- Vaux H.J., and R.E. Howitt. 1984. Managing water scarcity: An evaluation of interregional transfers. *Water Resources Research*, 20:785–792.
- White D., F. Wester, A. Huber-Lee, C.T. Hoanh, and F. Gichuki, 2008. Water Benefits Sharing for Poverty Alleviation and Conflict Management: Topic 3 Synthesis Paper. CGIAR Challenge Program on Water and Food, Colombo
- Williamson O.E., 2000. The New Institutional Economics: Taking Stock, Looking Ahead. *Journal of Economic Literature*, 38(3), 595-613.
- Wolf A.T., 1999. Criteria for Equitable Allocations: The Heart of International Water Conflict. *Natural Resources Forum*. 23 (1), 3-30.
- World Bank, 1992. *Development and the Environment. World Development Report 1992*. Washington, D.C.: World Bank.
- World Resources Institute (WRI), 2005. *World resources 2005: the wealth of the poor-managing ecosystems to fight poverty*. World Resources Institute, Washington D.C.
- Yakubov M. and H. Manthrithilake, 2009. Water for Food as Food for Thought: Case Study of Applying the PODIUMSIM Model to Uzbekistan. *Irrigation and Drainage*, 58, 17–37. doi: 10.1002/ird.451
- 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.
- Zonn I.S., 2010. Socio-Economic Conditions of the Aral Sea Region Before 1960. In: Kostianoy A.G. and A.N. Kosarev (Eds.): *The Aral Sea Environment*. Springer: Dordrecht/Heidelberg/London/New York, pp 65-73.