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## Reducing conflict in development and allocation of transboundary rivers

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This article explores opportunities for water scarcity to motivate neighboring nations in transboundary basins to cooperate in the development and allocation of water. Climate change raises the importance of discovering foundations for this cooperation. We examine the development of infrastructure and allocation of water in the controversial Amu Darya Basin. An analysis is presented that characterizes politically constrained and economically optimized water-use patterns in the basin. Using information on the basin's energy potential, water supplies, land area, crop water requirements, and crop economics, we analyze total basin-wide economic welfare over a 20 year period. Results show that the development and operation of the planned Rogun Dam has the potential to secure agricultural benefits downstream for Afghanistan, Uzbekistan and Turkmenistan, while supplying some winter power upstream in Tajikistan in normal water conditions. Results show that the ongoing conflict in the Amu Darya Basin over water infrastructure and allocation has the potential to be resolved in a way to secure economic gains for all four nations. However, patient and difficult political negotiations will be required to achieve the gains indicated.

**Keywords:** water scarcity; conflict resolution; basin management; Amu Darya; Central Asia

Данная работа исследует возможности мотивации соседних стран для взаимодействия в развитии и распределении воды по причине дефицита водных ресурсов в трансграничных бассейнах. Изменение климата повышает важность нахождения основ для такого рода кооперации. Мы исследовали развитие инфраструктуры распределения воды в противоречивом бассейне реки Амударья. Рассмотренный анализ характеризует политически ограниченное и экономически оптимизированное распределение воды в бассейне. Используя данные по энергопотенциалу, имеющимся водным и земельным ресурсам, потребностям сельскохозяйственных культур в воде и экономике сельскохозяйственных культур, мы провели анализ совокупного экономического благосостояния в бассейне реки на 20-летний период. Результаты показывают, что функционирование Рогунского водохранилища имеет потенциал для обеспечения сельскохозяйственных выгод для стран низовья: Афганистана, Узбекистана и Туркменистана, в то же время обеспечивая некоторое количество зимней энергии для расположенного выше по течению Таджикистана в годы с

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нормальной водообеспеченностью. Результаты показывают, что текущий конфликт в бассейне реки Амударья за водную инфраструктуру и распределение имеет потенциал разрешиться путем экономического выигрыша для всех четырех стран. Однако, требуется терпение и сложные политические переговоры чтобы достичь указанных выигрышей.

## 1. Introduction

### 1.1. Background

Global water demands are increasing, but usable freshwater resources appear to be constant or decreasing. This situation points to emerging water scarcity as a source of conflict (Hensel and Brochmann 2007). The potential for growing conflict over international rivers is magnified by fact that more than 260 river basins in the world are shared by two or more countries (Brochmann and Gleditsch 2012). Rigorous analysis of mechanisms that promote outcomes characterized by cooperation over water is new. The existing academic research is dominated by two views that predict outcomes of growing water scarcity: greater conflict or more cooperation.

Proponents of the first view believe that rising competition over increasing water scarcity could result in growing conflict. Under this view, growing water scarcity is seen as a motivation for both domestic and international conflict (Brochmann and Gleditsch 2012; Gleick 1993). This competition over scarce water could be intensified in the face of ongoing global climate change (Klare 2001). Other similar studies have warned about approaching water wars and predict that under certain circumstances water scarcity may prompt international conflict (Gleick 1993, 2004; Homer-Dixon 1999; Irani 1991).

While these studies present a pessimistic view, a rather different view reaches more optimistic conclusions about the potential for growing cooperation over international rivers. This view places more emphasize on positive role of economic, institutional, and technical adaptation to growing water scarcity. For example, Lomborg (2000) believes that technology, resource substitution, clear property rights in water with well-defined rules for sharing shortages, and rising prices that signal growing water scarcities could help avoid conflict. Moreover, growing scarcity could be overcome by cooperation that shares the benefits of water development (Wolf 1996). In a range of water scarcity scenarios, cooperation is shown to be the more likely outcome for countries that share international rivers (Kalpakian 2004). As evidence for that view, Wolf (2002) points to the fact that no wars in history have been fought exclusively over water, while 3600 water-related treaties were settled between 1805 and 1984 alone. More recently, Wolf and his colleagues updated those earlier findings in a new study using data from 1945 to 2008. The new findings again rejected the conventional wisdom that growing water scarcity necessarily leads to dangerously escalated military tensions (Diamond 2013).

Despite the extensive theoretical literature on water conflict, few empirical studies have been conducted to identify motivations for reducing conflict or measures by which conflict can be avoided on international rivers. This gap is striking in light of the importance of growing populations, growing demands for all water uses, and climate change, all of which are driving debates in much of the water policy sphere (e.g. Diehl and Gleditsch 2000). To date, no research has examined principles or provided empirical evidence for ways to achieve Pareto improving outcomes over shared transboundary waters, outcomes in which all riparian countries could be made better off by sharing the benefits of water development and allocation. Because of this existing gap in the

literature, the objective of this paper is to start the search for an economic basis to discover Pareto improving outcomes that could guide the cooperative development and allocation of transboundary waters. Our study focuses on the geographic region defined by Amu Darya Basin (the Basin) of Central Asia (Figures 1 and 2).

### 1.2. A study in water conflict

Tensions over scarce water resources in the Amu Darya Basin of Central Asia continue unabated, particularly between Tajikistan and Uzbekistan. As of early 2013, the Rogun Dam (Dam) and Reservoir is under construction on the Vakhsh River in southern Tajikistan (Figure 2). It is one of a series of planned hydroelectric projects of the Vakhsh Cascade. If completed, the ambitious Dam would be the world's highest, with a potential height of 335 m. First proposed in 1959, technical plans were unveiled in 1965, with construction beginning in 1976.

The project stopped after the dissolution of the Soviet Union in 1990 when many of the former Soviet countries became independent. A draft agreement to complete construction was signed between Tajikistan and Russia in 1994. However, the agreement was not implemented. In 2004 another agreement was signed with Rusal, the world's largest aluminum manufacturer, in which Rusal agreed to complete the Dam and to build a new aluminum plant that would take advantage of the large quantities of

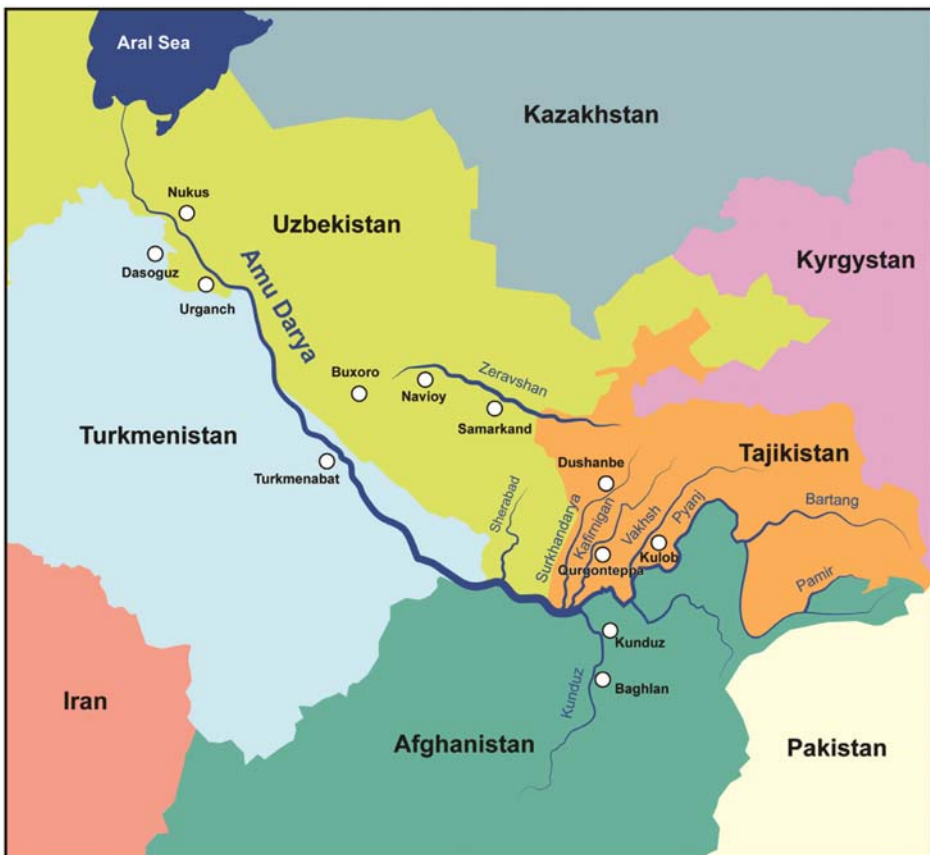


Figure 1. Amu Darya Basin, Central Asia.

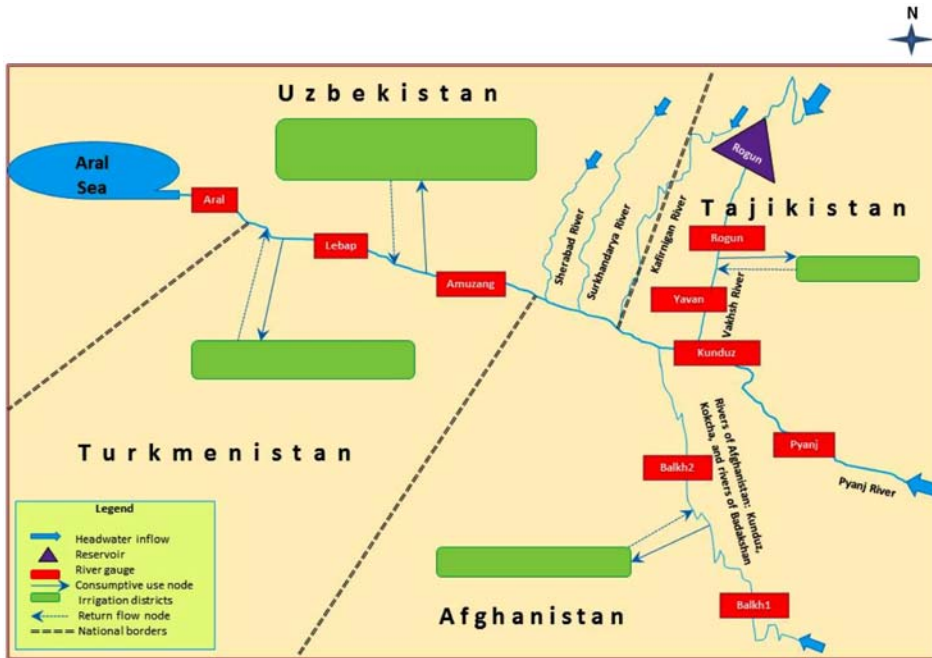


Figure 2. Amu Darya river basin schematic: sources and uses of water.

hydropower produced. In 2007, a new partnership between Russia and Tajikistan to complete the Dam was announced but later was rejected by Russia because of disagreements over control of the project.

In 2008, Tajikistan announced that construction on the Dam had started again. In 2010, Tajikistan launched a plan to raise US\$ 1.5 billion to complete construction of the Dam. As of April 2010, the Tajik government had raised US\$ 185 million, enough for two years of construction. The hydroelectric power plant is expected to have six turbines with total capacity of 3600 MW. When constructed, it is planned to supply just over 13 terawatt hours (TWH) of power per year.

Uzbekistan, a downstream riparian, vigorously opposes development and operation of the Dam, citing the potential for serious economic losses for its irrigated agriculture. Among other things, Uzbekistan argues that losses would result from the release of unused winter flows at the Dam due to energy production that would occur year around. These winter releases would have little economic value for Uzbek summer-irrigated agriculture, in which lucrative income is earned from cotton production. The size and scope of that income is described later in this paper.

Longstanding disputes over the allocation of energy and water have been a defining feature of relations between Tajikistan and Uzbekistan since the early 1990s. While the distrust between the two countries is old, current disputes are driven largely by the Dam project. As of 2012, both Tajikistan and Uzbekistan have shown little willingness to discuss solutions that would be acceptable to both countries (Sodiqov 2012). Yet, without a compromise over the Dam, it is unlikely that the strained relations between the two neighboring states will cool down.

The competition for water in the Basin's river system presents the following conflict between these two countries: the irrigation season in Uzbekistan ranges from March

through the early fall. Peak irrigation demands for that country occur in the summer months. The timing of these irrigation demands is close to the natural hydrological supply regime of the river system, with high flows in summer months and considerably reduced supplies in winter. By contrast, after completion of the Dam, major anticipated reservoir water releases in Tajikistan would occur in the winter months to support hydroelectric power production in that country's peak energy demand period. If the Dam is completed, reservoir releases to the river could be used either in energy or agricultural production, or for both uses at the same time. Therefore, the search for a mutually beneficial solution to operate the Dam is politically and economically important for both those countries and for the remaining riparians in the Basin.

### ***1.3. Need for integrated analysis***

Without negotiated water allocation framework based on well-defined property rights for water in the Basin, there are few institutional mechanisms to efficiently, equitably, and sustainably share the economic benefits produced by water (Ward in press). An integrated basin-scale hydrologic, economic, and institutional framework could contribute information on how a water sharing arrangement could be designed. Such a framework could provide a systematic approach for efficiently allocating existing supplies as well as dealing with growing future water scarcity. Like many other basins, the Amu Darya supports a number of water-related human activities. These activities include water storage, diversions, distribution, pumping, evaporation, return flows, and several water uses. Basin-scale analysis is a mechanism to provide a comprehensive framework for informing policy debates and contribute to better informed outcomes. Such an informed policy could produce a more efficient and sustainable level of water-related economic benefits (Ward and Pulido-Velazquez 2008).

Despite the geopolitical importance of the Basin, to date few comprehensive basin-scale analyses have been conducted there. Several partial analyses have been conducted in the Basin: for example, Schlüter et al. (2005) presented an analysis that optimized long-term water allocation in the delta of the Basin with an emphasis on ecological assets. Raskin et al. (1992) developed and applied a simulation model of water supply and demand for the entire Basin, but little attention was given to an analysis of policy choices. Other studies have examined water allocation improvement potentials for certain sectors: Cai, McKinney, and Rosegrant (2003) examined irrigation water demands; Glantz (2005) conducted an analysis of connections between water, climate, the environment, and demographic factors, but little analysis was conducted of policy choices available; Wegerich (2008) examined the competition between water used for energy vs. crop irrigation, but no formal optimization was conducted among those choices. Jalilov, DeSutter, and Leitch (2011) identified economic impacts to Uzbekistan produced by the Dam during its construction and operation, but no analysis of economic tradeoffs among competing uses of water released from the Dam was made. In a more recent study, Schlüter and Herrfahrdt Pähle (2011) analyzed the structure and resilience of water use patterns in the Basin, but no formal analysis was conducted of economic values of alternative water allocations.

Despite the achievements above, each of which analyzed a limited scope of the water use patterns in the basin, there has been little attempt in any of these previous studies to comprehensively examine potential impacts of the Dam over time, space, and use. Even less has been done to examine measures that could achieve a Pareto improving outcome, in which at least one country could be better off and no country worse

off. For these reasons, there is a considerable gap in attempts to identify economically or politically optimized measures for water allocation among the Basin's riparians that could reduce future conflicts by improving the economic welfare of all riparians. The quest continues for ways in which upstream Tajikistan can receive economic benefits from energy generated in winter, while downstream countries can also sustain greater economic benefits from better-timed irrigation to lands the important summer months. For these reasons, the main motivation for our study is the need to identify practical solutions for this difficult challenge, in which all parties could be at least as well off with the Dam as without it. Its motivation is a search for Pareto improving use patterns of the river system if the Dam is built.

A number of articles published since the late 1990s have dealt with conflict over transboundary water resources. Steinberg and Clark (1999) described ongoing tensions between rural resource supply areas and metropolitan urban areas that require resource development and use for growth. They used the example of water conflicts between the Wachusett region and the Boston urban area, USA. Their results showed that despite this conflict, numerous outcomes were characterized by serious attempts to bring a local or regional resolution to that conflict. Fischhendler and Feitelson (2003) analyzed conflicts between the USA and Mexico over shared flows of the Rio Grande and Colorado rivers. The authors found that the countries could better negotiate a settlement when both rivers' shares were negotiated jointly than if river shares were negotiated in isolation. Toset, Gleditsch, and Hegre (2000) described rhetoric that warned of the potential for armed conflict over shared transboundary rivers, but found little recent evidence that military conflict has occurred over shared waters. With more than 200 river systems shared by two or more countries, surprisingly few cases of armed conflict have occurred. Gleditsch et al. (2006) also identified diplomatic, economic, and hydrologic challenges in sharing transboundary rivers, but concluded that the mere fact that several nations share the waters of a single river system is not enough of a cause to lead to armed conflict. Similarly, Hensel, Mitchell, and Sowers (2006) explored the connection between water scarcity and multi-state conflict. Remarkably, they found that greater water scarcity increases the likelihood of both military conflict and peaceful settlements. Sneddon and Fox (2006, 2007, 2012), in studies of the transboundary Mekong Basin, presented an important role for basin-scale hydrogeopolitics in resolving transboundary disputes. Gizelis and Wooden (2010) found both direct and indirect linkage among water shortage, governance, and water conflict. They concluded that well-organized political institutions have considerable influence on water shortage, and these shortages need not motivate armed conflict.

All the above studies present important advances in the understanding of conflicts over water resource allocation and policy in river basins. Yet none has conducted a comprehensive basin-scale policy analysis of tradeoffs among efficiency, equity, and sustainability with the mission of sustaining water, food, and energy security. More importantly, no policy-informing research has been published that addresses impacts of the proposed Dam. These research gaps re-emphasize the importance of this paper's objective to present a development and operation plan for the Dam that could produce economic benefits for both Uzbekistan and Tajikistan while making the remaining countries in the Basin no worse off with the Dam than without it.

To implement the objective, this paper examines the potential for a mutually beneficial development and allocation of the Basin's waters to sustain demands for summer water use in downstream irrigated agriculture in addition to securing high-valued winter

water demands to support high-valued upstream hydroelectric power production. Using long-term data on the basin's energy potential, water supplies, land area, crop water demands, crop prices, crop yields, and crop production costs, we analyze total economic welfare in the Basin for a future 20-year-time horizon. This article presents two water supply scenarios (normal and dry) for each of two policy choices (without and with the Dam).

## **2. Methods of analysis**

### **2.1. Study area**

The Amu Darya River system (the River) is the largest in Central Asia both in length and production, with a length of 2540 km (Wegerich 2004) and an average annual supply of about 65.46 km<sup>3</sup> (Spoor and Krutov 2003). The mainstem is supplied by the confluence of two main tributaries, the Vakhsh and Pyandj Rivers (Figure 1). The Basin drained by the River terminates in the Aral Sea. The River is shared by Afghanistan, Turkmenistan, Tajikistan, and Uzbekistan. The Basin includes about 309,000 km<sup>2</sup> (Wegerich 2008) and is home to 70 million people (CIA 2011). On its route from the headwaters to the Aral Sea, the River borders Afghanistan and Tajikistan as well as Uzbekistan. Most of the Basin lies within a steppe climate that is too dry to support a forest but not sufficiently dry to be a desert. This climate condition combined with fertile soils give rise to heavy water demands to support crop irrigation (Spoor and Krutov 2003). For this reason, there have been considerable policy debates for many years among the riparians in the Basin on the best ways to manage the River's waters.

### **2.2. Basin framework**

Our basin-scale analysis treats the entire Basin as an integrated unit. The integrated approach brings the hydrology, economics, and institutions of the region within a unified framework for policy analysis. The model begins with the basic water supply, which includes all major tributaries (Figure 2). The hydrologic data used are observed average annual discharge of the water supplies of the basin based on 50 years of historical data (Global Runoff Data Center 2013). The model integrates hydrology, agronomy, economics, and policy choices at the basin level. In terms of total economic value, the two most important water users are irrigated agriculture and potential hydropower production. Water is also used in the basin to support key ecological assets supplied by streams, reservoirs, and wetlands. The model takes into account the economic importance of irrigated agriculture in the four Basin countries in addition to the potential for energy production in the headwaters of Tajikistan.

The model is formulated as a dynamic nonlinear optimization, for which the objective is to maximize the discounted net present value of the Basin's water over a 20 year analysis, subject to a number of hydrological, agricultural, institutional, and economic constraints. The model predicts crop output, land use, energy, and water use. Results from each water supply scenario and each policy choice require separate models. An important constraint built into the model is that total economic benefits for each of the downstream countries *with* the Dam's development and operation must be equal or greater than benefits *without* it. That is, the model seeks a water development and use plan that could promote cooperation rather than conflict.

### 2.3. Data

Table 1 presents the important assumptions used to characterize headwater supplies. It shows information on water supply by source, month, and water supply scenario. Water supply is characterized by two scenarios: base and dry. Base water supply reflects stochastic variation around the historical observed mean water runoff in the Basin. The drought scenario reflects similar stochastic supplies for a simple 50% reduction in runoff compared to the base scenario. Thus, average annual water discharge of the various supply sources to the River in the base year is  $65.46 \text{ km}^3$ , with half that much for the drought scenario. The two most important tributaries of the River, the Pyandj and Vakhsh rivers, constitute 49 and 30% of the River's total flow, respectively. Four other tributaries make up about 21% of that total flow.<sup>1</sup>

Table 2 presents data on agriculture by country, crop, and season (World Bank 2003). For each country, the most important agricultural production occurs from three crops: cotton, wheat, and a range of vegetables. The climate of Central Asia typically permits two cropping seasons per year. Crop prices are sensitive to production levels. The price of each crop falls with increased output, so crop prices are determined by the model's constrained optimization and depend on the allocation of water among crops and countries. Thus, both the hydrologic scenario and the policy scenario affect crop prices. Prices are based on published crop price elasticities of demand and a linear demand price response at historically observed prices and production levels. Table 3 shows data used for the reservoir capacity and hydroelectric power capabilities in addition to other Dam characteristics. Shown are reservoir height, storage capacity, length, surface area, depth, hydropower capacity, power prices, and estimated construction costs.

### 2.4. Economics

Economic benefits of hydropower and irrigated agriculture are derived from water used for energy and for crop production. Water used for hydropower is typically more economically valued than for irrigated agriculture, because of its high price, low variable costs, and modest water depletion compared to water consumption by irrigated agriculture. Data were assembled on crop water use and cropping patterns by country, crop, and season. These data were combined with farm production details. The most important details included crop prices, cost of production, and crop yields. Net profitability per hectare was identified in addition to estimating total existing land in production by country, crop, and season. Profitability for any single crop per unit land was calculated as crop price multiplied by yield minus average costs of production.

#### 2.4.1. Efficiency

Our analysis examines ways to allocate water supply for both crops and power to maximize discounted net benefits that are compatible with a number of political and hydrologic constraints. Benefits identified for this study include farm income and hydroelectric power production summed over crops, seasons, time periods, and countries. With the Dam in place, the Reservoir is operated in our analysis subject to (1) a sustainability constraint and (2) an international water allocation constraint, both of which are described in detail subsequently. Consistent with economic demand and welfare theory, reduced water quantities supplied to agricultural users decrease crop production and, as a consequence, increase crop price. Energy benefits were measured as power production multiplied by price of energy, while power production varies with

Table 1. Average<sup>a</sup> historical water supply by headwater supply source, month, and drought scenario (billion cubic meters/month).<sup>b</sup>

Month	Water supply scenario	Vakhsh Country TJ	Pyandj Country TJ&AF	Kunduz Country AF	Kafmigan Country TJ	Surkhandarya Country UZB	Sherabad Country UZB	Total All Sources
January	Base	0.46	1.01	0.23	0.15	0.12	0.08	2.05
	Dry	0.23	0.51	0.12	0.08	0.06	0.04	1.03
February	Base	0.45	1.05	0.23	0.16	0.12	0.08	2.09
	Dry	0.23	0.53	0.12	0.08	0.06	0.04	1.05
March	Base	0.55	1.30	0.26	0.48	0.19	0.09	2.87
	Dry	0.27	0.65	0.13	0.24	0.09	0.04	1.42
April	Base	1.16	2.15	0.29	0.76	0.41	0.10	4.87
	Dry	0.58	1.07	0.15	0.39	0.20	0.05	2.43
May	Base	2.07	3.34	0.73	1.05	0.51	0.25	7.94
	Dry	1.03	1.66	0.37	0.53	0.26	0.13	3.98
June	Base	3.16	5.13	1.40	1.00	0.44	0.49	11.62
	Dry	1.57	2.61	0.71	0.51	0.21	0.24	5.86
July	Base	4.15	5.93	0.67	0.70	0.19	0.23	11.86
	Dry	2.06	2.94	0.33	0.35	0.09	0.12	5.89
August	Base	3.50	5.06	0.30	0.33	0.04	0.10	9.32
	Dry	1.76	2.54	0.15	0.17	0.02	0.05	4.68
September	Base	1.82	2.72	0.15	0.18	0.04	0.05	4.96
	Dry	0.91	1.36	0.07	0.09	0.02	0.03	2.48
October	Base	0.87	1.68	0.17	0.16	0.07	0.06	3.01
	Dry	0.44	0.83	0.08	0.08	0.04	0.03	1.50
November	Base	0.64	1.34	0.23	0.16	0.09	0.08	2.53
	Dry	0.32	0.67	0.12	0.08	0.05	0.04	1.27
December	Base	0.53	1.15	0.29	0.16	0.11	0.10	2.34
	Dry	0.26	0.57	0.14	0.08	0.06	0.05	1.16
Total	Base	19.36	31.85	4.94	5.28	2.32	1.71	65.46
	Dry	9.66	15.93	2.48	2.67	1.15	0.86	32.75

<sup>a</sup>Stochastic inflow supplies equal historical mean and variance by month and year for accessible period of record.<sup>b</sup>Data source: UNECE (2007).

Table 2. Agricultural data by country, crop, and season.

Country	Crop	Yield <sup>d</sup> (tons/ha/season)		Cost <sup>b</sup> (US\$/ha/season)		Water use (ET) <sup>c</sup> (meters depth/ha/season)		Crop price <sup>e</sup> (US\$/ton)						Net income (US\$/ha/season)							
		Second crop		First crop		Second crop		First crop		Without Dam		With Dam		Without Dam		With Dam		Without Dam		With Dam	
		First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry
Tajikistan	Cotton	1.8	1.8	444	296	12	7	5153	5639	5174	5650	8832	9706	8870	9725	8980	9854	9018	9873		
	Wheat	1.5	1.5	168	112	8	6	401	411	400	404	434	449	433	439	490	505	489	495		
Afghanistan	Vegetables	12.0	12.0	500	333	12	8	678	651	666	646	7631	7317	7487	7256	7798	7484	7654	7423		
	Cotton	1.8	1.8	444	296	12	7	5153	5639	5174	5650	8832	9706	8870	9725	8980	9854	9018	9873		
Uzbekistan	Wheat	1.6	1.6	165	110	8	6	401	411	400	404	477	493	476	482	532	548	531	537		
	Vegetables	12.0	12.0	503	335	12	8	678	651	666	646	7628	7314	7484	7253	7796	7482	7652	7421		
Turkmenistan	Cotton	2.3	2.3	390	260	14	8	5153	5639	5174	5650	11,463	12,580	11,511	12,604	11,593	12,710	11,641	12,734		
	Wheat	1.5	1.5	283	189	6	4	401	411	400	404	319	334	318	324	413	428	412	418		
Turkmenistan	Vegetables	11.0	11.0	702	468	11	7	678	651	666	646	6752	6463	6619	6407	6986	6697	6853	6641		
	Cotton	2.2	2.2	392	261	14	8	5153	5639	5174	5650	10,945	12,014	10,991	12,037	11,076	12,145	11,122	12,168		
Turkmenistan	Wheat	1.5	1.5	283	189	6	4	401	411	400	404	319	334	318	324	413	428	412	418		
	Vegetables	11.0	11.0	702	468	11	7	678	651	666	646	6752	6463	6619	6407	6986	6697	6853	6641		

<sup>a</sup>Data Source: World Bank (2003).<sup>b</sup>Data Source: Ibid.<sup>c</sup>Data Source: Ibid.<sup>d</sup>Data Source: Based on a published elasticity of demand from Tokarick (2005) for cotton; Lipsey and Chrystal (1999) for wheat; Rosen (1999) for potato; and a linear demand price response at observed prices and production levels.

Table 3. Design data, Rogun Reservoir.<sup>a</sup>

Height of the Dam (m)	335	Hydropower capacity (MW)	3600
Design capacity (km <sup>3</sup> )	13.3	Long-term average annual	
Active regulation storage (km <sup>3</sup> )	8.6	Hydropower production (TWH)	14.5
Length (km)	70	Power price constant (US\$ per KWH)	0.04
Surface area (km <sup>2</sup> )	170	Average cost of completion (million US\$)	2800
Maximum depth (m)	310		

<sup>a</sup>Data Source: Jalilov, DeSutter, and Leitch (2011).

the Dam's height, water flow, a gravity constant, and a turbine energy efficiency coefficient. The model, written in the General Algebraic Modeling System, has code and a large spreadsheet posted at <http://agecon.nmsu.edu/forward/water/>, under the title "Amu Darya Basin."

For many years, there has been a widely recognized competition for water use among the Basin's countries and water uses. However, in debates over the Dam, it is sometimes forgotten that water use tradeoffs between irrigation and energy production can be complementary. This complementarity can occur because under some summertime conditions, reservoir releases at the Dam can be used to generate hydropower as well as irrigate croplands. If these complementarities can be discovered and put to use, they have the potential to partly offset the more obvious competition for scarce water. For these reasons, the basin-scale model we developed was used to seek out and take advantage of these complementarities where they could be found. If they could be found, the total level and distribution of economic benefits among the Basin's riparians could be expanded with development and operation of the Dam.

#### 2.4.2. *Equity*

Our approach accounts for the political importance of equity. For this analysis, equity is defined as operating the Dam so that all countries downstream of Tajikistan are as well or better off with the Dam as without it.

Practically, this constraint requires searching for a way to ensure that agricultural benefits could be as high or higher for all downstream countries' irrigation demands with the Dam as without it in both normal and drought conditions. To implement this special view of basin-wide equity, Tajikistan would need to store water in the winter and release water downstream in the summer without producing as much winter energy as it would prefer in a politically unconstrained environment.

#### 2.4.3. *Sustainability*

This analysis also implements a sustainability goal for the Dam and Reservoir, which requires that the Reservoir is filled to at least half its maximum capacity by the last period (last month of year 20). This constraint is an imperfect rule because there is no consensus for defining a terminal condition for reservoir storage that can be shown to promote sustainability. Still, by imposing this constraint on the reservoir level at the terminal period, equally sustainable water supplies and uses under both project alternatives (without and with the Dam) are assured. The "no Dam" policy reflects the current situation, which focuses exclusively on an efficient river system operation for irrigated

agriculture mostly for the benefit of Uzbekistan, consistent with recent historical land use patterns. By contrast, the policy with the Dam seeks a constrained optimization of discounted net present value summed over countries and over both kinds of economic benefits.

### 3. Results

#### 3.1. Overview

Our findings are presented in detail below. Briefly stated they reveal several messages: First, the development and operation of the Dam and Reservoir offer the opportunity for each country of the Basin to be at least as well off with and without the Dam under both the base and drought water supply scenario. Second, extensive political negotiation will be required to translate our evidence of opportunities for an actual Pareto improvement into real welfare gains for all countries. In addition, total water-related economic benefits for the basin harnessed with the project are up to 7.5% higher than without the project under the base water supply scenario, and up to 4.3% higher under the drought scenario. Also, requiring each country to be no worse off with the Dam than without it requires balancing uses of the Reservoir for irrigation and power. Another point is that the development and operation of the Dam and Reservoir has the potential to maintain downstream irrigation income at least as high with the Dam as without it, while significantly increasing winter hydropower production in Tajikistan. An additional important finding is that the operation of the Dam would produce some energy throughout the year, but the majority would occur in the winter months when the demand for and economic value of power is highest. Finally, Tajikistan has the potential to secure an economic benefit from energy production in the Reservoir, averaged at US\$ 305 million per year in the normal water supply scenario and US\$ 145 million in the drought scenario. Detailed results are summarized below for both policy options for each water supply scenario.

#### 3.2. Water

##### 3.2.1. Streamflows

Table 4 shows predicted streamflows by gage, policy, water supply scenario, and month averaged over a 20 year period. Streamflows are shown for nine gages along main-stream and tributaries of the River. The table presents the important message that no riparian country needs to be worse off with the construction and operation of the Dam as under the status quo. The overall economic benefits sustained by the downstream countries mean that the gains are sufficiently high to pay for the Dam and still leave something left for Tajikistan to secure economic benefits from power production. With careful operation of the Dam and Reservoir, our results show that the downstream countries have the potential to share in the gains supplied by the Dam.

Streamflow reductions between any two contiguous gages downstream of the Dam result from net depletions to support irrigated agriculture between the gages. The base water supply scenario is defined as having stochastic inflows matching average inflows for the period of record, while the drought water supply is constructed by reducing native inflows by half of their long-term historical average. The table shows that more than half of total native flows occur in the summer months of June through August with the remainder occurring in the other nine months. The “no Dam” water-use patterns replicate current conditions in the Basin when water is diverted from the river system

Table 4. Predicted streamflow by gage, policy, and water supply scenario, averaged over future years (billion cubic meters/month).

Gage	Policy	Water supply scenario	Water supply											
			January	February	March	April	May	June	July	August	September	October	November	December
Rogun	Without Dam	Base	0.46	0.45	0.55	1.16	2.07	3.16	4.15	3.50	1.82	0.87	0.64	0.53
	With Dam	Dry	0.23	0.23	0.27	0.58	1.03	1.57	2.06	1.76	0.91	0.44	0.32	0.26
Yavan	Without Dam	Base	0.46	0.45	0.32	0.32	2.21	1.50	0.76	0.76	1.91	1.61	2.08	2.35
	With Dam	Dry	0.23	0.23	0.17	0.77	1.16	2.25	3.55	2.90	0.00	0.02	0.03	0.03
Pyandj	Without Dam	Base	0.46	0.45	0.08	0.39	0.78	1.31	1.80	1.51	0.91	0.44	0.32	0.26
	With Dam	Dry	0.23	0.23	0.20	0.20	1.45	0.74	0.23	0.23	1.91	1.61	2.08	2.35
Kunduz	Without Dam	Base	0.46	0.45	0.10	0.10	2.52	1.98	1.62	1.71	0.00	0.02	0.03	0.03
	With Dam	Dry	0.23	0.23	1.30	2.15	3.34	5.13	5.93	5.06	2.72	1.68	1.34	1.15
Balkh1	Without Dam	Base	0.46	0.45	0.65	1.07	1.66	2.61	2.94	2.54	1.36	0.83	0.67	0.57
	With Dam	Dry	0.23	0.23	1.30	2.15	3.34	5.13	5.93	5.06	2.72	1.68	1.34	1.15
Balkh2	Without Dam	Base	0.46	0.45	0.65	1.07	1.66	2.61	2.94	2.54	1.36	0.83	0.67	0.57
	With Dam	Dry	0.23	0.23	1.46	2.92	4.50	7.39	9.48	7.96	4.54	2.55	1.97	1.67
Amuzang	Without Dam	Base	0.46	0.45	0.73	1.46	2.44	3.93	4.75	4.04	2.27	1.27	0.99	0.83
	With Dam	Dry	0.23	0.23	1.49	2.35	4.79	5.87	6.16	5.28	4.63	3.29	3.42	3.49
	Without Dam	Base	0.46	0.45	0.74	1.16	4.18	4.60	4.56	4.24	1.36	0.85	0.70	0.60
	With Dam	Dry	0.23	0.23	0.26	0.29	0.73	1.40	0.67	0.30	0.15	0.17	0.23	0.29
	Without Dam	Base	0.46	0.45	0.13	0.15	0.37	0.71	0.33	0.15	0.07	0.08	0.12	0.14
	With Dam	Dry	0.23	0.23	0.26	0.29	0.73	1.40	0.67	0.30	0.15	0.17	0.23	0.29
	Without Dam	Base	0.46	0.45	0.13	0.15	0.37	0.71	0.33	0.15	0.07	0.08	0.12	0.14
	With Dam	Dry	0.23	0.23	0.13	0.16	0.52	1.19	0.54	0.17	0.15	0.17	0.23	0.29
	Without Dam	Base	0.46	0.45	0.04	0.05	0.27	0.62	0.24	0.06	0.07	0.08	0.12	0.14
	With Dam	Dry	0.23	0.23	0.13	0.16	0.52	1.19	0.54	0.17	0.15	0.17	0.23	0.29
	Without Dam	Base	0.46	0.45	0.04	0.06	0.27	0.61	0.24	0.06	0.07	0.08	0.12	0.14
	With Dam	Dry	0.23	0.23	2.09	4.35	6.82	10.51	11.13	8.59	4.96	3.01	2.53	2.34
	Without Dam	Base	0.46	0.45	1.14	2.15	3.63	5.51	5.55	4.34	2.48	1.50	1.27	1.16
	With Dam	Dry	0.23	0.23	2.38	3.78	7.11	8.99	7.81	5.93	5.05	3.75	3.98	4.15
			0.80	0.82	1.16	1.86	5.36	6.18	5.36	4.54	1.57	1.08	0.98	0.93

(Continued)



for irrigation during the late spring, summer, and early fall. Without the Dam, no storage optimization occurs since there is no significant storage to regulate. With the Dam, streamflows are heavily regulated by the Reservoir while ensuring that each country receives at least as much irrigation economic benefit with the project as without it.

With the Dam, the politically constrained reservoir operation that would produce an actual Pareto improvement requires the accumulation of water stocks during the high inflow months to build up a large reservoir storage volume and associated high head for power production. After this buildup of storage occurs, releases take place during the low-flow summer months for joint energy and agricultural production. The table also reveals important information on water-use patterns for each country. Home to the largest irrigated area in the Basin, Uzbekistan diverts and consumes much more water for irrigated agriculture than the other three countries combined: under the “no Dam” policy Uzbekistan averages  $22.4 \text{ km}^3$  water consumption per year in the base water supply scenario and  $11.8 \text{ km}^3$  in the drought scenario. However, with the Dam, Uzbekistan uses  $22.2$  and  $15.8 \text{ km}^3$ , respectively, for the two water supply scenarios. The next largest water user is Turkmenistan, while the lowest estimated water use occurs for Afghanistan, largely because of its damaged irrigation infrastructure caused by sustained military conflict since the 1970s.

### 3.2.2. Reservoir storage

Results showing operation of the Reservoir are based on a constrained optimization of the discounted net present value of water storage and use in the Basin. One important constraint of the optimization is that irrigation income for each country in the Basin must be at least as high with as without the Dam. Table 5 shows reservoir storage volume by month and year for the 20 year time horizon for the Reservoir that satisfies these constraints.

With a capacity of  $13.3 \text{ km}^3$  for storing an average annual discharge from the Vakhsh River of  $20 \text{ km}^3$ , the Reservoir has the capacity to store about two-thirds of the river system’s annual supply. Taking into account that the discharge of the Vakhsh River contributes about a third of Basin’s total discharge, it becomes clear that the proposed Project could regulate a very high percentage of the basin’s agricultural production, making useable supplies available in a dry year, and saving supplies from wet years for later periods when future supplies are low and most agricultural benefit would otherwise be lost.

The Reservoir under current planning is designed with a total capacity of  $13.3 \text{ km}^3$  with  $8.6 \text{ km}^3$  of active storage. Despite these capacity limits, the table shows that the optimized Dam water storage never reaches those limits. This surprising result occurs because releases from storage produce a higher economic value for power and irrigation taken together than increased storage from releases held back for higher future energy production. These results are consistent for both water supply scenarios. The maximum storage volume averaged over the 20 year analysis is shown to be  $6.65 \text{ km}^3$ , typically reached in the month of September (base water supply scenario) in preparation for energy production during the subsequent fall and winter. However, the reservoir never reaches anything close to a zero storage volume. This means that the optimized storage and release pattern typically generates power throughout the typical year. The operation regime of the Reservoir is optimized to satisfy requirements of both agricultural needs of riparian countries and energy needs of Tajikistan.

Table 5. Rogun Reservoir storage volume by year, month, and water supply scenario (km<sup>3</sup>).

Year	Water supply scenario	January	February	March	April	May	June	July	August	September	October	November	December
1	Base	0.24	0.46	0.46	0.75	0.72	1.44	3.08	4.38	5.29	5.31	4.91	4.25
	Dry	0.12	0.23	0.22	0.36	0.05	0.15	0.80	1.21	1.68	1.90	2.06	2.19
2	Base	3.41	2.49	2.41	2.60	2.50	3.50	5.24	6.65	6.65	6.32	5.58	4.62
	Dry	2.30	2.41	2.37	2.47	1.77	1.68	2.06	2.29	2.73	2.95	3.10	3.24
3	Base	3.55	2.47	2.39	2.65	2.55	3.53	5.23	6.65	6.65	6.41	5.78	4.90
	Dry	3.35	3.46	3.42	3.54	2.83	2.71	2.99	3.14	3.58	3.80	3.97	4.10
4	Base	3.88	2.81	2.81	3.13	3.12	3.72	5.36	6.65	6.65	6.38	5.70	4.79
	Dry	4.22	4.33	4.33	4.45	3.72	3.47	3.72	3.66	4.10	4.33	4.49	4.62
5	Base	3.75	2.67	2.58	2.80	2.70	3.54	5.25	6.65	6.65	6.41	5.78	4.91
	Dry	4.73	4.85	4.81	4.91	4.20	4.12	4.39	4.42	4.87	5.09	5.25	5.37
6	Base	3.90	2.84	2.84	3.15	3.14	3.73	5.32	6.65	6.65	6.43	5.81	4.94
	Dry	5.49	5.60	5.60	5.74	4.92	4.65	4.74	4.66	5.10	5.33	5.49	5.62
7	Base	3.93	2.87	2.87	3.18	3.18	3.70	5.33	6.65	6.65	6.32	5.60	4.66
	Dry	5.73	5.84	5.84	5.99	5.21	4.93	5.00	4.93	5.37	5.59	5.75	5.89
8	Base	3.60	2.51	2.43	2.65	2.54	3.51	5.24	6.65	6.65	6.30	5.57	4.61
	Dry	6.00	6.12	6.08	6.20	5.41	5.00	5.13	5.04	5.48	5.70	5.86	5.99
9	Base	3.54	2.45	2.37	2.64	2.53	3.51	5.26	6.65	6.65	6.37	5.71	4.80
	Dry	6.10	6.21	6.18	6.31	5.52	5.23	5.37	5.30	5.75	5.97	6.13	6.26
10	Base	3.77	2.70	2.70	3.00	2.99	3.70	5.39	6.65	6.65	6.32	5.59	4.65
	Dry	6.38	6.49	6.49	6.65	5.71	5.29	5.38	5.35	5.82	6.04	6.21	6.33
11	Base	3.58	2.49	2.41	2.63	2.53	3.49	5.24	6.65	6.65	6.33	5.62	4.69
	Dry	6.44	6.56	6.53	6.65	5.73	5.23	5.27	5.19	5.66	5.87	6.03	6.15
12	Base	3.63	2.55	2.47	2.68	2.57	3.51	5.23	6.65	6.65	6.35	5.65	4.72
	Dry	6.27	6.38	6.35	6.46	5.56	5.31	5.33	5.16	5.61	5.83	6.00	6.13
13	Base	3.67	2.58	2.51	2.72	2.61	3.57	5.25	6.65	6.65	6.28	5.52	4.54
	Dry	6.25	6.37	6.32	6.43	5.50	5.21	5.23	5.05	5.50	5.72	5.88	6.01
14	Base	3.46	2.36	2.28	2.51	2.41	3.50	5.24	6.65	6.65	6.31	5.58	4.62
	Dry	6.13	6.24	6.21	6.32	5.41	5.00	4.95	4.73	5.20	5.42	5.58	5.70
15	Base	3.55	2.46	2.38	2.61	2.50	3.54	5.29	6.65	6.65	6.40	5.75	4.86
	Dry	5.82	5.93	5.90	6.03	5.06	4.56	4.60	4.39	4.85	5.06	5.21	5.35

(Continued)

Table 5. (*Continued*).

Year	Water supply scenario	January	February	March	April	May	June	July	August	September	October	November	December
16	Base	3.85	2.78	2.70	2.91	2.85	3.54	5.24	6.65	6.65	6.37	5.70	4.79
	Dry	5.47	5.58	5.56	5.73	4.64	4.12	4.16	3.91	4.37	4.58	4.74	4.86
17	Base	3.76	2.68	2.68	3.01	3.01	3.59	5.31	6.65	6.65	6.33	5.63	4.70
	Dry	4.98	5.09	5.09	5.23	4.16	3.65	3.42	3.08	3.54	3.75	3.91	4.04
18	Base	3.64	2.56	2.49	2.71	2.59	3.50	5.22	6.65	6.65	6.31	5.58	4.64
	Dry	4.16	4.27	4.23	4.38	3.30	2.84	2.76	2.42	2.87	3.09	3.24	3.38
19	Base	3.57	2.49	2.41	2.62	2.51	3.51	5.24	6.65	6.65	6.42	5.79	4.91
	Dry	3.49	3.60	3.56	3.67	2.51	1.89	1.76	1.41	1.88	2.10	2.26	2.38
20	Base	3.90	2.83	2.83	3.13	3.12	3.69	5.30	6.65	4.84	2.76	1.11	0.19
	Dry	2.50	2.61	2.61	2.72	1.49	0.82	0.48	0.01	0.44	0.42	0.25	0.06

### 3.3. Agriculture

#### 3.3.1. Land

Table 6 shows results of land area under crop production by country, policy, water supply scenario, crop, and cropping season. The table's most important message is that total irrigated land in production shows no reduction with the Dam compared to the "no Dam" option. Uzbekistan and Turkmenistan could irrigate as much or more lands with the water made available by the Dam even in the drought water supply scenario. Our results show that the cropping area need not be reduced by the construction and operation of the Reservoir. This occurs because of our requirement of an equitable distribution of benefits among the riparians.

Closer inspection of the table shows that in the presence of the Dam, each Basin country could sustain an equal or higher level of irrigated land with the Dam than without it for both water supply scenarios. In the drought scenario, the Dam can serve the role of seasonal regulator of farmland in Uzbekistan and Turkmenistan, although this is not the case for Tajikistan and Afghanistan. Under the development and operation of the Dam, an average of 2.3% increase in irrigated land area is seen for the base water scenario for all countries. Turkmenistan is located at the bottom of the Basin, and even that riparian can slightly increase its irrigated land with the Dam.

Wheat is the major crop for all countries in the basin and performs an important role in domestic food security. As the least cost wheat supplier in the Basin, Uzbekistan has the most land under wheat cultivation, followed by Turkmenistan. However, since wheat is essential for food security, it also makes up an important part of the crop mix in both Tajikistan and Afghanistan. For example, Tajikistan allocates 70% and 62% of total irrigated land for wheat production with and without the Dam, respectively, for the base water supply scenario.

Similar water-use patterns are observed in Afghanistan, which allocates an even higher 75% of total land under irrigation for wheat, both with and without the Dam. But, in a drought scenario, both Turkmenistan and Afghanistan alter their total lands to favor additional vegetable production because of its higher price in the face of reduced water supplies. Produce prices have a long history of escalating in periods of drought in this part of the world, so price very much depends on production levels. While wheat and vegetable production is important for upstream countries of Tajikistan and Afghanistan, their production is also needed for the downstream countries. While Uzbekistan and Turkmenistan place wheat as a top priority for food security, cotton serves as an important hard currency source. For example, the land area under cotton production occupies from 26 to 42% of total irrigated land under the two policies and two water-supply scenarios for Uzbekistan and no more than 5% in Turkmenistan. The upstream countries practice little cotton production because of their higher elevations and colder climate.

#### 3.3.2. Production

Table 7 shows physical agricultural production by country, policy, water supply scenario, crop, and crop season. Consistent with findings from Table 6, agricultural production in the Basin shows no decrease brought about by the building and equitable operation of the Dam. Every riparian country could maintain its crop production level with a minimum alteration of its mix of crop production. The potential for sustainable agricultural production shows that the Dam could contribute to stable and sustained food security for all basin countries, each of which have a need to achieve food self-sufficiency for current and growing populations.

Table 6. Farmland in production by country, policy, water supply scenario, crop, and season, averaged over future years (millions of ha/season).

Country	Policy	Water supply Scenario	Water supply						Total land over crops					
			Cotton		Wheat		Vegetables		First crop		Second crop		Total land	
			First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop	Over seasons			
Tajikistan	Without Dam	Base	0.00	0.00	0.21	0.00	0.03	0.05	0.25	0.05	0.05	0.30		
	With Dam	Dry	0.00	0.00	0.00	0.00	0.07	0.02	0.07	0.02	0.02	0.08		
		Base	0.00	0.00	0.16	0.00	0.08	0.02	0.25	0.02	0.02	0.26		
Afghanistan	Without Dam	Dry	0.00	0.00	0.00	0.00	0.08	0.01	0.08	0.01	0.01	0.09		
	With Dam	Base	0.00	0.00	0.06	0.00	0.02	0.00	0.08	0.00	0.00	0.08		
		Dry	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.03		
Uzbekistan	Without Dam	Base	0.01	0.00	0.06	0.00	0.01	0.00	0.08	0.00	0.00	0.08		
	With Dam	Dry	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.03		
		Base	0.03	0.75	1.08	0.01	0.00	0.00	1.12	0.76	0.76	1.87		
Turkmenistan	Without Dam	Dry	0.02	0.38	0.53	0.09	0.00	0.00	0.54	0.46	0.46	1.00		
	With Dam	Base	0.04	0.73	1.08	0.01	0.00	0.00	1.12	0.74	0.74	1.86		
		Dry	0.02	0.36	0.52	0.58	0.00	0.00	0.54	0.94	0.94	1.49		
	Without Dam	Base	0.01	0.02	0.31	0.43	0.00	0.00	0.33	0.44	0.44	0.77		
	With Dam	Dry	0.01	0.01	0.15	0.24	0.00	0.00	0.16	0.25	0.25	0.40		
		Base	0.02	0.01	0.31	0.56	0.00	0.00	0.33	0.57	0.57	0.89		
		Dry	0.01	0.00	0.15	0.49	0.00	0.00	0.16	0.50	0.50	0.65		

Table 7. Agricultural production by country, year, season, policy, and scenario (million metric tons/season).

		Cotton				Wheat				Vegetables				Total over seasons					
		First season		Second season		First season		Second season		First season		Second season		Cotton		Wheat		Vegetables	
		Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry
Tajikistan	Without Dam	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.36	0.63	0.00	0.00	0.32	0.00	0.32	0.00	0.99	
	With Dam	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.82	0.18	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
Afghanistan	Without Dam	Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.21	0.00	0.00	0.25	0.00	0.25	0.00	1.18	
		Dry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.14	0.00	0.00	0.00	0.00	0.00	0.00	1.10	
	With Dam	Base	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.18	0.00	0.00	0.00	0.10	0.00	0.10	0.00	0.18	
		Dry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	
Uzbekistan	Without Dam	Base	0.01	0.00	0.00	0.10	0.00	0.00	0.00	0.09	0.00	0.00	0.01	0.10	0.01	0.10	0.01	0.09	
		Dry	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.33	
	With Dam	Base	0.07	1.73	0.87	1.63	0.79	0.01	0.13	0.00	0.00	0.00	1.80	1.64	1.80	1.64	0.00	0.00	
		Dry	0.04	0.87	0.87	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.92	0.90	0.92	0.00	0.00	
Turkmenistan	Without Dam	Base	0.08	1.68	0.84	1.62	0.02	0.00	0.00	0.00	0.01	0.01	1.76	1.64	1.76	1.64	0.01	0.01	
		Dry	0.04	0.84	0.84	0.79	0.87	0.00	0.00	0.00	0.00	0.00	0.88	1.65	0.88	1.65	0.00	0.00	
	With Dam	Base	0.03	0.03	0.03	0.47	0.64	0.64	0.00	0.00	0.00	0.00	0.06	1.10	0.06	1.10	0.00	0.00	
		Dry	0.02	0.02	0.02	0.23	0.36	0.36	0.00	0.00	0.00	0.00	0.03	0.58	0.03	0.58	0.00	0.00	
With Dam	Base	0.03	0.02	0.02	0.46	0.84	0.84	0.00	0.00	0.00	0.00	0.05	1.30	0.05	1.30	0.00	0.00		
	Dry	0.02	0.01	0.01	0.23	0.74	0.74	0.00	0.00	0.00	0.00	0.02	0.96	0.02	0.96	0.00	0.00		

Vegetables are the most profitable crop for both Tajikistan and Afghanistan, and therefore vegetables achieve first place in terms of production value, after food security needs are met from wheat production. The next highest volume of physical production for these countries is wheat. Tajikistan produces more vegetables than any other country and Afghanistan achieves the same results of higher vegetable production. Both Tajikistan and Afghanistan can reallocate areas among crops with the Dam for both water supply scenarios.

### **3.4. Energy**

The national motivation for energy independence and its potential to capitalize on exports has been an important force for the desire by Tajikistan to build the Dam. Table 8 shows that the Dam's construction and operation could be carried out to satisfy those energy security motivations. Building and operating the Dam and Reservoir could achieve self-sufficiency in energy with an additional potential to export unused energy. Moreover, under a carefully designed reservoir operation scheme, the Dam could simultaneously serve energy requirements of Tajikistan while also contributing to food security needs of the downstream riparians. So, our findings suggest that with careful negotiation on the water-use rights downstream of the Dam, all riparians could be better off with the Dam than without it. This would permit all countries to achieve important development goals. According to results shown in the table, the Reservoir could start producing power at nearly its maximum capacity in the second year of the 20 year horizon after completion.

The pattern of water accumulation at the Dam from early spring until late summer, then releasing water from September to February, takes place to support power production during peak energy demand periods. The reservoir produces on average 60–70% of its maximum power production from September to February when energy demand is high. However, even such an operation pattern does not prevent water releases for downstream irrigation needs. This desirability of operating the reservoir to release water in the spring and summer occurs because releases during that period simultaneously produce power and irrigation benefits. Under the constrained optimized operation, the Reservoir supplies nearly 40% of its yearly electricity production in just three winter months.

One unexpected result occurs in the dry (low flow) water supply scenario: the Reservoir generates no power at all in the winter period while releasing water for irrigation of downstream lands. This occurs because of the above-mentioned constraint that requires agricultural benefits with the Dam to be higher or at least equal to agricultural benefits than without it. This finding shows that the reservoir acts as a drought regulator during low water years. However, for this ideal condition to occur in future years, patient, thoughtful, and deliberate political negotiations between Tajikistan and the other riparians will be needed, as described in more detail in the Conclusions. Without such negotiations, the reservoir could easily continue to produce energy at the expense of irrigated agriculture, worsening the consequences of drought for downstream agriculture and giving rise to increased likelihood of escalating conflict.

### **3.5. Economics**

#### *3.5.1. Economic value of agriculture*

Table 9 describes farm income by country, policy, and scenario. The table shows an important general finding that farm income can be at least as large with Dam as without it for each country in the Basin. These findings are entirely compatible with results

Table 8. Rogun Reservoir energy production by year, policy, and scenario, averaged over future years (GW hours/month).

Year	Scenario	January	February	March	April	May	June	July	August	September	October	November	December	Total
1	Base	0	0	280	299	1130	1041	533	553	0	554	952	1222	6563
	Dry	0	0	124	134	564	624	355	505	0	0	0	0	2307
2	Base	1357	1404	431	435	1368	778	468	480	1239	1060	1415	1608	12,042
	Dry	0	0	206	207	1395	1027	760	832	0	0	0	0	4427
3	Base	1663	1606	431	436	1362	711	469	481	1259	907	1287	1513	12,123
	Dry	0	0	231	232	1563	1159	928	938	0	0	0	0	5050
4	Base	1618	1616	343	346	1364	1359	571	584	1251	972	1345	1557	12,926
	Dry	0	0	171	172	1592	1330	1048	1176	0	0	0	0	5489
5	Base	1644	1619	444	445	1443	903	476	484	1224	903	1273	1505	12,363
	Dry	0	0	238	237	1620	1161	1023	1067	0	0	0	0	5345
6	Base	1602	1605	345	348	1384	1237	573	586	1274	894	1265	1501	12,613
	Dry	0	0	184	184	1772	1340	1175	1263	0	0	0	0	5918
7	Base	1601	1615	347	350	1307	1306	574	587	1237	1040	1389	1589	12,942
	Dry	0	0	199	200	1735	1405	1228	1244	0	0	0	0	6011
8	Base	1659	1621	433	437	1374	770	470	482	1255	1053	1414	1611	12,580
	Dry	0	0	230	230	1764	1584	1250	1333	0	0	0	0	6390
9	Base	1668	1615	434	439	1446	734	472	483	1241	960	1326	1539	12,356
	Dry	0	0	230	230	1780	1420	1201	1223	0	0	0	0	6083
10	Base	1626	1612	352	356	1368	1130	578	591	1268	1045	1395	1603	12,924
	Dry	0	0	192	192	2003	1665	1262	1286	0	0	0	0	6600
11	Base	1666	1615	443	443	1389	834	477	485	1265	1028	1375	1580	12,601
	Dry	0	0	228	227	1898	1680	1345	1265	0	0	0	0	6643
12	Base	1653	1613	437	440	1432	760	473	483	1228	1002	1367	1580	12,468
	Dry	0	0	226	226	1879	1342	1366	1431	0	0	0	0	6469
13	Base	1650	1612	427	431	1372	766	462	474	1239	1095	1448	1635	12,612
	Dry	0	0	256	256	1937	1500	1330	1369	0	0	0	0	6647
14	Base	1684	1618	435	438	1344	656	474	484	1225	1056	1411	1611	12,436
	Dry	0	0	227	226	1947	1572	1381	1403	0	0	0	0	6757
15	Base	1673	1615	444	444	1374	708	479	485	1251	934	1303	1513	12,221
	Dry	0	0	233	231	1991	1594	1409	1419	0	0	0	0	6877

(Continued)

Table 8. (Continued).

Year	Scenario	January	February	March	April	May	June	July	August	September	October	November	December	Total
16	Base	1613	1606	443	447	1379	1144	482	491	1242	961	1332	1547	12,686
	Dry	0	0	212	213	2105	1673	1323	1502	0	0	0	0	7028
17	Base	1634	1614	334	337	1345	1261	565	578	1230	1011	1369	1578	12,855
	Dry	0	0	189	189	2089	1715	1551	1500	0	0	0	0	7232
18	Base	1644	1613	430	434	1418	923	466	477	1230	1045	1396	1595	12,671
	Dry	0	0	227	228	2044	1534	1424	1538	0	0	0	0	6995
19	Base	1657	1614	428	432	1415	736	465	476	1262	911	1283	1509	12,188
	Dry	0	0	234	235	2062	1661	1400	1430	0	0	0	0	7022
20	Base	1606	1608	345	348	1307	1308	573	586	3606	3132	2198	1040	17,658
	Dry	0	0	172	172	1974	1594	1323	618	25	230	310	227	6647

shown above. Potential farm income that could be earned with the Dam is 1.5 and 4% higher than without it for the base and dry water supply scenarios, respectively. No country in the Basin needs to see a reduction in its farm income. These findings provide evidence that the presence and operation of the Dam need not have an adverse impact on the downstream riparians.

Even with efficient development and allocation of water, drought imposes costs. Without the Dam, drought imposes high costs, but after the investment has been made to build it, those costs are reduced considerably. Even when producing power for Tajikistan, the Dam is a mechanism to regulate flows, and as a consequence, reduce the economic costs of drought. The difference between farm income in the base and dry water supply scenarios is a 25% reduction. Among countries, the table shows that the highest farm income is earned in Uzbekistan, producing on average, five times more farm income than any other riparian country. Uzbekistan alone earns about 80% of total farm income in the Basin. In Uzbekistan, the lion's share of that income is produced by cotton.

Afghanistan has the lowest gain in farm income among Basin countries with the Dam due to its (estimated) lowest irrigated area in the Basin. Afghanistan sees an increase in income under the "with dam" policy, in which the Rogun Dam would be built, by a very modest 1.5% in dry conditions, but fails to achieve even that in the base scenario, showing nearly the same income for both policy scenarios. Many studies published since 2000 have shown that Afghanistan has suffered historically and it continues to suffer from drought because of its limited in-country reservoir storage as well as its weakly-developed water institutions for sharing water shortages. Numerous ongoing planning efforts by the Afghan government are examining ways to deal with these two related challenges.<sup>2</sup>

Table 9 shows that with the Dam, farm income is equal or larger than without it for all countries in the Basin. Our results show that the basin countries taken together could increase their income by US\$ 2 billion in the base water supply scenario or by US\$ 4.2 billion in dry future conditions in present value terms. Additional storage capacity takes on a higher economic value in the face of greater annual variability in water supplies. This additional economic value with greater supply variability occurs because greater reservoir storage capacity provides a mechanism to better capture high flows in wet years for use in future dry years when there would have otherwise been no water available had a smaller reservoir been built (Gohar, Ward, and Amer 2013). This finding takes on considerable importance to the Basin's riparians, who will be likely seeking more resilient water shortage sharing technologies and institutions for adapting to future climate change.

### 3.5.2. *Economic value of energy*

Table 10 shows the trend of energy production by policy and water supply scenario. For the base water supply scenario, average annual energy production is US\$ 305 million, while for the drought scenario it is no surprise that this production takes on a much smaller value of US\$ 145 million, as reservoir storage declines in the face of increased water demands for irrigated agriculture. Our results show that the Dam has considerable potential to help Tajikistan achieve economically and politically important energy security. Furthermore, the economic benefits earned by energy production with the Dam project stands to be a considerable addition to the economic resources of this impoverished country.

Table 9. Farm income by country, policy, and scenario (in million US\$/year).

Year	Tajikistan						Afghanistan						Uzbekistan						Turkmenistan						Total, all countries					
	Without Dam		With Dam		Without Dam		With Dam		Without Dam		With Dam		Without Dam		With Dam		Without Dam		With Dam		Without Dam		With Dam		Without Dam		With Dam			
	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry	Base	Dry		
1	545	435	554	447	103	167	103	167	6128	4402	6128	4406	391	233	391	233	391	233	391	233	7167	5237	7167	5237	7176	5237	7176	5237		
2	515	429	625	482	133	173	133	175	5912	4226	5912	4309	572	365	572	365	583	393	583	393	7132	5194	7132	5194	7291	5194	7291	5194		
3	520	437	628	486	128	169	128	170	5975	4282	5975	4357	529	335	529	335	540	362	540	362	7153	5223	7153	5223	7310	5223	7310	5223		
4	526	429	526	436	122	172	122	172	6188	4432	6188	4536	405	237	405	237	405	315	405	315	7241	5270	7241	5270	7241	5459	7241	5459		
5	546	442	653	484	102	162	102	170	5974	4302	6018	4379	518	333	518	333	530	360	530	360	7140	5239	7140	5239	7303	5239	7303	5239		
6	535	425	535	433	113	177	113	177	6164	4419	6164	4542	392	229	392	229	392	312	392	312	7204	5251	7204	5251	7204	5465	7204	5465		
7	543	438	543	445	104	168	104	168	6153	4435	6153	4545	385	230	385	230	385	310	385	310	7186	5271	7186	5271	7186	5468	7186	5468		
8	525	434	632	482	123	169	123	171	5982	4307	6021	4400	523	336	523	336	534	367	534	367	7153	5247	7153	5247	7310	5247	7310	5247		
9	530	432	635	479	119	172	119	173	6032	4345	6072	4433	496	316	496	316	507	347	507	347	7177	5265	7177	5265	7333	5265	7333	5265		
10	575	432	575	437	74	173	74	173	6174	4419	6174	4571	403	235	403	235	403	325	403	325	7226	5259	7226	5259	7226	5506	7226	5506		
11	554	438	660	485	95	167	95	167	5947	4259	5992	4392	559	357	559	357	572	398	572	398	7155	5221	7155	5221	7318	5221	7318	5221		
12	534	428	640	476	115	175	115	176	5987	4297	6028	4416	526	334	526	334	537	372	537	372	7161	5235	7161	5235	7319	5235	7319	5235		
13	492	437	606	501	158	168	158	170	6029	4317	6063	4430	546	346	546	346	555	385	555	385	7226	5267	7226	5267	7383	5267	7383	5267		
14	538	436	643	483	111	168	111	169	5938	4274	5980	4402	577	376	577	376	588	414	588	414	7164	5254	7164	5254	7322	5254	7322	5254		
15	560	436	665	482	89	168	89	171	5994	4304	6039	4440	535	342	535	342	548	384	548	384	7179	5249	7179	5249	7342	5249	7342	5249		
16	552	431	649	472	96	172	96	173	6098	4360	6140	4551	436	262	436	262	436	321	436	321	7183	5225	7183	5225	7321	5225	7321	5225		
17	494	435	494	442	154	170	154	170	6187	4432	6187	4609	407	239	407	239	407	335	407	335	7242	5275	7242	5275	7242	5556	7242	5556		
18	506	433	618	492	143	169	143	179	6054	4351	6090	4486	475	297	475	297	485	342	485	342	7177	5250	7177	5250	7336	5250	7336	5250		
19	502	436	615	497	147	167	147	178	5959	4279	5995	4440	566	365	566	365	576	414	576	414	7175	5248	7175	5248	7333	5248	7333	5248		
20	536	434	536	443	111	169	111	171	6157	4428	6157	4631	385	227	385	227	385	330	385	330	7189	5258	7189	5258	7189	5576	7189	5576		
Total	10,630	8678	12,033	9383	2337	3395	2337	3443	121,033	86,868	121,552	89,276	9628	5996	9628	5996	9763	7064	9763	7064	143,629	104,938	143,629	104,938	145,685	104,938	145,685	109,165		

The exception to the trend of high energy economic benefits with the Dam project occurs in the first year, when the reservoir begins accumulating water from its starting level of zero storage. But the reservoir reaches nearly its maximum energy production in the second year, with energy benefits of US\$ 437 and US\$ 161 million for base and dry scenario, respectively. The table shows that on a monthly basis, Tajikistan can secure on average US\$ 25 million in the base scenario and US\$12 million in the dry scenario. Energy economic benefits summed over 20 year period are huge for Tajikistan and would be approximately a third to a fourth of its national public budget.

### 3.5.3. Total economic value

Table 11 shows total benefits summed over both uses. It also shows a comparison between the value of water for agriculture and energy averaged over 20 year period by country, policy, and water supply scenario. The table's results show that all countries of the Basin have the potential to be better off with the Dam. Depending on the country, those total benefits vary considerably in comparison to total benefits without the Dam. But all show an increase, a clear indication that the development and operation of the Dam has the potential to be arranged so that all countries can avoid being worse off with the Dam compared to not having it, which amounts to an actual Pareto improvement. This could occur while securing sizeable energy benefits for Tajikistan, so the Reservoir and Dam could maintain or increase agricultural benefits of Afghanistan, Uzbekistan, and Turkmenistan at a higher level than without their presence.

With the exception of Tajikistan all remaining Basin countries could secure improved agricultural benefits with the Dam. With mountains occupying more than 90% of this country, Tajikistan has only a minor irrigated agricultural sector. With the Dam,

Table 10. Energy production by year and scenario (in million US\$/year).

Year	Without Dam		With Dam	
	Base	Dry	Base	Dry
1	0	0	250	88
2	0	0	437	161
3	0	0	419	175
4	0	0	425	181
5	0	0	387	168
6	0	0	376	177
7	0	0	368	171
8	0	0	341	173
9	0	0	319	157
10	0	0	317	162
11	0	0	295	155
12	0	0	278	144
13	0	0	268	141
14	0	0	251	137
15	0	0	235	132
16	0	0	232	129
17	0	0	224	126
18	0	0	211	116
19	0	0	193	111
20	0	0	266	100
Total	0	0	6092	2902

Table 11. Total discounted economic benefits (over 20 years) by country, policy, water supply scenario, and water user (million US\$ npv, discounted at 5%).

Country	Policy	Water supply	Energy benefits	Agricultural benefits	Dam cost	Total net benefits
Tajikistan	Without Dam	Base	0	4006	0	4006
		Dry	0	3270	0	3270
	With Dam	Base	6092	4535	2800	7827
		Dry	2902	3536	2800	3639
Afghanistan	Without Dam	Base	0	881	0	881
		Dry	0	1280	0	1280
	With Dam	Base	0	881	0	881
		Dry	0	1297	0	1297
Uzbekistan	Without Dam	Base	0	45,616	0	45,616
		Dry	0	32,740	0	32,740
	With Dam	Base	0	45,812	0	45,812
		Dry	0	33,647	0	33,647
Turkmenistan	Without Dam	Base	0	3629	0	3629
		Dry	0	2260	0	2260
	With Dam	Base	0	3679	0	3679
		Dry	0	2662	0	2662
Total	Without Dam	Base	0	54,132	0	54,132
		Dry	0	39,550	0	39,550
	With Dam	Base	6092	54,907	2800	58,200
		Dry	2902	41,143	2800	41,246

Tajikistan would benefit considerably from much increased energy production. With the Dam, Tajikistan could increase its total economic value of water by 1.9 times its “no dam” level for the base water supply conditions and by 1.1 times in drought conditions. In general, all countries in the Basin stand to sustain or increase their water-related economic benefits with the construction and operation of the Dam and reservoir. Afghanistan sees the lowest benefit with its current infrastructure limits because of its location parallel to the reservoir and weak existing reservoir capacity in the Basin. But, given improved irrigation infrastructure, even Afghanistan could use water from the mainstream of the River and therefore receive some benefit from the Dam and Reservoir.

#### 4. Conclusions

Facing recurrent power shortages since the early 2000s, Tajikistan has attempted to develop and use its major endowment, the large potential for hydropower production, to become a more prosperous country. The Rogun Dam project became a pillar of the ambitious economic development program of the Tajik government. The Dam is seen as a major resource to achieve energy independence and future economic growth. If the Rogun Dam is completed, it will help the country meet all of its domestic needs as well as making Tajikistan a net power exporter (Sodiqov 2012). Seen in that context, this paper has examined the economic potential for jointly beneficial reservoir development and operation in the Amu Darya River Basin among the four transboundary nations of Tajikistan, Uzbekistan, Afghanistan, and Turkmenistan.

Using an integrated empirical model, this paper develops a basin-scale economic framework that can provide policy insights for analyzing tradeoffs between water, food, and energy security. A 20 year planning framework is applied to assess, analyze, and identify impacts of two policies for each of two water supply scenarios. A without-Dam policy and a with-Dam policy for both base and dry water supply scenarios are

analyzed. Results of the analysis indicate a strong economic basis for all four countries to benefit in the face of the planned development and operation of the Rogun Dam. Each policy and each scenario is examined to find out if there is a basis for a Pareto improvement, in which all four countries could be made better off with the Dam's development and operation than without it.

Our results show that under conditions of negotiated agreements to support an equitable operation of the Rogun Dam, the river system has the potential to increase farm income for Afghanistan, Uzbekistan, and Turkmenistan. The reservoir and Dam, operated with a sensitivity to political and economic needs, could also generate energy income to Tajikistan worth an average of about US\$ 305 million per year under the base water supply scenario and US\$ 145 million under the drought scenario. Several conclusions are reached that illustrate the potential for mutual gain.

First, the economic value of useable water supplies available need not decline for any country with the building of the Rogun Dam. In fact, under optimized operation of the reservoir, economic benefits to all three downstream countries could potentially increase for irrigated agriculture in both normal and drought conditions. Second, the economic value of agricultural production of all riparian countries has the potential to increase in the face of better-timed water application to irrigated agriculture as a consequence of the reservoir-regulating capacity of the Rogun Dam. A third conclusion is that Tajikistan has the potential to secure significant economic benefit from energy production in the Rogun Reservoir, especially in the low water supply scenario, from which the discounted net benefit of the Dam is considerable. Finally, total discounted basin-wide water-related economic benefits for power and agriculture with the Rogun Dam in place can be increased on average by 6%.

Important limitations of this study include weak hydrologic information throughout the basin as a consequence of a damaged or destroyed hydrometric network, making it hard to track recent data on streamflows. Similarly, because of poor data-sharing among the four riparians, little verifiable and consistently collected agricultural data are available on the level of crop production, cost, yields, or crop water use. Therefore, our study requires major assumptions on cropped area, crop mix, streamflows, and crop water use, all of which were difficult to verify. While a few of the farms of the Basin continue to use pre-1990 Soviet style collective resource allocation methods in agriculture, our model is predicated on the presence of efficient institutions, such as markets, for allocating land, water, crops, and energy. It is also based on the presumption that it is both possible and desirable to move scarce water to its highest-valued uses.

Another important limitation of the study comes from the fact that our conclusions show only the potential economic gains from the development of the Rogun Dam, with no details on how that potential could be realized through political negotiation or other action. Such negotiations will not be easy since these four countries have little recent history of well-coordinated cooperation. Still, there may be hope. Recent work by Rahaman (2012) found that two existing water-related agreements in Central Asia incorporate a number of internationally recognized transboundary water management principles. These two agreements are (1) the 1992 Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources and (2) the 2008 Statute of the Interstate Commission for Water Coordination of Central Asia. The author has concluded that the presence of widely recognized principles in these agreements offers hope for promotion of cooperative sustainable water resources management in Central Asia. Other authors describe a variety of mechanisms that could be incorporated into the basin's water use patterns to allow for flexibility in the face of climate

change. McCaffrey (2003) and Fischhendler and Feitelson (2004) present four such mechanisms: (1) flexible water allocation strategies; (2) drought adaptation; (3) adjustment and review; and (4) joint management and allocation institutions.

More recently, Ward (in press) describes a framework that combines these four mechanisms. Under that framework, all riparians could attempt to forge an agreement for sharing headwater flows (natural supplies). One example of this framework, modeled on the North American Rio Grande Compact of 1938, would derive an actual mathematical formula summarizing the recent historical allocation of the basin's headwater flows. This mathematical formula would assign no value judgments over history's allocation of flows among the riparians. After this mathematical formula is developed, the basin's negotiators could debate how future allocations among the states should be different from historical ones. Criteria for dividing the waters could include things like population levels, the human right to water, flows assigned to national watersheds of origin, and historical injustices.

Nevertheless, as of early 2013, relations between Tajikistan and its downstream neighbor Uzbekistan were at an all-time low, with their long-simmering water dispute still a long way from resolution (Arbour 2011). Tajik President Rahmon has stated repeatedly since 2005 a desire to build the Rogun Dam. Downstream, Uzbek President Karimov, has vowed to take whatever steps are needed to stop the project because he believes the Dam will give Tajikistan the capacity to regulate water flows, and therefore hurt the lucrative cotton crop in Uzbekistan. At a UN General Assembly meeting in September 2012, Tajikistan's foreign minister, Zarifi, stated that his country's power shortages gave Tajikistan few choices but to pursue the hydro project. Uzbek Foreign Minister Kamilov used the same venue to argue against the project. Uzbekistan has asked for independent international evaluation of projects on both the Amu Darya and Syr Darya Basins (Babadjanov and Chernyavskiy 2010).

Turkmenistan attempts to secure and sustain good relations with all its neighbors in the Basin. With large natural gas reserves and a small agricultural sector, it perceives less threat from reduced water allocation that could occur from the upstream Rogun. Tajikistan, Turkmenistan, and Uzbekistan are all geographically close neighbors with Afghanistan, and have developed good trade relations with the Afghans. All three countries sell power to Afghanistan. Turkmenistan has developed border trade with the Afghans, while Uzbek companies have built railroads in northern Afghanistan. None of those three countries views Afghanistan as an immediate competitor for water resources in Amu Darya basin, largely because the Afghans have been unable to afford the large infrastructure needed to store, convey, deliver, and use water for irrigated agriculture.

The historical and ongoing weak relations between Uzbekistan and Tajikistan will make it difficult to negotiate ways to divide the waters. Regardless of how future water supplies in the basin are allocated among the riparians, it is clear that sustained, patient, and flexible political negotiations among the countries will be required to secure the potential benefits that our results indicate are possible.<sup>3</sup>

Another limitation of this paper is that it has examined only two policy alternatives under two potential water environments. In the future, we plan to expand the framework to consider more policy choices and more water supply scenarios. Our integrated analysis could be extended for a longer time than 20 years. That expansion would be required to comprehensively address important ongoing policy debates such as climate change, negotiated agreements on water sharing among the affected countries, and regional and international measures to adapt to or even mitigate an altered climate. A greater length of time into the future magnifies the questions about the adequacy of data and increases

the value of investments to upgrade the quality and reliability of those data. While our analysis is based on stochastic water supplies that are compatible with observed data over the available period of record, a more comprehensive analysis model would account for stochastic crop prices and yields, stochastic water demands, and a range of risks associated with future climate variability and change. Despite these limits, this paper has taken a first step at conducting a comprehensive analysis of policy options for addressing the need for food, water, and energy security in the Amu Darya Basin, where all three needs continue to receive growing scrutiny.

## Notes

1. The four tributaries are the Kunduz, Kafirnigan, Surkhandarya, and Sherabad.
2. An unpublished Draft National Water Resources and Irrigation Development Program Plan (February 2012) written by the Afghan government presents a vision to improve agricultural production, raise access to basic services like potable drinking water, and improve sanitation services for livelihoods and economic growth. There are sufficient water resources in the country to allow for further improvement of the water service reliability. However, this will require the establishment of reservoirs for storing water during periods of high runoff from the upper catchments, and releasing it gradually during periods of low supply. It will also require a water-rights system to support sustained operation of the reservoirs. Undertaking such projects is costly and requires considerable preparation, not only because of technical challenges, but also for the need to assess the project against wider river basin development plans. An additional complication occurs where projects change the flow regime of a river crossing into a neighboring country. Improvement of quality and expansion of irrigation services therefore requires considerable preparation and a high level of government capacity that is not currently present.
3. Effective conflict resolution methods vary widely by culture. In western cultures, successful conflict resolution often can be achieved by promoting direct discussion and debate among parties about the conflict itself. An example is drafting agreements that meet all parties' needs. In western cultures, negotiators often openly and directly discuss ways to find a win-win solution for everyone involved. In many nonWestern cultures, such as seen in the Amu Darya Basin, it is still important to find win-win solutions; however, getting there can require different approaches. In these cultures, communication among the negotiators that directly raise the issues at stake can be viewed as rude because they invade sensitivities, exacerbating the conflict and delaying resolution. In those cultures, the search for common denominators may see greater success by bringing in religious or other community leaders, or by communicating sensitive truths indirectly through a third party. One example of a successful conflict resolution model for a transboundary river is the Indus Treaty of 1960. Under it, India and Pakistan agreed to divide the six most important headwaters supplying the Indus Basin.

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