Playing the Dam Game:

How a Proposed Hydroelectric Dam Could Trigger Central Asia's First Water War

Abstract

In 2012, President Islam Karimov of Uzbekistan threatened to use military action against Kyrgyzstan if the Kyrgyz government went ahead with plans to build a large hydroelectric dam called Kambarata-1 and entrap a large amount of water on its territory. This paper investigates whether or not using military force against Kyrgyzstan would be a rational choice according to expected utility theory. The expected utility change for Uzbekistan on account of Kambarata-1's construction was investigated by using GIS software to estimate the size of the reservoir that would be created by the dam. The size of the reservoir can be used to estimate the economic losses Uzbekistan would endure as a result of having less water flow into its territory from Kyrgyzstan on the Syr Darya River. A small survey was conducted in Kyrgyzstan to investigate the probability of Uzbekistan emerging victorious from a bilateral war with Kyrgyzstan. These results were used alongside data from academic literature to support an original game theory model called The Mafioso's Dilemma. It predicts that Uzbekistan will not engage Kyrgyzstan in a military conflict due to the possibility of being punished by Russia and Kyrgyzstan's other treaty allies in the Collective Security Treaty Organization (CSTO). However, if political conditions changed and Kyrgyzstan did not have CSTO allies to guarantee its security in the future, a different theoretical model – the Prisoner's Dilemma – would more appropriately reflect the situation. Uzbekistan could then rationally invade Kyrgyzstan to secure water resources trapped in Kambarata-1's basin.

Keywords: Uzbekistan, Kyrgyzstan, Kambarata-1, Syr Darya, Mafioso's Dilemma

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Introduction: A Possible Conflict over Scarce Water in Central Asia

In 2012, President Islam Karimov of Uzbekistan publicly threatened to engage in war against the neighboring Kyrgyz Republic, commonly called by its former name, Kyrgyzstan. The threat was issued to warn Kyrgyzstan against building a proposed hydroelectric dam called Kambarata-1 (K1) that would block a large amount of water from flowing into Uzbekistan via the Syr Darya River. This paper draws on expected utility theory to determine whether or not Uzbekistan would rationally start a war to secure its water resources if K1 were built.

Geographic Information System (GIS) software was used to assess the impact K1 would have on Central Asia by estimating the maximum amount of water that K1 could potentially hold in its reservoir. The hydrological conditions, reservoir estimates and existing political dynamics of the region were combined to construct a game theoretic model that explains the conditions necessary for Uzbekistan to rationally engage in warfare. This paper does not attempt to determine whether or not Kyrgyzstan will actually complete the construction of K1. The research question is limited to asking if Uzbekistan could have a rational argument for taking military action against Kyrgyzstan once the dam is built.

This paper begins by examining the political, geological and economic factors at play in Uzbekistan and Kyrgyzstan. This background information is followed by a section outlining the viability of game theoretic models as means for studying the interactions of Uzbekistan and Kyrgyzstan in the post-soviet era. Existing models such as Prisoner's Dilemma and Stag Hunt do not reflect the decisions made by both Uzbekistan and Kyrgyzstan. However, it is clear that a model could be invented to reflect Uzbek-Kyrgyz

interactions with supportive evidence from geological and political data. The paper then moves into an assessment of the region's geology, climate, and the potential impact that K1 would have on the flow of water in the Syr Darya. This data is used to assess the change in utility Uzbekistan would perceive after K1 is built. Next is a review of the political dynamics dominating the region's affairs and results from a small survey conducted in Kyrgyzstan to investigate the likelihood of an Uzbek-Kyrgyz military conflict and its potential outcomes. This data is used to assess the probability that Uzbekistan would gain utility in terms of access to water from the use of military force against Kyrgyzstan. This data collectively informs a geopolitical analysis of Uzbek-Kyrgyz relations and the potential for conflict arising between them. Uzbek-Kyrgyz interactions are framed by a new theoretic model called the Mafioso's Dilemma, which is tested in a likely future scenario.

The results suggest that war over water resources in Central Asia is unlikely to occur in this specific case because of large disincentives perceived by Uzbekistan. These disincentives stem from Russian hegemony in the region. Russia exercises military hegemony via the Collective Security Treaty Organization (CSTO), a collective defense alliance including the Kyrgyz Republic. However, the chances of Uzbekistan using military force to offset the negative effects of K1 would increase if Russia displayed a lower level of interest in guaranteeing Kyrgyzstan's security, as Kyrgyzstan is a very weak state.

Political Background

The Kyrgyz Republic wants to build hydroelectric dams on the upstream segments of the Syr Darya River system, specifically on a branch called the Naryn River. These projects, known collectively as the Kambarata projects, are meant to ensure Kyrgyzstan will have self-sustaining electrical capacity, with some electricity left over for export. As of

2012, the Toktogul hydroelectric dam provided about 90% of Kyrgyzstan's electricity while controlling the flow of the Syr Darya's Uzbekistan-bound water, which is held in the Toktogul reservoir (E. P. Kraake 2012). Toktogul was built during the Soviet era, and the situation today is basically the same as it was then. Completing the Kambarata projects as currently planned would cause a reduction in the volume of water moving downstream because the new dams would create more reservoirs.

In 2001 Kyrgyzstan passed a law titled "On interstate use of water objects, water resources, and water facilities of the Kyrgyz Republic." It nominally spelled out a policy of cooperatively dealing with other nations on water resource issues. However, the law declares that all waters in Kyrgyz territory belong to the state, and that waters emanating from Kyrgyzstan must be paid for by the downstream countries (McKinney 2003). The purpose of this legislation was therefore to monetize the nation's water, since Kyrgyzstan felt it was not being duly compensated for the water resources released to Uzbekistan under the Interstate Commission for Water Coordination (ICWC) governing system and its various agreements. Kyrgyzstan's position of considering its water to be a commodity remains in effect today.

There are three parts of the Kambarata projects: the large Kambarata-1 dam, the smaller Kambarata-2 dam, and a series of small dams that are collectively known as the Upper Naryn Cascade. Throughout this paper, I will refer to them as K1, K2 and the UNC, respectively. Parts of K2 were completed in 2010 and are now generating power. K2 will be able to generate 360 megawatts (MW) when fully operational (Schwind 2010). But K2 cannot actually be completed until after K1 is finished. K2 is downstream of the K1 site, and its architectural plans depend on the river's flow being regulated by K1 (E. P. Kraake 2012).

If everything proceeds according to schedule, K1 will be complete about 7 years from the start of construction, which began in 2013 (Kudryavtseva 2016).

K1 will not be operational until 2020 at the earliest. K1 will be located in western Kyrgyzstan at 41°47′02″N, 73°28′38″E[1] and will be 275 meters high. It is projected to produce 1900 megawatts per year (MW) of electricity, which will greatly benefit Kyrgyzstan. The UNC is a four-dam system that will be able to provide 240 MW in total. The UNC is projected to generate its first electricity in 2016 and be fully operational by 2019 so long as construction remains on schedule. K1 and the UNC together would add 2,140 MW to Kyrgyzstan's pre-existing 3,800 MW (Kalybekova 2014). In total, the three dams will add 2,500 MW.

Kyrgyzstan's desire for hydroelectric power stems from the collapse of the USSR. When the Soviet Union broke up in 1991, Moscow's control of Syr Darya water distribution evaporated. In turn, the Interstate Commission for Water Coordination (ICWC) was established among Central Asian nations, who pledged to maintain the Soviet-era status quo of water allocations. This gave Uzbekistan rights to a total of 52% of Central Asia's water (from the Syr Darya and other sources), while Kyrgyzstan retained the rights to use 4% (McKinney 2003).

The ICWC framework was unsustainable, and did not give any guidelines related to energy production, so a new framework was needed. Under the 1998 Syr Darya Water and Energy Use Agreement, Uzbekistan must compensate Kyrgyzstan when it releases water downstream without producing energy. Basically, when Kyrgyzstan opens its dam

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[1] These coordinates are according to Wikipedia – I have not found any other written documentation of this location, but several existing maps used in prior scholarly literature on the subject corroborate the same location, such as E. P. Kraake 2012 and a Russian-language interactive map produced by the ICWC available at http://www.cawater-maps.net/kyrgyzstan/default.aspx

floodgates to release water for Uzbekistan in the summer, and therefore does not produce

hydroelectricity for itself, Uzbekistan is obligated to provide other sources of energy.

However, Kyrgyzstan must pay for the transportation of the electricity or fuel sources. It

also must turn resources such as coal or oil into electricity at its own expense. Since

Uzbekistan is not responsible for these costs, it receives relatively inexpensive water from

Kyrgyzstan (McKinney 2003). This explains why Kyrgyzstan is often reluctant to release as

much water as Uzbekistan demands. In fact, no transfers of funds or commodities have

been recorded under the auspices of the 1998 agreement. A Kyrgyz official lamented in

2011 that "more than twenty regional agreements have been signed over the last decades,

but none of them are effective" (E. P. Kraake 2012).

Uzbekistan needs to ensure that it receives enough water from the river to sustain

its economic activity and the welfare of its citizens, which explains its refusal to adhere to

regional agreements. Due to this heavy dependence on the Syr Darya's water, Uzbek

President Islam Karimov warned that war could be a result of Kyrgyzstan going forward

with its hydropower projects (Nurshayeva 2012). Karimov's rhetoric has securitized water

resources in the region, "leading to much sabre-rattling, economic sanctions and the

closure of borders" (E. P. Kraake 2012). Uzbekistan has good reason to be concerned about

its water supplies: it is the most populous Central Asia nation, and it is heavily dependent

on the agricultural sector of its economy, which produces exportable cash crops like cotton.

In the 2013-2014 market year, the area of cotton harvested in Uzbekistan shrank by 2

percent and the total production decreased by 5.5% (Stratfor 2014). According to a

European Parliament report:

"The agricultural sector continues to play a central role in Uzbekistan's economy, representing about one fifth of GDP and employing about 40% of the country's active population. Only 11% of the land, mostly located in irrigated river valleys, allows intensive agriculture, while another 40% is occupied by natural pastures. Uzbekistan's agricultural sector is still largely dominated by cotton farming, although production has dropped by 35% since 1991. Uzbekistan is now the world's fifth largest cotton exporter and sixth largest producer" (Bendini, Uzbekistan: Selected Trade and Economic Issues 2013).

Today, Uzbekistan is highly dependent on the Syr Darya (among other rivers, such as the Tajik-controlled Amu Darya) to support its agricultural sector. The map below shows the Syr Darya's path through Central Asia relative to the region's agricultural centers.

Map 1: This map from Stratfor shows that the Syr Darya is used for irrigation primarily in the Uzbek portions of the Fergana Valley, which is almost entirely shaded pink or red (50-100% irrigated land). One can see that its Kyrgyz, Tajik and Kazakh banks are only lightly irrigated (Stratfor 2014). *Note: Map originally produced in 2012 but is used most recently in a 2014 Stratfor document.*

Uzbekistan has been facing an increasingly severe water deficit in recent years (Bendini 2013). The Uzbek water deficit stems from both poor management practices and climate change, and both will continue to play a role in Uzbekistan's future. The Syr Darya's geographic importance cannot be understated. It brings water through the Fergana Valley, which is the most populous and productive area in Uzbekistan. With the agriculture sector accounting for roughly a fifth of its GDP and around 40% of employment, Uzbekistan has no choice but to actively monitor its water supply situation. Despite its favorable position in the existing agreements, Uzbekistan often feels it must bully Kyrgyzstan into releasing water from its reservoirs. Most recently, the Uzbek government released a lengthy tirade on the state of its security issues, making ludicrous claims and condemning many of its neighbors' actions. It was particularly vehement about the Syr Darya situation:

"Contemporary Uzbekistan, as a legal successor to the Kokand khanate[2], has the full right to territorial claims on the entire republic of Kyrgyzstan, not to mention the property claims of all the transboundary waters and the structures built on them, including [hydroelectric dam project] Kamburata-1... *[sic]* In the case that Russia or Kyrgyzstan further act arbitrarily after the government of Uzbekistan presents a note, addressed to Russia and Kyrgyzstan, demanding the immediate cessation of construction of Kambarata-1, the Uzbek side will have the full and justified right to take that object under its control, take it under its jurisdiction with all of the military-political and economic ramifications" (Kucera 2013).

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[2] The Kokand Khanate was an eighteenth and nineteenth century state dominated by ancestral Uzbek clans. Its territorial extent included the Fergana Valley and surrounding lands in present-day Kyrgyzstan and Tajikistan (Penati 2010). It is not clear if the K1 dam lies squarely within former Kokand Khanate lands, and even so the Uzbek claims to Kokand territory are not easily verified, since the best surviving land surveys of the region were conducted by the Russian Empire and Soviet Union after the khanate had collapsed (Penati 2010).

The state-sanctioned rant goes on to include other preposterous plans, including an idea to join NATO (which Uzbekistan has actually sought before) as a means to balance Russia and conquer its neighboring foes. Someone in the Uzbek public relations apparatus with a bit of common sense got wind of the article and removed the original post (Kucera, Uzbekistan Media: We Should Join NATO, Conquer Eurasia 2013). An independent Uzbek media outlet called UzNews.net that posted a copy of the statement was later shut down in 2014.

Such state-sanctioned rhetoric cannot be ignored – even when hidden – because it reveals an inclination towards brash policies among Uzbek officials. It signals that there are actors with decision-making power within Uzbekistan who are considering all possible options for dealing with its water security issues regardless of their viability. Obviously NATO would have no interest in adding Uzbekistan to its ranks, but if the offer was extended, Uzbekistan would have no qualms about leveraging the military weight of its new allies. Therefore, Uzbekistan can be expected to act more brashly if it gains power relative to Kyrgyzstan and perceives a high likelihood of achieving water security through warfare.

Uzbekistan currently seems unlikely to explore other options. There had been little evidence that Uzbekistan is moving to improve its domestic irrigation systems until the Cabinet of Ministers approved a plan to financially recover underperforming water supply facilities (AKI Press 2014). Between 1980 and 1995, Uzbekistan never spent more than $5 million annually to develop basic assets in its water sector (ICWC 2015). Although that number rose to $14 million by 2000, investments in existing water asset maintenance were halved from the 1985 peak of $611 million to $308 million in 2000 (ICWC 2015). In 2013,

the Asian Development Bank pledged a $220 million loan to Uzbekistan meant to "secure

reliable irrigation to 6,500 farms and provide drinking water access to 725,000 consumers"

in two provinces by 2020. But 720,000 consumers is a small fraction of Uzbekistan's

population of over 30 million (Asian Development Bank 2013). These projects appear

large on paper but are unlikely to prevent massive quantities of water from going to waste

in Uzbekistan. No precise or accurate measurements exist to show how much water in

Uzbekistan is lost to unnecessary evaporation, failing or broken canals, pollution, or sheer

waste. But one researcher familiar with the situation estimated in 2011 that roughly half of

Uzbekistan's water supplies are unused, and that number will only increase without a large

commitment by the state to fix its irrigation systems, which have been ignored since the

end of the Soviet period (UzNews.net 2011). A report from the International Crisis Group

estimates that 50-80% of water designated for agricultural use never arrives at Uzbek

farms, and the remainder that does reach its location is used with low efficiency

(International Crisis Group 2014). Based on the regime's rhetoric, the government seems

more likely to blame its water problems entirely on its neighbors rather than actively take

responsibility for maintaining its own infrastructure.

But Uzbekistan is not the only Central Asian nation lacking critical infrastructure.

The winter of 2007-2008 was excruciatingly cold in Kyrgyzstan, and domestic demand for

electricity skyrocketed as a result. This in turn led the state to run Toktogul at full capacity,

which was still not enough to prevent rolling blackouts and electricity rationing. The years

from 2007-2009 were also exceptionally dry. This meant that the Toktogul reservoir levels

dropped to record low levels, and the Kyrgyz government could not afford to release the

quantities of water demanded by its downstream neighbor in the summer, as shown in

Figure 1 (E. P. Kraake 2012).
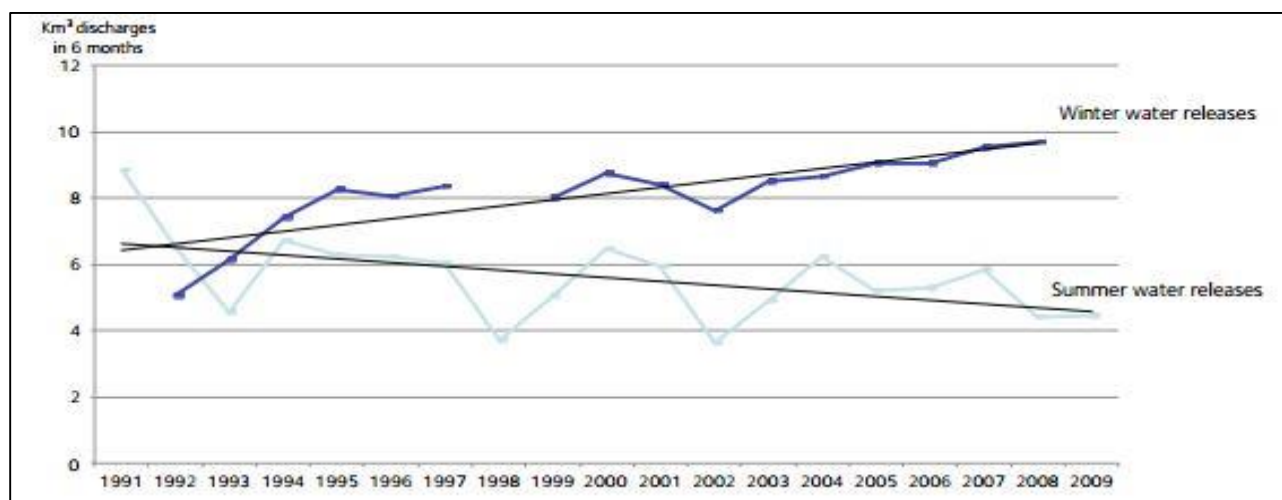
Figure 1: Seasonal water discharges from Kyrgyzstan's Toktogul Reservoir from 1991 to 2009, taken directly from Kraake 2012. Climate trends exacerbated Kyrgyzstan's post-independence pattern of releasing more water in winters than in summers (Kraake 2012).

The Kyrgyz government is hoping that its new Kambarata projects will ease its

electricity shortage problems. But the future of the dam projects is also uncertain,

according to a 2014 report from Eurasia Net, the only major Western media outlet devoted

to covering Central Asia. The dams are largely being built and financed by Russia. The

Russian Duma approved financing for both projects, but not without some major

conditions. Inter-RAO, a Russian firm, is building the Kambarata facilities, which are being

paid for with a financial deal from the Russian government worth $2 billion. The cost of this

financing to Kyrgyzstan is often assumed to be 1) getting rid of the American-run Manas Air

Base, and 2) Kyrgyzstan agreeing to join Russia's Customs Union (International Crisis

Group 2014). Additionally, Inter-RAO will hold a 50% ownership stake in K1. Although the

K2 site is well underway and partially operating, the larger K1 project is now in limbo and

now holding up the development of K2. Another Russian company called RusHydro is

building the UNC, which is also on hold. If completed, RusHydro will receive 75% of the dam's revenue until the investment in the project breaks even, at which point the revenues will be split evenly with the Kyrgyz operator (Kalybekova 2014).

In January 2016, the Kyrgyz Parliament voted to allow the Russian financers and builders to withdraw from the contracts if they desired (FreeNews 2016). The Russians have to decide by June 2016 on whether or not to take the option to withdraw from the projects. Since this date is beyond the required completion date of this research project, the K1 project is still effectively alive and well until Russia formally opts out. Depressed energy prices and a receding economy are forcing Russia to reconsider many foreign aid and investment projects like K1, which has a projected price tag of $2 billion (Leonard 2016). Kyrgyzstan's energy hopes are at the mercy of Russian interests (currently focused on Ukraine and Syria) and face the prospect of more dry, cold years ahead.

Even if the dams are successful, Kyrgyzstan will still be wracked with other issues, the first being Uzbekistan's response. But there is another major electricity problem in Kyrgyzstan. According to The Free Library, which posted a report from AKIpress (an online Kyrgyz pay-per-article publication), a consulting firm called Tetra Tech has concluded that half of Kyrgyzstan's generated electricity is lost or stolen. This results in $100 million annually lost, and a major loss of services for the Kyrgyz people as well (The Free Library 2011). Systematic corruption is obviously a root cause of this massive waste of resources.

There is another issue with Kyrgyzstan which complicates the situation: Kyrgyzstan's membership in the Collective Security Treaty Organization (CSTO) military alliance. Article 4 of the CSTO charter declares that aggression against any member state will be considered an act of aggression against all member states:

"If an aggression is committed against one of the States Parties by any state or a group of states, it will be considered as an aggression against all the States Parties to this Treaty.

"In case an act of aggression is committed against any of the States Parties, all the other States Parties will render it necessary assistance, including military one, as well as provide support with the means at their disposal through an exercise of the right to collective defense in accordance with Article 51 of the UN Charter..." (CSTO 1992).

Although the treaty was signed in the Uzbek capital of Tashkent, Uzbekistan is no longer a member of the CSTO. Because Kyrgyzstan is still a member, an Uzbek attack on Kyrgyz hydroelectric infrastructure would be defined as an act of aggression against the CSTO according to the organization's current treaty. In this case, the Uzbek military would be subject to retaliation from not only Kyrgyzstan, but also Russia, Kazakhstan, and others.

However, the CSTO has not always been politically cohesive. This became apparent when Belarussian President Alexander Lukashenko lashed out at the organization for doing nothing to prevent bloodshed in Kyrgyzstan during a 2010 coup d'état. Belarus, a CSTO member state, sheltered ousted Kyrgyz President Bakiyev in the wake of the revolt while Russia threw its support behind the new government in Bishkek. Lukashenko bitterly asked "What sort of organization is this one, if there is bloodshed in one of our member states and an anti-constitutional coup d'etat takes place, and this body keeps silent?" (Makhovsky 2010). The situation regarding this coup is complicated and outside the scope of this research paper, but the event shows that the CSTO may be selective in abiding by its own rules, especially with regards to Kyrgyzstan. It also shows that members interpret the

CSTO's responsibilities differently: Belarus considered it the CSTO's duty to prevent bloodshed in its member states, while Russia did not in this case.

More recently, another incident highlighted the lack of cohesion among CSTO members. On March 18, 2016, Uzbekistan sent a contingent of about 40 soldiers and several armored vehicles to enforce its claim over land located along a poorly demarcated section of the Uzbek-Kyrgyz border (Stratfor 2016). Kyrgyzstan responded by deploying a contingent of its own troops to the area, and called a special session of the CSTO (Kucera 2016). The commanders on the ground worked out a solution and the standoff ended peacefully after eight days (Stratfor 2016). But the CSTO and Russia were accused of "passivity" during the incident, as the only action taken by the security bloc was to dispatch the organization's deputy secretary general to Bishkek for the purpose of monitoring the situation (Kucera 2016). This incident created uncertainty about Russia's commitment to the collective defense of its CSTO partners, especially Kyrgyzstan, and heightened the risk of a water war. Uzbekistan may perceive Russia's commitment to the CSTO as insincere and choose to act militaristically towards Kyrgyzstan.

Another important political element that could influence the possibility of a water war is the chaotic, opaque world of Uzbek domestic politics. Uzbekistan is divided into seven clans: the Samarkand, Tashkent, and Fergana are the most powerful. The smaller Jizzakh, Kashkadarya, Khorezm and Karakalpak clans generally align with the three larger clans according to their interests and play relatively minor roles in domestic politics. The clans are informal institutions that wield the real power in Uzbekistan. President Karimov is from the Samarkand clan, but he has multiple allegiances. Karimov has fostered ties with other clans to consolidate loyalty and protect himself from potential coup attempts

(Stratfor 2013). He has long lists of friends and enemies in every clan, and at 77, he is approaching the end of his time in power. Rumors have swirled about Karimov being in declining health for several years. With no clear successor ready to take his place with unified support from all clans, a power struggle appears imminent (Stratfor 2014).

Uzbek politics under Karimov have been volatile. The Islamic Movement of Uzbekistan (consisting of largely Fergana clansmen, who reside in the agricultural lands supplied with water from the Syr Darya) burst on the scene with terror attacks in 1999 and then again in 2004 during a power struggle between Karimov and another Samarkand leader. In 2005, Fergana protesters in Andijan province (which is agriculturally productive and receives water from the Syr Darya) were killed in the Andijan Massacre, when 1,500 civilians were gunned down by security forces. In the following years, Karimov's Samarkand clan slowly rekindled ties to the Fergana clan, but the Tashkents gained power in government. Then in 2014, Karimov had a series of Tashkent officials abruptly arrested or fired from government positions and replaced with his own Samarkands. In short, Karimov has shared power among clans and frequently reassigned responsibilities for various government functions to different clans during his tenure (Stratfor 2013, 2014, 2015). His maneuverings have held the government together while intensifying political fractures that could lead to instability and militancy after his death, especially in areas bordering Kyrgyzstan.

Uzbekistan's significant youth unemployment, high social inequality between rural and urban classes and systemic corruption also contribute to its unstable domestic politics. All of these characteristics are associated with political instability in developing countries (Azeng and Yogo 2013). To quell instability, Karimov needs to keep people in rural areas

working instead of standing idle or converging on cities. Forcing people into the cotton industry appears to be a solution already in practice. Human Rights Watch alleges that 2 million people are consistently forced into working in the Uzbek agriculture sector against their will. Many Uzbek citizens are often pressed into service as cotton pickers. In Andijan province and elsewhere, some Uzbeks pay replacement workers to take on their mandated shifts (Putz 2016). With the services sector growing steadily over the past several years to support the country's annual 6-8% GDP growth rates, the regime is apparently comfortable with doing little to offset the declining agricultural output so long as the people remain employed. Even with the steady decline in output, cotton exports still provided $1 billion of revenue to the Uzbek regime in 2013 (Shaku 2016).

Everyone in the Uzbek government knows that change is coming soon. The impact of political turnover on labor institutions is higher in polarized political systems (Lucifora and Moriconi 2012). Given that the Uzbek political scene is heavily polarized in three to seven different directions at any given time, each clan has an interest in keeping other clans employed when power changes hands. No one would want to see a rival clan mobilize their populations and foment unrest. The easiest way to do that is to forcibly maximize agricultural employment levels. Another way is to conscript the eligible population into the military for service in an interstate war, but there have been no indications that the Uzbek regime has considered such an ostentatious move.

In spite of decreasing output in agriculture (32% of GDP in 1995 to 21.9% now), employment in agriculture has remained disproportionately high at 40-44% of the labor force (Laruelle and Peyrouse 2013). This figure has been steady despite frequent changes among the leadership of the Ministry of Agricultural and Water Resources (MAWR) and

associated agencies as documented by Stratfor; every clan clearly recognizes the value of keeping the rural Uzbeks employed. But rural farmers need the MAWR to provide them with water and other necessary inputs for the agriculture industry. In this area, the government has consistently failed, regardless of what clans Karimov chose to be responsible for the MAWR and associated agencies over the years. An agricultural collapse could free up millions of people willing to participate in a spectacularly bloody civil war among clans or a war against Kyrgyzstan. Either scenario would take one of the world's top cotton suppliers out of international markets and jeopardize peace in Central Asia.

Geological & Economic Background

Uzbekistan and Kyrgyzstan neighbor one another at a critical geographic point in Central Asia called the Fergana Valley. The Fergana Valley is a small, fertile land held by Uzbekistan, but the surrounding mountains are mostly held by the Kyrgyz. The Syr Darya River (also known as the Naryn River in Kyrgyzstan) flows from the east into the Fergana Valley, sustained by melting snow from Kyrgyzstan's mountains. This water is among the most economically and strategically valuable resources in Central Asia, but the river's supplies are not enough to satisfy the needs of both nations. The Fergana Valley consists of about 22,000 square kilometers, or 5% of Central Asia's land area. However, approximately 14 million people, or roughly 25% of Central Asia's population, live in the valley and depend directly on the Syr Darya for water (Stratfor 2013). It also accounts for 85% of Uzbekistan's cotton growing region (Chapagain, et al. 2005).

Climate change is expected to hit Central Asia hard over the coming decades. In the first decade of the twenty-first century, the region experienced a warming trend similar to the trends observed elsewhere in the world during the same time period (Westphal 2010).

Central Asia is particularly vulnerable to drought due to geographic factors (highly variable precipitation and reliance on snowmelt) and structural factors (dependence on agriculture, inadequate water resource management, etc.) that have worsened in recent years (Westphal 2010). Uzbekistan's water situation is already precarious, and it is listed as having the sixth worst water security in the world in Verisk Maplecroft's Water Security Index (Verisk Maplecroft 2011).

Central Asia is projected to see a 1.6°C to 2.6°C increase in mean temperature by 2050, resulting in 30-40 less frost days and 20-30 more hot days per year (Westphal 2010). Regional climate models have not been developed well enough to make reliable estimates of future levels of annual precipitation in Central Asia (Westphal 2010). However, runoff is expected to mildly increase in Kyrgyzstan while decreasing dramatically in Uzbekistan, leaving the region with less net runoff water in the future (Westphal 2010).

The Syr Darya is supplied by meltwater from Kyrgyzstan, whose mountainous topography collects snow each winter and houses many glaciers. The Intergovernmental Panel on Climate Change (IPCC) has stated with high confidence that glaciers are shrinking worldwide due to climate change in its Fifth Assessment Report (AR5), leading scientists to conclude with medium confidence that downstream water resources and runoff levels are being affected globally (IPCC 2014). The World Glacier Monitoring Service (WGMS) collects data on fourteen glaciers[3] that lie within K1's watershed. All these glaciers have shown signs of abatement in recent years due to climate warming. For example, the Sary Tor

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[3] The 14 glaciers are monitored independently by different researchers. They are the SUEK/SUYOK ZAPADNIY, DZHUUKUCHAK, SARY TOR (NO.356), AKSHIIRAK GLACIER GROUP, NO.393, NO.394, BOLSHOY CHONTOR, BORDOO, DVOINOI LEVIY, GREGORIEV, PETROV, POPOV, GLACIER NO. 354, AKSHIYRAK, and DAVYDOVA glaciers. While the names have no particular significance and some are remarkably similar, they each have a unique WGMS identification number.

glacier (WGMS ID 805) shrank by 310 meters in length between 1990 and 2003 after being stable from 1957 to 1990 (WGMS 2015). Others shrank consistently for the last half century or longer.

Globally, the IPCC identifies the likely effects of climate change. The several that follow are particularly relevant risks in Central Asia (IPCC 2014):

- "Systemic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services."

- "Risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings."

- "Risk of loss of rural livelihoods and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions."

- "Risk of loss of terrestrial and inland water ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for livelihoods."

Kyrgyzstan and Uzbekistan are both relatively poor, underdeveloped states dependent on a shared inland riparian basin, and they are already dealing with food and water resource problems. There is well documented evidence of water shortages in Uzbekistan (Bendini, Uzbekistan: Selected Trade and Economic Issues 2013). Overuse of inefficient Soviet-era irrigation systems in the last 50 years has contributed to the rapid decline of the Aral Sea, since most water is diverted, left to evaporate, or otherwise lost.

Bendini cites World Bank figures which estimate Uzbekistan's water deficit in 2005 was 2 cubic kilometers (km^3) and will likely be 11-13 km^3 by 2050.

One of the Kyrgyz Republic's few natural blessings is the abundance of water within its territory. Estimates vary, but one experienced researcher claimed in 2003 that approximately 29.2 billion cubic meters (bcm) of water flow formation occurs annually within Kyrgyzstan's portion of the Aral Sea Basin (McKinney 2003). After the Soviet period, electricity became the cheapest source of power in Kyrgyzstan, and the cheapest way to generate it came from Soviet era hydroelectric power stations, particularly the Toktogul hydroelectric dam system (Kalybekova 2014).

The future supply of water to Kyrgyzstan's dams and Uzbekistan's fields is also in doubt because Kyrgyzstan's glaciers are melting. Those in the K1 watershed are not immune to the effects of climate change. The WGMS accumulates glacial measurement data from different scientific studies conducted around the world. Glacier size is measured in several ways, such as frontal variation,[4] mass balance,[5] area, and volume. All the glaciers in K1's watershed have shown signs of ablating in recent decades, according to WGMS data. Due to inconsistent glacial record keeping in Kyrgyzstan, it would be impossible to make a statistical statement estimating the precise percent change in volume of all glaciers in the K1 watershed over any period of time. However, an overall ablation trend has clearly been ongoing since the middle of the 20th century, as shown in Figure 2.

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[4] Frontal variation is a measurement of where a glacier's lowest point is located over time. The "front" of the glacier is the end at the lowest altitude. If the end of a glacier moves up a mountain from one year to the next, it is shrinking.

[5] Mass balance is a measurement of the change in a glacier's estimated mass over time.
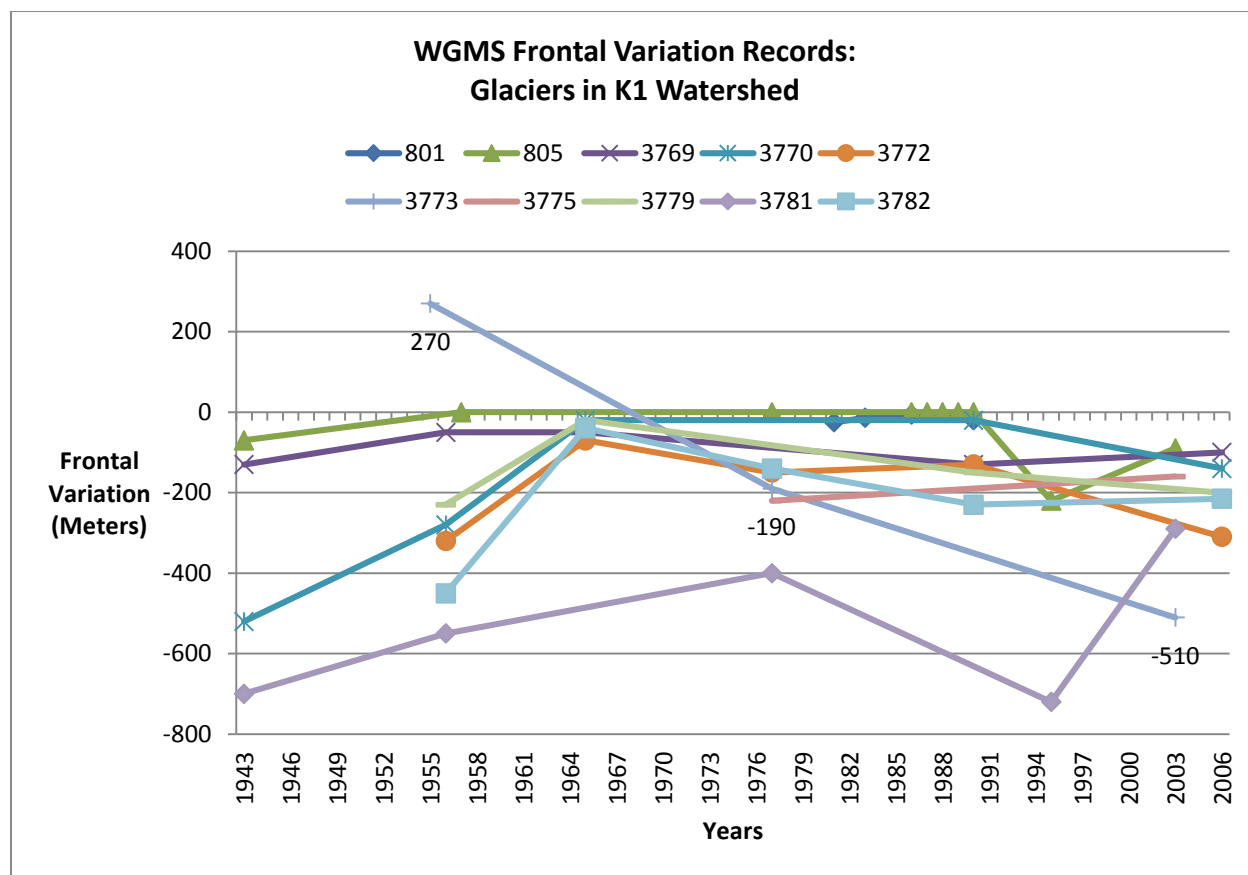
Figure 2: Frontal Variation of Glaciers in the K1 watershed. This graph shows that all glaciers have retreating fronts. The sole positive value, reported at Glacier 3773, is the only reported instance of glacial growth in the K1 watershed since 1943 (WGMS 2015).

The observed melting trend is in agreement with a 2015 study that found a 27% decrease in glacial volume throughout the Tian Shan Mountains, which dominate Kyrgyzstan's terrain and have been losing 5.4 gigatons of ice per year since the 1960's (Farinotti, et al. 2015). It will only continue as global temperatures continue to rise. Regardless of measures that humanity may take to curb the effects of climate change, at this point anthropogenic activities have likely pushed humanity past the point at which glaciers could recover (Ruddiman 2005). Levels of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) are higher than they were in the atmosphere at any point during the last several hundred thousand years and show no signs of decreasing anytime

soon (Ruddiman 2005, IPCC 2014). The question is how fast will the Earth warm, and how

will the warming climate impact glaciers in the K1 watershed in the future? Figure 3

depicts our changing climate conditions and the uncertain future of glaciers.
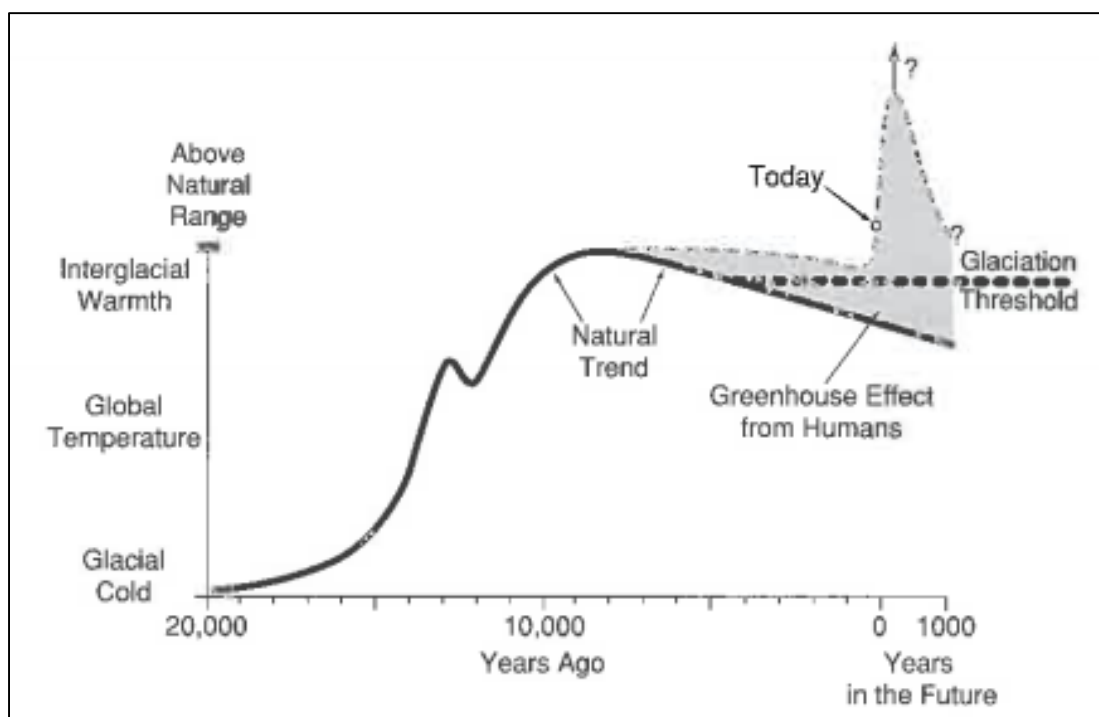
Figure 3: This figure from Ruddiman 2005 shows that greenhouse gases have taken the Earth's climate out of its normal glacial cycle, preventing glaciers from returning to larger sizes. Instead, recent warming trends over the last two centuries have melted glaciers further (Ruddiman 2005). It is increasingly unlikely that our climate will return to a state supportive of glacier formation.

It is impossible to tell for sure when or if Central Asia's glaciers will disappear and

the Syr Darya would be in jeopardy of drying up. But for now, the overall long-term trend

indicates that the region's water sources will become scarcer. Publicly available records

provided by the ICWC only include data from 1980-2000, so it is difficult to find reliable

present-day sources of information about the state of the Syr Darya. However, during the

1980-2000 time period, the river's annual discharge rate seemed to be unaffected by

predominant climate change trends, as shown in Figure 4. Discharge varied regularly

within a range of values between about 2 and 4 bcm.

Total Naryn River Discharge, 1980-2000

◆ Total Naryn Discharge, millions of cubic meters
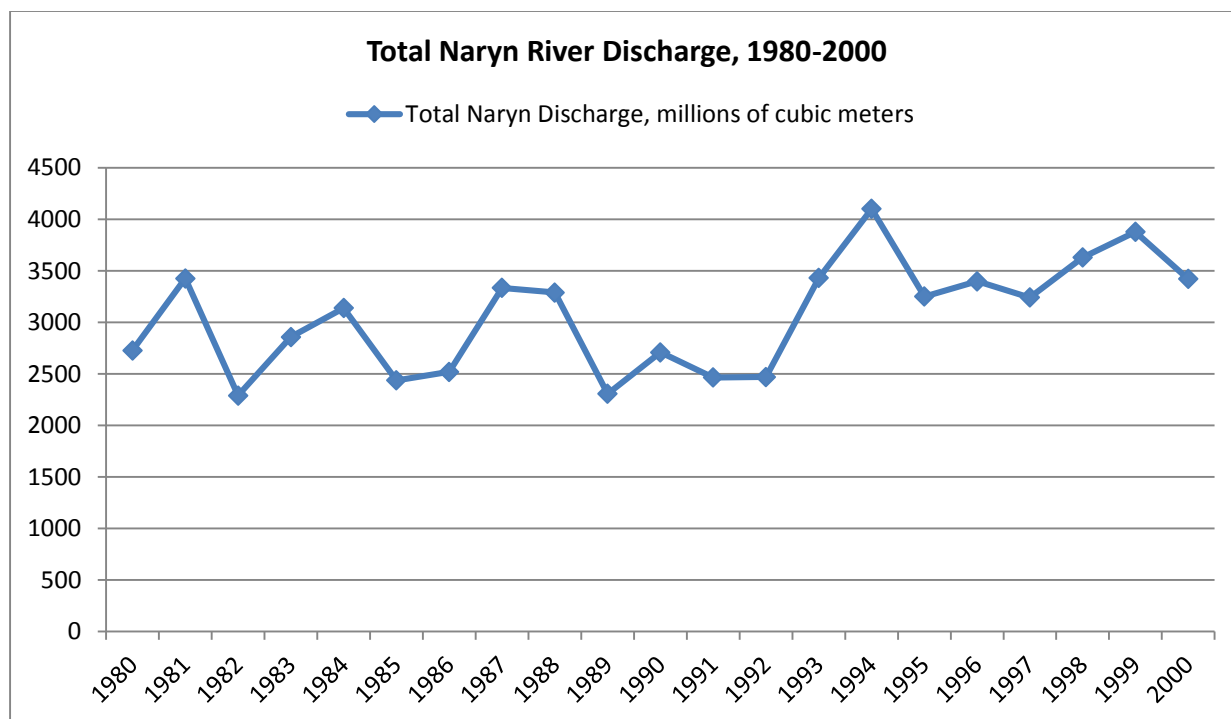
Figure 4: Annual Naryn River discharge rates from 1980-2000 give an indication that glacial ablation in the 20th century did not negatively impact the amount of water available in the river (ICWC 2015).

Despite the gloomy climatic outlook, the Syr Darya has apparently maintained discharge rates high enough to sustain the societies dependent on its waters, even if just barely. Depending on how the river is managed by the Kyrgyz dam system and local weather patterns, the Syr Darya in Kyrgyzstan discharges anywhere from 40 million cubic meters to 1 billion cubic meters of water per month (ICWC 2015). This wildly wide range in volume is largely a result of shifting temperatures and variations in ice melting. Water velocity has also varied greatly over time. The river ran at only 17.6 cubic meters per second during the month of February 1982, but reached a peak discharge rate of 380 cubic meters per second in July 1994 (ICWC 2015). Generally, the amount of water allowed to transit out of Kyrgyzstan fluctuates seasonally (Figure 5). Discharge is highest in summer months when warm temperatures cause more meltwater to flow downstream. Reservoirs

are overburdened by all the extra water and Kyrgyzstan must release at least some of it to

keep the dams stable, generating excess electricity in summer (Figure 6).

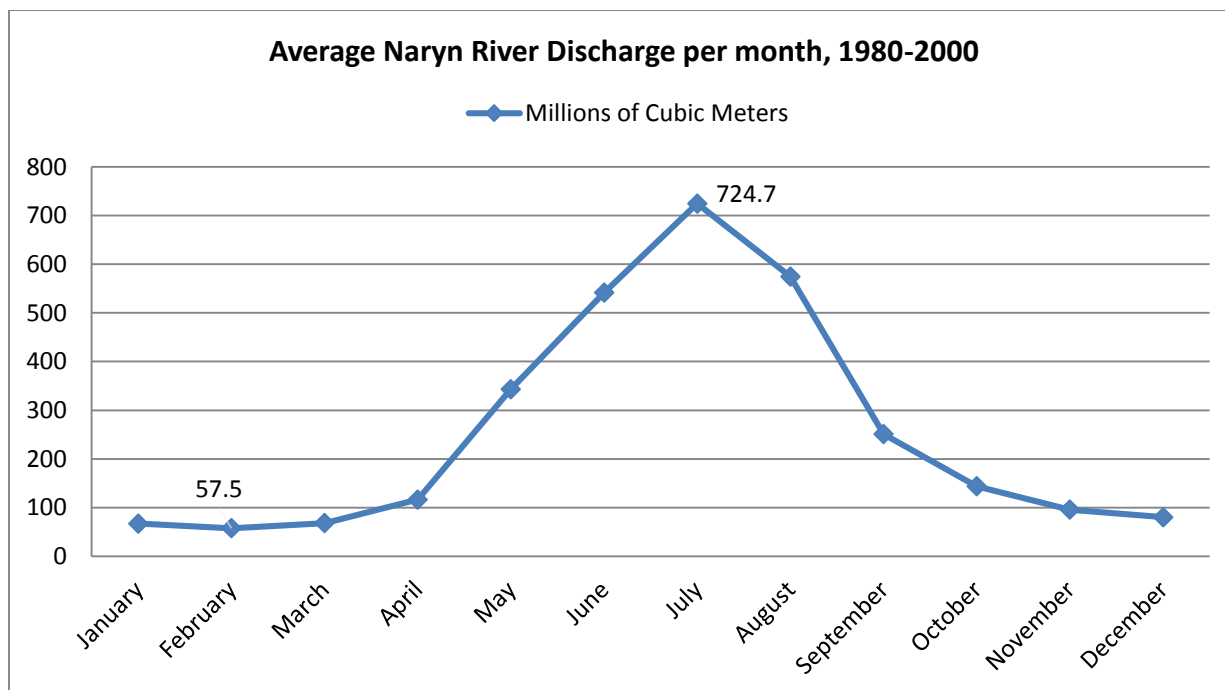**Figure 5: Average discharge per month, 1980-2000, Kyrgyzstan (ICWC 2015). Despite high demand for hydropower in winter months, dams are opened in summer to let vast amounts of water move downstream.**
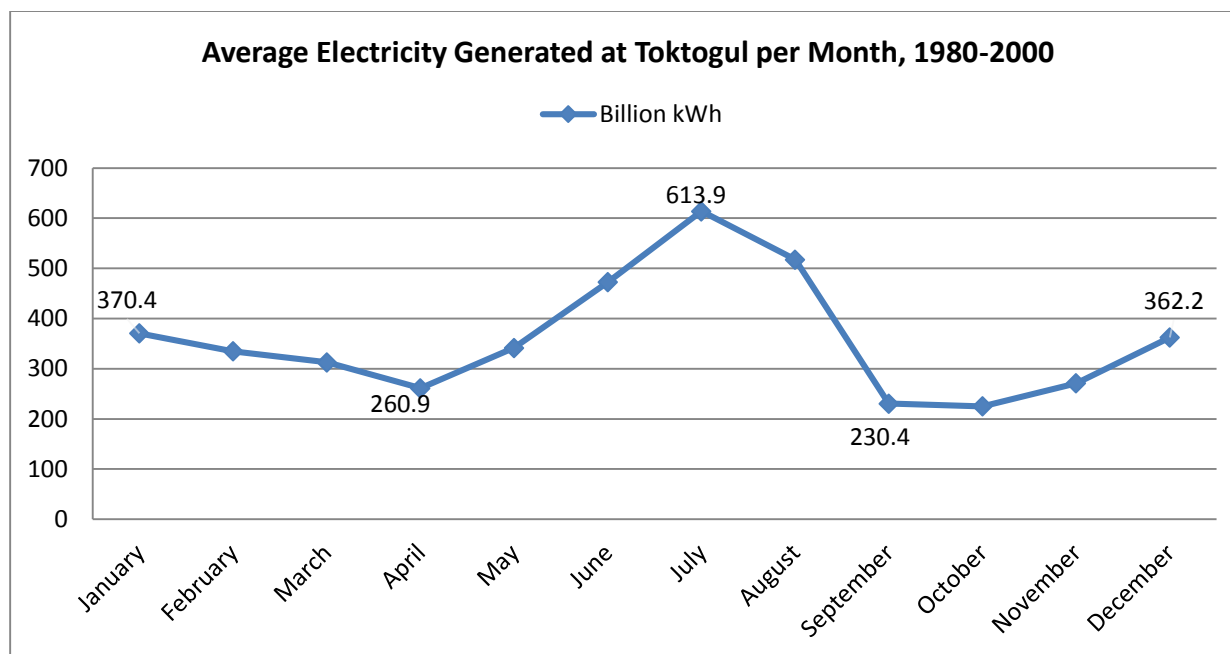

Figure 6: Average electricity generation from Toktogul hydropower station in Kyrgyzstan. Note the high production levels in summer and winter compared to low levels of production in more temperate times of the year (ICWC 2015).

Kyrgyzstan's hydropower usage does not reflect the patterns of discharge rates. Despite production being highest in the summer months, consumption peaks in the winter, when the Kyrgyz people are battling the frigid temperatures of the Siberian winter and need more electricity to heat their homes (Figure 7). Kyrgyzstan's largest existing hydroelectric dam, Toktogul, is used at maximum efficiency in the winter in an attempt to meet the demands placed on the grid by Kyrgyz citizens. In summer it creates excess electricity due to the high volume of water moving through the dam.
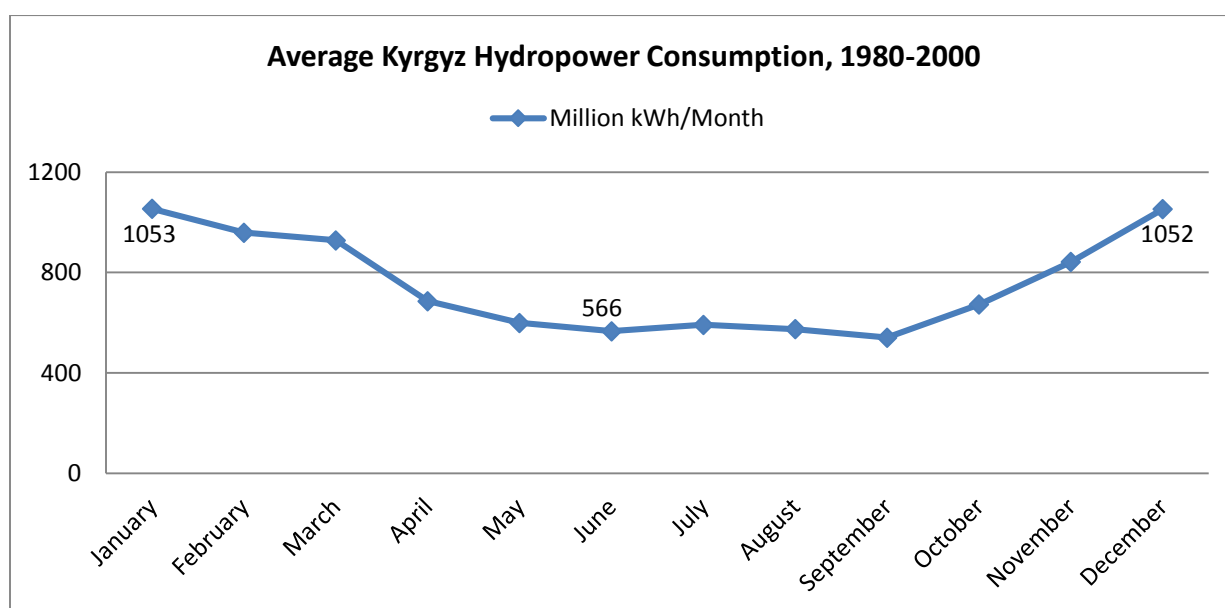
Figure 7: Kyrgyz hydropower consumption on average per month (ICWC 2015). Note that these figures are reported in million kWh, whereas production is reported in billion kWh. This implies that a large amount of electricity is lost in transmission, exported, or simply wasted.

In spite of the Kyrgyzstan's practice of releasing the most water during the summer growing season and the Syr Darya's consistent levels of discharge, Uzbekistan has seen declining agricultural output. Its overall annual harvests decreased by about 25% from 1980 to 2000 (Figure 8). Uzbekistan's cotton harvests declined by over 50% in the same period of time due to a variety of factors.

Uzbek Crop Production, thousands of tons per year, 1980-2000
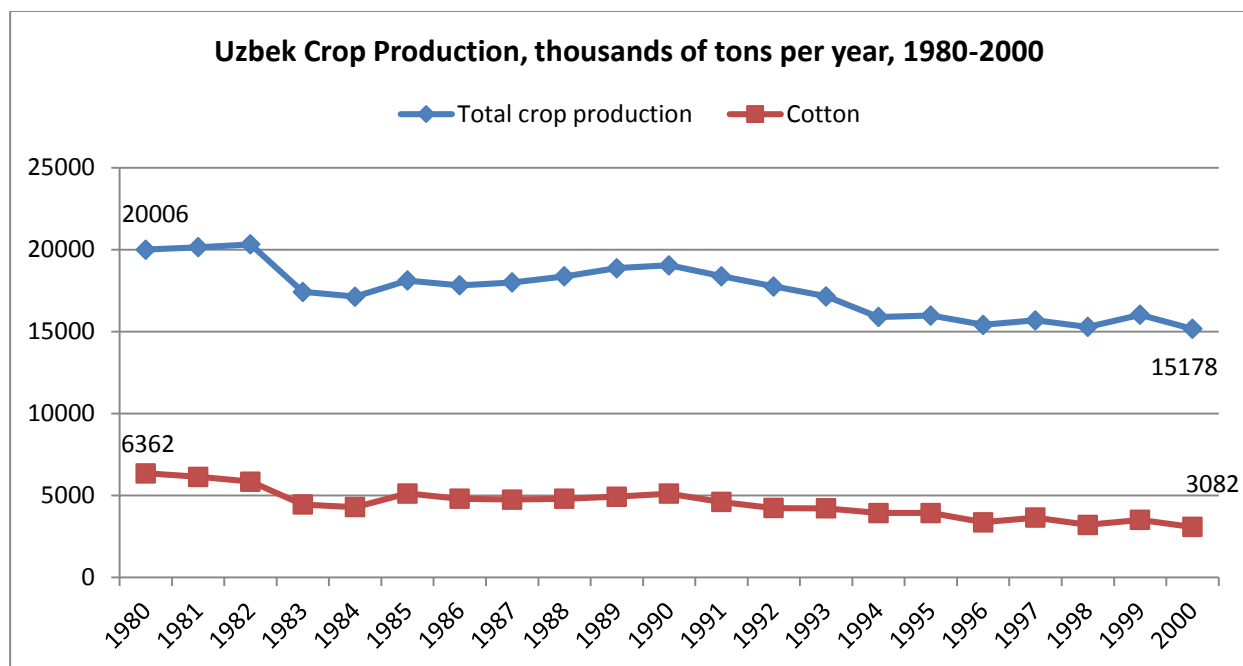
Figure 8: Despite relative consistency in Syr Darya water levels and Kyrgyzstan's policy of releasing the largest amounts of water during the summer growing seasons from 1980-2000, Uzbekistan has seen its agricultural production decline (ICWC 2015).

Sources other than the ICWC have tracked Uzbek cotton production and it has continued to decline in the past two decades. In the 1990's, Uzbekistan produced at least 15% of global cotton exports, but that figure has declined to just over 5% in 2015.
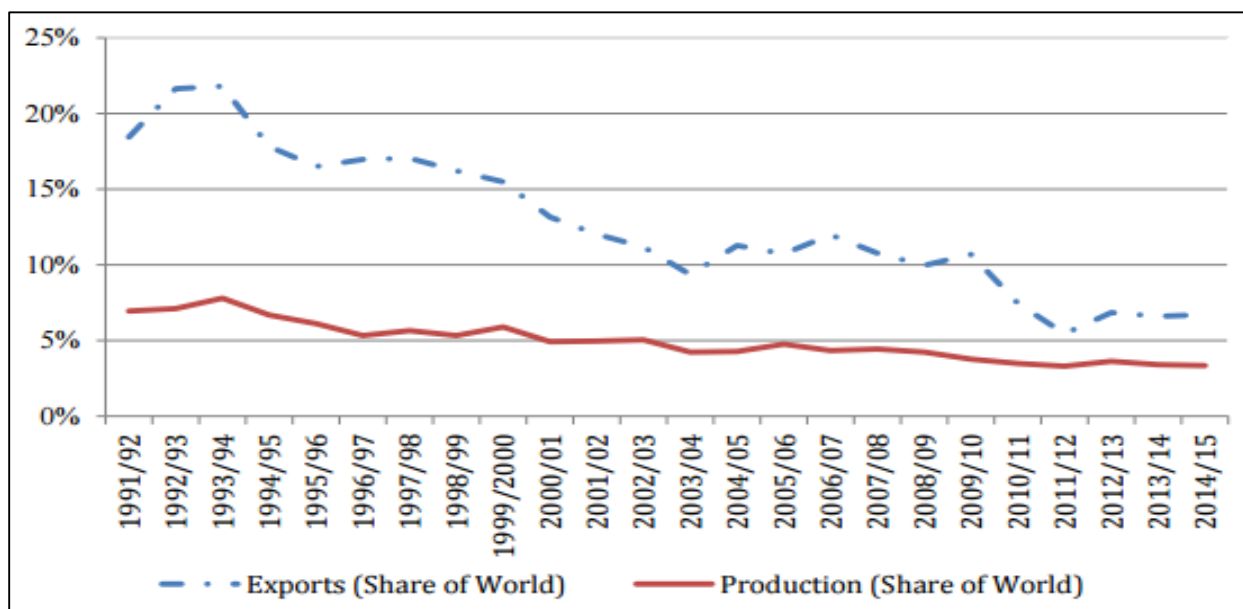
Figure 9: Uzbekistan's percentage of world cotton exports and total production, taken directly from Golub and Kestleman 2015 (Golub and Kestleman 2015).

Of course, Uzbekistan could blame the decreased agricultural output at least partially on water shortages, since the nation's water intake decreased substantially during 1980-2000. Cotton requires 700-1300 millimeters of water to reach full maturity over a growing season of approximately 150 to 180 days, which is the equivalent of about 27 to 51 inches of rain over the course of five to six months at 100% application efficiency (FAO Water 2015). Assuming Uzbek cotton required 40 inches of water per square foot in a given year, one can calculate how much water is required for cotton cultivation in Uzbekistan. There were 1,300,000 hectares of cotton fields harvested in 2015 (Golub and Kestleman 2015). Forty inches of water per square foot over 1,300,000 hectares amounts to 13.1 billion cubic meters (bcm) of water per year dedicated solely to cotton production.

While cotton is not the only Uzbek crop, it has remained the most profitable one in Uzbekistan. The Uzbek state has pursued a policy of food self-sufficiency and transitioned a small proportion of cotton producing farms to grow other crops, but the state has consistently maintained a policy of producing cotton for export (Wegerich 2002). Additionally, the Uzbek regime controls cotton markets by purchasing all of the country's cotton from farmers at a set price (the State Procurement Price, or SPP) before reselling it on the global market (Golub and Kestleman 2015). The SPP has always been well below world market price, even at a "curbed" rate to reflect black market currency exchange rates within Uzbekistan (Figure 10).
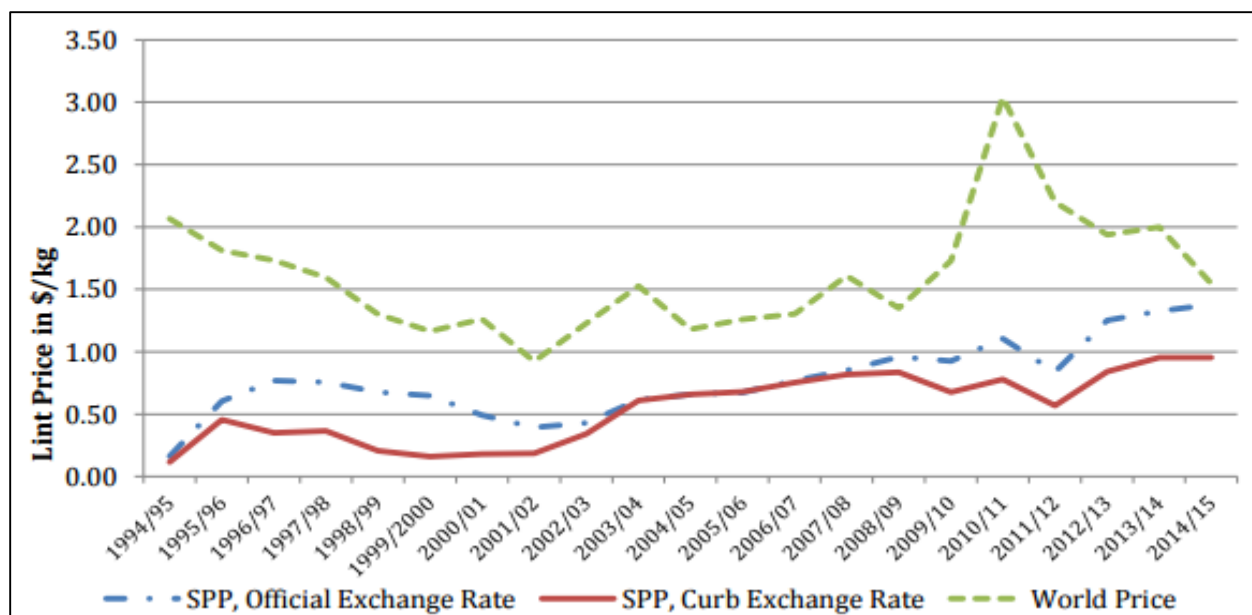
Figure 10: As shown in this chart from Golub and Kestleman, cotton prices in Uzbekistan have been lower than global prices from 1994 to 2015. However, SPP prices have gradually risen over time (Golub and Kestleman 2015).

Despite the gradual decline in production and price volatility, Uzbekistan's government has consistently reaped massive profits from the sale of cotton and products made from domestic cotton, adding a substantial sum to the regime's coffers. Only three times in the past 20 years have Uzbek cotton export profits sunk below $1 billion (Figure 11).
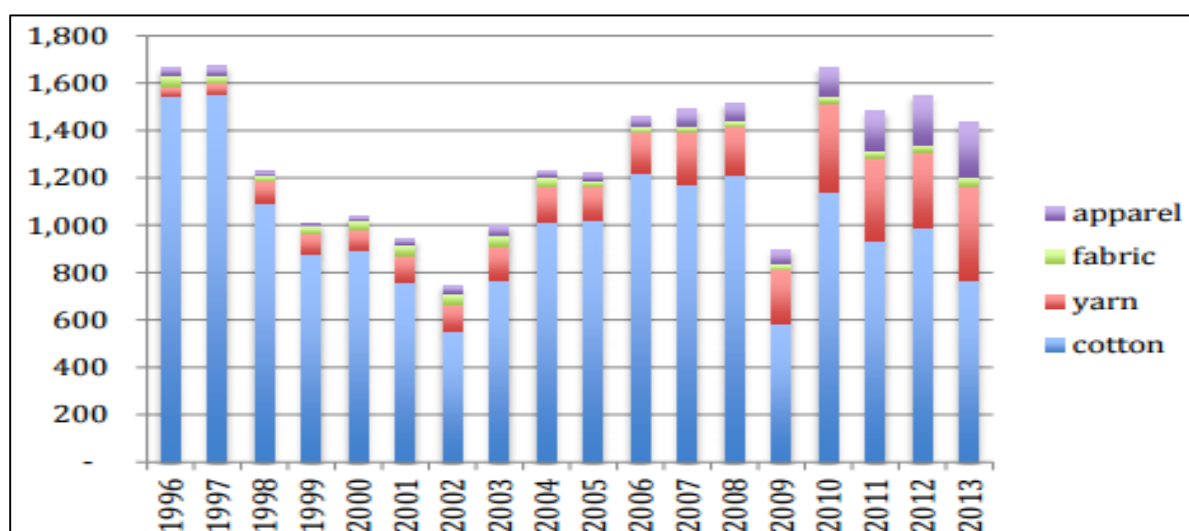
Figure 11: Golub and Kestleman's records of Uzbekistan's exports of cotton products in millions of US Dollars (Golub and Kestleman 2015).

Reaping enormous profits is not enough to keep the Uzbek regime from being concerned about its water security – it takes about 13 billion cubic meters of water to produce that kind of profit. Yet the Syr Darya cannot be the culprit behind Uzbekistan's recorded production losses, since its discharge rates have not diminished in accordance with the observed water losses and accompanying agricultural decline in Uzbekistan as shown in Figure 12.
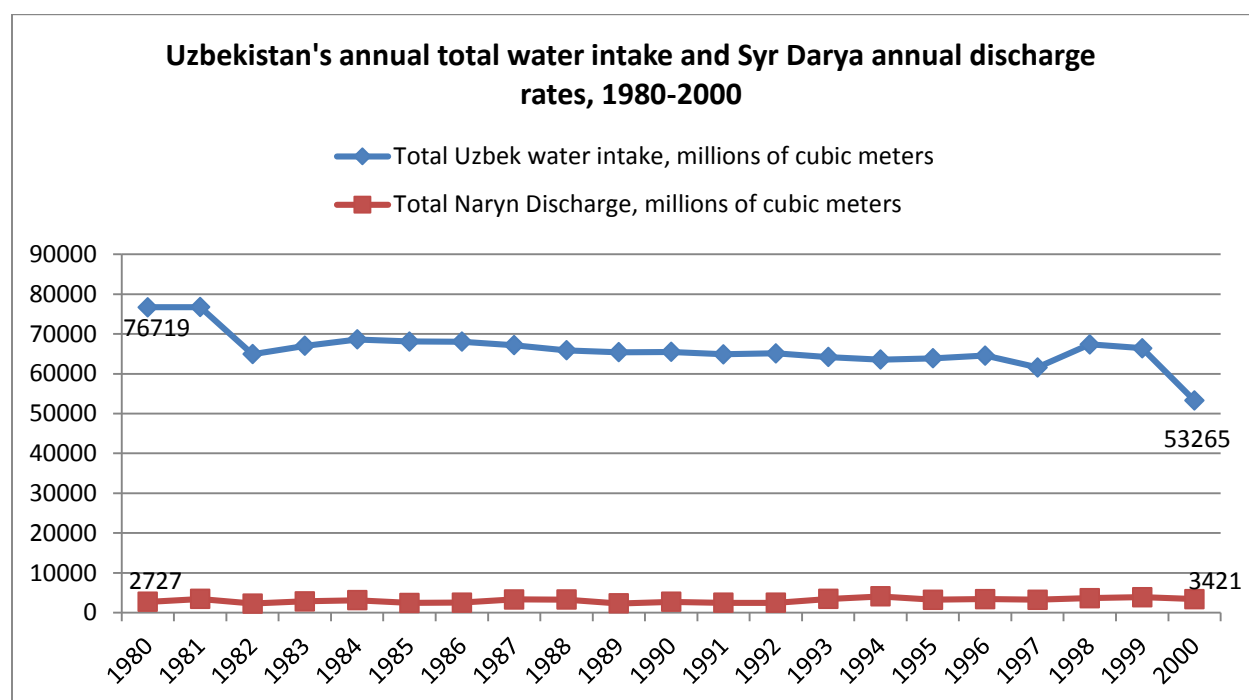
Figure 12: Uzbekistan's water intake from all sources declined from 1980 to 2000, but Syr Darya discharge rates from Kyrgyzstan remained relatively constant (ICWC 2015).

There is little doubt that the addition of K1 will impact Uzbekistan's water supply, but it won't be responsible for the majority of Uzbekistan's water problems. Most academic literature on the subject of Uzbek agriculture has focused on finding flaws in the state's water management practices. A number of scholars and organizations have noted that water shortages have negatively affected Uzbek cotton production (Wegerich 2007, Schluter et al 2010, International Cotton Advisory Committee 2011, Hirsch 2013, Bendini

2013). There is also a consensus that the authoritarian Uzbek government has maximized state control over the agricultural economy via its bureaucratic institutions, and this has directly hurt the economy (Melvin 2000, Wegerich 2007, MacDonald 2012, Bendini 2013, Laruelle and Peyrouse 2013).

International efforts to improve governing institutions in Uzbekistan at the national level via the MAWR and at the local level via Water Users' Associations (WUAs) have seen extremely limited success (Wegerich 2007, Schluter et al 2010, Global Water Partnership 2013, Bendini 2013, Hirsch 2013). While the overall economic picture might not look too bad due to consistent 8% annual GDP growth rates in recent years (Bendini 2013), there is a body of evidence that the agricultural sector is badly mismanaged, water supplies are profoundly lacking, and production has been dropping consistently (Jalalov n.d., UzNews.net 2011, Bendini 2013, Global Water Partnership 2013). There is a general consensus that the state has allowed the sector to fall into decline, and economic growth in agriculture has stagnated under state supervision. Geological, hydrological and climate factors have been minor contributors to Uzbekistan's woes in past decades. But they could soon move to the forefront if current climate trends persist and Kyrgyzstan decides to fill up the K1 reservoir with increasingly scarce water.

Uzbek political rhetoric seems to ignore the reality that the Syr Darya is likely not to blame for long-term decreases in water supplies and crop yields over the years. The hydrological and agricultural realities would appear to be all but lost in the minds of President Karimov and his political elite, whose descriptions of Kyrgyz water policy make it seem like Kyrgyzstan's water management is to blame for Uzbekistan's agricultural woes. But the Uzbek geopolitical strategy regarding K1 is not focused on recovering past losses.

Instead, it aims to prevent worse conditions from arising in the future. The geological

methods section will outline how the amount of water Uzbekistan could potentially lose

due to K1 was calculated.

Applying Game Theory in Geopolitics

Can a game theory model be used to analyze how Kyrgyzstan and Uzbekistan

interact while trying to use the Syr Darya River resources? An appropriate game theory

model could shed light on the Kyrgyz-Uzbek relationship regarding the water resources of

the Syr Darya and lead to a conclusion of what a rational Uzbek decision about war would

look like. Using game theory can allow observers of Kyrgyz-Uzbek interactions to see

through the charged rhetoric, determine the dominant strategies of both nations, and

therefore predict what policies they will choose. The challenge with using game theory is to

pick a game that best reflects the situation at hand.[6]

Game theories with two players deciding between two strategies are simple to

explain. Two common examples are the Prisoner's Dilemma and Stag Hunt, both of which

will be used to help frame the specific dynamics of the game being played in Central Asia.

There are two strategies in both Stag Hunt and Prisoner's Dilemma, called cooperation (c)

and defection (d). These strategies can be summarized and noted with the following

variables, if we let Kyrgyzstan be i and Uzbekistan be j.

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[6] I will make a disclaimer here that I have a bias towards quantitative models such as game theory, since I find that qualitative arguments in politics and international relations are rarely settled definitively. Game theory, when properly developed, allows one to quantify the utility which can be gained or lost for each player pursuing a given strategy, the probability that his strategy will be successful, and therefore the dominant strategies for each player. However, it certainly has notable weaknesses. I will point them out wherever they occur; some things simply cannot be quantified, and sometimes details essential for understanding the world do not fit within the conceptualization of a game. The most common failure of game theory is an inability to accurately reflect a political or economic reality. In many scenarios, a modeled game cannot anticipate all the inputs guiding the decisions being made by each actor. Additionally, the values of probability and utility are often too difficult to calculate accurately. I hope that the ensuing geological, political and economic research will provide enough information to adequately estimate values of utility and probability to use a game theory model.

Kyrgyz Strategies:

- $c_{Kyrgyzstan}$ or c_i = not building any dams on the Syr Darya and/or operating existing and new dams in such a way that Uzbekistan receives the water it wants.

- $d_{Kyrgyzstan}$ or d_i = building and operating dams on the Syr Darya without any regard for Uzbekistan's water supplies.

Uzbek Strategies:

- $c_{Uzbekistan}$ or c_j = allowing Kyrgyz dams to be built and maintained on the Syr Darya.

- $d_{Uzbekistan}$ or d_j = preventing the Kyrgyz from building new dams and/or taking control of, sabotaging, or destroying existing Kyrgyz dams on the Syr Darya.

In a game theory model, each combined set of strategies leads to a payoff. There are four possible payoffs in any two-player game:

- **T: Temptation** (you defect, opponent cooperates; {d, c}) would occur if Uzbekistan uses military force against Kyrgyzstan despite genuine Kyrgyz efforts to manage the dams in a manner conducive to meeting Uzbek water demands.

- **R: Reward** (you cooperate, opponent cooperates; {c, c}) would occur if both Uzbekistan and Kyrgyzstan mutually cooperate to plan the construction and operation of hydroelectric dams.

- **P: Punishment** (you defect, opponent defects; {d, d}) would occur if Uzbekistan uses military force in response to Kyrgyzstan unilaterally constructing and operating hydroelectric dams without any regard for Uzbek concerns about water supply in the Syr Darya.

- **S: Sucker** (you cooperate, opponent defects; {c, d}) would occur if Uzbekistan makes genuine attempts to cooperate with the Kyrgyz regime but is rebuffed by unilateral

decisions by Kyrgyzstan to construct and operate dams without any consideration of Uzbek needs.

Expected Utility or *E(u)* is the utility a player expects to receive in a game from a particular strategy, but this may be skewed by his perceptions (McCaughrin 2014). Expected utility is a function of two things: probability and utility. Probability, *p,* is the likelihood that a chosen strategy (*c* or *d)* is successful, and is measured on a scale {0,1}. Utility, *u,* is the estimated material gain or loss resulting from the use of the chosen strategy, and is measured on a scale {-2, 2}. Oftentimes the utility of a strategy cannot be precisely calculated, but the utility of one strategy or outcome relative to the other is often very clear. Let p_i, u_i and eu_i stand for the probability, utility and expected utility for Kyrgyzstan, and p_j, u_j and eu_j for the probability, utility and expected utility of Uzbekistan.

$$E(u) = (p)(u)$$

A rational state chooses the strategy with the highest expected utility. For example, Uzbekistan would pursue *d* if the probability of winning a war was high and the utility gained was also expected to be high. So if p_{dj} = *0.8* and u_{dj} = *1.6:*

$$E(u)_d \ = \ (0.8)(1.6)$$

$$E(u)_d \ = \ 1.28$$

In this scenario with a positive expected utility, the Uzbeks would have an obvious incentive to go to war.

The Stag Hunt and Prisoner's Dilemma are two-sided games that partially reflect the present situation in Central Asia. Let us imagine that Uzbekistan and the Kyrgyz Republic will be the two sides in the games. Other nations, such as Russia, Kazakhstan and Tajikistan, are interested in how Kyrgyzstan and Uzbekistan make use of the Syr Darya, but

Kyrgyzstan and Uzbekistan are the two nations who control and use most of the river and its resources. As the primary competitors for the river's resources, they are the only two players in the games considered in the Prisoner's Dilemma and Stag Hunt. Kazakhstan and Tajikistan have relatively less at stake in Syr Darya affairs. Russia is pursuing influence over the Central Asian nations, not the river: it uses the river competition as a means to its own ends.

If neither Stag Hunt nor Prisoner's Dilemma can explain Uzbek and Kyrgyz behavior, further research would be needed to find a suitable two-sided game, or to prove that game theory does not actually offer a viable method for analyzing international relations at the bilateral level. At the very least, we would know that the Stag Hunt and Prisoner's Dilemma game theories cannot be used as paradigms for viewing the Kyrgyz-Uzbek relationship regarding the Syr Darya.

When I began this project in 2014, my initial hypothesis was that the Stag Hunt was in motion because the Prisoner's Dilemma has a clear dominant strategy of defection for each player. If the Prisoner's Dilemma was active, it would have been easy to observe Uzbekistan taking actions to prevent new dam projects in Kyrgyzstan from going forward, particularly the Kambarata projects. Uzbek leaders had denounced the projects, but I was unaware of any real Uzbek actions designed to prevent dams from being constructed at the time. Therefore, I believed the Uzbek strategy was one of cooperation. In the Stag Hunt, both cooperation and defection are pure strategies, but neither is completely dominant. The strategy choice is based on the choice of the other player; both players gain more utility by pursuing the same strategy.

There are only two strategies in each game: cooperation and defection. Academic literature on both the Stag Hunt and Prisoner's Dilemma shows that the dominant strategy for any player in either game is to defect. However, in the Stag Hunt, mutual cooperation will result in greater utility gains for both players, thus also making cooperation a dominant strategy, provided that the Reward outcome occurs. If both players cooperate in Stag Hunt, they will both reap the maximum rewards which can be won in the game. However, in the Prisoner's Dilemma, mutual cooperation will result in mutual punishment and losses for both players (Skyrms 2001).[7]

The Stag Hunt

The Stag Hunt originated in Rousseau's *Discourse on Inequality:*

"Taught by experience that the love of well–being is the sole motive of human actions, [man] found himself in a position to distinguish the few cases, in which mutual interest might justify him in relying upon the assistance of his fellows; and also the still fewer cases in which a conflict of interests might give cause to suspect them. In the former case, he joined in the same herd with them, or at most in some kind of loose association, that laid no restraint on its members, and lasted no longer than the transitory occasion that formed it. In the latter case, every one sought his own private advantage, either by open force, if he thought himself strong enough, or by address and cunning, if he felt himself the weaker.

"In this manner, men may have insensibly acquired some gross ideas of mutual undertakings, and of the advantages of fulfilling them: that is, just so far as their present and apparent interest was concerned: for they were perfect strangers to foresight, and were so far from troubling themselves about the distant future, that they hardly thought of the morrow. If a deer was to be taken, every one saw that, in order to succeed, he must abide faithfully by his post: but if a hare happened to come within the reach of any one of them, it is not to be doubted that he pursued it without scruple, and, having seized his prey, cared very little, if by so doing he caused his companions to miss theirs." (Rousseau 1754).

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[7] I will use Brian Skyrms' article "The Stag Hunt" for all information on the basic concepts for both games since it describes both very well and in contemporary language. All charts and information on the rules and strategies of the games are based on this source from Skyrms unless otherwise cited, such as the passage from Rousseau. Hopefully this will reduce the overall clutter of citations and make the paper more readable.

And so the Stag Hunt was born. It was later refined into its present form, which I will describe here in my own language: Two hunters live on either side of a mountain, one on the east side and the other on the west side. To obtain food, they must travel either to the north or the south of the mountain in search of prey. To the north, there are plenty of hares. Each hunter is sophisticated enough that he will always catch one hare if he decides to go north, and one hare is enough meat for one day's worth of food. To the south, there is a population of stags. The stags are more difficult to kill, so neither hunter can kill a stag on his own. But if they both go south and hunt together, they will be able to kill a stag. A stag will provide each hunter with four days' worth of meat so long as it is divided equitably. From this game, the following payoff matrix can be constructed to reflect the gains in utility (represented as food supplies) for each hunter in any given scenario.

Stag Hunt (i, j)

		j	
		Cooperate	Defect
i	Cooperate	+4, +4	0, +1
	Defect	+1, 0	+1, +1

Figure 13: Stag Hunt Payoff Matrix. Each payoff represents the number of days of food supplies attained by each hunter under a particular set of choices.

If a player chooses to defect from the other, he will always receive a +1 utility. The hunter will always get his hare. He will definitely eat that day. But if a player cooperates, he risks either getting no positive gain because the other player defected, or he will make an

immense gain because the other player also cooperated. Thus, the payoffs of the game can be ranked like this where the player is *i* in the solution set *(i, j):*

Reward (4, 4) > Temptation (1, 0) > Punishment (1, 1) > Sucker (0, 1)

While the Temptation and Punishment outcomes both yield a gain of 1 for the player who chooses to defect, Temptation is generally considered to be the greater outcome since it is a net gain against the other player. Think of it this way: there are only so many hares in the forest. If you hunt one of them and the other player hunts none, the population of hares will remain larger and you will have more resources at your disposal in the future.

There are two Nash Equilibria in the game. A *Nash Equilibrium* is an outcome in which a player would hurt himself by changing strategies. The Reward outcome is a Nash Equilibrium because by choosing to not cooperate, a player would move from +4 to +1, resulting in a total loss of three, while his opponent would lose four. The Punishment outcome is also a Nash Equilibrium because a player who unilaterally changed strategies would lower his payoff from +1 to 0, while his opponent retained a payoff of +1.

There is also a Pareto Optimal outcome in the game, which is the Reward outcome. A *Pareto Optimal* outcome is one where a player would hurt the other player by changing his strategy. In a Reward outcome, if a player unilaterally changed his strategy from cooperation to defection, the other player's payoff would immediately decrease from +4 to 0. Thus the Reward outcome provides a Nash Equilibrium and is a Pareto Optimal outcome, making it the best strategy in terms of producing a total positive payoff. Reward can only be achieved by cooperation, so cooperation is therefore a preferable strategy for both players.

For players of the Stag Hunt who are rational and self-interested in absolute gains, cooperation makes sense. As long as they can communicate and understand one another's needs, it is perfectly logical for the two players to always go hunt for the stag and achieve maximum utility from their mutual cooperation. However, if either player finds that his interest is not in having an absolute gain, but rather in having a relative gain against the other player, his strategy changes to defection. If his goal is simply to gain more utility than the other player, he will always defect and hunt the hare, hoping that his opponent may one day go hunt the stag and then starve. He may even attempt to deceive the other player into thinking he will cooperate, when in fact he will always defect. Cooperation offers no chance of relative gain, only equal gain or relative loss. Defection guarantees the player at least a Punishment payoff (equal gains of +1), and the possibility of a relative gain via a Temptation payoff of +1 over the other player.

The Prisoner's Dilemma

The Prisoner's Dilemma works like this: the two players in the game are both criminals who committed a crime together. Assume they robbed a bank, and they killed a guard along the way. The police have enough evidence to convict the men of robbing the bank (a lesser charge which carries a penalty of two years[8] in jail) but not enough to convict either of murder (a heavier charge which carries a penalty of eighteen years in jail). The key is that theft carries a lesser charge than murder, and in a Punishment outcome the responsibility for the greater crime is shared by the two criminals, so each receives a payoff worse than conviction of theft but not as bad as conviction of murder. Wanting to convict

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[8] I am arbitrarily making up numbers for this explanation of the game, not basing the sentencings off of any particular legal system or other scenario.

someone for murder, the police put each man in solitary confinement and offer each a deal: testify against the other criminal in exchange for a reduced sentence and possibly freedom.

Each player has to make a choice. Cooperation is staying loyal to his accomplice and refusing to give testimony to the police. Defection would be to betray his accomplice and make a bargain with the police instead. The payoff matrix will look like this:

Prisoner's Dilemma (i, j)

		j	
		Cooperate (C)	Defect (D)
i	Cooperate (C)	-2, -2	-20, 0
	Defect (D)	0, -20	-5, -5

Figure 14: Prisoner's Dilemma Payoff Matrix. Values are years spent in jail for each criminal.

The numbers represent years of freedom lost due to being in jail. Assuming the criminals prefer to avoid going to jail, it makes sense for both to defect from each other and give testimony to the police. If both criminals defect, the police now have conflicting testimony from both criminals, each blaming the other for killing the guard. The prosecution can use this to convict each for at least partial responsibility for the guard's death. This is worse than robbery and not as bad as outright murder. The police hold up their end of the bargain and drop the theft charges, but each criminal is convicted of something like second-degree manslaughter[9] and carries a five-year sentence, for example. The Punishment outcome occurs, and each criminal receives a payoff of -5 in this scenario.

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[9] Any sentence less than that of murder but greater than theft works in this model.

If both criminals cooperate with each other and do not offer testimony against one another, the Reward outcome occurs. Each goes to jail for two years for robbing the bank, receiving a payoff of -2 each. Now imagine one player cooperates and the other defects. The cooperative player receives the Sucker payoff and gets the murder sentence (-18) and theft sentence (-2), totaling a payoff of -20 years. Meanwhile, the defector gets the Punishment outcome payoff of zero years in jail, and he goes free. Thus, the payoffs can be ranked like this where the player is *i* in the solution set *(i, j):*

Temptation (0, -20) > Reward (-2, -2) > Punishment (-5, -5) > Sucker (-20, 0)

Therefore the dominant strategy is always to defect. Defection is the only strategy which offers the best possible outcome (not going to jail). Furthermore, choosing cooperation risks giving the other player an opportunity to go free and while you rot in jail for twenty years. For cooperation to be logical, both players would need some kind of insurance against the other; for example, a friend who would kill the criminal who betrayed the other.

The Punishment outcome, in which both defect, is a Nash Equilibrium. By changing from cooperation to defection, a player would get himself convicted of murder and watch the other go free. Meanwhile, the Reward outcome in which both cooperate is Pareto Optimal: the player who changes to defection ensures that the other player gets an extra eighteen years in jail.

Geological Methodology

The challenge of using game theory is to estimate values for utility and probability. Given that the situation at hand evaluates the usefulness of water for both Kyrgyzstan and Uzbekistan, a quantitative evaluation of the size of the K1 reservoir is necessary to

determine the value of water that would be contained therein. This paper specifically questions the value and usefulness of water that would end up in the reservoir created by K1 because the water held in that reservoir represents lost utility for Uzbekistan. The water would mostly be used to add power to the electrical grid in Kyrgyzstan if the dam is built, and this same water would be withheld from Uzbekistan for some amount of time. What economic losses would Uzbekistan potentially suffer if K1 is built? To answer this, the maximum capacity of the reservoir was calculated.

The volume of any container, including K1's reservoir, is a product of length, width, and height (in this case, height is interchangeable with reservoir depth). I used ArcGIS 10.3 and other visualization software to virtually build both 2D and 3D models of K1 and its reservoir within existing satellite imagery. I first inserted K1 into low-resolution imagery of the entire topography of Kyrgyzstan to estimate the location and size of the reservoir. After determining its approximate size and location within the country, I selected a smaller area of Kyrgyzstan to work within. In a smaller area, a computer can use higher-resolution imagery to capture a better 3D representation of the K1 dam and reservoir. The process has several broad steps.

I first downloaded relevant low-resolution maps (30 second data, which has 1 square kilometer per pixel) for the Syr Darya region. A low resolution map of Kyrgyzstan, plus some parts of Tajikistan and Uzbekistan, was the starting point to determine the area of the K1 reservoir's watershed. A watershed is the entire surface area from which water drains to a particular point. The watershed is the source area for any and all water entering

K1's reservoir. The K1 watershed was built in a common Geographic Information System (GIS) program called ArcMap.[10]

ArcMap only displays two-dimensional images despite its ability to interpret and compute layers of 3D data. ArcMap's sister program for 3D visualization, ArcScene, cannot project large maps. It simply is not powerful enough to display a 3D image of the entire topography of Kyrgyzstan. The country scale map data needed to be exported into a more powerful 3D visualization program. I was able to use an appropriate software program called Cinema4D (C4D) at Washington & Lee University's Integrative & Quantitative Center, or IQ Center, to create an estimated visualization of the reservoir. To get the map data from ArcMap to C4D, some map layers needed to be reconfigured in Adobe Photoshop or Adobe Illustrator first so that they would be compatible with C4D.

In C4D, a 3D map of the landscape can be viewed from any angle. The K1 dam was created by drawing a virtual line at the correct location. All points downstream from the line were removed from the map. The line was extruded to create a virtual wall 275 meters high to represent the dam. The reservoir was isolated from the rest of the map by instructing C4D to eliminate any points higher than the top of the K1 dam wall. The resulting shape was a rough estimation of the reservoir. Its volume could be approximated but not accurately measured. The reservoir also had visible discontinuities (gaps between sections of the reservoir) due to the low resolution of the initial elevation maps, casting doubt on its actual shape and size.

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[10] ArcMap is one of several software programs that entail ArcGIS, a suite of platforms that serve different purposes for the creation of maps. ArcCatalog, for example, is a tool used to categorize and store map files and associated data that cannot be stored in the typical kinds of folders provided by Windows or iOS. ArcCatalog also allows a cartographer to manipulate map files without needing to open or display them.

This initial reservoir shown in C4D was derived from low-resolution data covering three countries of Central Asia. By comparing it with the topographic map on display in ArcMap, a smaller area where the reservoir is located could be identified. I had used low-resolution country-scale maps so that ArcMap and C4Dcould make the initial computations to find the rough location and size of the reservoir. With a specific area of interest identified, I used high-resolution imagery of that area to create a more realistic reservoir that could provide better data for calculating its volume. I used a 1 arc-second topographic map (30m x 30m sized pixels) of the area surrounding the dam and estimated reservoir, and made it as small and localized as possible. Switching from 1km resolution to 1 arc-second resolution maps increased the accuracy and precision of the reservoir map. On the high resolution map, I isolated the points upstream of the dam at elevations between the bottom and top of the dam wall. These points would be entirely submerged if K1's reservoir was filled to capacity and form the reservoir's basin.

The volume of the reservoir was calculated by multiplying the area of each 1 arc-second (30m x 30m) point with the slope[11] and the depth of the water at each point. The slope values for each point were calculated in ArcMap. These values were transferred to Excel along with the area and depth values. There I determined what percentage of each point actually would appear in an overhead view. The area of each cell was multiplied by its fraction of area visible from overhead, resulting in area values for each cell, all less than 900 square meters. This number was multiplied by the depth of water, which was the

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[11] If each point was flat, its area would be simply 900 square meters, the product of a square measuring 30 meters on each side. ArcMap displayed the map with each pixel as a perfect square. But in reality, because most of the points are angled at a slope to some degree, they are not actually perfect squares when viewed from above by a satellite. Instead, they would appear as quadrilaterals with areas smaller than 900 square meters. ArcMap distorts the image and displays them as flat squares.

result of subtracting the elevation of each point from the maximum height of water in the reservoir (1253m). The whole equation for measuring the volume of a point in the reservoir is as follows:

$$Volume\ per\ cell = (Length)(Width)(Fraction\ of\ Visible\ Area)(Height)$$
$$V = (30)(30)(value\ from\ 0\ to\ 1)(1253 - elevation)$$

The total volume of the reservoir was calculated by finding the sum of all the volumes of each individual point shown to be within the reservoir on the 1 arc-second resolution map.

Geology Results

The volume of the K1 reservoir was calculated as 7,334,037.77 acre-feet, or 9.046 cubic kilometers. To put the number in similar terms of Syr Darya River flow and Uzbek cotton irrigation requirements, K1 could potentially hold 9 billion cubic meters (bcm) of water. Given that from 1980 to 2000 the Syr Darya averaged 3 bcm of discharge per year (ICWC 2015), it would probably take at least 3 years for the reservoir to be filled to its maximum theoretical capacity. In reality, it would take even longer, since some of the water would be released to generate electricity and flow downstream. Recalling that Uzbekistan's water intake declined from 76 billion cubic meters of water to 53 billion cubic meters from 1980 to 2000, the potential loss of another 9 bcm over a number of years is a very scary possibility, especially since the profitable cotton industry uses approximately 13 bcm per year. However, it is unlikely that Kyrgyzstan would store 9 bcm. K1 would probably hold about 5 bcm in its reservoir at any given time – still a tremendous volume by any standard (E. P. Kraake 2012). Once K1 is completed, Syr Darya records suggest it would still take nearly two years for the reservoir to fill up to that level if all its water was trapped in the

reservoir without any passing through the dam's floodgates. Realistically, it would take much longer, but the exact timeline is impossible to predict since it depends totally on how the Kyrgyz decide to manage the river system.

In addition to calculating the reservoir volume, I also investigated how water is used and wasted in Uzbekistan. Reliable statistics on Uzbek water usage efficiency are hard to find, but the few available sources of information indicate that roughly half of the country's water is lost annually. The lack of water is obviously harming the output levels of the agricultural sector, but its implications for employment are unclear.

Reports on water usage from internal Uzbek sources are particularly hard to find and verify. An undated briefing[12] from the MAWR submitted to the Global Water Partnership (GWP) puts the national irrigation efficiency level at 0.63-0.64, with some areas seeing levels as low as 0.50-0.52 (Jalalov n.d.). An article on UzNews.net quoted an anonymous Uzbek expert in 2011 who said that half of Uzbekistan's water was going to waste, and that the main cause was widespread failures in the national irrigation system (UzNews.net 2011). UzNews was considered a reliable source for news from Uzbekistan until it was unfortunately shut down forcibly by the Uzbek government in late 2014.[13]

Assessments from non-Uzbek organizations may come from more credible sources than unnamed officials and undated government documents, but they may also have limited access to information within Uzbekistan. The International Crisis Group estimates that 50-80 percent of water allocated for agricultural use is lost in Uzbekistan, and only 25-

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[12] The briefing does mention statistics as recent as 2010, but does not specify its date of submission or when it was first posted publicly by GWP.

[13] I found the UzNews article in 2014 while conducting research in Azerbaijan for a paper about how Kyrgyzstan and Uzbekistan compete for water in the Syr Darya river basin. I cited it for "Playing the Dam Game: Analyzing Uzbek-Kyrgyz Competition over Water Resources with Game Theory" which was presented at the Central Eurasia Studies Society Annual Conference in October 2015. No UzNews.net materials are currently available.

35 percent of the water that reaches crops is used efficiently. A policy paper from GWP

estimated that national water losses are at 40% because pipelines are not used to full

capacity (Global Water Partnership 2013).

<u>Political Methodology</u>

Political game theory can be used in certain situations to model the decision making

of nation states. The use of expected utility theory to explain how nations decide to engage

in warfare has been studied in political science for decades (Bueno de Mesquita 1983,

Fearon 1995, 1998)*.* It assumes that the decision to engage in war belongs to a strong

national leader who makes his decision based on rational objectives, believing that war is

only worthwhile if a victory would deliver a certain amount of measurable utility and there

is an acceptable risk of defeat (Mesquita 1981). It also assumes that warfare is only viable

for a rational leader when bargaining or negotiation cannot deliver any desired outcome

(Fearon 1995) and that any negotiated resolution would not be enforceable (Fearon 1998).

While games based on expected utility have their flaws, realists often argue that expected

utility models can explain the occurrence of the majority of the interstate wars that have

occurred in history.

A critical part of developing any game theory model is investigating the perception

of each player. While Uzbek perceptions can be easily researched by procuring news

reports filtering out of the country, Kyrgyzstan is harder to judge. Media reports from any

country in Central Asia can usually be challenged given the nature of press freedoms across

the region. Courtesy of a small grant from the Washington & Lee Center for International

Education and the hospitality of my friend Bermet Zhumakadyr kyzy, I was able to travel to

Kyrgyzstan in August 2014 for a week and survey a small number of people at the

American University of Central Asia (AUCA) in Bishkek[14]. I hoped to obtain some data on

the perceptions of water resource needs and the political climate in the region.

I created a survey consisting of both multiple-choice and open ended questions to be

administered to participants in Bishkek. A list of questions can be found in the Appendix.

The survey was administered in English with the Survey Monkey online platform over the

course of three days I spent at AUCA. Participants all possessed advanced English skills, and

I stayed on site to help participants if they ran into difficulties due to translation.

Participants were compensated with the local equivalent of about $10, comparable to

undergraduate participants in human studies at American colleges and universities.

Participants could skip any question they were uncomfortable answering or quit the survey

at any time. All participants reported being within the age group of 18-24, and all but one

were residents of Kyrgyzstan at the time.

Political Results

The survey results were particularly interesting. When asked if they thought there

were problems with water in Central Asia, all respondents answered affirmatively. The

most commonly reported type of challenge was not having enough water for farming and

agriculture, with 60% of respondents calling this a problem in Central Asia. 90% of

respondents said that the "single biggest water problem in Central Asia" was poor

management and misuse. 83.3% believed that building K1 would be good for Kyrgyzstan,

while a remarkable 100% of respondents believed that Uzbekistan would not go to war

with Kyrgyzstan over water. However, only 6 participants answered this question out of 20

total participants. It is likely that participants were hesitant to speculate on the likelihood

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[14] It should be noted that Bishkek does not lie within the K1 watershed area.

of war for any variety of reasons. When asked which country would win a war in a strictly two-sided conflict, two-thirds of participants said that Uzbekistan would be the victor. 83.3% responded affirmatively when asked if they thought Russia would intervene on Kyrgyzstan's behalf in such a conflict. Only one respondent speculated that other countries besides Russia could join, suggesting that Kazakhstan may join Uzbekistan and Tajikistan may join Kyrgyzstan. However, the participant noted that such a scenario seemed very unlikely.

All else being equal, the probability of Uzbekistan being militarily successful in a war against Kyrgyzstan is high. The perceptions of Uzbekistan's strength relative to Kyrgyzstan I was able to gather and analyze appear to correspond to the openly available information about each nation's military. According to GlobalSecurity.org, an open-source military data website, the Uzbek military had about 55,000 personnel in 2006 split among one tank brigade, ten rifle brigades, a light mountain infantry brigade, an airborne brigade, an air assault brigade, four artillery brigades and the air force. The Uzbek military then possessed over 300 armored personnel carriers, 283 artillery pieces, 405 armored infantry fighting vehicles, 340 tanks, 13 armored recon vehicles, and 108 multiple rocket launchers. Then in 2015 Uzbekistan acquired 308 Mine-Resistant Ambush Protected Vehicles (MRAPs) from the United States, along with 20 Armored Recovery Vehicles (GlobalSecurity.org 2016). Uzbekistan's air force consists of 164 aircraft (FlightGlobal Insight 2014). In contrast, Kyrgyzstan's army had 8,500 ill-equipped troops in 2012, and the military there has a long history of disorganization and a lack of cohesion (GlobalSecurity.org 2016). The Kyrgyz air force is extraordinarily small, possessing only 12 helicopters and 3 other aircraft. In a fight, the Kyrgyz would depend on Russia's air force, which maintains a small base in Kyrgyzstan.

But there is more than just military strength for Uzbekistan to consider. A major factor in Uzbek decision making is the stability and consistency of the regime in Tashkent.

The Uzbek regime is in a position where there are many potential sources of discontent that could lead to political instability. The country is facing an economic decline due in part to Russia's current economic crisis, a drop in global commodity prices, and a weakened currency. Uzbekistan is also expected to destabilize politically in the near future due to an impending succession crisis. Domestic politics are dominated by competition among seven rival clans. Uzbekistan's aging president, Islam Karimov, is 77 and has not named a successor. No other figure appears able to consolidate control of the country's competing clans (Stratfor 2015).

A chaotic political transition in Uzbekistan, especially one marked by inter-clan violence or mass protests, would reverberate around the region and affect global cotton markets. High youth unemployment has been linked to political instability in developing countries (Azeng and Yogo 2013). Most unemployed Uzbeks are young and live in rural areas. Uzbekistan has largely kept its population employed, but by using forced labor in the agricultural sector (Human Rights Watch 2015). Karimov's regime is apparently keeping people forcibly employed to keep them busy, thereby reducing the risk of a popular uprising or other forms of domestic dissent.

Russian considerations also play an important role. Although Russia and the rest of the CSTO do not react urgently to small border skirmishes between Kyrgyzstan and Uzbekistan, the alliance would almost certainly take a great interest in Kyrgyz security if Uzbekistan launched a full-blown invasion aimed at taking over control of K1 and other hydroelectric facilities. Russia has more than just political and military capital at stake in

Kyrgyzstan. Russian firms are still the financiers and developers of Kyrgyzstan's Kambarata projects, which collectively are worth nearly $3 billion, with $2 billion being devoted to K1. Although Kyrgyz President Almazbek Atambayev recently said Kyrgyzstan would find alternative ways of building the dams if Russia withdraws from the projects, its chances of finding another partner are low (Hashimova 2016). Russia maintains a small but active air base in Kyrgyzstan and could probably deploy its military into Kyrgyzstan and Uzbekistan with relative ease, as could other CSTO partners like Kazakhstan. While Uzbekistan's military is formidable, Russia's is much bigger and technologically superior. Uzbekistan would be foolish to risk being militarily engaged by a nuclear power.

Geopolitical Discussion: Playing the Dam Game

This paper argues that existing games are insufficient for explaining the behavior of Uzbekistan and Kyrgyzstan in this situation. However, the Prisoner's Dilemma and Stag Hunt must be ruled out before arguing for a new game that is better representative of the Uzbek-Kyrgyz interactions regarding dam infrastructure.

Game theory generally assumes that actors are rational and self-interested. The regimes of Uzbekistan and Kyrgyzstan are certainly self-interested. Their rationality is debatable, since both have serious issues with corruption, state weakness, and resource allocation, but they are both unequivocally rational enough to care about whom controls access to the Syr Darya's water. Neither regime can survive, much less thrive, without being able to harness the river's resources. Having summarized the importance of water to both nations, we can begin analyzing how each fits into the Prisoner's Dilemma and Stag Hunt.

Recall the definitions of strategies laid out earlier where i represents Kyrgyzstan and j represents Uzbekistan:

<u>Kyrgyz Strategies:</u>

- $c_{Kyrgyzstan}$ or c_i = not building any dams on the Syr Darya and/or operating existing and new dams in such a way that Uzbekistan receives the water it wants.

- $d_{Kyrgyzstan}$ or d_i = building and operating dams on the Syr Darya solely for its own interests and without any regard for Uzbekistan's water supplies.

<u>Uzbek Strategies:</u>

- $c_{Uzbekistan}$ or c_j = allowing Kyrgyz dams to be built and maintained on the Syr Darya.

- $d_{Uzbekistan}$ or d_j = preventing the Kyrgyz from building new dams and/or taking control of, sabotaging, or destroying existing Kyrgyz dams on the Syr Darya.

If the Prisoner's Dilemma were being played out right now, we would see both players defecting. Kyrgyzstan would be building the dams independently, and Uzbekistan would be doing everything in its power to stop dams from being built. The rhetoric of both sides appears to indicate that these are the intentions of both states. However, the reality is more complicated. Kyrgyzstan's dam development is crawling along at an incredibly slow pace, largely because of internal inefficiencies and Russian stalling due to lingering doubts about the feasibility of the ambitious projects; financing and construction activities at the Kambarata projects slowly ground to a halt in 2015 (Hashimova 2016). Currently, only part of the K2 dam is functional. The partial operation of K2 may be considered a strategy of defection, but it is a mild defection at best. Essentially, Kyrgyz plans are going nowhere at the moment and dam construction is suspended.

Meanwhile, Uzbekistan has essentially done nothing. The Uzbek government has not done anything to effectively prevent construction at K1 or K2, much less disrupt any other dam sites. It has simply continued its pattern of denouncing the Kyrgyz plans and making

wild territorial claims. In this sense, Uzbekistan is not actively pursuing a strategy of defection either. Uzbekistan could use force to disrupt the construction process further or destroy dam infrastructure that has been partially built. If it did, that would certainly be defection. But there is the inherent risk of provoking a military response from Kyrgyzstan and its CSTO alliance. Whether or not the CSTO responds with force to an Uzbek strategy of defection will certainly impact the payoff Uzbekistan receives from its strategy. Neither Stag Hunt nor Prisoner's Dilemma provide any insight for how the CSTO would react. As outlined in this analysis, these games only offer a paradigm for examining the two states without reference to their international agreements, commitments and treaties. This is a serious weakness in the usefulness of these game theories as paradigms for modeling the behavior of Uzbekistan and Kyrgyzstan.

Active cooperation is scant at best. The reality is that both nations could probably devote greater efforts to other means of securing their interests. There have not been any definitive studies, but it would seem logical that stamping out electricity theft in Kyrgyzstan would not require the government in Bishkek to pursue a $2 billion financial aid package. If half of Kyrgyz electricity is being wasted, it could double its electrical capacity relatively cheaply by doing a better job of maintaining its electrical grid. Uzbekistan could reinvest some of its cotton export revenues into fixing up its highly inefficient and outdated irrigation system, and probably save huge amounts of water, which would theoretically offset some of the effects of upstream dam projects. In any case, neither country is pursuing large-scale domestic reforms to fix these problems. Certainly they are not consulting with one another on how to fix these issues.

Ultimately, Uzbekistan is currently cooperating. It has not done anything to definitively disrupt the dam projects, directly manipulate Kyrgyz water controls or destroy Kyrgyz infrastructure. Kyrgyzstan is currently cooperating, but this may be due to its dependence on Russian support to actually construct the hydroelectric dams, and Russia has not actively continued construction in recent months (Kudryavtseva 2016). So if Uzbekistan is cooperating, and Kyrgyzstan is cooperating, the Prisoner's Dilemma cannot possibly be in motion right now. Mutual cooperation indicates that conditions similar to the Stag Hunt game may be in effect, since seeking the Reward payoff is a dominant strategy in that game.

However, since Kyrgyzstan is not cooperating out of its own rational interests so much as it is forced to currently cooperate due to reliance on another nation, this is truly not a Stag Hunt. Instead of the Kyrgyz hunter agreeing to hunt for a stag with the Uzbek hunter out of his own free will, it is more like the Kyrgyz hunter's family forces him to do so. But once he and the Uzbek hunter enter the stag hunting area, they disagree on hunting methods, and fail to gain the rewards of killing a stag together. The Prisoner's Dilemma completely fails to explain the current behavior of both nations, but the Stag Hunt only partially explains the story. Perhaps a different paradigm could explain it better.

A New Game Proposal: Mafioso's Dilemma

For the purposes of this research project, it will be useful to envision a variation on the Prisoner's Dilemma and the Stag Hunt and call it the Mafioso's Dilemma. This model could be useful for examining the situation as it currently stands, since neither the Stag Hunt nor the Prisoner's Dilemma present solid explanations of the relations between Kyrgyzstan and Uzbekistan. Right now, Kyrgyzstan is a member of the Russian-led

Collective Security Treaty Organization, and Uzbekistan has been a member in the past. Russia is the regional hegemon, and the entire Kyrgyz-Uzbek dynamic can be affected by Moscow. In short, for our purposes it would be useful to imagine Russia as a regional "don."

Imagine that the players are "mafiosos," lower-level members of a Mafia, which is a powerful criminal organization that values loyalty among its members. They find themselves in the situation described in the Prisoner's Dilemma, having robbed a bank and killed a guard, and have been arrested. If one of the members chooses defection and betrays the other, the rest of the Mafia will see this as a betrayal of their code of conduct and kill the traitor. In this case, the dominant strategy becomes cooperation: both men go to jail for the minimum sentence, serve their time and come out to be rewarded by their Mafia brethren two years later. In this case, the payoff matrix looks different. I will use $-\infty$ to signify the death payoff for the traitor.

Mafioso's Dilemma (i, j)

		j	
		Cooperate (C)	Defect (D)
i	Cooperate (C)	-2, -2	-20, $-\infty$
	Defect (D)	$-\infty$, -20	-5, -5

Figure 15: Mafioso's Dilemma payoff matrix.

In this case, the payoff rankings change for the player *i*:

Reward (-2, -2) > Punishment (-5, -5) > Sucker (-20, -∞) > Temptation (-∞, -20)

The payoff ranking is what makes this game different from the other two. This variation is actually similar to the Stag Hunt since the Reward payoff is the best possible outcome for each player. In the Mafioso's Dilemma, cooperation is the dominant strategy since it offers a safeguard against assassination and the could result in shortest possible time spent in prison for each mafioso. Assuming that the criminals find living in jail preferable to dying, each should cooperate.

Defection results in either a payoff of -5 or death. The -5 payoff is given to each by the police if both defect, as in the Prisoner's Dilemma described earlier: the police drop the charges of robbery in exchange for each prisoner accusing the other of murder. But since both accuse one another of the murder, and the evidence from each contradicts the other, both are charged with a second-degree crime and receive the five years of incarceration. At this point, the Mafia knows both men betrayed each other and their code of conduct, and both are in jail, so there is no point in killing either man; the mafiosos betrayed each other, not the mafia as a whole, so the don has little if anything to gain from killing both of them five years later. They simply go to jail and are not allowed back into the Mafia ranks after they get out. Reward is also a Nash Equilibrium: a player who changes his strategy from cooperation to defection will die. It does not appear that either can trust the other to defect as much as they can expect the other to cooperate due to fear of drawing the Mafia's ire.

In the Mafioso's Dilemma, the game is dictated by two rulemakers: the police and the Mafia. In the Prisoner's Dilemma, only the police make the rules of the game. In the Stag Hunt, the rulemaker is Nature itself. Kyrgyzstan and Uzbekistan are not lonesome hunters, and they are not a solitary pair of crooked states awaiting trial at The Hague. They are nation-states with self-interested regimes who act as freely as they can within the political

constraints of the world around them. The most relevant political force comes from Russia, which enjoys asserting its power in the former Soviet nations.

If one nation cooperates and the other defects, the outcome could be similar to what was described above. The cooperating nation would certainly be harmed by the other nation's defection (hence the -20 payoff for the cooperator), but Russia would have the ability to punish the defector. In the case of Uzbekistan defecting and destroying Kyrgyzstan's ability to construct or operate its dams, Kyrgyzstan would lose the benefits of millios of dollars spent over many years on expensive projects. Russia would also be hurt, since it is funding the projects, so it seems logical that Russia would seek retribution. It could easily use the CSTO framework as a legal means for striking back at Uzbekistan in an attempt to destroy Karimov's regime. In the opposite scenario, if Kyrgyzstan defected and built the dams despite Uzbekistan's cooperation, Uzbekistan would lose access to badly needed water. Raw cotton and cotton yarn together make up 21.6% of Uzbek exports; the top destination for Uzbek exports of agricultural goods is Russia (Observatory of Economic Complexity). If the relatively productive Uzbek economy was destroyed by a water shortage, Russia would also feel the effects (although certainly not as severely as in the aforementioned scenario). Many observers suspect Russia of engineering the 2010 coup in Kyrgyzstan in order to get rid of a regime which was not cooperative enough with Moscow (Tisdall 2010). Theoretically, it could be possible for Russia to engineer such a maneuver in the future if the regime defected against Uzbekistan without Moscow's approval.

If both nations defect, both will bear the costs of a two-sided war between Kyrgyzstan and Uzbekistan. This is a highly illogical and unlikely outcome under the Mafioso's Dilemma paradigm. If both cooperate, each will incur the least amount of damage

from their actions. The utility gained or lost for each as a result of how K1 is built and operated pales in comparison to the utility that would be lost in a war. Both Uzbekistan and Kyrgyzstan appear to be playing the Mafioso's Dilemma, cooperating because Russia makes the rules and could punish both.

Analyzing A Likely Scenario

To verify the argument that the Mafioso's Dilemma is at work in Central Asia, the utility changes perceived by Uzbekistan as a result of the construction of K1 must be estimated. The change in utility as a result of losing water to the K1 reservoir can be thought of as an economic loss resulting from the inability to grow as much cotton as in years when K1 did not prevent water from reaching Uzbek fields.

Cotton needs anywhere from 27 to 51 inches of water each year to reach maturity, depending on the species of cotton and climate conditions. Assuming that Uzbekistan's cotton requires 40 inches (a mid-range amount of water) to reach maturity, it would need to use about 13 bcm of water per year to produce a harvest that would reap about $1 billion, presuming Uzbekistan still maintains 1.3 million hectares of cotton fields (Golub and Kestleman 2015). 85% of the Uzbek cotton crop is located in Fergana, where it is heavily dependent on water from the Syr Darya. The International Crisis Group estimates that 50-80% of water allocated to agriculture in Uzbekistan is wasted, and that only 25-35% of water that actually reaches the crops is used efficiently.

Let's conservatively assume the lowest waste estimate of losing 50% of dedicated water before reaching the fields is true, and that only 66% of water at the fields is used inefficiently (therefore 34% is used efficiently). Then the 13 bcm used successfully on cotton production is only a third of the approximately 39 bcm of water that made it to

cotton fields out of an initial allocation of 78 bcm of water dedicated to cotton. At this conservative estimate, only 16.6% of water dedicated to cotton is used successfully in a year, resulting in about a billion dollars of economic productivity in Uzbekistan. 78 bcm is above the high end of the range of water received by Uzbekistan from its annual transnational intake, implying that Uzbekistan is using more than all the water it receives from Kyrgyzstan's portion of the Syr Darya on agriculture, in addition to its own domestic sources.

As a whole, Kyrgyzstan contributes about 29 bcm of water in the Aral Sea Basin annually, much of which flows through Uzbekistan (McKinney 2003). K1 will capture water from only part of this basin, and will retain about 5 bcm of water most of the time (E. P. Kraake 2012) despite having a maximum capacity of about 9 bcm. If this water was subtracted solely from Uzbekistan's budgeted water for cotton, it would bring the total allocation down to 73 bcm. With 50% of that water lost in transit to fields, 36.5 bcm is available for cotton farmers. Assuming they use it at 35% efficiency, 12.775 bcm of water is absorbed by Uzbekistan's cotton harvest.

The profits reaped by Uzbekistan from cotton depend not only on the amount of water used in irrigation but also on global prices, the productivity of its workers, the weather, and other factors. Holding everything but water use constant, assume that 13 bcm of irrigation will grow enough cotton to be sold for $1 billion and that any change in water supply will have a linear impact on the amount of cotton harvested and sold. A decrease in irrigation from 13 bcm to 12.775 bcm would cause an $18 million loss for Uzbekistan. The actual impact on Uzbekistan's cotton profits would therefore be negligible and easily offset

by investments into the domestic water infrastructure. Surely Karimov's regime can afford

to save 3% of the currently wasted water to maintain its cotton profits.

K1 status:	K1 non-existent or empty	K1 at expected capacity
Water held in K1:	0 bcm	5 bcm
Water allocation to agriculture by Uzbekistan:	78 bcm	73 bcm
Water that reaches cotton farms:	39 bcm	36.5 bcm
Water used efficiently to irrigate cotton:	13 bcm	12.775 bcm
Cotton productivity:	$1 billion	$982 million
Net change:	$0	- $18 million

Figure 16: Uzbekistan's utility loss from the construction of K1 is estimated to be $18 million when using a median estimate for cotton's water requirement and a conservative estimate of Uzbekistan's water losses due to mismanagement.

If Russia was not backing Kyrgyzstan and its Kambarata projects via the CSTO and

special financing, the situation would more likely resemble the conditions portrayed in the

Prisoner's Dilemma, and Kyrgyzstan would be easily overrun by Karimov's army if it dared

to unilaterally build K1, as my survey participants and relevant research suggest would

occur in an Uzbek-Kyrgyz war. However, while Russia and other CSTO members may have

less interest in Kyrgyzstan than elsewhere, they have not signaled that they would let

Kyrgyzstan be invaded. Ergo, the Mafioso's Dilemma is a better representation of the

current state of affairs in Central Asia.

The Mafioso's Dilemma tells us that the cost of defection is greater than the cost of

cooperation. Compared to being defeated by the Russian military, an $18 million economic

loss is a relatively easy pill to swallow. Considering that a T-72 tank operated by

Uzbekistan costs $1-2 million (Sputnik 2009), the loss of just 9-18 tanks in a war would

make the effort economically irrational. Such a loss of material would be all but guaranteed

in a war against the CSTO.

The likely scenario described here was designed by assuming that Uzbekistan's domestic water losses are at the low end of the spectrum of estimates given by observers of Uzbek water use. If Uzbekistan loses 80% of its water before it reaches the fields and uses only 25% of it efficiently, that would mean the country is losing even more water, and the construction of K1 would have an even smaller economic impact.

Conclusions

The analysis of a likely scenario in which Uzbekistan loses $18 million of agricultural output from a strategy of cooperation confirms the hypothesis that Mafioso's Dilemma can explain Uzbek-Kyrgyz interactions. With this in mind, I make the following six conclusions:

1. Kyrgyzstan's preferred unilateral policy is to complete K1. An opportunity to add almost 2,000 Megawatts at Russia's expense is too good to pass up.

2. Kyrgyzstan's actual current strategy is cooperation, which matches up with the Mafioso's Dilemma game. K1 construction is delayed to such an extent that it has essentially stalled, so defection is simply impossible given the circumstances of Russian involvement. Therefore, Uzbekistan's water access is not being affected by new dam infrastructure.

3. Uzbekistan's current levels of water access are tolerable. It has displayed discontent about the situation K1 might create through its public statements, but overall Uzbekistan's economy and society can still function. Uzbekistan has not reached a point where defection would bring greater gain that cooperation. That inflection point may occur in a situation where water supplies are so inadequate that they are damaging the economy and society as

badly as an interstate war, but it is difficult to envision the Uzbek regime allowing its nation to fall into such disarray.

4. Prisoner's Dilemma and Stag Hunt are not truly representative of the situation. Neither nation is defecting (although both may want to), ruling out Prisoner's Dilemma. Their cooperation is a result of the potential punishments that may be incurred from Russia rather than seeking mutual gains in utility from cooperative strategies, so Stag Hunt can also be ruled out.

5. Mafioso's Dilemma offers a more complex understanding of the game. It provides a space for accommodating Russian regional hegemony in the game, while the other two models do not. Mafioso's Dilemma explains the current situation of mutual cooperation as a function of the Russian Mafia's rules, rather than the naked interests of Uzbekistan and Kyrgyzstan. However, this all hinges on Russia's willingness to enforce a set of mafia-style rules in Uzbekistan and Kyrgyzstan.

6. The weakness of the Mafioso's Dilemma is its assumptions about Russia. It assumes that Russia willingly acts as the head of a mafia, and it assumes that the mafia has certain rules that are applied equally to all members. It is possible that this is not entirely true. More research is needed to conclude exactly how Russia influences the rules of the game, and whether it applies the rules equally or applies them selectively.

In this particular case, I have high confidence that the Mafioso's Dilemma is the best possible theoretic model for predicting Uzbek and Kyrgyz interactions. The GIS study and assessment of hydrological conditions in the Syr Darya together make a compelling argument that Uzbekistan's future water deficits will result from domestic mismanagement and climate change rather than Kyrgyzstan's impoundment of 5 bcm at K1. The region's

political dynamics are clearly rooted in Russia's omnipresent political, economic and military interests, as I was able to observe on the ground in Kyrgyzstan. Game theory models based on expected utility are often criticized for making judgments about payoffs with insufficient information to back up the estimations of utility gained or lost and the probability of success for each nation's chosen strategy. By incorporating in-depth geological data and political research to inform the Mafioso's Dilemma model, I can state with high confidence that the utility gained by Uzbekistan from pursuing a strategy of defection. It will be low if the CSTO does not respond (only $18 million from recovering 5 bcm), and negative if the CSTO does respond to any use of force against Kyrgyzstan (the total economic loss of war against a nuclear power). I can also state with high confidence that the likelihood of the CSTO coming to Kyrgyzstan's defense is high and that there is almost no possibility that Uzbekistan would prevail against combined CSTO military forces. There is strong evidence that Uzbekistan's regime acts rationally in international relations despite its emotional rhetoric, and therefore I conclude that there will not be a water war in Central Asia because of a hydroelectric dam.

<u>Criticisms and Suggestions for Future Work:</u>

The Mafioso's Dilemma needs to be tested; its logic needs to be reviewed, critiqued, and refined. But if the payoff order of *Reward>Punishment>Sucker>Temptation* can be proven to exist under the rules of a game, it could be shown to exist in the real world. Ultimately, the best test of the Mafioso's Dilemma will be time. Continued peace between Uzbekistan and Kyrgyzstan is the best possible evidence for the strength of this particular model and the viability of expected utility theory for examining international relations.

Obviously the Mafioso's Dilemma is a simplified model and not a perfect representation of the contemporary situation in Central Asia. The outcomes I have described depend on Russia punishing a defector. If either nation could defect without being punished by Russia, they would get the Temptation payoff from a Prisoner's Dilemma instead.

This could be possible if Kyrgyzstan defects while Uzbekistan cooperates. For example, this would occur if Russia decides to cash in on its investments in the dam projects while sacrificing some of its cheap cotton imports from Uzbekistan. In this case, Kyrgyzstan receives the Temptation payoff from the Prisoner's Dilemma. Uzbekistan then receives the Sucker payoff from Prisoner's Dilemma, assuming the Uzbek regime irrationally chose c instead of d in the Prisoner's Dilemma, where the dominant strategy is always defection. There are only two explanations for Uzbekistan choosing to cooperate in this circumstance. The first is that the regime in Uzbekistan acted irrationally and chose cooperation in the Prisoner's Dilemma despite its rhetoric, and is therefore punished for its irrational decision. The other explanation is that Uzbekistan did not see the game as a Prisoner's Dilemma. Instead, it misinterpreted the game as a Mafioso's Dilemma.

Another possibility is that Uzbekistan could find ways to implement a strategy of defection without undertaking military action against Kyrgyzstan. For example, it may someday find itself in a position to use diplomatic or economic leverage to pressure Kyrgyzstan into allowing the Syr Darya to flow freely without provoking the CSTO. But Uzbekistan apparently does not have these kinds of tools available; surely it would make use of such tactics if they were viable, as they limit the risk of CSTO retaliation.

Uzbekistan's observed actions are in line with playing the Mafioso's Dilemma game, so it is possible that it could mistakenly perceive a continuation of the Mafioso's Dilemma if Russia stopped acting like a *don* with equal interests in the behavior of its mafiosos. The rhetoric from Uzbekistan is so hostile that open cooperation, which would be observed in the Stag Hunt, is unlikely to ever occur independent of Russian involvement. Therefore, it is cooperating under the guise of the Mafioso's Dilemma in order to avoid punishment from the Russian-led CSTO.

Game Theory has its strengths and weaknesses. The payoff order of Mafioso's Dilemma appears to accurately label the outcomes of various strategy choices, but it needs to be scrutinized and critiqued. Another possible explanation could be that Kyrgyzstan is the only Mafioso, and Uzbekistan is a random, unaffiliated criminal. In this case, the rules of the game would be different for each player, which could make the perceived payoff order different for each player as well. Such a scenario would be highly complex and very difficult to define. Perhaps the development of expected utility theory and game theory needs to move in the direction of two player games where the rules are not applied universally, as is often the case. This could make room for new types of games more reflective of observed behaviors in international relations.

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Appendix: Geologic Analysis Methods & Political Survey

Parts 1-6 provide step-by-step instructions written to allow a reader to replicate the study as I have conducted it. Part 7 lists survey questions used in Kyrgyzstan.

Part 1: Data

I used publicly available maps from DIVA-GIS (www.diva-gis.org/gdata) to create a map of Kyrgyzstan, Uzbekistan and Tajikistan. The Syr Darya River flows from Kyrgyzstan into Uzbekistan, briefly into Tajikistan, then back into Uzbekistan.[15] I retrieved maps of administrative areas, inland water, elevation (masked to each country), and land coverage for each of the three nations (see Methods Table 1).

Object	Description	Source	Format	Resolution
Administrative Areas	Country outlines and administrative subdivisions.	GADM version 1.0 (Hijmans 2015)[16]	Vector (area)	N/A
Inland Water	Rivers, canals, and lakes. Includes separate files for line and area features.	Digital Chart of the World	Vector (line and area)	N/A
Elevation	SRTM30 Dataset, aggregated to 30 seconds. SRTM stands for Shuttle Radar Topography Mission, a US Space Shuttle program that mapped most of the world's topography in 2000.	CGIAR SRTM	Grid	30 Seconds
Land Cover	Original data resampled onto a 30 seconds grid. This displays land as farms, deserts, forests, etc.	GLC2000	Grid	30 Seconds

Appendix Figure 1: Table of GIS data descriptions for the base map (DIVA-GIS 2015)**.**

[15] Farther downstream the Syr Darya enters Kazakhstan before spilling into the Aral Sea basin. However, that area is beyond Uzbekistan's main agricultural centers, and very little water gets that far downstream. If the Syr Darya's water still made it that far, the Aral Sea would still be more than the mere puddle it is today.
[16] The GADM website acknowledges missing two small exclaves of Uzbekistani territory located inside Kyrgyzstan. They are just over the border from Uzbekistan and have no direct or obvious implications for this project.

Altogether, these four elements make a complete map of the three countries that contain the Syr Darya basin. One can visualize and manipulate the elevation, land cover, water features like rivers, lakes and canals, and national boundaries in ArcMap, the map creation program of the ArcGIS 10.3 software suite.

Part 2: Building the K1 Watershed

After accumulating this data into a map, I put a visible marker on the location of the Kambarata-1 dam site and then built K1's watershed in ArcMap using the following steps. Most of these steps involve using a "tool" in ArcMap. A tool is a pre-installed computational process in ArcGIS designed to yield a particular outcome, generate new data, and visualize the new or transformed information on a map.

The "Fill" tool was used on the map layer containing the SRTM elevation data masked within the boundaries of Kyrgyzstan. The "Filled" layer[17] has smoothed out smaller discrepancies in the overall slope of the map; this prevents errors in showing how water would flow over the landscape.

The "Flow Direction" tool determined the direction water would flow across each point. The "filled" map file that came from step 1 was necessary as the input layer. The flow direction tool[18] examined the slope of each point on the map and assigned it a direction pointing to one of the surrounding eight pixels depending on that individual point's slope. Water on that point will flow to the next point according to this direction. The map of flow direction is needed for the next step.

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[17] When working in ArcGIS, it is best to give each individual map layer a unique name signifying how it was created and how it should be used. For example, a filled map of Kyrgyzstan's elevation might be "KGZ_elev_fill."
[18] The flow direction tool also generated a "drop" file, but that is unnecessary for constructing a watershed.

The "Flow Accumulation" tool showed where water will accumulate on the landscape. It was used with the flow direction file from step 2 as the input. The flow accumulation tool added up the number of points flowing to a specific point; the points were shaded on a color scale to indicate how many other points flow into them. For example, a point with no other points contributing water to it would be black, while a point that collects water from thousands of others would be white, and points in between would be shades of gray. This process produced a map layer displaying clear lines that correspond to existing rivers and streams. The most obvious flow accumulation line corresponded to the Syr Darya River.

The "Snap Pour Point" tool was used to show a "pour point," or the furthest downstream location of the watershed. For this analysis, the pour point has to be the location of the Kambarata-1 dam on the Syr Darya River. This tool requires two inputs; a Flow Accumulation map (generated in the previous step) and a "pour point" which is created manually to show the dam's location with the following procedure.

On the far left side of the ArcMap interface is an icon that says "XY" with a small dot over it. This button was used to enter a desired set of coordinates and identify that exact point on the map.

On the bottom of the ArcMap interface is a drawing tool. It was used to draw a point on the coordinates and save it on the map by using the "Convert Graphics to Features" command on the Drawing drop-down menu.

Once the pour point was created, I used it with the flow accumulation map layer to inform the Snap Pour Point tool. The resulting layer is a "snapped" pour point, locked in place as the end of the watershed region.

The next step was to use the "Watershed" tool. Using both the original pour point from step 4b and the flow direction map from step 2 as the inputs, the watershed tool combined all the data and layers to define the bounded region that is upstream of the snapped pour point. It represents the whole area upstream of the Kambarata-1 dam. This tool visualized the extent of where water originated before it reaching the dam. The entire watershed was shown to be within the national boundaries of Kyrgyzstan. Logically, the reservoir would be in the area immediately upstream of the dam in the lower end of the watershed.

The "Raster to Polygon" tool changed the watershed shapefile from a raster data file to a vector data file, or shapefile. The shapefile is easier to manipulate as it has less metadata attached to each point, and is faster to display on the map. It also will not change in size unless manually adjusted with very specific manipulations. The shapefile form of the watershed is compatible in other programs like Adobe, whereas the raster form of the watershed is not compatible with non-GIS programs.

Part 3: Building the Initial 3D Basin

The next challenge was to get the topographic map of the watershed area into C4D to approximate the K1 reservoir's size and location.

In ArcMap, a rectangle was drawn around the watershed polygon as vector data (not raster because it has to be useful in other programs). The "Clip" tool was used to cut out the portion of the topographic map (also called a "topo map") contained within the rectangle and saved as a TIFF file (Tagged Image File Format – the file type suffix is .tif).

The topo map was exported[19] as an Adobe Photoshop file, rather than as a TIFF. In Photoshop, the topographic image was cropped down to just the rectangular image that had been cut out in ArcMap (this removes the large blank border around the image of the topo map, which was generated automatically by Photoshop). Every single file in ArcMap is made to be displayed with 0% transparency, or completely opaque.[20]

In ArcMap only the water lines, water bodies, Kambarata-1 dam location pour point, watershed, the outline of the rectangle used to clip the topo map, and Kyrgyz national boundaries were left on the display, and everything else was removed.[21] The entire map document was exported in the format of an ".ai" file type for use in Adobe Illustrator (AI).

In AI, the exported map was opened and the "generate point" tool was used to add several dozen points tightly packed on the pour point and the edges of the watershed shape. Then one generated point was picked off of the pour point, and dragged to the top left corner of the rectangle. Then another was picked off the pour point and dragged to the bottom right corner of the rectangle. This gave the pour point a defined location relative to that of the rectangle, which is identical to the one in Photoshop. The same process was used for the watershed to define its location. Anything that extended beyond the rectangle, such as portions of the Kyrgyz national boundary, was clipped off. All the new files were saved as AI and Photoshop files.

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[19] A file is exported by right-clicking on the file name in ArcMap's table of contents and selecting the Export command, then putting it in the appropriate file format.

[20] Any transparency in a layer – even the slightest bit – would cause the non-GIS programs to analyze the map layers improperly.

[21] This is done by checking the appropriate boxes in the "Table of Contents" on the left and leaving all other layers blank – don't delete them from the map.

The new Photoshop and Illustrator files were opened in C4D.[22] The topo map from Photoshop and was resized to fit inside the rectangle from Illustrator. Once the topo map was snug inside its rectangle, the watershed shape and the pour point were detached from the corners of the rectangle by deleting the points generated in Adobe. When viewed from above, they now appeared exactly like they did in ArcMap and in the same places. The rectangle outline, the water lines and Kyrgyz boundaries can be removed because they served as visual references.

The topo map was now visible in 3D. The contours of the land were made more visible by exaggerating the Y values in C4D (They were magnified 2.8x larger by adjusting the Y value up to 15 from its default).

A plane was inserted at the elevation of the top of the K1 dam. In the larger, low-resolution topo map of Kyrgyzstan, the elevation at the point of the dam was listed as 1151 meters, and the dam is going to be 275 meters high, so the plane was installed at the elevation of 1426 meters.

An obvious canyon was now visible at the location of the dam. A line was drawn across the canyon on the 1426m plane, and extruded downwards so that it reached the bottom of the topo map at the location of the dam.All areas of the topo map above the 1426m plane were removed, leaving the mold of the topography below that level. This is all the land that would be at or below water level in the reservoir.

Once extruded downwards, the line crossing the canyon should looks like a rectangle blocking the canyon. It was locked against the topo map, and then everything on the downstream side of it was deleted. The remaining portion of the topo map is a mold of

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[22] If they initially appear perpendicular to each other, rotate them until they align.

the reservoir. When compared to the map of elevation in ArcMap, it reveals a general location and size of the K1 reservoir. With this area located, a new elevation map with higher resolution can be made in the area of the dam and its approximate reservoir, eventually leading to an accurate calculation of the reservoir's volume.

The mold is made up of thousands of pixels, each 1 square kilometer in area, but slightly distorted by their own changes in elevation. They could be used to calculate an approximated volume of the reservoir, but this approximation is very different from the actual volume and not necessary for the completion of the analysis, but it is good to have a number to reference for later on. To calculate the approximate volume, the following procedure was used.

The C4D file was saved and reopened in another C4D window. Here, all the points at the top edge of the basin were selected and assigned a new elevation value of 0 (zero) meters. All the other points automatically changed their own elevation values accordingly, so the walls of the canyon did not move and the shape was not distorted.

Each point now has an area of 1km and an elevation relative to zero. That information was extracted from the basin's data table and pasted into Excel. The elevation figures were divided by whatever amount they had been exaggerated (I used 2.8x magnification of the elevation earlier, so the elevations were divided by 2.8).

To calculate the volume, the number of cells was multiplied by the area of each pixel and the absolute value of the elevation of each pixel. The result is a rough estimate of how much water K1 could hold in its reservoir.

This value for volume is inaccurate because slope was unaccounted for in the calculation. Since each 1km cell rests at an angle and not flat on the ground, when viewed

from above it is neither a perfect square nor is it the actual area as displayed on the map.

Because the cells rest at an angle, its volume overlaps with the volumes of other cells.

Instead of each cell lying flat and facing the sky so that perpendicular lines drawn to each

are parallel, perpendicular lines drawn to the center of each cell would overlap. This

represents the computer double-counting certain amounts of volume. Across a 1 square

kilometer of land, there is a great variation in slope, so the required slope values will have

to be generated from a map with higher resolution to get an accurate value for the volume

of the reservoir.

Part 4: Building a Better Reservoir Basin in ArcMap

The point of building the approximate reservoir was not so much to generate volume of

the K1 basin as it was to give a visual reference of where it is. By shading the topographic

map of Kyrgyzstan in ArcMap and so that the elevations 1151m and 1426m are breaking

points between different colors, an area about the same size of the basin in C4D will be

shown as a single unit with a uniform color. The reservoir has to be roughly that size or

smaller. Given the low resolution of 1 square kilometer and futility of calculating area at

that resolution, a closer look at the approximate basin area is necessary.

I downloaded new topographic data from the ASTER dataset. ASTER is a joint

project between NASA and Japan's space agency to map the Earth's topography in one

degree tiles, all with 30meter x 30meter resolution (one arc-second). These tiles provide

far more accurate elevation data than a 1km resolution image of Kyrgyzstan. The

approximate reservoir basin generated earlier is wholly contained within two ASTER tiles:

41North, 73East and 41North, 74East.

The two tiles were loaded into the ArcMap document containing all the map layers and files generated previously. The "Mosaic" tool was used to stitch the two ASTER tiles together into a single rectangle. The "Integer" tool produced an attribute table for the new rectangular map of the reservoir area. The attribute table generated columns of data for each point, "Count" and "Value." The "Value" column lists elevation for each point, and "Count" lists how many points have that particular elevation value.

I examined the 30x30 resolution map and found the lowest elevation value on the line where K1 will be built. Because the ASTER tiles have higher resolution, a new base elevation was revealed. 978m is the lowest point in the river basin at the location of the dam, so this is where the bottom of the K1 dam's wall will actually start. 275 meters higher is 1253m. The "Select by Attributes" option was used in the attribute table to select the points at elevations between the bottom and top of the dam wall. It will highlight those points on the tiles. The highlighted points upstream from the dam location should roughly correspond with the first basin built earlier. However, the aggregate area of the basin should be smaller, since the more accurate elevation has the dam being erected from a base elevation of 978m instead of 1051. This means a lower water table in the reservoir less water covering less land. The command typed in to use the "Select by Attributes" feature for this to work was:

"VALUE" >= 978 AND "VALUE" <= 1253

A small polygon was drawn around the highlighted cells, but crossing over them at the location of K1. This shape was used with the Clip tool to cut the 30x30m resolution map down to an area surrounding the highlighted cells. This generated a new map layer

showing only the area upstream of the dam containing the reservoir. The values between

978 and 1253 were selected in the attribute table and exported to Excel as a text file.
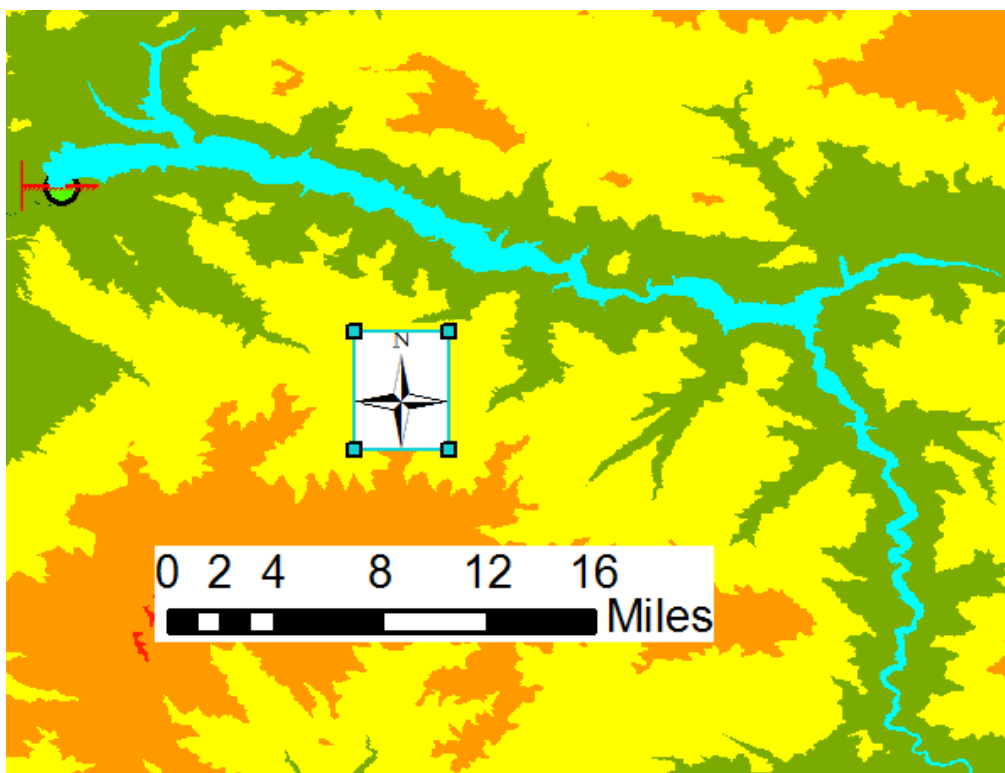
Appendix Map 1: The 9bcm K1 Basin generated in ArcGIS from 1 arc-second resolution raster data is highlighted in blue.

To get slope, the ASTER data needed to be re-projected into a non-geographic

coordinate system (GCS) projection.[23] The Project Raster tool is used to take the clipped

basin layer and re-project it using the bilinear resampling technique into

WGS_1984_UTM_zone_43N, which is the zone covering the geographic location of the entire

reservoir. The resulting layer is the same shape but with slightly different elevation values,

as they have been projected precisely within the correct area of Earth's surface. The

maximum and minimum elevation values of the whole map shifted by just a meter or two,

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[23] While the two tiles of elevation data were located in the right place on the map because of their geographic coordinates, a slope map layer needs to have an assigned map projection in its metadata because it will not automatically know its own location. That is because the points in a GCS layer are labeled by precise coordinates, and the computer cannot compute slope based on coordinates. It needs meters or another unit of linear measurement for the length, width and height of each point, not the decimal degrees for its location.

but the elevation at the dam location was the same as it had been, still at 978m. The Slope tool in the Spatial Analyst toolbox was used to get the slope of each point in the re-projected basin, with the output measurement being degrees.

The slope map layer will not have an attribute, table, nor can one be generated. To extract the slope data for each point, the Sample tool was used to create a table with both the elevation data and slope data for each point on the map. Both the re-projected elevation data and the slope map were used as input rasters and the re-projected elevation map was used as the input location raster. The resulting table was exported as a .dbf file.

Part 5: Calculating Reservoir Volume

The equation for calculating volume is quite simple. The product of length, width and height of a container will yield its volume. In this experiment, the reservoir is the container whose volume is being measured. Length and width alone yield area, and the area of the reservoir is the sum of the areas of all the elevation points between 978m and 1253m. Each cell is a square with 30m sides, thus having an area of 900 square meters. However, this assumes that the surface is flat. In reality, each cell has a slope value. The slope means the cell is tilted to some degree, and therefore does not appear as a perfect square when viewed from above. It will appear as some kind of quadrilateral with smaller sides and thus a smaller area. So, the correct calculation for area is to multiply the sides of the square and the visible fraction of the cell. The final part of the volume equation, height, is found by subtracting the elevation of each cell from the maximum elevation of 1253. Therefore the equation is as follows:

$$Volume\ per\ cell = (Length)(Width)(Fraction\ of\ Visible\ Area)(Height)$$

$$V = (30)(30)(value\ from\ 0\ to\ 1)(1253 - elevation)$$

The .dbf file containing the location, elevation and slope of each basin point was opened in Excel. The values[24] were sorted by the elevation, and everything less than 978 and greater than 1253 in elevation was removed.

Slope was given in ArcMap as a value between 0 and 90 degrees. In the next column, it was changed to a percent by multiplying the original slope value by 100 and then dividing by 90.

Next, the slope was converted to a decimal value between 0 and 1 by dividing the percent given in the prior step by 100. This is the fraction of the cell's area that is lost due to slope. Finally, the number representing a fraction of lost area was subtracted from 1. This number is the actual fraction of the area of the cell.

The remaining fraction of the area of the cell is multiplied by the length and width of the cell, both of which are 30 meters. The resulting product should be less than or equal to 900 for all cells. Next, the depth at each cell was calculated by taking the elevation of each cell and subtracting it from the elevation at the top of the dam, which is 1253m. The greatest value possible was 275m. The results were multiplied together to find the volume of each cell. Then volumes of all the cells were added together. The sum is the total capacity of the reservoir.

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[24] There should be multiple points for each elevation level, each with its own row displaying that point's X and Y coordinates and slope.

Part 6: Additional Maps & Figures
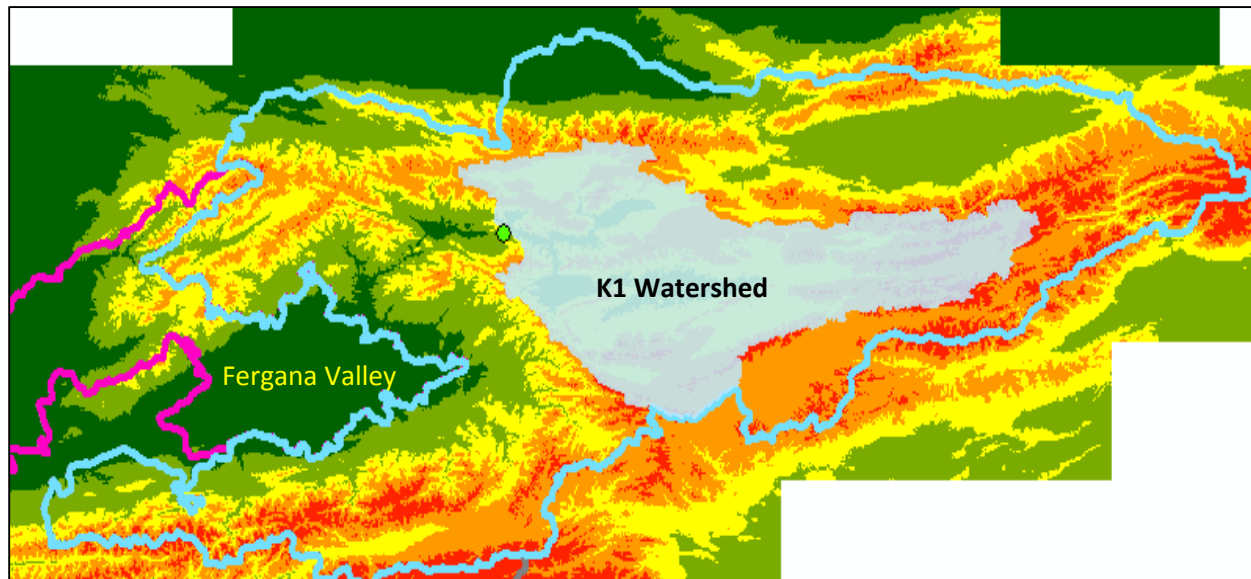
Appendix Map 2: The K1 Watershed is shaded light blue. This entire area drains into the K1 dam site, which is denoted by a green dot. Elevation values increase by color from dark green to red. The borders of Kyrgyzstan are blue and the borders of Uzbekistan are pink.
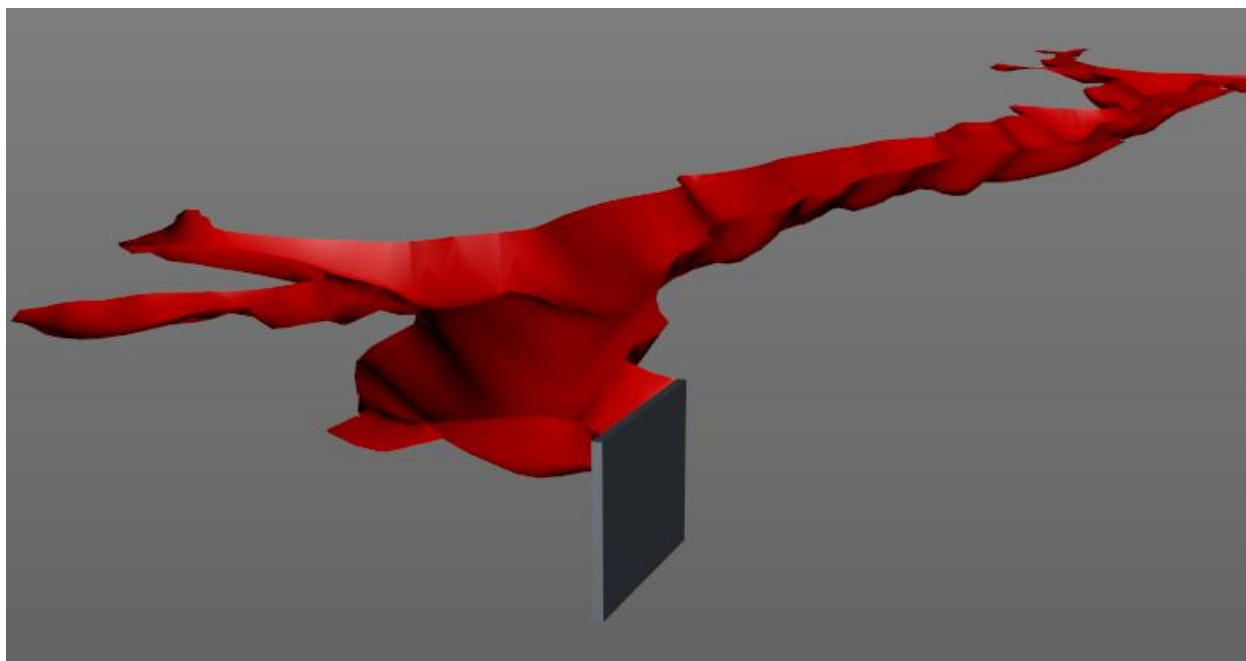
Appendix Figure 2: Close-up view of the K1 dam wall and beginning of the reservoir visualized in Cinema4D based on 1 kilometer resolution elevation data.
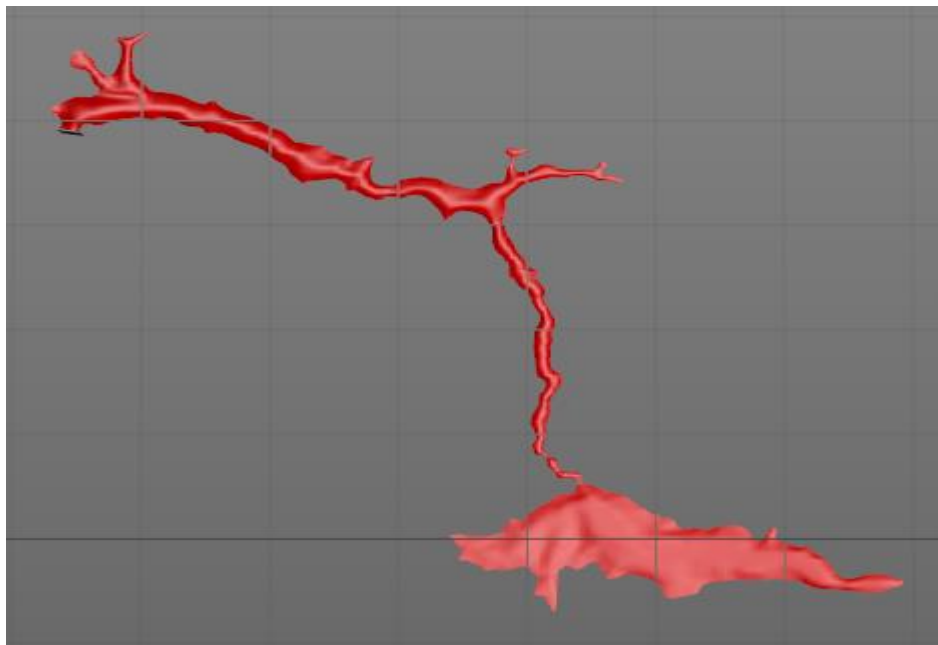
Appendix Figure 3: Overhead view of the reservoir visualized in Cinema4D based on 1 kilometer resolution elevation data. The use of a low resolution elevation map led the system to calculate that the K1 reservoir would extend into a large flood plain southeast of the K1 dam site. Later work with higher resolution elevation data in ArcGIS showed that the reservoir would not extend into this flood plain. The use of more precise elevation data led to a more accurate estimate of the reservoir's actual capacity, which is much smaller than the volume predicted in Cinema4D.
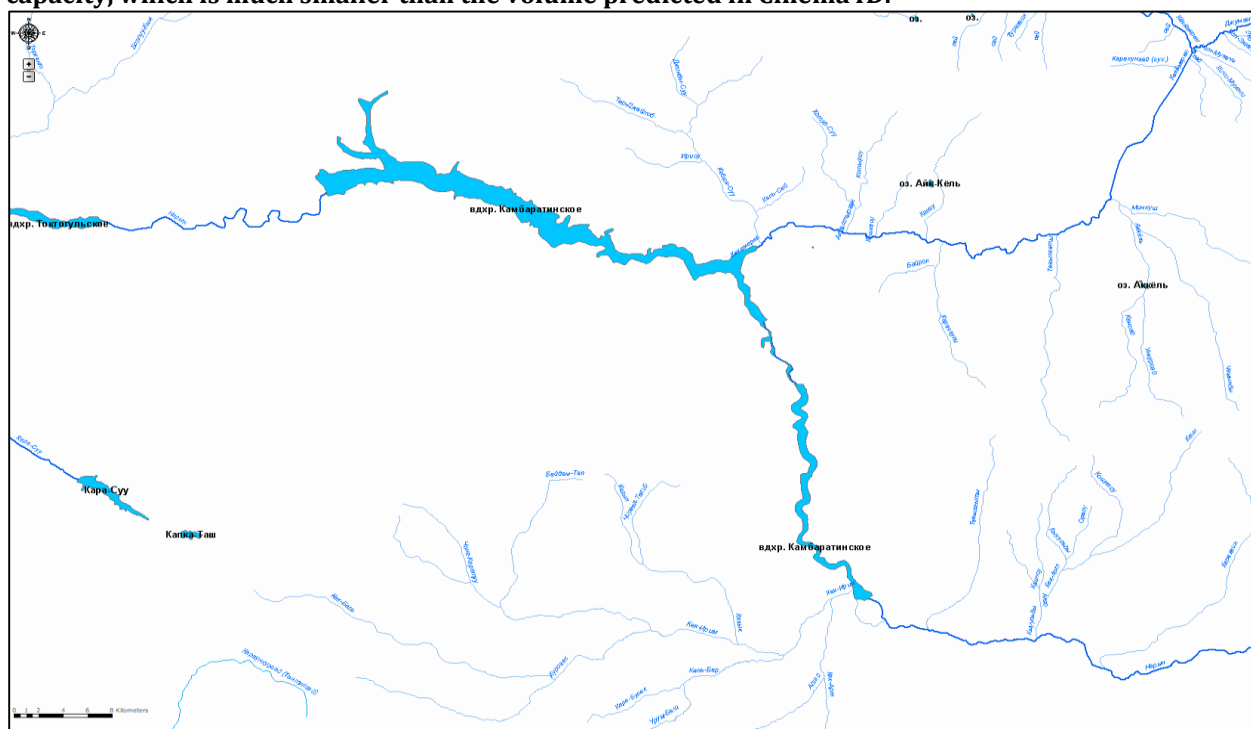
Appendix Map 3: This image is from a Russian-language map of Central Asia and shows an anticipated reservoir similar in size and shape to the one I created in ArcGIS. The shape of this basin is slightly narrower than the one I generated, probably due to a lower estimate of how much water will actually be stored in the reservoir (ICWC 2015).

Part 7: Kyrgyzstan Survey Opinion Questions[25]

Do you think there are problems with water in Central Asia?

Yes

No

Not sure

What kind of water supply problems do you think Central Asia has?

Not enough water for people to drink

Not enough water for sanitation

Not enough water for farming and agriculture

Not enough water for industry and businesses

Not enough water for other purposes

Too much water, there are floods

There are no problems with water supplies in Central Asia

The water people drink is poor quality

The water used for sanitation is poor quality

The water used for agriculture and farming is poor quality

The water used for industry and businesses is poor quality

Other (please specify)

What is the single biggest water problem in Central Asia?

Not enough water

Too much water

Inconsistent water (sometimes too much, sometimes not enough)

Poor quality water

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[25] Biographical questions were also asked but are omitted here.

Water is poorly managed and not used properly

Other (please specify)

In your home nation, what are the biggest problems with water supplies?

Not enough water for people to drink

Not enough water for sanitation

Not enough water for farming and agriculture

Not enough water for industry and businesses

Not enough water for other purposes

Too much water, there are floods

There are no problems with water supplies in my country

The water people drink is poor quality

The water used for sanitation is poor quality

The water used for agriculture and farming is poor quality

The water used for industry and businesses is poor quality

Other (please specify)

What is the single biggest water problem in the nation where you currently live?

Not enough water

Too much water

Inconsistent water (sometimes too much, sometimes not enough)

Poor quality water

Water is poorly managed and not used properly

Other (please specify)

Kyrgyzstan has plans to build the Kambarata-1 hydroelectric dam on the Naryn river, which later runs into the Syr Darya river. The dam would provide 1,940 Megawatts of energy, but cost over 2 Billion US Dollars (103 839 200 000 Kyrgystani Som, or 69 793 000 000 Russian Ruble). Russia is funding the project. Some

construction has already started. Do you think it is a good idea for Kyrgyzstan to finish building the dam?

Yes

No

Islam Karimov, the President of Uzbekistan, threatened to start a war if the Kambarata-1 Dam is built and water stops flowing through the Syr Darya to Uzbekistan . Do you think that Uzbekistan would actually attack Kyrgyzstan to make sure Uzbeks get enough water from the river?

Yes

No

If Uzbekistan does attack Kyrgyzstan because of Kambarata-1, who do you think would win the war?

Uzbekistan will win (Kyrgyzstan surrenders or a cease-fire/truce is reached in which Uzbekistan secures its water supply from the Syr Darya)

Kyrgyzstan will win (any result in which Kyrgyzstan successfully defends against Uzbek aggression and can keep control of the water supply and its hydroelectric dams)

If Uzbekistan attacks Kyrgyzstan, do you think Russia will help defend Kyrgyzstan?

Yes, Russia will send soldiers, its air force, and supplies to help Kyrgyzstan fight against Uzbekistan.

Yes, Russia will help by sending Kyrgyzstan supplies and its air force, but not soldiers.

Yes, Russia will help by only sending supplies to Kyrgyzstan.

Russia will not help Kyrgyzstan or Uzbekistan, and try to stop the war.

Russia will not help Kyrgyzstan or Uzbekistan, and try to make the war last a long time.

Russia will help Uzbekistan against Kyrgyzstan.

If Uzbekistan and Kyrgyzstan fight a war, what other countries will join? Please indicate who will join Kyrgyzstan, who will join Uzbekistan, or if you think no other countries will join the war.

In your own words, please describe how you think Kyrgyzstan should deal with its energy and water supply challenges.

Projects like Kambarata-1 are expensive and will require outside investment. If you were in charge of Kyrgyzstan's efforts to secure funding for the project, in exchange for political and economic concessions, what nations or organizations (such as the World Bank or IMF, for example) would you try negotiating with?

Imagine there can only be one partner to fund Kyrgyzstan's hydroelectric dam projects, and that partner would receive some general economic and political concessions from Kyrgyzstan in exchange (the details would be different for each partner and are not important here). Rank the following potential partners in order of preference (first being most desirable, last being least desirable).

 Russia

 USA

 China

Imagine a global organization could provide funding for Kyrgyzstan's hydroelectric dam projects. Rank the following potential partners in order of preference (first being most desirable, last being least desirable).

 The World Bank

 The International Monetary Fund (IMF)

 The New Development Bank (NDB, also known as the "BRICS Bank" because it was founded recently by the BRICS nations of Brazil, Russia, India, China and South Africa)

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