IMPACT OF ROGUN DAM ON DOWNSTREAM UZBEKISTAN AGRICULTURE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

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Strains among the states of Central Asia caused by overuse of the region's scarce water resources have been increasing in recent years. This is especially true for the relations between Tajikistan, upstream, and Uzbekistan, downstream, on the Amudarya River. Major controversy exists over constructing Rogun Dam on the Vakhsh River, a tributary of the Amudarya River. Construction of Rogun Dam, with a planned height of 335 m (1099 ft), began in 1976 but was stopped in 1991 with the breakup of the former Soviet Union. The intent of this dam is to supply Tajikistan with energy, but a side effect will be the changed flow regime of the Amudarya River to downstream states (especially Uzbekistan). The major impact will be on the agricultural sector of Uzbekistan. The objectives of this study are to estimate the monetary impacts of Rogun Dam and propose mitigation measures to minimize impacts. The study investigates the nature and extent of those impacts and indicates policy implications to mitigate negative consequences of the possible water shortage in summer by assessing the baseline situation and comparing that situation with future status-quo (no changes) level of water. Future water shortage could cost Uzbekistan annually over US $609 million economic loss in agriculture, reduce the country's GDP by 2.2%, and result in 336,000 unemployed people. If Uzbekistan changes its present water use practice and increases water use efficiency, the future water shortage during irrigation periods will not as seriously affect the country's economy, as adaptive management measures could cut the losses by 40%.

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LIST OF ABBREVIATIONS

The abbreviations used in this thesis are listed below.

BAT	Best available technology
CA	Central Asia
EDB	Eurasian Development Bank
EIS	Environmental Impact Assessment
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GNP	Gross National Product
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
IA	Impact Assessment
ICWC	Interstate Commission for Water Coordination
O&M	Operation and Maintenance
RCR	Run-off control rate
RHPP	Rogun Hydro Power Plant
SDI	Subsurface drip irrigation
THC	Tuyamuyun Hydroengineering Complex
UN	United Nation
UNECE	United Nation Economic Commission for Europe
UN SPECA	Special Programme for the Economies of Central Asia (SPECA)
USSR	Union of Soviet Socialist Republics

CHAPTER 1. INTRODUCTION

Worldwide, 70% of freshwater used by humans goes to satisfy irrigation agriculture needs, and demand for irrigation water is still increasing as irrigated land continues to rise (Cai et al. 2003). For the countries of the Amudarya River basin, 93.4% of water resources is used for irrigated agriculture (Froebrich et al. 2006). Taking into consideration that upstream countries are keenly interested in developing hydropower energy potential and downstream countries need to satisfy their irrigated agriculture, the region is experiencing conflict between two conflicting interests in using the region's already scarce water resources.

In 2008, Tajikistan announced intentions to resume construction of Rogun Dam on the Vakhsh River, a tributary to the Amudarya River (Schmidt 2008). Construction of Rogun Dam, with a planned height of 335 m (1099 ft), was started in 1976. Construction was stopped in 1991 with the breakup of the Union of Soviet Socialist Republics (USSR; Soviet Union). The purpose of this dam is to supply Tajikistan with hydropower, but a side effect may be a threat of reduced water supplies or changed annual flow regimes for downstream countries (especially for Uzbekistan). This side effect is what economists call an "externality" (Box 1).

> Box 1. Externality
> Externality occurs whenever one economic entity's action affects the well-being of another economic entity for better or worse unintentionally. The most interesting point, whether positive or negative externality occurs, it does not need to be paid. In our case, Tajikistan's action may result in an unintended side effects or negative externality on Uzbekistan.
> *Source:* Mount Holyoke (2010)

Problem statement

Water resources management is within the exclusive sovereignty of countries. Due to political issues and sovereignty rights, the damming of international rivers represents a politically sensitive issue (Uitto and Duda 2002). Remembering the recent

Aral Sea case (Micklin 1993), politicians became involved in the disputes over the need for construction of Rogun dam, followed by environmentalists who questioned the impacts that Rogun dam would have on the environment. These disputes demonstrated how important water is to the socio-economic and environmental well-being of Central Asian countries.

Rogun Dam has led to growing tensions among riparian countries ever since its construction was first envisioned. Rogun Dam caused widespread public opposition not only because of aggravating a social situation by resettling people, but also because this dam would be constructed in a highly active seismic location (Badenkov 1990). The total capacity of the planned hydro investments of Rogun Hydro Power Plant (RHPP) in Tajikistan is expected to be 3,600 MW (average annual performance 13.1 billion kWh) at a cost of US $2.2 billion (EDB 2008). The cost of energy per MWh in Tajikistan is going to be US$10-40, while in neighboring Afghanistan it is US$25-350, in Pakistan US$65-150, and in China US$30-75 (UN SPECA 2004). The importance of the Rogun Dam for downstream Uzbekistan is that: 1) Uzbekistan's use of water from the Amudarya River almost equals the water use of all other five Central Asian (CA) countries combined (Figure 1), and 2) water flow of the Vakhsh River (the second biggest tributary) accounts for 27% of the total flow of the Amudarya River (Figure 2). The construction of the Rogun Dam puts Uzbekistan in a potentially difficult situation of dependence on water release from upstream Tajikistan during the irrigation season.

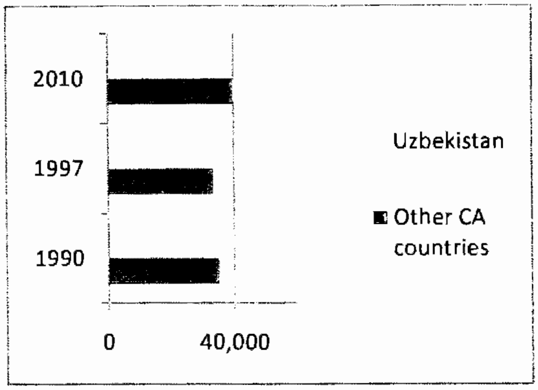

Figure 1. Water use and prospective requirements, Amudarya River (million m^3/yr)
Source: CAREWIB (2010)

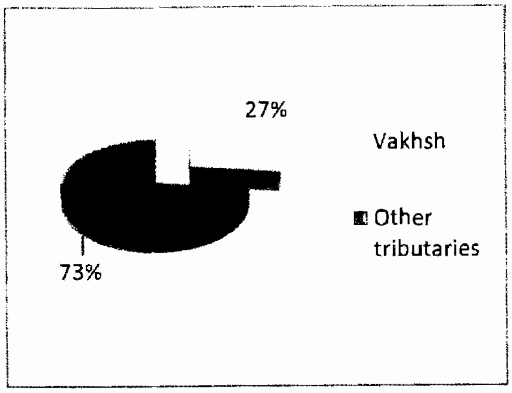

Figure 2. Natural surface flow in the Amudarya River basin (mean annual runoff, %)

Research goals

The goal of this research is to *ex ante* identify possible outcomes of Rogun Dam construction on the economy of Uzbekistan. The objectives of this assessment are to:

1. Estimate the strategic level impacts of the proposed Rogun Dam, in terms of its future water supply volume;
2. Identify impacts to Uzbekistan's agricultural economy during construction of Rogun Dam; and
3. Propose mitigation measures to minimize those impacts under worst case and adaptive scenarios.

Research methods

Research will be conducted in the context of water resources management issues with the specification of transboundary water management. The research will use a generally descriptive and qualitative case study approach. Findings will be interpreted in relation to the working regime of Rogun Dam and in relation to their significance to strategic planning of Uzbekistan's economy.

The steps for developing a general Impact Assessment (IA) include the following:

1. *Describe an existing situation in water resources management as a baseline.* This includes a history of water resources management practices in the former Soviet Union period and after its collapse. This chapter allows for an understanding of the current model of water resources management practices among adjacent riparian countries, with a focus on the positive and negative points for the economies of Tajikistan and Uzbekistan.
2. *Analyze the future economic situation with regard to the construction of Rogun Dam.* Taking into consideration that construction of Rogun Dam is already occurring and completion of the project will take approximately ten more years, a time period of 10 to 15 years was analyzed. Estimation of the available water supply for downstream Uzbekistan and water usage was created through this 10 to 15 year timeline.
3. *Create future possible scenarios for strategic development of the Uzbekistan economy in condition of modified flow regime.* Two possible scenarios were analyzed: 1) Uzbekistan keeps its current practice of water resources management (*worst case*) and 2) Uzbekistan changes its current practice and accepts new methods of water resources management (*adaptive case*).

The proposed research will be a new piece of information for the region of Central Asia. Although an impact assessment should be done before the construction of Rogun Dam, results of the study can provide useful information for policymakers in future damming projects in the study region.

Thesis organization

The thesis consists of five chapters. Chapter 1 is the thesis introduction. Chapter 2 examines the current literature in the fields of water resources management in the study region. Chapter 3 discusses assumptions and methods used in this thesis. Chapter 4 provides the results of the study. Chapter 5 states the conclusions drawn from the current work and suggests directions for future studies.

CHAPTER 2. REVIEW OF LITERATURE AND BACKGROUND

> Nature does not respect national borders; yet human beings seem incapable of managing their affairs without them. Nature has also not endowed every place on earth or every nation with the same type and amount of resources. Herein lie the roots of interstate conflict and cooperation over essential and scarce natural resources, such as freshwater. In Central Asia both possibilities will continue to exist for a long time. (Elhance 1997, p.207)

Central Asia is a region which had been largely unknown to the international community for a long time. Central Asia encompasses five republics of the former Soviet Union: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan (Figure 3) (McKinney 2003).

Figure 3. Map of Central Asia
Source: Blueyurt Central Asia (2010)

The territory of Central Asia covers about 4 million km^2 (1.5 million mi^2) and has about 55 million people (UN 2007a). Most of Central Asia lies within steppes and deserts, which require water to conduct agricultural activities on fertile spots of land (Spoor and Krutov 2003). The climate of the region is generally dry with cold winters and hot summers. The average daytime temperature in July ranges between 25° and 32°C (77° and 90 °F) and the mean temperature in January is between –15° and 3°C (5° and 37°F) (Kharin 2002). Annual precipitation in the region ranges from 200 mm (7.9 in) in deserts and valleys to 800 to 1600 mm (31 to 63 in) in elevated mountain areas; where potential evaporation ranges from more than 2250 mm (88 in) in arid zones to less than 500 mm (20 in) in mountain areas (O'Hara 2000). The region is rich with natural resources, especially oil and natural gas. An estimated reserve of the main natural resources of Central Asia is 33 billion metric tons (250 billion barrels) of recoverable oil and 9.3 trillion m^3 (328 trillion ft^3) of recoverable natural gas (Daly 2009).

The economies of all Central Asian countries, except Kazakhstan, are largely dependent on agricultural production and this agriculture is almost fully dependent on irrigation (ICG 2002). Currently, 60% of the rural population in the basin of the Aral Sea[1] is employed by agricultural related businesses (UN 2007a, Elhance 1997). The well-being of 53% of the people in CA, including 20 million people in Uzbekistan, is directly dependent on an irrigation-based economy (Elhance 1997). Currently, only 18 million hectares (44 million acres) of the 59 million hectares (146 million acres) of arable land are being cultivated (UN 2007a). The third largest country of the region, by area, Uzbekistan, has the largest arable land area of more than 9 million hectares (22 million acres). In contrast, countries of Kyrgyzstan and Tajikistan, collectively have

[1] The Aral Sea basin includes states in Central Asia – Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan – and parts of Afghanistan and northern Iran (Elhance 1997). However, for the purpose of this study, Aral Sea basin, presumes only territories of five Central Asian countries.

only 14% of all arable area of the Aral Sea basin, but these countries are upstream, water flow-generating countries (Table 1). As more than half of the Gross Domestic Product (GDP) directly comes from agriculture and about 40% of human resources are employed in that sector, effectively managing the region's rich, but unequally spread, water resources is critical (O'Hara 2000). Access to fresh water resources is becoming the most vital issue in Central Asia.

Table 1. Land resources of the Aral Sea basin

Country	Area, ha	Potential arable land, ha	Arable land, ha
Kazakhstan*	34,440,000	23,872,400	2,445,000
Kyrgyzstan*	12,490,000	1,570,000	1,017,000
Tajikistan	14,310,000	1,571,000	1,593,000
Turkmenistan	48,810,000	7,013,000	3,540,300
Uzbekistan	44,884,000	25,447,700	9,441,200
Aral Sea Basin	**154,934,000**	**59,474,100**	**18,036,500**

Source: FAO (1997)
Note: * Territories within the Aral Sea basin

The distinctive feature of the region is the uneven distribution of energy resources where Kazakhstan, Turkmenistan, and Uzbekistan have almost all proven reserves of hydrocarbons (oil and natural gas), while Kyrgyzstan and Tajikistan have approximately 90% of all hydropower potential (UN 2007a). However, water is the most important conflict-prone resource, along with land and mineral reserves (UN 2007b). Therefore, disputes and strains over the use of scarce water resources within the region are escalating (Sievers 2002). Smith (1995, p. 353) gave a dangerous forecast for the future of Central Asian countries by stating "nowhere in the world is the potential for conflict over the use of natural resources as strong as in Central Asia." Therefore, careful management of natural resources in Central Asia is becoming a critical issue for political stability in the region.

Central Asia has two major rivers, the Amudarya[2] and the Syrdarya[3]. Both rivers originate in mountainous areas in Central Asia. Both rivers flow into the Aral Sea and contribute to the water resources of the Aral Sea basin, which constitutes approximately 90% of the region's usable water resources, which is about 125 km^3 (30 mi^3) annually (O'Hara 2000) (Figure 4).

Figure 4. Aral Sea basin
Source: Roll et al. (2003)

Along its route to the Aral Sea, the Amudarya River serves as a border between Afghanistan and Tajikistan and between Afghanistan and Uzbekistan. Surface runoff constitutes a large portion of inflow for both rivers (Elhance 1997). The Amudarya River is the largest river in Central Asia (both in length and flow) with a length of 2,540 km (1,578 mi) (Wegerich 2004) and is shaped by the confluence of two main tributaries, the Vakhsh and Pyandj Rivers (Figure 5).

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[2] Amudarya = Amu Darya
[3] Syrdarya = Syr Darya

Figure 5. Symbolic map. The Amudarya River basin

The Amudarya River basin's drainage terminates in the Aral Sea and comprises territories of Afghanistan. Kazakhstan. Turkmenistan, Tajikistan. and Uzbekistan. The Amudarya River basin catchment zone includes between 250,000 and 304.000 km^2 (96.000 and 117.000 mi^2) and is shared by Afghanistan and four central Asian states of Kyrgyzstan. Tajikistan. Turkmenistan, and Uzbekistan (Wegerich et al. 2007. Schluter et al. 2005). The two reservoirs along the main flow of the Amudarya River are the Tyuyamuyun and Tahiatash reservoirs (Schlüter et al. 2005). The Amudarya's average annual runoff is 73.6 km^3 (18 mi^3) with variations between 47 and 108 km^3 (11 and 26 mi^3) (Spoor and Krutov 2003).

The second largest river in the Aral Sea basin is the Syrdarya River. which starts in Kyrgyzstan and ends in the Aral Sea. The Syrdarya River is shorter than the Amudarya River with a length of 2.200 km (1.367 mi) and has an average annual discharge of 38.8 km^3 (9 mi^3) with a variation ranging between 21 and 54 km^3 (5 and 13 mi^3) (Spoor and Krutov 2003).

The Amudarya and Syrdarya river flows are heavily regulated. A UN Diagnostic report estimates that the run-off control rate (RCR) is 0.78 for the Amudarya River and 0.94 for the Syrdarya River. Flows of both rivers are heavily regulated through a number of water management facilities such as diversion dams and reservoirs.

> Box 2. Run-off control rate
> Run-off control rate is how much surface water cannot be discharged onto areas of natural vegetation and where RCR of 1.00 is equal to no water reaching its natural flow areas.
> *Source:* UN (2007a)

In the Aral Sea basin, high RCR occurs due to the presence of 18 water reservoirs on the previously mentioned rivers. Total capacity of water storage of all 18 water reservoirs on both rivers approximates to 57 million m^3 (2 billion ft^3), where twelve reservoirs are on the Syrdarya River [total capacity of 36.5 million m^3 (1.3 billion ft^3)] and six reservoirs on the Amudarya River [total capacity of 20.2 million m^3 (0.7 billion ft^3)] (Elhance 1997). In addition, the two rivers have collectively 274 water diversion structures and 612 km (380 mi) of main canals (Elhance 1997). The Syrdarya River is more heavily regulated than the Amudarya River, although there are a few new dams under construction on both rivers (Libert et al. 2008, Wegerich 2008). Reservoirs in Tajikistan control approximately 60% of the total Amudarya flow and also 9% of Syrdarya storage volume, while Kyrgyzstan controls only 58% of the Syrdarya storage volume (O'Hara 2000). Diversions from these two rivers have made available enough water for agricultural, industrial and other uses in most of Central Asia as there are few sources of freshwater outside these two main river basins (Elhance 1997). The reservoirs upstream of the Amudarya and Syrdarya Rivers control water discharge, and disputes between upstream and downstream countries have occurred in recent decades.

Water resources are unequally distributed among the states of Central Asia (Table 2). Upstream countries of Kyrgyzstan and Tajikistan together control about 68% of the total water flow in the Aral Sea basin; in the same time the downstream countries of Kazakhstan, Turkmenistan and Uzbekistan consume the most water, about 85% of water resources in the Aral Sea basin (Libert et al. 2008). Such a large disproportion in water consumption transferred problem from just hydrological issue to the political aspect (Libert et al. 2008). At present, Central Asian states concern themselves with resource catch through increasing their water consumption without following official agreements (Wegerich 2008).

Table 2. Surface water resources in the Aral Sea basin (mean annual runoff, km^3/year)

	River basin, km^3/year		Aral Sea basin	
	Syrdarya	**Amudarya**	**km^3**	**%**
Kazakhstan	2,516	-	2,516	2.2
Kyrgyzstan	27,542	1,654	29,196	25.2
Tajikistan	1,005	58,732	59,737	51.5
Turkmenistan	-	1,405	1,405	1.2
Uzbekistan	5,562	6,791	12,353	10.6
Afghanistan and Iran	-	10,814	10,814	9.3
Total	**36,625**	**79,396**	**116,021**	**100**

Source: Scientific-Information Center of the Interstate Commission for Water Coordination in Central Asia (SIC ICWC), 2010.

Development of water resources management in the Central Asian states

Water resources management has been a critical issue in Central Asia since ancient times (Hartman 2007). As long as people have been engaged in traditional agricultural practices, the profession of "mirab" (water distributor) has been highly respected and important (Abdullaev et al. 2009). Mirabs are still present in remote areas of the region's countries. The 21^{st}-century brought new challenges in water resources development through diverting rivers and constructing dams for purposes of irrigation and hydropower generation. Along with new technology and techniques the new century opened room for conflict over the use of water resources in Central Asia (Hartman 2007).

Soviet Union period

During the era of Soviet rule, Central Asia's water resources were developed and managed as one integrated scheme (O'Hara 2000). Although all republics had their own Ministries of Water Resources, in reality they were just departments of the Ministry of Land Reclamation and Water Resources (*Minvodkhoz*) of the Soviet Union (Spoor and Krutov 2003). Thus, decision-making processes related to water resources were concentrated in Moscow. Such policy created situations where water resource development schemes were established without taking into account national borders of Central Asian states (Wegerich 2004). For instance, reservoirs were built upstream in Kyrgyzstan and Tajikistan that had high potential of hydropower generation, but no hydrocarbons reserves (UN 2007a).

During the Soviet era, Moscow was managing water releases for downstream countries' needs during the growing season (irrigation) while, in exchange, they provided upstream countries with natural gas, oil, and coal during the winter. The water allocation structure in the former Soviet Central Asia consisted of two interrelated components:

> (i) Water allocation quotas for each republic and every irrigation project established, which were strictly controlled by the USSR Government, and (ii) planned deliveries of energy to the Kyrgyz and Tajik Soviet Republics for use in the winter (Libert 2008, p. 11).

O'Hara (2000) claims conflicts between water-abundant and water-shortage countries were created inventively by Soviet policy-makers to avoid regional cooperation which was dangerous for Soviet rule, and to strengthen the role of Moscow as a problem-solving administration between republics.

> In effect, the Soviet administration created a situation which would ensure competition between water-surplus and water-deficit republics. This situation worked to Moscow's advantage in two ways. First, disputes over water reinforced the national distinctiveness of the republics, thus limiting the potential for regional co-operation which would threaten Soviet control. Second, as competition for water increased the Republics were forced to ask Moscow to intervene, a role it was more than willing to undertake. In short, water policy was central to Moscow's efforts to divide and rule the region (O'Hara 2000, p. 430).

However, such "divide and rule policy" described by O'Hara (2000) is doubted by Lange (2001) and Wegerich (2004). Lange (2001) argues that water resources management facilities were intended to unify and were "placed where it made sense." Moreover, Lange (2001) states that the building of dams upstream was done especially to gain full control over downstream countries' irrigated agriculture. Wegerich (2004) goes further stating that the old Soviet system, with interrelations between water, energy, and food, was an advantage for the entire region and was advantageous for all countries. Wegerich (2004) further concludes that the Soviet management of water resources was efficient and advantageous for all riparian countries in the Aral Sea basin. Also, establishment of a large water allocation infrastructure in the region might have had political reasons by increasing employment and increasing agricultural production (Wegerich 2008). Thus, there is no one conclusion why Soviet planners put reservoirs in upstream republics of Kyrgyzstan and Tajikistan and made downstream republics heavily dependent on water release from upstream, while these upstream states were dependent on energy supply form their downstream neighbors.

Wegerich (2008) indicates that the Soviet policy of water allocation in the region was beneficial for downstream countries, while ignoring Afghanistan and placing Tajikistan into the role of water controller through building dams in its territory. Qaseem Naimi (2005) mentions that the Soviet Union always ignored water claims of

Afghanistan and only in 1987 specified a limit of 2.1 km^3/yr (0.5 mi^3) of water for Afghanistan. However, an International Crisis Group (ICG) report mentions that according to an agreement between the Soviet Union and Afghanistan in 1946, Afghanistan has a right to consume 9 km^3/yr (2.1 mi^3), which comprises 50 percent of the Pyandj River flow (ICG 2002). Concerning these data, Wegerich (2008) holds doubts because no other sources have verified that number and he adds that important information was mentioned only in footnote (Wegerich 2008). Irrespective of consequences, the former USSR simply considered the Amudarya River its own inland river and not a transboundary river as it is today.

Independent period

In 1991, when the Soviet Union collapsed and Central Asian republics became independent and sovereign nations, the newly independent nations found themselves in a situation of uneven water allocation and in a large degree of interdependence with respect to water management facilities (Wegerich 2008). The former water distribution scheme that resolved all intra- and inter-republic water disputes and was managed by central authorities in Moscow disappeared almost overnight with the breakdown of the Soviet Union, which left the newly emerged sovereign countries with problems of highly uneven distribution and consumption of water resources (Elhance 1997). The disputes between upstream and downstream states arose because of the mode of operation of dams that controlled both energy generation and irrigation water. From the Soviets, the upstream countries inherited control over water allocation and could define when and what amount of water is permitted to go downstream (O'Hara 2000). Independence had significant implications for Central Asian water resources allocation.

In 1987 USSR Ministry of Land Reclamation and Water Resources established the following surface water allocations in the Amudarya River basin (in percent of flow per year):

- Kyrgyzstan – 0.6% (0.4 km^3or 0.1 mi^3),
- Tajikistan – 15.4% (11.3 km^3or 2.7 mi^3),
- Turkmenistan – 35.8% (26.3 km^3or 6.3 mi^3), and
- Uzbekistan – 48.2% (35.5 km^3or 8.5 mi^3).

After gaining independence, these four countries reached an agreement (again without Afghanistan) to keep the Soviet system of water resources allocation (Wegerich 2004, Wegerich 2008). The "Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources" was signed in February 1992 by the presidents of all five Central Asian states and confirmed the "status quo" of water allocation structure of the former Soviet Union until new forms and arrangements of water allocation were developed (Libert et al. 2008). To implement provisions of the 1992 Agreement, the presidents formed the Interstate Commission for Water Coordination (ICWC), which became the main institution responsible for monitoring water allocation of the Amudarya and Syrdarya Rivers (Libert et al. 2008).

The 1992 Agreement missed one main statement – provision of energy supplies to Tajikistan and Kyrgyzstan to use in the winter period (Libert et al. 2008). Therefore, although Central Asian leaders agreed to continue the Soviet system of water allocation, the situation became more complicated when downstream countries stopped supplying Kyrgyzstan and Tajikistan with relatively cheap mineral resources, which were highly subsidized during Soviet time and were now transferred to current world prices. However, the upstream countries of Kyrgyzstan and Tajikistan could not afford to pay these world prices. In response to such policy they simply switched their dams from irrigation mode to hydro-energy generation mode, which means that dams started to accumulate water in the summer and release water in winter (Wegerich 2008). The downstream impacts of this situation have been substantial. Uzbekistan claimed that Kyrgyzstan's actions negatively affected Uzbekistan's agriculture and resulted in about $700 million (US dollars) lost in crop production in 1996 because of water shortage during the irrigation period (Oxford Analytica 1997). Similarly, release of excess water in winter creates not only a problem of water shortage in summer for downstream countries, but also causes floods and natural disasters for these countries during winter (Lange 2001). Disagreement between these newly independent countries resulted in issues that directly impacted the economies of the region's countries.

The Soviet administration managed Central Asian water resources based on the borders of the river basin and did not pay attention to administrative and national borders (Wegerich 2004). However, independence brought new challenges for the region since political borders now dissect the Aral Sea basin creating a situation of uncontrolled water consumption by riparian countries of Central Asia. The interstate Council for the Aral Sea (ICAS) in 1998 requested that the regions' countries present their estimates of water needs and based on their evaluation, and it became clear that the demand of 151.8 km^3 exceeds the natural flow of 119.2 km^3 (O'Hara 2000). Recent data presented by Glantz (2005) provide annual estimates of water resources distribution of the Amudarya River (Figure 6). Uzbekistan, Turkmenistan, Tajikistan use water resources within their defined water distribution limits. Glantz (2005) did not have data for Kyrgyzstan.

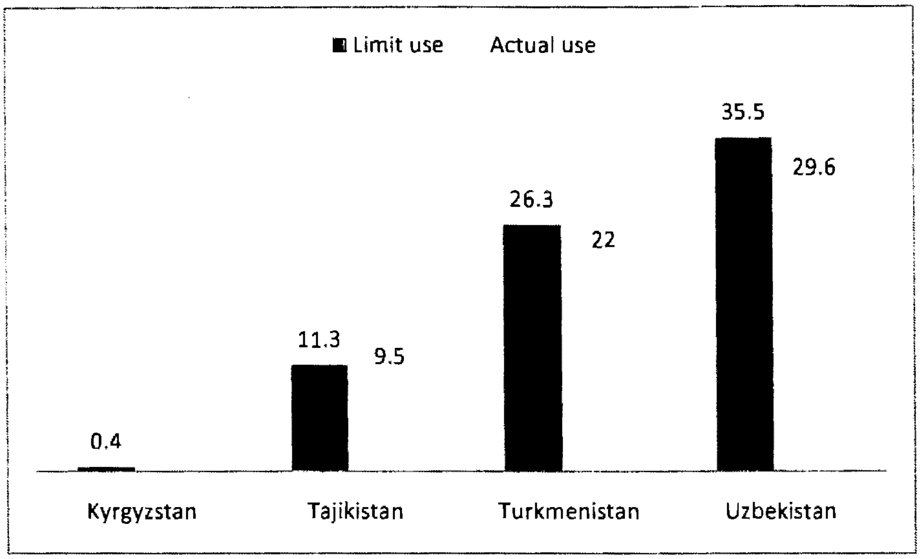


Figure 6. Agreed water allocation and actual water use by the Amudarya River basin countries (in km^3)
Source: Adapted from Glantz (2005)

Uzbekistan tries to reduce water consumption by converting areas formerly used to grow cotton (*Gossypium hirsutum L.*) to wheat (*Triticum aestivum*), which is a less water consuming crop. However, this water saving strategy might be minimized due to more water needed for leaching soluble salts (leaching maintenance) and due to deterioration of the old irrigation infrastructure (Spoor and Krutov 2003). Currently, with the absence of one superior control agency, every country of the region tries to get as much water as it can, which essentially leads to a further deterioration of the Aral Sea.

Although 19 years have passed since the collapse of the Soviet Union, countries of Central Asia have made little progress in changing the Soviet style of water resources management. Moreover, some these countries try to keep old, outdated systems, and therefore put the whole region onto the edge of conflict.

> The water allocation in the Amu Darya reflect the colonial legacy of the Soviet Union: the downstream riparian states, Turkmenistan and Uzbekistan, were utilized to produce cotton, the upstream state, Tajikistan used water for energy production and it was anticipated to increase its reservoir capacity further to

> provide water storage and facilitate agricultural production downstream, Afghanistan and Kyrgyzstan were simple producers of water without having a real claim to it (Wegerich 2008, p.71).

Current status of water resources management in the region

The possibility for conflict among riparian states in international river basins occurs because transboundary water resources, particularly on rivers that go beyond national borders, provoke two main concerns of the riparian states: sovereignty and territorial integrity (Elhance 1997). Elhance (1997) further states why potential conflict is the possible case for the Central Asian countries where barely any other water sources exist outside of the Amudarya and Syrdarya River basins.

> The potential for acute conflict intensifies when severe scarcities of water – an essential, nonsubstitutable, and increasingly shared resource – are experienced or anticipated by one or more states, or when such a resource is rightly or wrongly perceived as being overexploited or degraded by others at a cost of oneself. This is clearly the case in Central Asia... (Elhance 1997, p. 211).

Principles of transboundary water management in the region

Strains between upstream and downstream countries over the use of water resources are common in many parts of the world (Stone 2010). At present, research on this topic is mostly based on two main components: 1) who (population) and 2) what (environment) are impacted by building of a dam (Wegerich 2004). The expression "upstreamers use water to get more power, downstreamers use power to get more water" (Warner 2004, p. 11) can be used to describe current water policies of riparian countries in the basin of the Amudarya River. The solution to water allocation is difficult, especially when upstream countries follow their national interests and are unwilling to compromise in this potentially zero-sum game (Spoor and Krutov 2003). The conflict happens because the downstream countries like Turkmenistan and Uzbekistan are still preserving old, ineffective irrigation systems and continue to grow cotton, which is highly water-consumptive (Spoor and Krutov 2003) and where countries like Afghanistan, Tajikistan and Kyrgyzstan are source of water and use only minimal quantities of water (Wegerich 2008).

According to data presented by the World Bank (1996), three downstream countries of Central Asia overuse water compared to flow originating in their territories. The data indicates Kazakhstan uses 7.5 times more water, Turkmenistan uses 8.5 times more water and Uzbekistan uses 6.5 times more water than available water resources within each respective country; while upstream countries of Kyrgyzstan and Tajikistan are the source for 3 and 5 times more water than each country uses for their needs (Table 3). Such a big discrepancy in water consumption became a source for disputes between water-abundant and water-poor countries of the region.

Table 3. Water flow (km^3) in the Aral Sea basin watershed.

Country	Amudarya	Syrdarya	Totals	Water used in agriculture	Water used in industry
Afghanistan	6.18	-	6.18	-	-
Kazakhstan	-	4.50	4.50	27.41	6.26
Kyrgyzstan	1.90	27.40	29.30	9.50	0.59
Tajikistan	62.90	1.10	64.00	10.96	0.91
Turkmenistan	2.78	-	2.78	23.29	0.49
Uzbekistan	4.70	4.14	8.84	54.37	3.68
Totals	**78.46**	**37.14**	**115.60**	**125.53**	**11.93**

Source: World Bank (1996)

Wegerich (2004) identifies two kinds of solutions in the situation of water allocation for upstream hydroenergy generation and for downstream irrigation suppliers: "win-win" or "zero-sum." Win-win happens when both sectors need water at the same time. So, water is released to generate power during irrigation period. However, release of water and hydropower production when water is not needed for irrigation creates a zero-sum solution (Wegerich 2004). Wegerich (2004) concludes that a win-win solution could occur for all riparian countries, while a zero-sum solution is most beneficial for upstream countries because the cost of hydroelectricity is considerably lower than the cost of hydrocarbons for fuel. As a solution, Wegerich (2004) proposes a one-to-one exchange of energy between countries and discontinuing use of world market prices. Under one-to-one exchange Wegerich (2004) means, for instance, one ton of water to one ton of natural gas. This one-to-one exchange seems a highly unreliable scenario as it is hard to believe that downstream countries will agree to these terms of exchange. Another kind of solution is also possible. The main idea of this solution is when one country loses less than another country gains or vice-versa, one country gains less than another country loses. This situation of "win-lose" can be more clearly interpreted in monetary type: country X, through building a dam, gains 200 units when downstream country Y loses 100 units. Although this kind of scenario has not been extensively described in scientific literature, the idea could be used as a basis for negotiation between conflicting countries.

Another factor is that about 5% of water resources that are available to former Soviet republics come from Afghanistan, but, to date, Afghanistan has not been involved in disputes over the allocation of the Amudarya River basin water resources. While Afghanistan occupies 23% of the Amudarya River basin, it currently withdraws only about 1.5 km^3 (0.4 mi^3) of the Amudarya River water inflow per year (Elhance 1997). Since Afghanistan is progressing towards stability and developed agriculture, the country may eventually demand its portion of water resources, which may increase the competition for the region's water resources and potentially start new conflicts (O'Hara 2000, Spoor and Krutov 2003). The greatest impact in this situation will be incurred by Uzbekistan, which will suffer reduced water resources from the Amudarya River basin (ICG 2002). Uzbekistan should understand that without changing its practice of water usage and without negotiation with upstream countries, an equitable and reliable distribution of the basin's water may no longer be possible. Water distribution may also affect Uzbekistan's desire to have a steadily developing economy. Some agreement between water-rich and energy-rich countries of the region will help to regulate transboundary water issues along the Amudarya River basin. Concerning the management of transboundary water resources in Central Asia, Libert et al. (2008) states:

> The water situation in Central Asia is unique, determined in particular by the fact that the main river basins were previously used and developed as national within a single state (USSR) but are presently transboundary and shared by independent nations. In this situation, it is not easy to provide a straightforward answer in regards to the determination and interpretation of the rights and obligations of upstream and downstream countries (Libert 2008, p. 12).

Present situation in the study area

The many documents of international water law, multilateral as well as bilateral and including the most known and important non-binding "The Helsinki Rules on the Uses of the Waters of International Rivers," the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (in force since 1966), and the worldwide UN Convention on the Law of the Non-Navigational Uses of International Watercourses (not in force), do not determine common legal basis for transboundary water management. Moreover, international water law consists of two contradictory definitions: balanced and reasonable use of transboundary water resources and the obligation of one country not to make significant harm to another country by using common water resources (Libert et al. 2008). Further, Libert et al. (2008) explains that international water law stipulates cooperation and consultations between riparian countries on sustainable use of transboundary water resources, but if states do not come to an agreement, a state, in exceptional cases, can start action without the consent of neighboring states.

Tajikistan controls, or is going to control, water discharge in the Amudarya River through one of the main Amudarya River's tributaries, the Vakhsh River (27% of Amudarya River flow). The Vakhsh River has eight dams: Shurob, Nurek, Baipaza, Sangtuda 1, Sangtuda 2, Golovnaya, Prepadnaya, and Central, but all of them, with the exception of Nurek Dam, are small dams and do not represent a real threat for downstream water allocation (Figure 7).

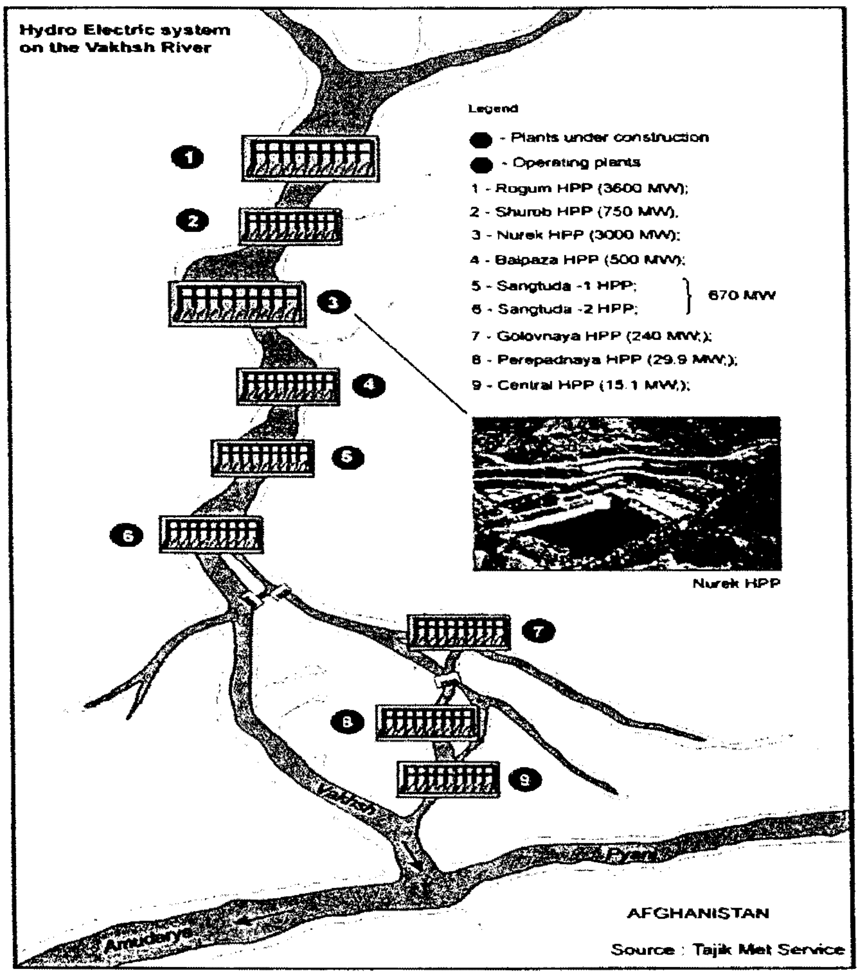


Figure 7. Current and planned infrastructure in the Vakhsh River basin
Source: Tajik Met Service as referenced in World Bank (2004)
Note: Rogum means Rogun

In the case of Rogun Dam, development should focus on mutual benefit for both upstream and downstream countries. Tajikistan needs to have agreements with riparian countries and according to international institutions, the Vakhsh River is a transboundary river and is out of exclusive control of one country (Schmidt 2008). Uzbekistan is strongly against Rogun Dam construction on the base of negative effects to its agriculture (ICG 2002, Spoor and Krutov 2003). Rogun Dam is a very delicate project balancing between interests of riparian countries and the situation is too complex to say whether its construction is "good" or "bad." Although Rogun Dam is under construction, there has still not been an assessment done relating the dam's impacts on the downstream Uzbekistan economy, which is heavily dependent on irrigation water from the Amudarya River.

Impact assessment of large dams

The International Commission on Large Dams specified that large dams are those where height exceeds 15 m from the foundation, or if its reservoir volume is more than 3 million m^3 (World Commission on Dams 2000). According to these definitions, at present, about 50,000 dams in the world can be classified as large dams (Tullos et al. 2009). The 20^{th}-century is characterized by advanced technologies and high-capacity machinery, so engineers are able to build larger and higher dams to meet increasing demands for electricity generation or irrigation (Dorcey et al. 1997). However, the construction of large dams became a disputable issue as large dams can result in social and environmental costs, unforeseen geological changes, unexpected adverse outcomes, and other negative economic externalities (Dorcey et al. 1997).

Table 4. Examples of socioeconomic factors and their potential changes resulting from project implementation

Type of concern	Factor	Potential Changes
Demographic	General characteristics and trends in population for state, substate region, county, and city.	Increase or decrease in population.
	Migrational trends in study area (study area is a function of alternatives and available data base).	Increase or decrease in migrational trends.
	Population characteristics in study area, including distribution by age, sex, ethnic groups, educational level, and family size.	Increase or decrease in various population distributions; people relocation
	Distinct settlements of ethnic groups or deprived economic/minority groups.	Disruption of settlements pattern; people relocations
Economic and employment	**Economic history for state, substate region, county, and city.**	**Increase or decrease in economic patterns.**
	Employment and unemployment patterns in study area, including occupational distribution and location and availability of work force.	**Increase or decrease in overall employment or unemployment levels and change in occupational distribution.**
	Income levels and trends for study areas.	**Increase or decrease in income levels.**
Land use, values, and taxes	Land-use patterns and controls for study area.	Change in land usage; may or may not be in compliance with existing land-use plans.
	Land values in study area.	Increase or decrease in land values.
	Tax levels and patterns in study area, including land taxes, sales taxes, and income taxes.	Changes in tax levels and patterns resulting from changes in land usage and income levels.
Public service and social concerns	Housing characteristics in study area, including types of housing and occupancy levels and age and condition of housing.	Changes in types of housing and occupancy levels.
	Health and social services in study area, including health manpower, law enforcement, fire protection, water supply, wasterwater treatment facilities, solid waste collection and disposal, and utilities.	Changes in demand on health and social services.
	Public and private educational resources in study area, including K-12, junior colleges, and universities.	Changes in demand on educational resources.
	Transportation systems in study area, including highway, rail, air, and waterway.	Changes in demand on transportation systems; relocations of highways and railroads.
Community attitudes and cohesion	Community attitudes and life-styles, including history of area voting patterns.	Changes in attitudes and life-styles.
	Community cohesion, including organized community groups.	Disruption of cohesion.
Miscellaneous	Tourism and recreational opportunities in study area.	Increase or decrease in tourism and recreational potential.
	Religious patterns and characteristics in study area.	Disruption of religious patterns and characteristics.
	Areas of unique significance such as cemeteries or religious camps.	Disruption of unique areas.

Source: Canter, 1977
Note: The concerns in bold are studied in this thesis as the impacts resulted by the Rogun Dam Project

Dam construction should comply with Pareto welfare optimum "where no one can be made better off without making someone worse off" as it actually means development failure (Goodland 1997).

Aspects characterizing the socioeconomic environment comprise many interrelated and nonrelated components, which represent a number of items that are not related to the physical, chemical, biological, or cultural environments (Canter et al. 1985). On the other hand, these aspects are the most descriptive in describing human interactions and relationships (Canter et al. 1985). The brief version of socioeconomic parameters that are used in an Environmental Impact Statement (EIS) and the generalized changes that can occur after construction and functioning of suggested projects are given in Table 4, where the concern addressed later in this thesis are highlighted. However, there are no universally agreed or accepted methods and standards for conducting socio-economic impact assessments that can be applied to most development projects (Canter et al., 1985). Canter et al. (1985) outlined typical criteria for assessing impact significance:

- Nature of the impact: probability of occurrence, people affected, geographic pervasiveness, duration;
- Severity: local sensitivity, magnitude; and
- Potential for mitigation: reversibility, economic costs, institutional capacity.

These criteria are used as a starting point in assessing proposed projects and every development project has its own features and characteristics. Increasing world population and unlimited goals to increase living standards require construction of more dams for the purpose of hydropower, irrigation, drinking water supply, flood control, navigation, recreation and others to meet growing needs (Tullos et al. 2009).

Dams are used as instruments for human development, yet their socioeconomic impacts on people, either intentional or unintentional, are potentially considerable (Egre and Senecal 2003). These socioeconomic impacts include resettlement and migration, changes of size and structure of household, employment and income, way of using land and water resources, changes in community level as well as the potential psychosocial consequences of resettling people (Tullos et al. 2009). In order to manage negative socioeconomic impacts, mitigation measures are applied. However, these impacts are in most cases "spatially significant, locally disruptive, lasting, and often irreversible" (World Commission on Dams 2000, p. 102). Assessment of social impacts of large dams always represents a challenge (Egre and Senecal 2003) and dams, depending on their unique construction scale, design, and operation, have different potential for adverse effects.

As the nature of impacts which could occur by dam construction is wide and extensive (Table 4) this study is going to focus attention on impacts of Rogun Dam on downstream Uzbekistan GDP, government revenues, and employment in agricultural sector. Through the above-mentioned economic indicators the possible impact of Rogun Dam on the economy of Uzbekistan will be discussed.

CHAPTER 3. METHODS AND ASSUMPTIONS

Construction and operation of Rogun Dam will cause temporary and permanent water resources changes in the Vakhsh River and, consequently, in flow of the Amudarya River. Temporary changes will be observed during filling of the reservoir, while permanent changes will be associated with the electricity generation regime of Rogun Reservoir after it is filled. This chapter consists of five successively developing sections: 1) establishment of the baseline condition, 2) estimation of the Rogun Reservoir annual filling rate, period of filling, and possible changes to the flow of the Amudarya River during this time, 3) estimation of the flow of the Vakhsh and the Amudarya Rivers after Rogun Reservoir is filled (electricity generation mode), 4) identification of monetary impacts (if any) during section 2 and 3 above under status-quo or "worst case" scenario (Uzbekistan keeps business-as-usual), and 5) identification of monetary impacts (if any) during the Rogun Reservoir filling stage and full operation mode under adaptive management case or "adaptive" scenario.

Current situation as a baseline condition

The current situation without Rogun Dam is the baseline condition where all data related to flow level, agricultural production, and employment were collected before Rogun Dam construction. The data include the average monthly (Table 5) and total and average seasonal flow (Table 6) of the Vakhsh and Amudarya Rivers, the irrigated land area of Uzbekistan and water use volume along the Amudarya River (Figure 9, p. 33), and Uzbekistan economic situation (Box 3).

Table 5. Mean monthly water flow of the Vakhsh and Amudarya Rivers (km^3) (Amudarya flow is measured at the point of Kerki)

Rivers	**Months**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Vakhsh	0.46	0.45	0.55	1.16	2.06	3.16	4.15	3.50	1.81	0.87	0.64	0.53
Amudarya	2.12	2.13	2.54	4.33	6.92	9.85	11.66	9.00	5.05	4.51	2.48	2.33

Source: Adapted from UNECE (2007)

Table 6. Total and average seasonal water flow of the Vakhsh and Amudarya Rivers (km^3) (Amudarya flow is measured at the point of Kerki)

Periods	**Vakhsh**		**Amudarya**	
	Annual Total	Monthly Average	Annual Total	Monthly Average
Summer (Apr-Sept)	15.84	2.64	46.81	7.80
Winter (Oct-Mar)	3.5	0.58	16.11	2.69
Total of two periods	19.34	1.61	62.92	5.24

Source: Adapted from UNECE (2007)

The peak flow of the Amudarya and Vakhsh Rivers occurs in July, when flow reaches 11.66 km^3 and 4.15 km^3, respectively, and minimum flow level is observed in January (2.12 km^3 and 0.16 km^3, respectively) (Table 5). Consequently, water flow in the summer period (April-September) in the Amudarya River increases to almost 47 km^3 (75%) out of 63 km^3 of annual flow, and the Vakhsh River's flow during the same period reaches almost 16 km^3 (80%) out of 20 km^3 of annual flow level (Table 6).

Box 3. Key economic indicators of Uzbekistan

- Population, total – 27.3 million people
- Labor force, total – 15.37 million people
  Labor force composition by sectors of economy:
  Agriculture – 44% or US$ 6.77 million
  Industry – 20% or US$ - 3.07 million
  Services – 36 % or US$ 5.53 million
- Gross Domestic Product (GDP) (current US$), (billions) – 27.9
  GDP composition by sectors:
  Agriculture – 25.8% or US$ 7.2 billion
  Industry – 31.4% or US$ - 8.7 billion
  Services – 42.8 % or US$ 11.9 billion
- GDP per labor force (current US$) – 1,815
- Budget (US $ billion): Revenues 8.884, Expenditures 8.474

Source: CIA (2009)

Rogun Reservoir filling stage

Currently, the biggest dam on the Vakhsh River is the Nurek Dam, located approximately 30 km (18 mi) below Rogun Dam, which is currently being constructed (Wegerich et al. 2007). As there are not sufficient data available about Rogun Dam construction, damming, filling and working regimes, a number of assumptions about the Rogun Dam were based on Nurek Dam. These assumptions allow us to apply some information about the filling period and working regime of Nurek Dam to the Rogun Dam. So, for the purpose of the study, data of Nurek Dam is being used and extrapolated for Rogun Dam. Such a comparison is viable due to all characteristics, except active regulation storage and surface area, are similar (Table 7).

Table 7. Characteristics of Nurek and Rogun Reservoirs

Characteristics	Nurek Dam	Rogun Dam
Height of the dam (m)	300	335
Design capacity (km^3)	10.5	13.3
Active regulation storage (km^3)	4.5	8.6
Length (km)	70	70
Surface area (km^2)	98	170
Maximum depth (m)	220	310
Hydropower capacity (MW)	3000	3600
Long-term average annual hydropower production (TWh)	11.2	14.5

Source: Adapted from source Wegerich et al. (2007), Schmidt, (2008), The Rogunskaya HPS (2009).

To assess the impacts of Rogun Dam on the agriculture and overall economy of Uzbekistan and to understand the nature of those impacts, severity, and mitigation measures, the overall structure of water consumption in the Amudarya River basin should be taken into consideration. Different sources give different estimations (Cai et al. 2003, Ikramov 2000) of water use by the sectors of economy, but all sources indicate that irrigated agriculture uses the largest portion of the Amudarya River water flow, which exceeds 90% of the total water consumption from the river (Figure 8) (Froebrich et al. 2006. Ikramov 2000). The quantity of water used by Uzbekistan for irrigation is certainly substantial and some authors even speculate that during the recent decade. 50% to 90% of irrigation water never reached crop lands because of the poor quality of irrigation infrastructure (Sievers 2002). In addition. Sievers (2002) mentions that such a big number can be the result of "the fact that water users have historically received water for free" (Sievers 2002, p.365).

At present. estimates indicate that irrigated agriculture uses about 93% of the water of the Amudarya River total flow (Figure 8). Agricultural irrigation is the main sector of the Uzbekistan economy that will be the most impacted by possible seasonal water reductions caused by the construction of Rogun Dam. or so called "recipient" of the impacts. Due to the relatively low portion of water used by other sectors of the economy compared to agriculture, non-agricultural sectors will be left for another, more in-depth, study.

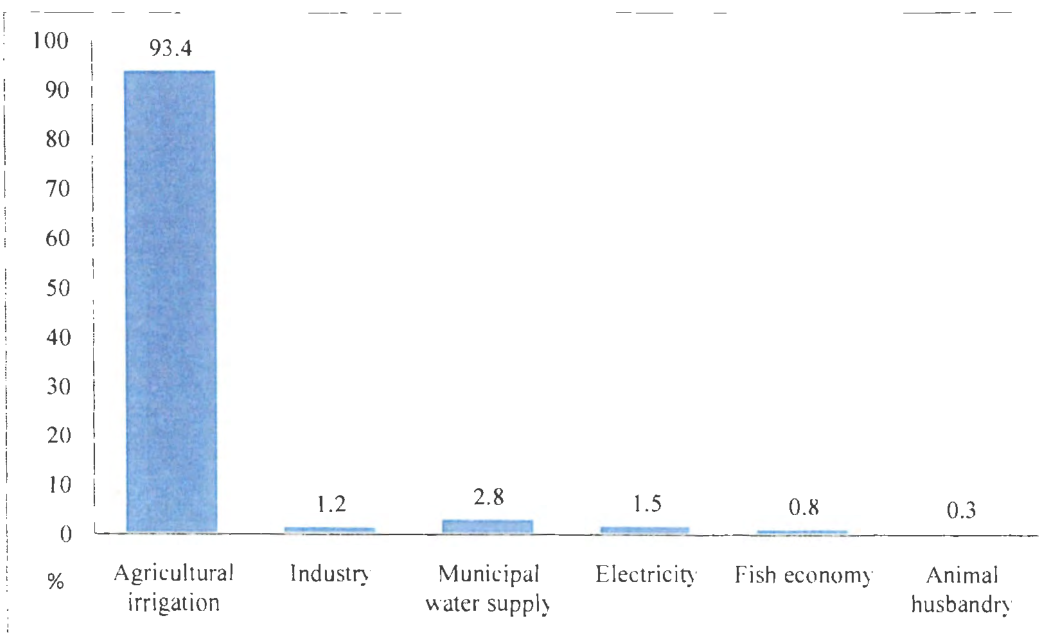


Figure 8. Main water consumers in the Amudarya River basin (%)
Source: Adapted from Froebrich et al. (2003)

However, this assumption does not mean that the rest of the economy may not be impacted because other sectors of the economy are closely linked with agriculture through production chains and different kinds of subsidies (Abdullaev et al. 2009).

Due to suitable natural conditions, Uzbekistan has more than four million hectares of irrigated lands (Table 8), and agriculture accounts for 32% of the country's GDP (Ikramov 2000).

Table 8. Total land area and agricultural land area, by regions of Uzbekistan (as of January 1, 2005; thousand hectares)

Region	Total land area (ha)	All agricultural land (ha)	Including	
			Arable land (ha)	Hayfields and pastures (ha)
Karakalpakstan	16,100.6	5,146.9	419.5	4,709.4
Andijan	430.3	250.4	196.8	21.2
Bukhara	4,193.7	2,901.2	199.6	2,674.1
Djizak	2,117.8	1,248.5	479.2	746.0
Kashkadarya	2,856.8	2,198.1	674.9	1,466.7
Navoiy	10,937.4	9,265.1	110.4	9,137.5
Namangan	718.1	388.9	196.7	153.1
Samarkand	1,677.4	1,297.5	440.9	795.7
Surkhandarya	2,009.9	1,176.0	280.4	862.0
Syrdarya	427.6	297.0	256.3	23.6
Tashkent	1,558.5	804.2	335.9	429.7
Ferghana	700.6	314.3	249.8	24.5
Khorezm	681.6	399.3	208.6	172.2
Uzbekistan	**44,410.3**	**25,687.4**	**4,049.0**	**21,215.7**

Source: Statistical Bulletin (2006)

According to forecasts, agriculture will preserve its leading role in the economy accounting for 20 to 25% of the GDP (Ikramov 2000). Agriculture employs 36.2% of the total labor force in Uzbekistan (Gemma 2003). However, agricultural production is not diversified and largely consists of cotton and wheat (Abdullaev et al. 2009). Cotton is considered a major strategic crop that, through export, earns approximately 1/3 of hard currency revenue (US$) (Gemma 2003). Uzbekistan is the fourth largest cotton producer in the world on gross production and cotton production consists of 35% of irrigated land (Bloch 2002). Other major agricultural crops are rice (*Oryza sativa*), jute

(*Corchorus Capsularis*), tobacco (*Nicotiana Tabacum*), and fruits and vegetables (Bloch 2002). Irrigated agriculture has been practiced in Uzbekistan since ancient times, but large-scale irrigation infrastructure was built during former Soviet Union rule in response to the growing demand for cotton (Ikramov 2000). Ikramov (2000) states that 90% of available water resources in Uzbekistan is used for cotton production. Uzbekistan has 1,645,000 hectares of irrigated land area along the Amudarya River and uses 28 km^3 of water annually to irrigate those lands [17.000 m^3 (0.000017 km^3) per hectare] (Figure 9).

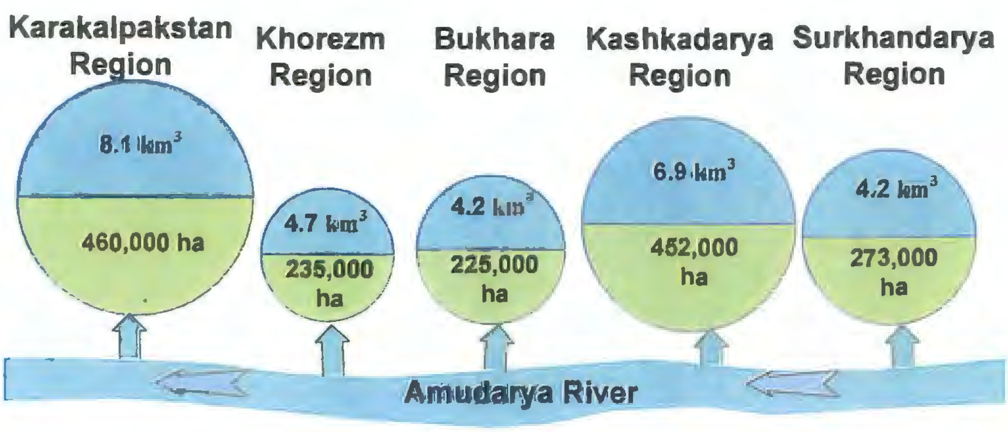
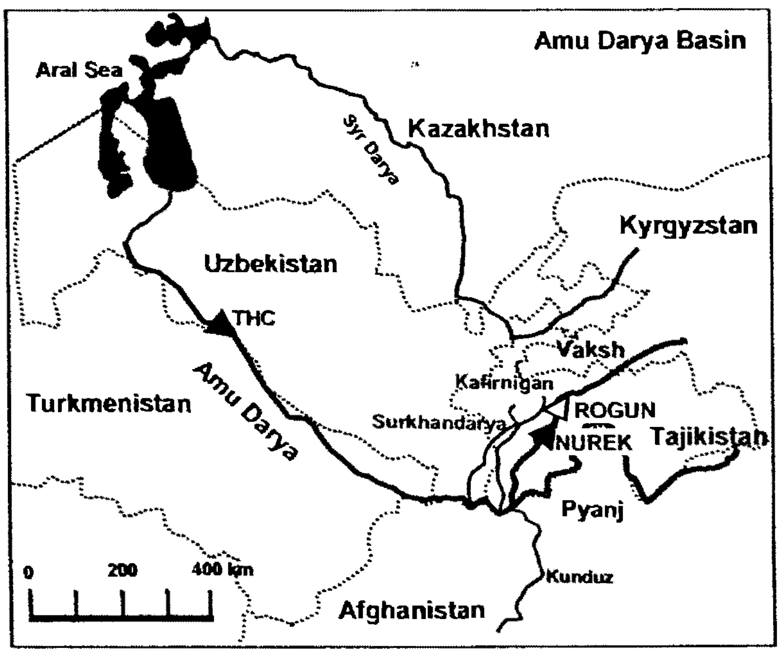


Figure 9. Irrigated land and water use by regions of Uzbekistan along the Amudarya River
Source: Statistical Bulletin (2006)

Hydropower generates 27.3% of all electricity in Central Asia (Tajikistan meets 98% its energy needs through hydropower, while Turkmenistan only 1%) (UN SPECA 2004). Tajikistan has nearly 4% of the world's hydropower potential and is eighth globally overall in hydropower potential per capita in the world (Schmidt 2008). Due to constraints coming from the lack of finance, Tajikistan stays rich in untapped hydropower resources. However, Tajikistan is starting to develop hydropower because of shortages in energy resources. Tajikistan, being located in a water flow formation area, is keenly interested in developing hydropower and wants to switch its existing reservoirs to electricity generation (Froebrich et al. 2006).

The Rogun Dam project was designed by Soviet engineers in the 1960s (Figure 10). It consists of a high dam (335 m, 1099 ft), a hydropower generating plant (14.5 TWh/yr), and a large water reservoir (13.3 km^3, 3.2 mi^3) (Libert et al. 2008). Construction started in 1982 and were halted in 1991 because of the Soviet Union break down and civil war in Tajikistan. Rogun Dam is being built on the Vakhsh River which starts its flow from south-east of Kyrgyzstan and is fed by Abramov and Fedchenko glaciers and has a reservoir with length of 524 km (326 mi) and has a catchment zone in Tajikistan between 31,200 and 39,000 km^2 (7,500 and 9,400 mi^2) (Schmidt 2008, Wegerich et al. 2007).



▲existing dam

Δ proposed dam

Figure 10. The Amudarya basin with its main tributaries and the Dams of Rogun, Nurek and Tuyamuyun Hydroengineering Complex (THC)
Source: Oliver et al. (2008)

The reservoir created by Rogun Dam will occupy 17,100 hectares (42,300 acres) of land, of which 6,800 (16,800 acres) hectares are agricultural land (Niyazi 2003). The discharge of Vakhsh River at the site of projected Rogun Dam is about 20 km^3/yr (4.8 mi^3/yr), which coincides with an average discharge of 635 m^3/sec (22,425 ft^3/s) and hydropower generation of approximately 14.5 TWh/yr (at 335 m height of dam) (Schmidt 2008). The time of completion of Rogun Dam construction is still not clear, but it is expected that the dam will accumulate its necessary water volume in 8 to 10 years. The total capacity of the planned hydro investments in Rogun Hydro Power Plant (RHPP) in Tajikistan is expected to be 3,600 MW (average annual performance 13.1 billion kWh) at a total cost of US$2.2 billion (EDB 2008). The cost of construction is too high for Tajikistan's budget, but the government of Tajikistan hopes to attract investments and loans from international financial organizations and foreign governments (EDB 2008).

The benefits of Rogun Dam are electricity generation and water supply. Rogun Dam will supply electricity not only for Tajikistan, but, as estimated, it will export extra energy to south-east Asian countries. Also, Tajikistan plans to develop new lands and increase agricultural production, which will require additional water (EDB 2008). The negative impacts on the reservoir site include flooding of agricultural land and cultural and historic sites, silting in the reservoir, and socioeconomic impacts surrounding people resettling (Schmidt et al. 2006). Concerns of Uzbekistan are that much of the accumulated water will be released from Rogun Reservoir during winter time to generate electricity, and as a consequence, in summer, water flow will be reduced, which will have a negative impact on the population, agriculture, and environment in Uzbekistan (Libert 2008). Wegerich et al. (2007) argues those negative impacts are questionable and concludes that an additional dam would be beneficial for all the region's countries and even outside the basin. In contrast, Spoor and Krutov (2003) mention that Tajikistan, through Nurek Dam, already controls approximately 40% of Amudarya flow and construction of new Rogun Dam would allow Tajikistan complete control of water flow to Uzbekistan (ICG 2002). Further development of Tajikistan's hydroenergy potential will have negative consequences on downstream countries' seasonal water allocations (ICG 2002).

The feasibility study, completed by the German construction company Lahmeyer International, indicates three separate stages in building of Rogun Dam: Stage I, the dam's height will be 225 m (738.1 ft) with a total volume of reservoir of 2.78 km^3 (0.6 mi^3), a live storage volume of 1.92 km^3 (0.4 mi^3), and a capacity to produce 1000 MW (this will give energy output of 5.6 TWh/yr); Stage II, the dam's height will be increased to 285 m (935 ft) (volume 6.78 and live storage 3.98 km^3 (1.6 and 0.9 mi^3, respectively); and Stage III, the dam's height will reach 335 m (1099 ft) (reservoir volume 13.3 km^3, live storage 10.3 km^3 (3.2 and 2.5 mi^3, respectively) (Schmidt et al. 2006). Wegerich et al. (2007) argues that neither Stage I nor Stage II would be detrimental for Uzbekistan, but Stage III would threaten Uzbekistan's agricultural production.

Nurek Dam is the largest dam on the Vakhsh River and is located 30 km (18 mi) downstream from the uncompleted Rogun Dam. Lacking data for Rogun Dam, characteristics of Nurek Dam are assumed to be a reasonable proxy (Table 7). Nurek Reservoir has a full storage volume of 10.5 km^3 and it took 11 years to fill. The filling rate of Rogun Reservoir will be extrapolated from the filling data of Nurek Reservoir:

$$Q_{an} = \frac{V_n}{11} + W_{loss} \qquad [1]$$

where Q_{an} is the Vakhsh River flow to be stored in Rogun Reservoir during its filling (km^3/yr), V_n is the total storage volume of Nurek Reservoir (km^3), *11* is the time period required to fill Nurek Reservoir (years), W_{loss} is the total water loss due to reservoir bottom and shores saturation and evaporation (given equal to 0.12 km^3/yr) (Vuglinsky 1990). Water losses for saturation occur mainly during the reservoir filling stage (Vuglinsky 1990).

Rogun Reservoir filling period can be estimated from the following equation:

$$T_r = \frac{V_r}{Q_{an}} \quad [2]$$

where T_r is the time period required to fill Rogun Reservoir (years), V_r is the total storage volume of Rogun Reservoir (km^3).

The last step is estimation of changes in the Amudarya River flow due to water storing in Rogun Reservoir:

$$\%X = \frac{Q_{an}}{Q_{Am}} 100 \quad [3]$$

where $\%X$ is the change in flow of the Amudarya River, Q_{Am} is the mean annual flow of the Amudarya River (63 km^3/yr) (Table 6).

Rogun Reservoir electricity generation mode

Rogun reservoir has a total volume (13.3 km^3), which consists of active storage (8.6 km^3) and dead storage (4.7 km^3) (Table 7). The reservoir active storage is water stored above the level of the lowest offtake and the active storage is maintained to generate electricity. Savchenkov et al. (1989) indicates that the discharge regime of the Vakhsh River water flow varies by season, characterized by an increase of water flow in spring and reaching the maximum flow level in summer after the winter low flow. This phenomenon is mainly explained by melting snow and glaciers into the Vakhsh River

(Konovalov 2009). Therefore, Rogun Dam is expected to accumulate water in active storage volume during April to September (summer period) and release water to generate electricity during the winter period (October-March) of low flow when the most electricity needed. Taking into account this case, average monthly water flow of the Vakhsh River when Rogun Reservoir accumulates water in the summer period (or Rogun Dam flow) can be estimated:

$$Q_s = \frac{QV_s - 8.6}{6} \quad [4]$$

where Q_s is the average monthly flow of the Vakhsh River from Rogun Reservoir during summer period (km^3/month), QV_s is the total water flow of the Vakhsh River during the summer period (km^3) (Table 6), and *8.6* is the Vakhsh River flow volume stored in Rogun Reservoir during the 6 month (April to September) (the active water storage volume of Rogun Reservoir) (km^3).

The average monthly water volume of the Vakhsh River flowing to downstream water users when Rogun Reservoir will release water to generate electricity in the winter period is quantified as:

$$Q_w = \frac{QV_w + 8.6}{6} \quad [5]$$

where Q_w is the average monthly water discharge of the Vakhsh River from Rogun Reservoir during winter period (km^3/month), QV_w is the total water flow of the Vakhsh River during the winter period (km^3) (Table 6), and *8.6* is the Vakhsh River flow volume released from Rogun Reservoir during the 6 month (October to March) (the active water storage volume of Rogun Reservoir) (km^3).

The Vakhsh River contributes 27% of the annual flow of the Amudarya River (Figure 2) and every change in the Vakhsh River flow volume reflects on the Amudarya

River flow. Therefore, changes in the usual flow of the Amudarya River associated with changes in the Vakhsh River flow during the summer period are estimated:

$$\%X_s = \frac{QA_{sRogun} - 7.80}{7.80} 100 \qquad [6]$$

where $\%X_s$ is the change in flow of the Amudarya River in summer period, QA_{sRogun} is the average water flow of the Amudarya River (with Rogun Dam) during summer period (km^3/month), and *7.80* is the average flow of the Amudarya River (with no Rogun Dam) during the summer period (km^3/month) (Table 6);

QA_{sRogun} is calculated as:

$$QA_{sRogun} = 7.80 - (2.64 - Q_s) \qquad [7]$$

where *7.80* is the average flow of the Amudarya River (with no Rogun Dam) during the summer period (km^3/month) (Table 6) and *2.64* is the average monthly flow of the Vakhsh River during the summer period (with no Rogun Dam) (km^3/month) (Table 6). Similarly, a change in the historical flow of the Amudarya River associated with changes in the Vakhsh River flow during the winter period is estimated:

$$\%X_w = \frac{QA_{wRogun} - 2.69}{2.69} 100 \qquad [8]$$

where $\%X_w$ is the change in flow of the Amudarya River during the winter period, QA_{wRogun} is the average water flow of the Amudarya River (with Rogun Dam) during the winter period (km^3/month), and *2.69* is the average flow of the Amudarya River (with no Rogun Dam) during the winter period (km^3/month) (Table 6).

QA_{wRogun} is calculated as:

$$QA_{wRogun} = 2.69 - (0.58 - Q_w) \qquad [9]$$

where QA_{wRogun} is the average water flow of the Amudarya River (with Rogun Dam) during the winter period (km^3/month), *2.69* is the average flow of the Amudarya River (with no Rogun Dam) during the winter period (km^3/month) (Table 6), and 0.58 is the average monthly flow of the Vakhsh River during winter period (with no Rogun Dam) (km^3/month) (Table 6).

Estimation of monetary impacts under "worst case" scenario

To assess monetary impacts of a changed flow volume of the Amudarya River on Uzbekistan agriculture it is assumed that changed flow volume will impact upstream and downstream water users in Uzbekistan in different ways. The Uzbekistan government cannot fully control water distribution from the Amudarya River because of the lack of water distribution infrastructure and poor water management (Wegerich 2002). Therefore, seasonally reduced flow in the Amudarya River will be unequally distributed among the upstream and downstream water users. Seemingly, upstream water users will withdraw the same water volume as they did before and downstream water users will experience a water shortage. Justification for this assumption is from 2000-2001when Uzbekistan experienced a severe drought which has been called the "worst in 95 years" (Wegerich 2002). Recent studies show that the water scarcity during the 2000-2001 drought in Uzbekistan was the worst in the downstream regions of the Amudarya (Figure 9, p. 33) (Wegerich 2002). Wegerich (2002) concludes "the phenomenon of unequal water scarcity could be an indication that the causes are not only natural, but also management and, therefore, institution related." (Wegerich 2002, p. 23) A similar opinion was expressed by Kohn who quotes McKinney (2001), "I think it's more a function of simple geography: the Karakalpaks are downstream." (quoted by Kohn 2001, p.2) (Figure 9, p. 33).

On the basis of the above assumptions, the land area that will not get irrigated is estimated. Although the exact availability of water in Uzbekistan during the summer period is uncertain, 8.6 km^3 of Rogun Reservoir stored volume is assumed as the water that is needed for irrigation. The assumed volume needed for irrigation (8.6 km^3) is divided by the average water requirement per hectare in Uzbekistan:

$$L_a = \frac{8.6}{W_l} \qquad [10]$$

where L_a is the estimated land area that does not receive irrigation water in the summer period (ha), *8.6* is the Vakhsh River flow volume stored in Rogun Reservoir (the active water storage volume of Rogun Reservoir) (km^3), and W_l is the average water requirements in Uzbekistan agriculture (km^3/ha) (given 0.000017 km^3/ha) (Figure 9).

GDP

Monetary value of one hectare of irrigated land consists of two parts. The first part is income of farmers from particular crop, this can be referred as a direct agricultural sector income. To estimate the monetary value of one ha of irrigated land for the agricultural sector, the term of aggregated revenue from one composite hectare (H_{far}) is used. Aggregated revenue of H_{far} is a sum of revenue from cotton, wheat, and vegetables calculated according to each crop share in the composite hectare and equal to US $566/ha:

$$H_{far} = (\$825x0.44)+(\$400x0.48)+(\$1,369x0.08) = \$566$$

One composite hectare (100%) consists of cotton (44%), wheat (48%) and vegetables (8%), which are the main irrigated crops in Uzbekistan (World Bank 2003). The World Bank (2003) estimates the gross economic income of cotton, wheat, and vegetables as US $825, $400, and $1,369 per hectare, respectively (Table 9).

The second part of the monetary value of one ha of irrigated land is the government revenues which are the difference between price of buying cotton and wheat from farmers and then reselling those crops in the world market by the government. To estimate the monetary value of one hectare of irrigated land for the government of Uzbekistan, the term of aggregated value of one composite hectare (H_{gov}) is used. Aggregated value of H_{gov} is a sum of world price for cotton and wheat calculated according to their shares in the composite hectare and equal to US $694/ha:

$$H_{gov} = (\$1{,}305x0.48)+(\$130x0.52) = \$694$$

One composite hectare (100%) in this case consists of cotton (48%) and wheat (52%) as these are the main irrigated and exported crops in Uzbekistan (World Bank 2003). The World Bank (2003) projects the world price for cotton and wheat as US $1,305 and $130 per hectare, respectively (Table 9).

Table 9. Comparison of economic gross margin (irrigated crops)

	Cotton	Wheat	Vegetables
World Price Projected For 2015 (US$/ton)	1,305	130	N/A
Yield (ton/ha)	2.2	2.5	11
Revenues (US$/ha)	825	400	1,369
Costs (US$/ha)	392	283	702
Gross Margin (Before Energy Costs)	433	117	667

Source: Adapted from World Bank (2003)

Using H_{far} and H_{gov} the total value of foregone agricultural production of land area that will not get irrigated is calculated:

$$P_t = L_a 566 + L_a (0.92) 694 \qquad [11]$$

where P_t is the total value of foregone agricultural production of land area that will not get irrigated (US \$), L_a is the land area left without water during the summer irrigation period in Uzbekistan (ha) [10], *566* is the estimated value of one hectare of irrigated land for farmers (US \$/ha), *694* is the estimated value of one hectare of irrigated land for the government of Uzbekistan, and *0.92* is the 92% of land which is under cotton and wheat (minus 8% of land under vegetables). The impact of that lost total value on GDP (Box 3, p. 29) of Uzbekistan is estimated by:

$$\%GDP_c = \frac{P_t}{27.9}100 \qquad [12]$$

where $\%GDP_c$ is the change rate in Uzbekistan GDP, and *27.9* is the Uzbekistan GDP (US $ billions) (Box 3, p. 29).

Change in revenue of Uzbekistan government revenue can be computed by:

$$\%B_c = \frac{P_t}{8.884}100 \qquad [13]$$

where $\%B_c$ is the change rate in the revenue portion of Uzbekistan government revenue and *8.884* is the revenue portion of Uzbekistan's budget (US $ billions) (Box 3, p. 29).

Employment

The number of people affected by lost revenue from land area left without irrigation water due to changed water flow can be found through:

$$N_p = \frac{P_t}{1{,}815} \qquad [14]$$

where N_p is the number of people in Uzbekistan affected by Rogun Project and *1,815* is the Uzbekistan GDP per labor force (Box 3, p. 29) (US$/per capita) (Box 4). The last four equations ([11], [12], [13], and [14]) describe Rogun Reservoir impact, working in electricity generation mode, on Uzbekistan's economic situation under the "worst case" scenario.

> Box 4. Some important economic indicators
> Gross Domestic Product (GDP) represents the value of goods and services produced inside the territory of a country without income received from abroad, while Gross National Product (GNP) or Gross National Income (GNI) is the sum of domestic and foreign incomes of all residents of a country.
> *Source:* Peterson and Lewis (1999)

Estimation of monetary impacts under "adaptive" scenario

There is a wide range of methods, practices, and techniques that can be applied by the Uzbekistan government to mitigate results of changed water regime for irrigated agriculture. These measures should lead to one goal: to maintain the agricultural production of lands under the condition of less water availability through the decreasing of the present level of water use in agriculture. Two exclusive methods of reducing water use are proposed: 1) introduction of drip irrigation (Option A) and 2) introduction of water pricing in agriculture (Option B).

Option A, introduction of drip irrigation, would be considered a "mandatory technology" that would be required by the government of Uzbekistan in order to reduce water use. However, the cost of drip irrigation is high, therefore, some part of the cost would need to be paid by the government and the other part could be financed in the form of low-interest loans or subsidies. By using drip irrigation, cotton producing farms in Uzbekistan can save 32% or 9 km^3 annually of irrigation water compared with the presently used furrow irrigation (Ibragimov et al. 2007). Transferring the current irrigation infrastructure to drip irrigation could be beneficial, taking into account the result of the mentioned study. However, the cost of drip irrigation is high and varies between US$1,331 to $1,408 (average US$1,370) per hectare (O'Brien et al. 1998). As more than 90% of irrigated agricultural lands in Uzbekistan along the Amudarya River are used to grow cotton, the total cost of transferring to drip irrigation along the Amudarya River will be:

$$V_{drip} = A_t 1{,}370 \qquad [15]$$

where V_{drip} is the total cost of introduction of drip irrigation in the regions of Uzbekistan located along the Amudarya River (US $), A_t is the total irrigated area of those regions (ha) (given 1,645 million ha) and *1,370* is the average cost of drip irrigation (US $/ha). The cost for Uzbekistan to transfer to drip irrigation could be based on the length of time to fill Rogun Reservoir:

$$V_{andrip} = \frac{V_{drip}}{T_r} \qquad [16]$$

where V_{andrip} is the annual cost of introduction of drip irrigation in the regions of Uzbekistan located along the Amudarya River (US $) and T_r is the time period required to fill Rogun Reservoir (years) [2].

Option B, water pricing, would be considered an incentive for farmers to use the best available technology (BAT) which could result in reducing water use and reducing costs of water. Under Option B, farmers would be free to choose which technology to implement. Choices may include, but are not limited to, using groundwater resources, using recycled water, or switching to less water consuming crops (Pimentel et al. 1997). Other technologies might include subsurface drip irrigation (SDI), precision agriculture, or growing high value crops such as almond and pistachios (Ayars 2010). Taking into account that Rogun Dam has not been fully constructed and that it will take certain years for reservoir filling, Uzbekistan has the advantage of gradually preparing for future conditions. Pricing of water as a demand management tool is considered less popular, but the most effective method of increasing efficient water use and decreasing demand for irrigation water (World Bank 1995). Of the few types of water pricing methods, including per unit area pricing, output pricing, input pricing, tiered pricing, water markets, and volumetric pricing, volumetric pricing is proposed as the best method for Uzbekistan (Box 5).

Box 5. Water pricing methods

- Volumetric pricing – water charged depending on direct measurement of consumed water
- Per unit area pricing – water is charged per unit of irrigated area. Charge depends on type of irrigated crop, irrigation method, season of the year, etc.
- Output pricing – water is charged on the basis of output (water users pay a certain water fee for each unit of produced output)
- Input pricing – water is charged by taxing inputs (water users pay a water rate for each unit of a certain input used)
- Tiered pricing – multi-rate volumetric method, where rates for water vary as the amount of consumed water exceeds defined threshold limits
- Water markets – some developed economies formed water markets or water rights to determine price for water

Source: Adapted from World Bank (1995)

Volumetric pricing can be efficient in limiting water use by farmers, however, it also requires capital investment in construction and maintenance of measurement points, equipment, concreting channels, and training of people (O'Brien et al. 1998). The government of Uzbekistan should start with a relatively low water price and increase the price for water until the desired change in water demand is reached. On the basis of data and analysis of different countries, in order to cover costs of operation and maintenance (O&M) of irrigation infrastructure, water price must be \$0.003-0.005 per m^3(Perry 2001). In order to substantially influence demand, water price must be higher (\$0.02-0.05 per m^3) (Perry 2001). Perry (2001) states that water costs need to be enough to cover O&M costs. Knowing the possible water flow reduction rate during the Rogun Reservoir filling period and assuming that Uzbekistan will have the same irrigation area after filling is completed, the future water demand is estimated:

$$D_{wf} = 28 - 28R \qquad [17]$$

where D_{wf} is the demand for water in the future (after Rogun Reservoir filled) (km^3/yr), *28* is the present water demand (km^3/yr), R is the reduction rate (%) (assumption).

Under adaptive management, the area that will not get irrigated is estimated using future water demand and saved water volume (difference between present and future water demand). The main assumption is that Uzbekistan will have the same irrigated land area, GDP, GNI, and budget levels, and employment indicators. Then, equations [10], [11], [12], [13], and [14] are used to assess the level of impacts of Rogun Reservoir, working in electricity generation mode, on Uzbekistan under adaptive management measures.

CHAPTER 4. RESULTS AND DISCUSSION

The results and discussion section is divided into four main parts: 1) identification of potential changes anticipated during Rogun Reservoir filling stage, 2) identification of potential changes anticipated when Rogun Reservoir is full and working in electricity generation mode, 3) assessment of those changes under the "worst case" scenario, and 4) assessment of those changes under adaptive management measures, "adaptive" scenario.

Rogun Reservoir filling stage

Using equation [1] and [2], the Vakhsh River annual water flow volume needed to fill Rogun Reservoir and time period required for fill Rogun Reservoir, respectively, is estimated:

$$Q_{an} = \frac{10.5km^3}{11years} + 0.12km^3/yr = 1.07km^3/yr \qquad [1]$$

and

$$T_r = \frac{13.3km^3}{1.07km^3/yr} = 12.4years \qquad [2]$$

Rogun Reservoir will be filled within 12.4 years with the Vakhsh River average annual water flow volume of 1.07 km^3/ yr. Next, changes in annual flow volume of the Amudarya River due to presence of Rogun Reservoir are estimated:

$$\%X = \frac{1.07km^3/yr}{63km^3/yr}100 = 1.7\% \qquad [3]$$

Thus, during 12.4 years of filling, Rogun Reservoir will use approximately 2% of the Amudarya River annual discharge. Taking into account that the annual discharge of the Amudarya River can vary between 47 and 108 km^3 (11 and 26 mi^3) (Spoor and Krutov 2003), a 1.7% decrease is neglected in this study. In average, flow of the Amudarya

River is 5.25 km^3/month ($\frac{63km^3 / yr}{12month}$). With a decrease of 1.7%/yr, flow of the river will decline to an average 5.17 km^3/month. However, a reduction in flow to 5.17 km^3/month would not appear to present a threat to Uzbekistan as the total remote-sensed precipitation feeding the Amudarya River also shows a trend to decrease (Figure 12A) and this trend is more evident in the gauge-measured precipitation (Figure 12B). Therefore, the reduction of the flow volume of the Amudarya River during the predicted filling period of Rogun Reservoir, 12.4 years, should not noticeably impact Uzbekistan.

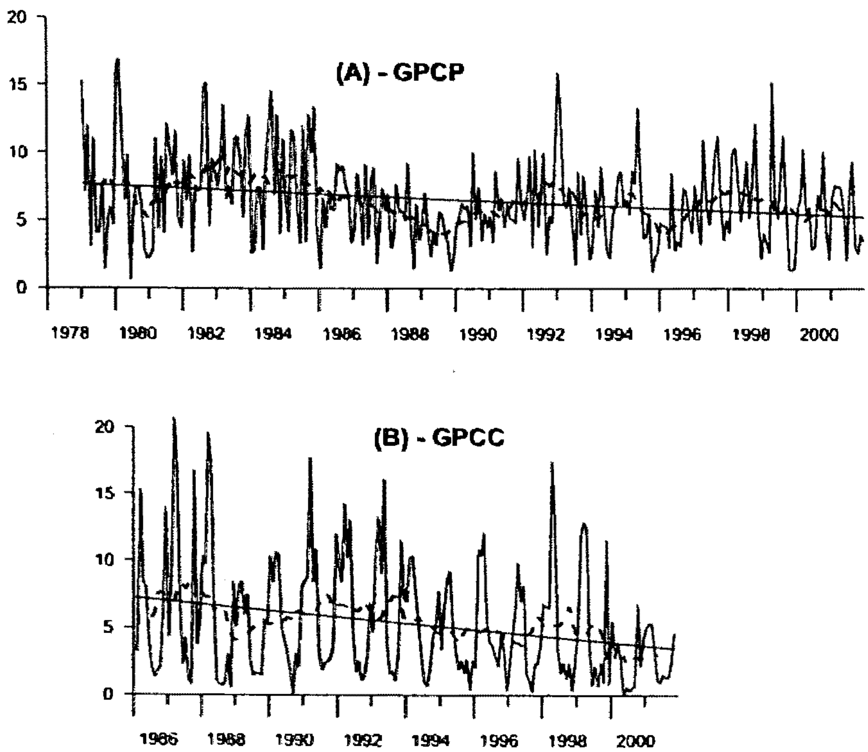


Figure 11. Interannual variations of the discharge of the Amudarya River derived from precipitation integrated over its catchment area. (A) satellite-measured (GPCP) precipitation (km^3/month); (B) gauge-measured (GPCC) precipitation (km^3/month). Dashed line is a moving average of about 1 year period.
Source: Nezlin et al. (2004)

Rogun Reservoir full operation mode

After Rogun Reservoir is filled, Rogun Hydropower Plant (RHPP) will accumulate the necessary water during the summer period, the most abundant flow time of the Vakhsh River and generate electricity in winter period. The discharge from RHPP during summer and winter periods is, respectively:

$$Q_s = \frac{15.84km^3 - 8.6km^3}{6} = 1.21km^3 / month \quad [4]$$

and:

$$Q_w = \frac{3.5km^3 + 8.6km^3}{6} = 2.02km^3 / month \quad [5]$$

Therefore, when RHPP starts working in full capacity the average monthly flow of Rogun Reservoir to downstream will be 1.21 and 2.02 km^3 per month in summer and winter periods, respectively.

To estimate changes in the Amudarya River flow associated with the changed flow level in the Vakhsh River in respective periods, the average monthly flow of the Amudarya River should be found in summer (QA_{sRogun}) and winter (QA_{wRogun}) periods with Rogun Dam in is place, respectively:

$$QA_{sRogun} = 7.80km^3 / month - (2.64km^3 / month - 1.21km^3 / month) = 6.37km^3 / month$$

[7]

and:

$$QA_{wRogun} = 2.69km^3 / month - (0.58km^3 / month - 2.02km^3 / month) = 4.13km^3 / month$$

[9]

Thus, average monthly flow of the Amudarya River, if Rogun Dam is placed on the Vakhsh River, will be 6.37 km^3/month in the summer period, and 4.13km^3/month in the winter period. Changes in the Amudarya River flow due to the presence of Rogun Dam are estimated as

summer:

$$\%X = \frac{6.37 km^3 / month - 7.80 km^3 / month}{7.80 km^3 / month} 100 = -18\% \qquad [6]$$

winter:

$$\%X = \frac{4.13 km^3 / month - 2.69 km^3 / month}{2.69 km^3 / month} 100 = 54\% \qquad [8]$$

The estimated of RHPP operating in full electricity generation mode will yield a decrease of the Amudarya River annual discharge to downstream Uzbekistan in the summer irrigation period by 18% and an increase of the discharge in the winter time by 54% (Figure 12). These computed data shows that: 1) during the irrigation period from April to September Uzbekistan will have less water, and 2) in the rest of the year, from September to April, Uzbekistan may experience water abundance, which may lead to flooding.

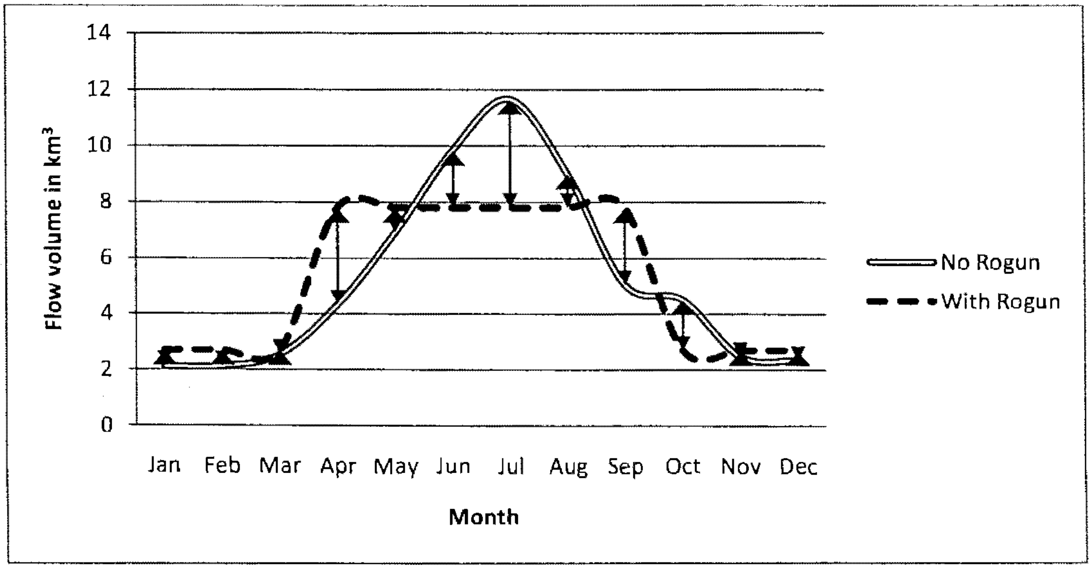


Figure 12. The Amudarya River hydrograph with and without Rogun Dam
Note: Data used in this figure was extrapolated from Table 6 (p. 29) and results of equations [7] and [9]

Estimation of monetary impacts under "worst case" scenario

Estimation of monetary impacts on the economy of Uzbekistan will be estimated. For these purposes equations [10], [11], [12], [13] and [14] are used. First, land area which will not get irrigated is estimated:

$$L_a = \frac{8.6km^3}{0.000017km^3/ha} = 506{,}000ha \qquad [10]$$

Uzbekistan may have to withdraw 506,000 ha from agricultural production, which constitutes about 11% of the country's irrigated agricultural land area (4,640 thousands ha, FAO, 2007).

Due to the withdrawal of 506,000 ha, the total lost revenue is estimated to be:

$$P_t = 506{,}000ha(US\$566) + 506{,}000ha(0.92)(US\$694) = US\$609{,}466{,}880 \qquad [11]$$

and the subsequent impact on the Uzbekistan GDP will be:

$$\%GDP_c = \frac{US\$610million}{US\$27.9billion}100 = 2.2\% \qquad [12]$$

So, the loss of US$610 million of economic income in agriculture and government revenues would result in a decrease of the country's total GDP by approximately 2.2%/yr. Moreover, this US$610 million will reduce the revenues portion of the budget by

$$\%B_c = \frac{US\$610million}{US\$8.884billion}100 = 6.9\% \qquad [13]$$

Regarding the demography which will be impacted,

$$N_p = \frac{US\$610million}{US\$1{,}815/labor} = 336{,}000jobs \qquad [14]$$

More than 336,000 people will be directly affected by the water shortage in the regions of Uzbekistan located along the Amudarya River.

The main industries of the Uzbekistan economy are textile production, food processing, machine building, metallurgy, gold mining, petroleum mining, natural gas mining, and chemical production (CIA 2009). Upon first consideration, all industries (with the exception of gold mining) will more than likely be impacted by crop reduction due to withdrawn land. However, the biggest affected industries will be textile production and food processing. To a lesser degree decline might be observed in machine building (agricultural direction), metallurgy (for machine building), petroleum and chemicals production.

Estimation of monetary impacts under "adaptive" scenario

The adaptive scenario uses measures of adaptive management, which may be applied by Uzbekistan to mitigate the potential negative impacts of the Rogun Dam.

Option A. Transferring of irrigation system to drip irrigation method. Along the Amudarya River in Uzbekistan there is 1,645,000 ha of irrigated land. Total cost of transferring to drip irrigation in the regions of Uzbekistan located along the Amudarya River is estimated:

$$V_{drip} = 1{,}645{,}000 \text{ ha x US\$}1{,}370/\text{ha} = \$2{,}253{,}650{,}000 \qquad [15]$$

And the annual cost of installing drip irrigation is

$$V_{andrip} = \frac{US\$2{,}253{,}650{,}000}{12.4\,years} = US\$182{,}000{,}000 / yr \qquad [16]$$

The cost of drip irrigation is high, but less than the lost revenue due to Rogun Dam's presence (US $609 million/yr). Moreover, introduction of drip irrigation can save 9 km^3 water annually, which is important over time (drip irrigation saves up to 32% of irrigation water compared with present furrow irrigation) (Ibragimov et al. 2007). Although the annual cost of transferring to drip irrigation is expensive (US$182 million in each of 12.4 years), the option seems more appealing than the loss of US$609 million annually after Rogun Dam is constructed. The author suggests that this case needs more detailed calculations and a cost-benefit analysis, as it might be more beneficial to spend US $182 million annually during 12.4 years and as a result save water, increase crop yield, or maintain and strengthen national security than to lose US $609 million annually plus have additional unemployment, decrease in GDP, and be dependent on Tajikistan for water resources after Rogun Dam is in full operation.

Option B. Using price for demand management. For the purpose of this estimation, Uzbekistan will have the same area of irrigated land after 12.4 years of Rogun Reservoir filling. Also, an assumption is made that over 12.4 years of Rogun Reservoir filling that Uzbekistan could be able to reduce water use by 15% (about 1% annually), which will result in an average annual water use decline from 17,000 to 14,600 m^3/ha (Table 10). The future water demand is estimated using the possible water flow reduction rate during the Rogun Reservoir filling period:

$$D_{wf} = 28km^3/yr - \left(28km^3/yr \times 0.15\right) = 23.8km^3/yr \qquad [17]$$

Table 10. Possible reduction of Uzbekistan water use during Rogun Dam filling

years	water use (m^3/ha)	reduction (%)
1	17,000	1.2
2	16,800	1.2
3	16,600	1.2
4	16,400	1.2
5	16,200	1.2
6	16,000	1.3
7	15,800	1.3
8	15,600	1.3
9	15,400	1.3
10	15,200	1.3
11	15,000	1.3
12	14,800	1.4
13	14,600	
Total reduction after 12 years	2,400	15.2

With water pricing, the estimated amount of water that will be saved is:

(1,645,000 ha x 0.000017 km^3/ha) - (1,645,000 ha x 0.000014 km^3/ha) = 4.2km^3

Next, equations [10], [11], [12], [13] and [14] are utilized and the assumption that all variables which were used in calculations of the "worst case" scenario impacts stay the same for the adaptive management scenario is made, with exception of water use per hectare.

$$L_a = \frac{8.6km^3 - 4.2km^3}{0.000014km^3 / ha} = 314{,}000ha \quad [10]$$

Uzbekistan will have to withdraw only 314,000 ha from irrigated agricultural production, which will constitute about 7% of the country's irrigated agricultural land area (4,640 thousands ha, FAO, 2007). The future total lost revenue computed as:

$$P_t = 314{,}000ha(US\$566) + 314{,}000ha(0.92)(US\$694) = US\$378{,}206{,}720 \quad [11]$$

Impact on the Uzbekistan GDP:

$$\%GDP_c = \frac{US\$378million}{US\$27.9billion}100 = 1.4\% \quad [12]$$

The loss of US$378 million of economic income from agriculture will result in decreasing the country's total GDP by 1.4% each year. This US$378 million will reduce the revenues part of the budget by 4.3%:

$$\%B_c = \frac{US\$378million}{US\$8.884billion}100 = 4.3\% \quad [13]$$

Regarding the demography, calculations show that 415,000 people will be directly impacted by the water shortage in the regions of Uzbekistan located along the Amudarya River:

$$N_p = \frac{US\$378million}{US\$1{,}815 / labor} = 208{,}000jobs \quad [14]$$

Regarding Uzbekistan industries impacted by the adaptive management scenario an assumption is made that almost thirteen years will likely be enough time to gradually cancel or diversify such industries as textile production, food processing, machine building, metallurgy, gold mining, petroleum mining, natural gas mining, and chemical production. Finally, if Uzbekistan undertakes adaptive management measures and tries to reduce water use in agriculture, the economic impacts of Rogun Dam will be much less than under the "worst case" scenario. Theoretically, a 15% reduction in Uzbekistan agricultural water consumption will result in an average 40% reduction of negative impacts (Table 11).

Table 11. Comparison of impacts under two outcomes

Type of impact	**Outcome**	
	Worst case	Adaptive management Option B (Water pricing)
Land area reduced (ha)	506,000	314,000
Lost revenue (US$ million)	610	378
Decline in GDP by (%)	2.2	1.4
Decline in budget revenue by (%)	6.9	4.3
Jobs affected (thousands)	336	208
Water shortage (km^3/yr)	8.6	4.4

Results obtained in the Table 11 show that if Uzbekistan would be able to introduce adaptive management (Option B) the land area in Uzbekistan which will not be irrigated would be reduced by 1.6 times. In the worst case scenario, Uzbekistan loses 31% of irrigated lands along the Amudarya River (1,645,000 ha) and thus using adaptive management is strongly recommended. The difference between revenue lost in the worst case and adaptive scenarios is estimated as US$232 million which is reduction of 38%. A reduction rate (36%) is observed in GDP and revenues portion of budget. The most important measure of adaptive management could decrease water application from 17,000 m^3 per hectare to almost 14,000 m^3 per hectare, which might be one of the main achievements of Uzbekistan's agriculture and can be viewed as the next step to further reduce water use in agriculture.

Table 11 does not have results of introduction of drip irrigation described in adaptive management Option A scenario because that case needs a more careful and detailed study. Although drip irrigation is extensively used for fruits and vegetables, drip irrigation is still limitedly used in cotton production (Ibragimov et al. 2007). In addition, the government of Uzbekistan should have a strong desire to change the mentality of people who have always used water in unlimited quantities and for free, encourage farmers to install drip irrigation, and help finance transfer to drip irrigation before Rogun Dam is completed and the filling stage has started.

CHAPTER 5. SUMMARY AND POLICY IMPLICATIONS

Water is a limited and important resource. It is crucial for economic and social development, and is fundamental for sustainable development. Water is scarce in the region of Central Asia, which is an arid region where its most fertile areas are former deserts made arable through irrigation. This is especially true for Uzbekistan. The country has the largest irrigation area and largest population among the central Asian states. Furthermore, Uzbekistan is largely dependent on water supplied from the two biggest rivers of Central Asia: the Amudarya and the Syrdarya. These rivers originate in the neighboring countries of Tajikistan and Kyrgyzstan, respectively. Recently, Tajikistan resumed construction of Rogun Dam on the Vakhsh River, tributary to the Amudarya River, without investigating future downstream impacts and without having consent from neighboring states.

Potential economic and employment impacts affecting neighboring Uzbekistan from the Rogun Dam project were investigated in this thesis. Being the highest dam in the world (335 m, 1099 ft) when completed and working in electricity generation mode, Rogun Dam will change the annual flow regime of the Amudarya River and as result will reduce by almost one-fifth the Amudarya River flow during the summer period. During this period, downstream Uzbekistan will need water for its irrigated agricultural crops, namely cotton and wheat. Uzbekistan has almost 2 million hectares of irrigated land along the Amudarya River and the reduction of water to irrigate those lands during summer months would impact the entire country's economy.

Through the comparison of present (*ex ante*) and future (*ex post*) conditions of water supply for agriculture and economic indicators of Uzbekistan, the following conclusions can be made:

1. The filling stage of Rogun Reservoir with a duration of 12.4 years will not have a substantial impact on Uzbekistan agriculture as Rogun Reservoir will capture 1.7% of mean annual discharge of the Amudarya River, and
2. The main impact will be seen when Rogun Reservoir will start working in full operation mode and will change annual flow regime of the Amudarya River, accumulating necessary water volume in the summer period and releasing water in the winter period. This case is in opposition of Uzbekistan's need where agricultural producers will then experience a water shortage during the crop growing period.

Taking into consideration that the main impact will be observed after Rogun Dam is filled and when RHPP will start working in electricity generation mode, two outcomes were defined: worst case (business-as-usual) and adaptive case (adaptive management scenario). The scope of impacts under each scenario was estimated and possible policy implications described.

Worst case

The worst case scenario implies that Uzbekistan will continue to maintain its present practice of water use, i.e., do business as usual. This case is considered a no-win option for the Uzbekistan economy because in this case the country will have to withdraw the equivalent of 506,000 ha of land from agricultural production, which means 336,000 people may lose their jobs and will be forced to relocate to less desirable positions or migrate to seek jobs in other countries. Also, production of cotton and wheat will decline, and such spheres of industrial production as textiles, food processing, machine building, metallurgy, petroleum, and chemicals will be impacted by a decrease in agricultural production. As a result, Uzbekistan's GDP will decrease by 2.2% and government revenues by 6.9%.

Adaptive case

This scenario assumes that Uzbekistan will undertake Option B in agricultural water use, particularly in irrigation practices, by introducing water pricing and thus adjusting irrigation requirements to fit the future seasonal water reduction. This scenario will give Uzbekistan a chance to reduce water consumption in agriculture by 15% over 12 years of Rogun Reservoir filling so the country will not be impacted as much as in the "worst case." This option also can increase water use efficiency in irrigated agriculture of Uzbekistan. Generally, a 15% reduction of water use can decrease negative impacts on average by 40%, meaning Uzbekistan will have to withdraw 314,000 ha of irrigated land, and find jobs for 208,000 people; the country's GDP will decline by 1.4%, and the revenue portion of the budget by 4.3%. Although this case has negative results too, this scenario seems more desirable considering current Uzbekistan conditions.

Policy implications

Each country has a right to implement policy which would be most beneficial for the population of that country and would reflect trends of economic development of that country. Irrespective of the position of Uzbekistan as a riparian country, Tajikistan will finish construction of Rogun Dam. In this context, the government of Uzbekistan should, as soon as possible, focus future development strategies on changing water use practices in agriculture by introducing water pricing and applying other advanced irrigation practices rather than furrow irrigation which is commonly used in the country. The revenue that is expected from water pricing should be strictly controlled and spent for the implementation of changes in water resources management, education and training of mid- and lower management personnel in the regions. Consequently, all undertaken measures must lead to reducing the negative impact of water use reduction in irrigated agriculture.

Another solution might be a scenario in which Tajikistan will share with Uzbekistan revenue from power generated from Rogun Reservoir. The basis for this action might be the "Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources" of 1992 where riparian states agreed to continue water allocation practices developed during the Soviet period. However, the 1992 Agreement does not address energy supply to upstream states. Therefore, Uzbekistan and Tajikistan could reach an additional agreement and determine Uzbekistan loses due to the presence of Rogun Dam and on this determination agree to how much Tajikistan compensates Uzbekistan for loss of agricultural opportunities during a respective time period. Thus, if Tajikistan shares its revenues from Rogun Reservoir, Uzbekistan could be able to transfer to advanced agricultural practices easier and sooner. This scenario might be a win-win case for Tajikistan and for Uzbekistan as well. However, this case needs strong political desire from the governments of both countries and this desire is currently not present.

One of the findings of this study was that the Amudarya River will have a 54% increase in flow discharge in the winter period which potentially may lead to flood events downstream. Therefore, for the next study, assessment of impacts of Rogun Dam during the winter period downstream of the Amudarya River is suggested. The proposed future study and this study could constitute useful information for use by policy-makers to determine possible changes in the Amudarya River basin after Rogun Dam is constructed.

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