THE ECONOMICS OF DAM SECURITY POST 9/11 AND THE THREAT TO CONSUMER CONFIDENCE

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ABSTRACT

In the post 9/11 era, the U.S. Department of Homeland Security has promoted securing vulnerable and valuable national resources and infrastructure from possible threats. Dams are unquestionably a critical national resource that must be protected. Terrorism poses a threat to the U.S.' water infrastructure, which is vulnerable to physical destruction, biological and chemical contamination, and cyber-attacks. This threat directly influences government and private security spending decisions, consumer costs, and confidence.

Consumer confidence is a driving influence behind economic decisions, and impacts consumption, spending habits, and investment. Actively reducing risk will ultimately influence an individual's economics choices, and have a positive effect on economic growth. The U.S. Government spent over $900m between 2001 and 2010 on dam security alone, providing assistance to state and privately owned facilities, while also increasing security regulations and identifying high risk facilities (Copeland, 2010).

Previous assessments of the economics of dam failures measured consequences based on the real costs of failure. While this approach is still crucial, the broader effects must also be considered. This paper examines the effects of risk mitigation on the nation's confidence in our water supply, and explores the economic impact of an attack on a U.S. dam. In the wake of a dam failure, goods that use water in production will experience higher prices and supply shortage. Complement and substitute goods will also experience shifts in demand, causing economic uncertainty. To further understand this relationship, this paper introduces the concept of water confidence, a measure of the level of confidence in having a readily available supply of water.

In an ever increasing financialized economy, water plays a major factor in its stability. It is essential to understand the impacts of securing infrastructure to bolster this confidence in water, and the risks of not doing so.

INTRODUCTION

Water is one of the most basic of human resources, and it follows that critical water infrastructure must be secured from potential threats. Outside of natural causes, the US has not experienced significant water supply issues compared to many developing nations. It is generally assumed that water will be accessible and treated to a high quality. Yet, as recent events such as lead contamination in Flint, Michigan have shown, failure to deliver on this assumption can catastrophically affect a community. There are numerous

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areas in which water supply is susceptible to issue, but this paper will focus on the threat of terrorism facing US dams, as we argue the effect of an attack would be contagious to multiple sectors of the economy, dealing a powerful fiscal blow beyond destruction. Prior to the September 11, 2001 terrorist attacks in New York, the concept of a massive attack on US soil was limited. While terrorism is not a new phenomenon, its recent global presence has revolutionized how the US government approaches security issues. Identified as one of 18 key components of US economic well-being, dams and other water resource facilities need protection from potential terrorist threats (Copeland, 2010). The Department of Homeland Security has recorded 25 attacks against dams worldwide between 2001 and 2011 (Homeland Security, 2012). Of these, 13 included explosive devices, and one incendiary device was used in an attempt to attack Black Rock Dam in the United States. Dams are a high profile target as they are significant national icons and provide essential services including drinking water, flood control, power generation, agricultural water, and industrial water, thus proving a significant target. The Patriot Act of 2001 changed the way that protection spending is distributed, and tasked many federal agencies with terrorism risk identification and mitigation (Prante, 2008). The federal government provides funds to states, which aggregately sums to 1.6 billion dollars over the last 12 years under the Homeland Security Grant Program (HSGP), which allows for states to secure their infrastructure (Prante, 2008). Congressional research focuses on informing the government of the risk of terrorism to water resources (Copeland, 2010). Providing this context has allowed for the appropriation of $923 million towards water security at facilities in the 10 years after 9/11, and funded research in determining effective ways to secure facilities and combat terrorism. Prior to this, the Bureau of Reclamation had only funded security measures at five dams, Hoover, Shasta, Grand Coulee, Glen Canyon, and Fulsom (Copeland, 2010). As a part of the effort to secure dams, there is need to identify high-risk facilities, with particular emphasis on water as a drinking resource and electrical generation. However, the US federal government owns and operates only 5% of the dams that could cause death under a failure scenario, but provides resources for dam owners and operators to secure facilities. Even though appropriations are provided, given this information, much of the private cost is still passed on to consumers. Copeland identifies gaps in security, including the lack of threat/vulnerability assessments, identification of potential biological/chemical threats, establishing community standards, and computer based monitoring systems. Under the management of the EPA, Homeland Security, FEMA, the Bureau of Reclamation, the US Army Corps of Engineers (USACE), and the Federal Energy Regulatory Commission (FERC) there is a push to establish more effective federal standards for municipal water districts and private water companies. As a part of these standards, agencies are providing training and physical security requirements. The Government Accountability Office (GAO) is responsible for oversight of these programs, and has analyzed security efforts, determining that physical and technological upgrades, training and law enforcement relationships will be the focus of future federal funding.

Legislation also adapted in response to this new analysis. The Drinking Water Security and Safety Amendments (SDWA) manifest Congress' new dedication to protecting drinking water as a valuable and scarce resource (Shermer, 2005). Water has no true substitutes, and the security regulations under SDWA provide impact over 265 million

Americans which has been a crucial factor in motivating these organizations to change the way they approach water infrastructure security (Shermer, 2005). This paper will discuss the origination of this concept through consequence-based analysis, such that dams are seen as one of the key infrastructure components of the country.

This paper will further examine the costs that are generated by increased appropriations to dam security and the benefits that this spending brings. Both these costs and benefits are shared by industries that rely on water. In the event of an attack on a dam, the resulting costs would be similarly shared such that it is economically devastating to multiple sectors. Tracing this affect back, we can understand how consumers' view of dam and water stability influences their economic decisions. Ultimately, this paper will provide a theoretical analysis to assess the economic impacts of securing dams against terrorism threats. Current literature is examined to show the impact of a dam failure scenario, water contagion and disruption of distribution, and the lack of economic impact to consumer confidence analysis. This literature will follow a historical trend in which the approach to water facility safety has evolved from natural disaster based modeling to consequence based modeling. Finally, a cost-benefit analysis of security related spending, and an analysis of consumer confidence under different security scenarios is done to examine water resources under the threat of terrorism.

LITERATURE REVIEW

Fortunately the US has not experienced a damaging attack on water resources or dams, but the threat remains and proxies for understanding the impacts play a key role. Literature to date has used three separate techniques to evaluate water security. These include natural disaster modeling, consequence based modeling, and primitive economic analysis of costs and funding allocation. This paper will look at the historical trend of these models to show the evolution of consumer perception of preparedness. Homeland Security reports are the culmination of public analysis to show the impact of a terrorist attack, but this paper will look at the broader economic implications, and the risk of contagion to other markets. Finally, it will examine how water impacts consumer confidence, such that we can link dams and water supply to macroeconomic stability.

Natural Disaster Modeling

Prior to 2001, academic research focused on development and distribution models for water in the most efficient manner possible, as well as natural disaster preparedness (Haimes, 2002). At this point, natural disasters were the only recognized significant threat facing the water industry. Grigg (2003) suggests that by modeling the effects of a natural disaster to water distribution, we accurately predict the potential future consequences of a terrorist attack. These models used loss of life simulation to predict the costs of a disaster in order to quantify the potential losses under a dam failure scenario (Lehman & Needham, 2012). Despite general disagreement with the accuracy of natural disaster models, this approach has been the focus of research for decades and continues to influence how the US approaches water security. As such, natural disasters were previously viewed as a close proxy to what a terrorist attack would do to the economy.

As outlined in studies done by Grigg (2003), Munger (2009) and Gleick (2006), in addition to the data presented to Congress by Copeland (2010), natural disaster models were the main mode used to distribute funding to secure dams from threats of terrorism.

Research has started to trend in the direction of disagreeing with Grigg's (2003) use of natural disasters as a complete proxy for risk analysis. Analyses use Sunny Day Failure (SDF) modeling in which dams fail under the most amenable conditions. Haimes (2002) argues that the Sunny Day Failure (SDF) model is inaccurate in analyzing terrorism failure scenarios, simply due to the diversity of facilities in their scale, structure and systematic configuration. SDF also assumes high warning time windows, allowing for minimal loss of life and potential mitigation of consequences, which would not be true in a terrorist attack. In addition, in an early study of this potential scenario, Haimes established the theoretical model for examining terrorist attacks on water facilities through showing that the natural disaster proxy is a lower bound of the economic damage potential. Research is trending towards considering a consequence-based analysis for terrorist attacks, in which risk analysis is based less on the type of disaster and more on the potential consequences in the wake of a failure scenario.

Consequence Based Modeling

After the popularity of natural disaster based modeling subsided, a new approach was formulated to evaluate preventative measures based on the respective potential consequences. From Homeland Security and Presidential directives originates a significant portion of this consequence-based research on water safety. Stemming from a desire to secure borders and prevent domestic terrorist activity, the specific focus of preventative measures is on infrastructure that could cripple the economy. In this way, the September 11th attacks were a significant turning point in water safety, prior to which this infrastructure had no special security measures in place (Haimes, 2002). Lack of security prompted internal review of which agencies are responsible for protecting the nation's assets, and how these facilities are evaluated. To provide resolution, the US government, under the Bureau of Reclamation, the Census Bureau, the Department of Homeland Security and the Congressional Research Service, collects most data regarding infrastructure spending. This data identifies preventative spending, but does not provide information on the mitigated consequences. Studies in the late 1900s identified water as at risk to human attack, however this was not thoroughly addressed in policy until 2001 through the Drinking Water Security Amendments (Haimes, 2002).

Scholars generally agree that there are three main modes of attack (Beering, 2002; Copeland, 2010; Gleick, 2006; Grigg, 2003; Shermer, 2006). These include physical, biological/chemical and cyber threats. For the purpose of this paper, we will focus on physical and biological/chemical threats, due to their extreme visibility and subsequent influence on consumer confidence. Cyber threats pose just as potentially devastating, but in the eyes of the consumer are less visible and therefore preventative measures may have less impact on behavior. These two modes have the potential to disrupt water distribution in a way that drastically affects how other industries operate (Qiao et al., 2005). Qiao et al. highlight the nature of water subsystems as necessary components of analysis when examining water infrastructure as a complete system. These systems are a series of independent water supply facilities that differ by geographic location and communities (Haimes, 2002). Systems serve to distribute water to different sectors, as water acts as a resource input for industries, as cooling and processing agents in power plants and manufacturing facilities (Folga et al., 2010). Folga et al.'s study shows the economic losses in each of these industries if water delivery was interrupted, with the top losses being in agriculture and manufacturing. Furthermore, the significant difference between localities presents a challenge in determining how spending is distributed. The interconnected nature of industry and agriculture becomes extremely important when analyzing the potential consequences. Water has always been considered important but never to the point that it could cripple production in one blow. Yet, with this research come problems in analyzing how different sectors will respond under an attack scenario. Compared to other researchers, Qiao et al. show the difficulty in creating a general model of response due to these differing systems.

With policy changes in the early 2000s, there has also been an evolution in the research conducted on water terrorism. While former studies used natural disaster dam failure scenarios to predict damage, the main current argument suggests there is a difference in how systems respond under terrorist conditions (Lehman & Needham, 2012). Furthermore, as evidenced in attacks on dams in other countries, workers and officials may be injured or killed in an attack, and unable to respond. Natural disaster modeling includes time for warning the general public. The warning time window, which is crucial to evacuation orders and preparation, would be significantly shorter in the terrorism scenario, meaning the breach would be far more catastrophic (Lehman & Needham, 2012). This model is still used in some consequence-based analysis, but other research has determined that this model would not hold true for terrorism, given that an attack would have little warning and response would be focused on saving lives over property and securing other industries (Munger, 2009). As the warning time window shrinks, the consequences grow. In a terrorist attack, the lack of warning time window would mean consequences would be at their peak. Almost all water facilities have Emergency Action Plans (EAPs) that dictate how a facility responds to an emergency or failure scenario. While these plans can account for the terrorism potential, facilities may unprepared or unable to respond to attacks that impact staff safety. Regardless of EAPs, the lack of warning time and the method in which the attack occurs could render an attack significantly more economically devastating.

As a major sector in the National Infrastructure Protection Plan (NIPP), Homeland Security has also taken the consequence based approach in determining priority dams that need to be secured (Homeland Security, 2015). Their consequence based model allows dam owners and administrators the ability to understand how their facility falls in the department's Consequence-Based Top Screen (CTS) methodology. This methodology incorporates human, economic, and critical function factors to determine the consequence of failure. The economic portion of their analysis looks generally at asset replacement value, remediation cost, and costs associated with business interruption. While critical function disruption would include interruption in water supply, irrigation, power generation and others, there is a broader macroeconomic impact associated with this that remain unquantified and unexamined in documented reports.

Current literature also revolves around identifying the means and feasibility of a terrorist attack. More specifically, Gleick (2006) analyzes the realistic nature of a chemical or biological attack by examining the means of dispersion of an agent into the water supply at a reservoir or in distribution control systems at a dam facility. Gleick determines contaminant stability in water, chlorine tolerance in parts per million, and whether the pathogen has been weaponized. Although speculative, this research coupled with historical attack data across the world shows the feasibility of a chemical or biological attack (Gleick, 2006). While this provides data on the potential of a threat, it does not provide an analysis of spending or operating changes in response to this type of an attack. Health consequences of water borne pathogens could be massive, hard to identify, and overwhelm response mechanisms (Meinhardt, 2005). Biological and chemical attacks have impacted the U.S. military abroad, where soldiers are at risk for water born bio-terrorism agents. Furthermore, the U.S. has experienced this domestically in an outbreak of Cryptosporidium in Wisconsin which caused over 100 people to become sick in a short period of time (Meinhardt, 2005; Gleick, 2006). On a larger scale, particularly when introduced to a community that relies on a dam for its water source, the magnitude of contagion could be exponentially higher. Bio-chemical terrorism could be difficult to detect given that some water systems exist or originate in a location that is not considered a high target, which is at odds with the general model of appropriations to regions where loss of life has a high potential (Meinhard, 2005). In examining biological and chemical terrorism, Gleick stipulates that confidence, communication, monitoring and response are key to addressing this threat.

Munger (2009) also highlights one of the major gaps in security analysis. Dams are often examined under what is considered to be a “Sunny Day Failure” (SDF) in which the failure occurs under normal or optimal conditions. However, it is important to note that this is not the case when terrorism plays a role in dam failure, as the conditions are likely less than optimal (Munger, 2009). In creating proxy variables for such an event, most research to date has used the SDF conditions model, which does not accurately depict the full expense of the economic costs associated with a dam failure in a terrorism model (Grigg, 2003). Haimes (2002) argues that this SDF model is inaccurate in analyzing terrorism failure scenarios, simply due to the diversity of facilities in their scale, structure and systematic configuration.

Economic Perspective of Costs and Funding Distribution

The September 11 attacks were a major turning point that started a conversation regarding how congressional appropriations should focus on protecting national infrastructure. Water's multitude of uses and lack of substitutes makes it extremely valuable to the US economy, and the potential for market contagion is high leading to potential high future national costs (Beering, 2002; Gleick, 2006; Meinhardt, 2005). Theoretical disagreements exist in how these costs impact the consumer, and this paper will supplement those gaps by providing a cost-benefit analysis related to protecting water facilities.

The price and value of water is a good indicator of the diffusion of costs to consumers. Water is an economic good and has value given that it is scarce resource with no true substitutes (Van der Zaag & Savenije, 2006). It is priced differently across municipalities based on distribution costs and availability. Still, to provide water to all levels of income, there is typically a block pricing system in which the price of water increases based on how much is used by the household per month. Van der Zaag and Savenije argue that the market for water is not homogenous in its consumable value, given that the preferences for quality differ between agricultural and industrial uses. The quantity demanded by agricultural sectors is much higher, but the quality needed is significantly lower, and it more restricted by budget. This makes determining the overall monetized value of water difficult, as the opportunity cost for each additional unit of water consumed by these markets different.

In the context of terrorism, Beering (2002) postulates that lack of warning systems in place, as well as a lack of institutional oversight and consistent regulation of infrastructure security make much of the costs that go into preparing for a potential attack more extreme. While security procedures and systems may be deterrents to an attack, many facilities lack these systems due to their high cost. However, this cost may be offset by the economic benefits enjoyed from stable confidence in the nation's dams and their services provided.

Quantitative analysis of the Homeland Security Grant Program, while offsetting the costs of security using public funding, begs the question: who is responsible for the security of water facilities? Given that spending is highly influenced by politics, it follows that this funding dispersion is controversial because many water facilities exist in rural areas, which some argue require less protection due to lower population density (Prante & Bohara, 2008). Placing water spending in an economic context, Prante and Bohara (2008) performed an econometric analysis of how funding is dispersed under the terrorism threat. In this model funding is a function of risk, politics, and power. This study highlights other factors that influence how funding is distributed, but also shows that one of the major difficulties in studying appropriations is that risk measures are often imprecise (Prante and Bohara, 2008). Similarly, Gleick (2006) shows that many of the issues in spending distribution originate from the very source of their necessity, which is the uncertainty of an attack. These recent studies focused on consequence based risk aversion, but have not focused on how uncertainty influences consumer confidence. Uncertainty provides great economic motivation that has not been empirically analyzed to a great extent in this issue. Gleick (2006) identifies that there was a significant, although not quantified, loss of productivity and wages during the Wisconsin cryptosporidium outbreak. We stipulate that this type of outbreak would cause higher damage under a terrorism scenario. What is lacking in this literature is the extent to which this threat generates new costs for consumers through the monitoring, prevention, and response measures recommended.

Analyzing the devastating market effect of an attack is crucial to show the reason behind spending. Munger (2009) shows the economic impact and devastating nature of a dam failure scenario. In this aspect, Munger highlights that potential future lost benefits can be analyzed as costs of a dam failure, dramatically increasing its impact. While not directly analyzing the data, Munger asserts that water loss to agricultural areas can be measured by looking at the opportunity cost for water in these areas, or by examining the value of water that is leased (or what would be considered the market value) by region. This highlights the importance of previous studies done in which appropriation divisions across states have been considerably debated. Typically, this debate revolves around population and potential physical damage, but it does not examine the differing costs of water in rural areas, and distribution costs associated with lower population density.

In essence, this is the difference between a short run impact and a long run impact analysis. As other research has shown, the long run impact will be far more costly to dependent industries, and this type of analysis has not been undertaken when examining the real cost of a threat. Furthermore, this long run impact also has a less visible impact to consumer confidence, as it will impact more sectors of output and consumption. Consumer confidence does play a large role in the overall economic effects that a water based terror attack would have. As roughly 70% of GDP, consumption plays a major role in economic growth and stability. An analysis by Adgrani and Macri (2010) found a strong correlational relationship between consumer perception of economic strength and stability, and confidence in the overall economy, and concluded that if consumer confidence were to decrease it would follow that economic stagnation, overall decreased production, decreased employment, and higher price levels would occur.

In the next section, this paper will address the gaps in the current research on dam security and the threat of terrorism in the form of examining the costs of terrorist threats to consumers and the role of consumer confidence in water resource terrorism. The literature presents a number of analyses but lacks models that quantify the loss of productivity, wages, and income, as well as broader macroeconomic impacts. Haimes (2002) identified the need for an economic evaluation of the consequences of water terrorism. Yet, literature does not analyze the economic cost of the threat alone, and the quantitative impact on consumer confidence that an attack would have.

ECONOMIC ANALYSIS

The questions raised by scholars establish the basis for the economic analysis of this paper. To fully understand the impact of terrorism to water resources, we must examine the costs and benefits that are created through securing water facilities, such that we can analyze the impact of terrorism on overall consumer confidence in both the macro economy and the water market. Literature emphasizes the potential consequence of a dam failure to other sectors that use water as an input. Whether this takes the form of agriculture or industry, if water supply and distribution are disrupted, the ripple effects would be enormous. While beneficial to modeling risk, no study has yet examined the impact to consumer confidence that would in turn affect global markets. This paper will focus on the abstract nature of consumer confidence in the water market, how dams play a stabilizing role ensuring consistent supply, and the psychological nature of a terrorist attack on a dam. The purpose in determining how funds are allocated is the perceived value to society associated with protecting water from a terrorist attack. It follows then that consumer confidence must become a necessary piece of this appropriations algorithm.

Before examining the effect of consumer confidence, we must first quantify the perceived value to society that security measures provide. The costs are measured in the form of dollars put towards security costs. Cash resources come from several sources, however the highest source of security funding comes from the federal government. The benefits come in the form of potential future costs that are avoided or mitigated through newly implemented security measures.

Consumer confidence cyclically fuels the macro economy in its ability to generate new levels of consumption and employment. Future expectation, which are heavily influenced by confidence, are one of the main drivers of demand. In this respect, it is important to add this future potential growth to the present benefits. In order to understand the confidence process, we must examine it under several different scenarios. As a constant, or control scenario, consumer confidence without terrorism will be the base for this analysis. Confidence will increase when consumers know that dams and water resources are protected, continuous and available. Furthermore, their confidence in other industries will increase knowing that prices are more likely to remain stable. To further fuel this argument for strong protective measures, confidence will drastically decrease if a terrorist attack occurs. In addition, confidence is drastically hindered under the constant threat of an attack. Even given the lack of true substitutes, consumers will likely change their levels of consumption of water if they perceive a threat. The threat alone thus has the potential to decrease growth, hurt jobs and decrease demand for water and other complementary goods and industrial production. To model consumer water confidence, security costs and benefits will be defined as inputs to show the effect of the protection on economic stability.

Quantifying costs

The costs of a terrorist attack on a dam can be broken in four categories: (1) damage, (2) the impact of disruption of water distribution or power generation, (3) increased security, and (4) the impact to consumer confidence and broader economic contagion. Dams are incredibly durable and able to withstand significant damage before failing, but even in a non-failure scenario, the damage would likely be in the order of magnitude of millions of dollars in repair and damaged equipment.

Homeland Security has published the direct impacts associated with the recorded attacks on worldwide dam facilities. Though these attacks did not result in failure leading to catastrophic loss of life, in many cases lives were lost as a result of the attack. This is the starting point for understanding how an attack on a dam will affect the broader economy. By understanding the risk and consequences of an attack, we can understand the benefits brought by mitigation and preventative security measures. This analysis also suggests that public spending to secure dams and other critical infrastructure is justified in comparison to the costs of an attack. Homeland Security quantifies the costs of lost benefits for a case study at Blue Dam in Colorado. Blue Dam was chosen due to its considerable size and its provision of recreation, power generation, irrigation, instream flow for fish and wildlife, and flood prevention. These expected lost benefits in power generation and other areas are estimated at $229m (Homeland Security, 2011). Furthermore, they estimate the repair or replacement cost to be $167m, and total damages from flooding to be $590m. Coupled with other remediation costs, the total cost of a Blue Dam failure is estimated at over $4.3 billion.

The roughly 100,000 dams in the US provide 10% irrigation to all US cropland, and 6.7% of all electricity (Homeland Security, 2015). In the Pacific Northwest, this number grows as dams provide 60% of electricity through hydropower dams. If we translate that to population impact, hydropower dams provide electricity to an estimated 2.6 million people nationally. As a major technology hub for companies such as Microsoft, Amazon, Facebook, and Google, interruption to power generation in the Pacific Northwest could have a globally catastrophic impact. An attack would costly to companies forcing decreased labor needs, lower wages, and goods supply shortages.

Table 1 below shows a summary of the attacks against dams worldwide between 2001 and 2011.

Table 1 Dam Attacks Summary by Incident Chronology[2]

Dam Attacks Summary					
Facility	Country	Date	Attack Type	Attacker Type	Result
Lhokseumawe Resevoir	Indonesia	August 17, 2001	Explosive Device	Separatist (Suspected)	Minor Damage
Panauti Plant	Nepal	November 24, 2001	Explosive Device	Communist Insurgent-Maoist (Suspected)	Damage - $500,000
Kidapawan Resevoir	Philippines	March 19, 2003	Standoff Weapons (Rockets)	Islamic Insurgent (Suspected)	Main pipline destroyed, disrupted water supply to 100,000 residents
Kajaki Dam	Afghanistan	May 2, 2003	Standoff Weapons (Rockets)	Islamic Insurgent	Failed Attack- None
Gomal Zam Dam	Pakistan	September 21, 2004	Assault Team	Islamic Insurgent	1 Civilian Fatality during hostage standoff
Zelenchuck	Russia	September 21, 2004	Assault Team	Islamic Separatist	Failed Attack- None
Dumarao	Philippines	December 15, 2004	Explosive Device	Communist Insurgent (Suspected)	Crane damage
Selaghat Dam Project	Nepal	December 19, 2004	Explosive Device	Communist Insurgent-Maoist (Suspected)	Electricity failure and damage to 200KW powerhouse
Mirani Dam	Pakistan	May 18, 2005	Explosive Device	Unknown	Failed Attack- None
Haditha Dam	Iraq	August 2, 2005	Explosive Device	Unknown	Damage to Dam (uknown cost)
Haditha Dam	Iraq	September, 2005	Standoff Weapons (Rockets)	Islamic Insurgent	No Damage, heavily guarded facility
Kajaki Dam	Iraq	September 17, 2005	Explosive Device	Islamic Insurgent	Attemped destruction of dam, failed. Work at facility haulted until NATO secured facility two years later
Hlaingbwe Dam	Burma	May, 2007	Explosive Device	Separatist (Suspected)	Employee Killed
Hlaingbwe Dam	Burma	May 2007 and September 2, 2007	Standoff Weapons (Mortar)	Separatist (Suspected)	Employee Killed
Waeng Station	Thailand	August 1, 2007	Explosive Device	Islamic Separatist (Suspected)	Control Station Damaged
Kajaki Dam	Afghanistan	March 30, 2008	Explosive Device	Islamic Insurgent	Two British Marines Killed
Tipaimukh Dam	India	April 26, 2008	Assault Team Explosive Device	Unknown	Machinery Destroyed, Security Increased
Mosul Resevoir Dam	Iraq	May 1, 2009	Explosive Device	Unknown	5-10 Shiite Killed
Balimela Power Station	India	December 19, 2009	Incendiary Device	Communist Insurgent-Maoist (Suspected)	Damage to power station valve house, water intake tunnels
Mytikyina Dam	Burma	April 17, 2010	Explosive Device	Ethnic Separatist	4 Chinese workers killed, 20 injured. Construction suspended indefinitely
Thawk Yin Kha Dam	Burma	April 27, 2010	Explosive Device	Ethnic Separatist	Failed Attack- 4 Injured
Black Rock Dam	United States	July 4, 2010	Incendiary Device	Unknown	Failed Attack
Baksan Power Plant	Russia	July 20, 2010	Assault Team Explosive Device	Islamic Separatist (Suspected)	Two guards killed, two generators destroyed
Machlagho Dam	Afghanistan	July 18, 2011	Assault Team	Unknown	Three police killed, several injured or captured
Thawk Yin Kha Dam	Burma	July 20, 2011	Standoff Weapons (Rockets)	Ethnic Separatist (Suspected)	Eight rocket grenades fired at construction site. No injuries.

Damage to a facility from an explosion, incendiary device, or mortar attack would have extremely high costs. If the facility was not damaged beyond repair, we would expect the costs of repairs to be proportional to the damage. It is difficult to quantify or monetize the widespread cost of lost water distribution to a community, agriculture, or industry, or loss of power generation provided by hydropower facilities. Given that 31% of dams have a high potential of hazard if they fail or even don't operate correctly, it follows that the economic consequence would be equally severe.

[2] U.S. Department of Homeland Security, 2012.

We must also consider the costs to the water industry through the amount of extra spending that has been used to provide new security measures to facilities. The following model attributes security costs as a function of the threat level, the marginal personnel costs under the threat, new training, recreation lost, and capital improvements, such that we can fully understand the impact to the industry that terrorism has.

$$\boldsymbol{security\ costs = \{f(threat\ level, marginal\ personnel\ costs,}$$
$$\boldsymbol{training, recreation\ loss, captial\ improvements, facility\ size, location, consequence\ scor}$$

The threat level in this model represents the measure of how the public perceives the practicality of a terror threat, and any recent evidence that an attack is imminent. While some measure of a threat is constant, there is room for fluctuation of costs based on how direct the threat is. Marginal personnel costs exist in the increase cost for each additional unit of labor that is required to secure facilities under the terror threat, each which require training. Existing staff also requires additional terrorism specific training to be able to implement effective emergency action protocols. There is some measure of loss to the public that is derived from the inability to enjoy and use reservoirs and lakes with new security measures in place. Finally, capital improvements, including new security systems, access restriction measures such as fences and gates, structural improvements and warning systems add significant costs to facilities. There have been few attempts to quantify these important components that comprise security costs. Capital improvements, marginal personnel and training costs are easily measurable, although data is not readily available. The other variables are more abstract in nature.

Yet, we can summarily look at security costs through the funds provided by congress to address security issues at water facilities. Congressional appropriations make up a large portion of funds being allocated for security purposes and safety regulation that support federal, state, and private facilities. To secure the water industry, facilities must take several measures. This paper argues that the most effective measures include providing additional security personnel, training existing personnel, restricting recreational use of lakes and reservoirs, and monitoring water for chemical and biological contaminants. Thus far, most analyses focused on the real costs to the industry, as opposed to the abstract variables that can generate higher costs. As such, data represents capital, personnel, training, and evaluation funding to the industry. The following data (Figure 1) was compiled from a study prepared by the Congressional Research Service, which outlines the amount of funding allocated to water security since 2001.

Figure 1 U.S. Water Infrastructure Security Appropriations (Millions of Dollars)[3]

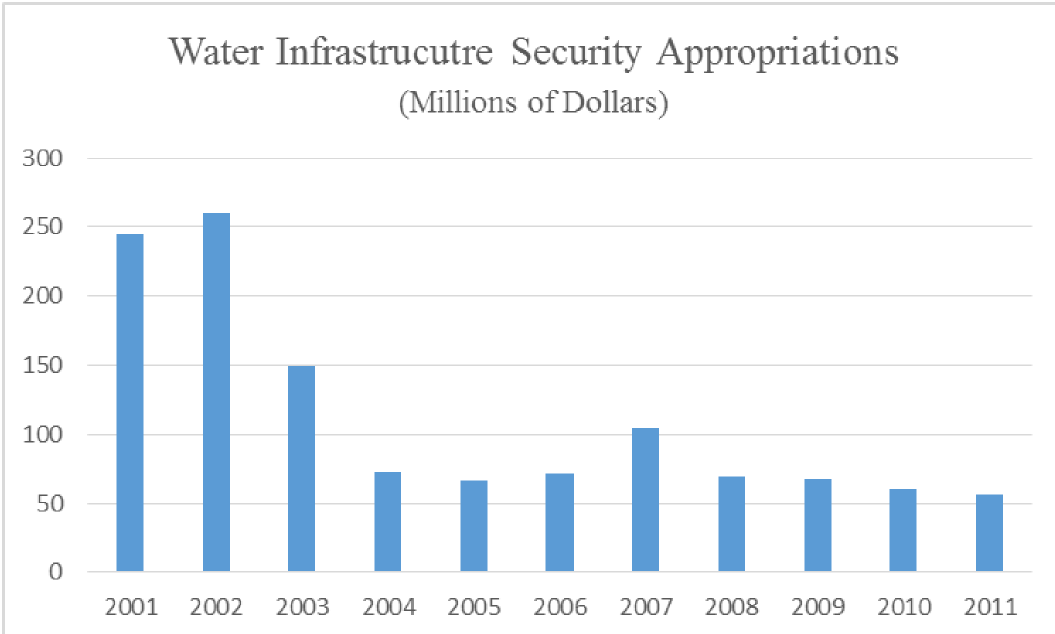

Figure 1 shows a spike in spending after the September 11th attacks to 260 million dollars, with a decline in fiscal year 2003 and then relatively similar amounts of spending in fiscal years 2004 through 2011 at an average of 71.425 million dollars. Copeland (2010) divides government spending into three parent agencies, the Environmental Protection Agency, Bureau of Reclamation, and the Corps of Engineers. Appropriations to the EPA and the Bureau of Reclamation, while decreasing since 2002, have decreased at a slower rate. The Corps of Engineers saw the highest amount of spending in 2002 and 2003 with very few appropriations in subsequent years. This suggests that one of the primary goals was to provide analysis of structural integrity with respect to potential terrorism in the post 9/11 era. These agencies are then responsible for distributing funds to local water facilities, both to provide higher security and analyze vulnerability (Copeland, 2010).

Another form of cost is considerably difficult to measure, which is the change in water prices in response to increased costs. While actual prices vary across utilities, water prices have been generally rising in the last 12 years (McCoy, 2012). Given that increased water security spending is correlated with higher utility water prices, for the purposes of analyzing cost, consumption and confidence, this paper makes the assumption that security costs lead to higher water prices. Making this assumption leads to the conclusion that consumers directly experience the costs of securing the water industry, providing relevant significance to their level of confidence.

[3] Copeland, 2010.

Quantifying Benefits

Before we directly examine water confidence, we must establish the benefits consumers derive from water and dam security. These benefits are both in the form of avoiding potential future costs and enjoying stable economic progress. As such, there are four categories of benefits including: (1) mitigation of damage to facilities, (2) uninterrupted water and power distribution, (3) new security related jobs and investment, and (4) increased confidence in water and the government.

Benefits derived purely from the mitigation of consequence are more abstract, and are not as visible to consumers as their associated cost if recognized. Thus, the amount of investment and spending to secure the infrastructure is not purely a function of the benefits, but of the perceived level of risk, public visibility, and the amount of risk the owner is willing to assume.

To examine this, researchers have looked at dams and water facilities under different scenarios. The purpose of this methodology is to calculate the perceived value to society that is generated by avoiding a failure scenario. Consumers do not receive any direct benefits, and rather incur higher prices and taxes. Yet this spending is justified by policy makers through arguing that present costs are far less than potential future costs (present benefits). To model these costs, researches look at several different factors. These include loss of life simulations, potential capital repair costs to the industry, and property damage. To model this, we establish the following equation where benefits in time t_0 are a function of future costs, future loss of life, property damages, lost wages, current consumption, and the future price of water.

$$\begin{aligned}\boldsymbol{security\ benefits_t} &= \boldsymbol{\beta_0 + \beta_1(capital\ cost_{t+1}) + \beta_2(loss\ of\ life_{t+1})} \\ &\quad \boldsymbol{+ \beta_3(property\ damage_{t+1}) + \beta_4(lost\ wages_{t+1})} \\ &\quad \boldsymbol{+ \beta_5(\Delta consumption_t) + \beta_6(water\ price_{t+1})} \\ &\quad \boldsymbol{+ \beta_7(ripple\ effects_{t+1})}\end{aligned}$$

Time (t) represents a point in time before a terror attack, and t+1 represents a point in time directly post terror attack, thus articulating the present benefits derived from increased current security measures to avoid high future costs experiences in a terror attack. Loss of life simulations model the number of lives that would be lost under a failure scenario. As discussed, simulations have primarily focused on natural disaster response. Under natural conditions, we would argue that less people would be affected. Depending on the type of terrorism, crucial warning systems may be ineffective in preventing loss of life. An act of physical terrorism would likely have little warning, meaning that evacuations prior to the attack are unlikely. In the event of a biological or chemical attack, new detection systems would prevent the mass outbreak. This is a key component that has been upgraded to prevent successful terrorism. With early detection systems, water facilities will be able to control the flow of water and alert consumers to the safety risk. However, even with these systems in place there would still be a cost to many industries if this type of attack occurs.

Most importantly, and far more difficult to measure, are the potential costs and rippling effects to other industries that would occur under a dam failure scenario, which is considered to be a present benefit. The macro economy relies on the cyclical nature of income and demand to keep steady economic growth. If industries that use water as an input were interrupted the costs would be extremely high. Long-term water shortage will cause high production costs leading to fewer jobs, less disposable income and less consumption. Not only will many people find themselves in dire economic situations, water has the potential to cripple both regional and national economies. This type of situation is difficult to fully quantify given its abstract nature.

Measuring Confidence

Finally, though influenced by previously discussed costs and benefits, dams interact most significantly with the broader economy through consumer confidence. As an added aspect of consumption decisions, confidence affects all decisions made in the water sector. A terrorist has three potential inhibitions to confidence. First, an attack would be incredibly psychologically traumatic to the population, such that consumers would be less likely to participate in economic transactions. This phenomenon is largely attributed to fear. Second, an attack would cause consumers to become less confident in industries, meaning that they are likely to find substitutes, or decrease their demand for water. While we argue that water has no "true" substitutes, people will still likely decrease their normal consumption habits in the event of attack. Third, the threat of an attack alone has the potential to influence consumption choices. If the population has little confidence in the water industry's ability to secure itself, it will likely consume other more expensive water sources, or migrate. For a large population, this would likely cause extreme economic hardship. As demonstrated in Homeland Security's 2012 report, terrorism goes hand in hand with political goals. As critical infrastructure, forces seeking to destabilize a region, country, society, or government, would find them of considerable value. If consumers do not have confidence in the government to provide drinking water, power, industrial water, and agricultural water, fiscal policy would in turn take a direct hit.

Terrorism has the potential to impact consumer confidence such that all industries are hurt. While arguably water is such an essential resource that it plays a great role in all aspects of life, certain industries do not rely on it as production input, but would still feel cyclical decline. In particular, complementary goods will experience significant recession after a dam failure, and as there are no true supplementary goods, people will be forced to migrate to find safe water. Consumer confidence further changes how other markets respond after an attack. In this respect water is connected to industries that do not rely on water as an input. This represents a long run approach, in which the macro economy adjusts to changes in consumer confidence. As literature suggests, a decrease in consumer confidence will cause aggregate demand to decrease as consumption decreases. Investment spending will also see a decrease, as will an increase in savings. Government funds will be tied up repairing water facilities, redirecting water supply that is necessary to sustain life, and providing emergency assistance to areas affected. The 2012 Homeland Security report is a proxy, giving insight into the threats that face critical infrastructure across the world. Security in the U.S. arguably far exceeds that of other nations, and it is important to understand the direct correlative effect between increased security operations, intelligence gathering, and deterrence to promote confidence. By understanding what possibly threats face US dams, owners and operators are better prepared. Even in cases where terrorism was not a factor of water disruption, such as lead contamination in Flint, Michigan, the society and economies of such places have suffered greatly. In Flint, confidence in political leaders, infrastructure, and safety caused migration and drastic changes in consumption habits.

Previous studies have established consumer confidence beyond an economic indicator such that consumption is a function it (Dees & Brinca, 2011). We establish a new indicator in the short run as water confidence, or the confidence that consumers have directly related to the water industry. Water confidence will directly impact the consumption of water in the short run, thus affecting other industries and local economies. While water confidence is impacted by other infrastructure components, including treatment facilities, lift stations, and linear distribution assets, dams are the biggest and most significant component of water supply in the eye of the consumer. Applying the consumption model to water resources, ceteris paribus, the basic equation is given as:

$$\Delta \boldsymbol{C_{water}} = \boldsymbol{\alpha} + \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{\beta_1} \Delta \boldsymbol{waterconf_{t-i}} + \boldsymbol{\epsilon_i}$$

This model suggests that consumption is not only correlated with a change in consumer confidence, but is actually caused by this measure of perception. Alpha represents other controlled (in this equation constant) variables that influence confidence. In evaluating the change in confidence of water based on this model, we establish the following equation:

$$\begin{aligned} \boldsymbol{waterconf_t} = {} & \boldsymbol{percieved\ threat_t} + \boldsymbol{\beta_1}(\boldsymbol{security\ \ benefits} - \boldsymbol{security\ costs}) \\ & + \boldsymbol{government\ spending} \end{aligned}$$

The perceived threat is assumed to be constant, leaving change in consumption to be derived from the amount of present value such that is a measure of perceived threat mitigation in the net amount of benefits derived from current security spending. Government response is also an incredibly important role in the wake of an attack. In discussing the impact of the threat alone, or the impact of current spending to confidence, government response will be equal to zero, and have no present effect. Only if an attack actually occurs will the government response help dictate how consumers view the water industry, as it ties into the psychological response of consumers. We are speaking in the abstract here, as data is unavailable for water and dam confidence, yet we must understand how these decisions are made as a function of relevant factors. As a supplier of water, power, flood prevention and more, dams represent the single biggest contributor to confidence in the U.S. water supply.

The confidence estimator incorporates all types of terrorism, but we stipulate that the resulting change would be different if an attack was physical or biological/chemical. This is because the failure effects are potentially far more catastrophic when the attack is visible and heavily damaging, and go far beyond disruption. Using the September 11, 2001 attacks as a base for this analysis gives us insight into how consumers will respond to a physical attack. 9/11 established that physical attacks on US soil are incredibly possible, drastically changing how consumers view infrastructure. Consumer response to a biological/chemical attack would be far more localized to drinking water in the short run, and agriculture in the long run. The impact to industry would be less severe, but the economy would still assume considerable costs through the health care industry and lost wages. Dams represent the most visible method of water supply and delivery, and as such have the biggest impact on confidence, and the biggest impact on economic stability in the water market. This research suggests that it is critical to protect dams to promote both economic growth, and prevent severe economic recession if a terror attack were to occur.

Future Spending on Security Measures

Because confidence is tied to so many facets of the economy, it must be the crux of the argument for investing in security at dams in the U.S. Providing stable, continuous supply of water is a top priority of ensuring a stable economy. Dam security is a designated sector of Homeland Security's infrastructure protection mandate. It is clear that as long as the threat exists there will be analysis and effort to secure dams from the types of attacks they are susceptible to. Compared to the relative consequences explored in this paper, we argue that the benefits of spending security far outweigh the costs. Based on the analysis of this paper, there are multiple implications for future water security measures. If we accept that confidence is key to consumption, then we must allow for continued future spending in the water industry to mitigate risk. This future spending should be proportional to the amount of perceived risk, such that future confidence is offset and consumption stays steady. If consumption is stable, then the aggregate economy will continue to be stable. This is the key necessity of water security, as the national economy relies on consumption and government spending for growth.

Based on the scenarios presented, future security measures may also evaluate protecting other industries from water disruption. This includes providing systems at farms that are meant to detect water based biological/chemical contamination, and the development of response plans at industries that rely on water distributions. Eliminating single points of failure related to water is critical to ensuring operations continue whenever possible. Having these types of mechanisms in place will allow these sectors to recover fast after an attack, and drastically check the decrease in confidence.

LIMITATIONS AND FUTURE ANALYSIS

One of the greatest limitations of evaluating the water industry is analyzing the change in prices relative to the change in spending. Data on water prices is not readily available, nor is it recorded in the national consumer price index**.** This is due in part to the vast array from prices, differing by municipality. In what may be a failure of economics, is our inability to accurately predict change in water prices due to perception of the water industry.

Given that this data is not readily available the models presented in this paper require the use of comparative statics to understand water consumption and confidence relationships. These models present the relationships between costs, benefits, consumption and confidence to explain the decisions behind government spending. While there are other factors that have a great influence on the water industry, this model holds all else constant in order to isolate the effect of terrorism. Understanding that other factors influence pricing, funding decisions, and confidence are still necessary when fully examining such an important infrastructure. Further examination of critical infrastructure is still necessary at the federal and state levels to understand how these decisions affect the nature of consumer confidence. As a critical part of individual and household decisions, the water industry cannot be secured in a vacuum.

CONCLUSION

This paper has highlighted much of the existing research around dam and water security and has shown the economic modeling necessary for a comprehensive analysis of water security. Previous research focused on providing national funds to facilities based on the level of perceived risk, but as our models show, there are other necessary factors that require attention to effectively determine the necessary expenditure.

Securing water infrastructure is an ongoing collaboration between many different federal agencies, coordinated by the Department of Homeland Security. Given that only 5% of dams are federally owned facilities, other facilities must make certain private decisions outside of what is mandated across the industry. While government programs address much of the risk to water, many facilities still go unprotected. The risk at these facilities may be lower, yet they are still vulnerable to terror attacks, which in some ways operates outside of traditional risk models simply due to the erratic nature of terrorism. While it is not the intent of this paper to showcase any means of disrupting water distribution or breaching physical security, it is important to note that the economic implications of a dam failure or water based attack are severe. Arguably these facilities have been secured in the last 10 years such that potential threats are deterred; yet there is still enough real possibility for a terrorist attack that we must explore the broader economic impact and on consumers.

The models presented here suggest that security costs are necessary to ensure the continued benefits that protection is offering. As discussed, confidence is the most volatile measure of how the market responds to a terrorist attack, given that consumer perception is one of the most powerful forces in the aggregate economy. Dam security, and for that matter overall infrastructure security, is becoming an important economic issue in national market. In a time when investment decisions are scrutinized like no other, understanding the impact that water resources have on consumer confidence presents a strong argument for ensuring that these assets remain functional, safe, and secure, is an unprecedented driver of economic stability.

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