Desalination under Uncertainty: Understanding the Role of Contractual Arrangements on the Adoption of Flexibility

by

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ABSTRACT:

The development of new infrastructure projects is a key part of global efforts to meet the demands of growing populations in times of increasing uncertainty. The deterministic approaches commonly used for the development of such infrastructure, however, are not adequately suited to the volatility of these new sources of uncertainty. Stochastic analytical methods have been identified as promising alternatives that are able to deliver considerable value in the face of uncertainty. Despite this promise, however, these approaches have seen limited application in the development of actual infrastructure projects.

Much of the existing body of work discussing flexibility identifies limited analytical abilities, and difficulties in the creation of flexible design alternatives as some of the barriers to the implementation of flexibility. This thesis posits that the contractual arrangements typically used to develop such projects can also act as barrier to the adoption of flexibility. Both the distribution of gains from flexibility and risks that each participant faces due to the different contractual arrangements as well as the interactions of the decisions made by each participant results in the adoption of different levels of flexibility under each contractual scenario. The specific way in which different contractual scenarios influence the ultimate adoption of flexibility is context specific and depends on how different participants might react to the risks posed by the contracts. Rather than make a recommendation for the adoption of a particular set of contracts, this thesis suggests that project proponents seeking to adopt flexibility need to take additional steps to evaluate the risks associated with flexibility and ensure that the distribution of value from the adoption of flexibility is in line with these risks.

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Chapter 1 INTRODUCTION

Large-scale infrastructure projects are part of the development strategies of many nations throughout the world. While there is nothing intrinsically new about the types of infrastructure projects being pursued, there has been a fundamental shift in the context in which they are being developed. Global migrations, urbanization, population growth, climate change and the increasing scarcity of resources have all raised concerns about the fragility of the world and an increasing importance on the consideration of sustainability in infrastructure projects. Beyond traditional financial and technical considerations, project performance is increasingly being evaluated under expanded criteria that include the environment, equity and growth both in the short term as well as in the long term.

This expansion of project performance to include considerations of the social, institutional and environmental spheres of which that system is a part brings with it the need to deal with greater levels of uncertainty. While traditional engineering practice is by no means free from uncertainty, much of this uncertainty is limited to that associated with discrete physical systems and is mitigated by the use of experience-based factors. Consideration of the broader consequences of infrastructure projects on social and environmental systems exposes engineering analysis to greater amount of uncertainty due to the complicated nature of those interactions. The uncertainties increase even further with the introduction of temporal concerns because the future reactions of some of the social and environmental systems are inherently unpredictable. The ability to design large-scale infrastructure projects in the face of these uncertainties is of critical importance to decision makers in the public sector that are in charge of these development programs.

By acknowledging the inevitable nature of uncertainty, rather than attempt to predict and control it, flexibility is a tool that seeks to allow engineers to design projects that respond and adapt to changing conditions. To date flexibility has demonstrated its usefulness as a project design tool that has the ability to add real value to projects. Furthermore it has been demonstrated that, while there are some challenges to the implementation of flexibility, all of these challenges can be met in theory. Despite the potential value that flexibility can add to the management of uncertainty, however, it remains a tool that is not widely used in the development of infrastructure projects.

A consideration of the broader context under which infrastructure project decisions are made is necessary to understand some of the barriers to the adoption of flexibility. The execution of infrastructure typically relies on the collaboration between the public and private sectors. The
public sector typically sets the conditions for participation in the development of infrastructure projects and the private sector then responds accordingly in a bidding process. These contractually-set conditions can play an important role in shaping the decisions regarding the adoption of flexibility for a given infrastructure project and can themselves be a barrier to the adoption of flexibility.

This thesis explores the role that contractual arrangements used by public agencies for the development of desalination capacity can shape the decisions to adopt flexibility in those projects. Decisions to adopt flexibility are not taken in a vacuum; they are made with reference to specific contractual arrangements and are subject to behavioral effects. These behavioral effects include each participant’s perception of risk and the game-theoretic interaction of each participant’s decision. This thesis first looks at the technical value that flexibility can add to a specific desalination project. It then looks at how different contractual arrangements can distribute both the gains and the risks associated with flexibility between the different participants. Finally it considers how these factors affect decision-making regarding the adoption of flexibility.

There are many variations in project contractual arrangements and the potential approaches for the incorporation of flexibility in the design of infrastructure projects. The purpose of this thesis is not to find an optimal solution amongst these choices, neither generally nor for a specific project, but rather to demonstrate that contractual choices for a given project can affect the kind of flexibility that is ultimately adopted in that project. In this way, contractual arrangements can act either as barriers to the implementation of flexibility or as ways of providing incentives for the adoption of flexibility. It points to the need for public agencies to consider the kinds of flexibility that private sector partners are likely to adopt in response to proposed contractual arrangements for the implementation of infrastructure projects.
Chapter 2 **Methodological Approach**

As shown in Figure 2-1, the evaluation framework consists of four distinct elements. The first element of the framework is the technical analysis. A base discounted cash flow model is created, inspired by a case study of the development of desalination projects in Qatar. This model uses deterministic projection of water demand to evaluate the total costs associated with the construction and operations of the desalination plant. While there are uncertainties associated with both of these costs, for the purposes of this assessment this uncertainty is ignored.

![Figure 2-1 Overview of Evaluation Framework](image)

The second element is the socio-economic analysis. Considerations of socio-economic impact focus on modelling the demand for desalinated water. A stochastic water demand model based on Qatar’s socio-economic conditions is built using an Excel-based, @Risk probability modeling tool. A Monte Carlo simulation is then used to sample various water demand scenarios to evaluate the performance of the desalination plant under stochastic conditions. Alternative design cases with different capacity expansion rules, selected mainly to illustrate the potential range of flexibility, are then evaluated and compared to the base case to evaluate the potential value that flexibility adds to the system.

The third element of the framework is the institutional analysis. Institutional considerations focus solely on contractual arrangements between project participants. Base contractual approaches typical of desalination processes are identified and various contractual scenarios are then defined by varying the typical terms of the base contractual approaches to illustrate the range of potential
contract scenarios. The stochastic cash flow models are used to conduct waterfall analyses to show the distribution of value between the private and public sector for each of the design cases under each of the contractual scenarios. For each contract scenario, the flexible design cases are compared to the base inflexible case under that contract scenario to get an indication of the relative performance of flexibility. In addition, the existing stochastic models are also used show the distribution of risks that each of the design cases, contractual arrangements and their interactions pose on public and private participants. Particular attention is paid to expansion, performance, and renegotiation risks.

The final element of the framework is the behavioral analysis. The decision to adopt flexibility depends both on the consideration of the gains and risks from the adoption of flexibility to each participant as well as from the interaction of the individual decisions made by each of the participants. A simple game theoretic model is used to explore how the interaction of the decisions shapes the flexibility that is ultimately adopted.

**Table 2.1 Summary of Analytical Methods**

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Chapter 3 Desalination and the Provision of Water

The first step to the evaluation of the adoption of flexibility for a desalination project is to understand the broader context in which desalination projects are pursued. The chapter begins with a description of the nature of the water problems faced by various regions around the world and the potential of desalination to address these problems. It describes some of the technical aspects behind desalination as well as the institutional ways in which desalination projects are developed. The chapter then considers the particular water context of the Arabian Peninsula and the role of desalination in that region. The chapter concludes by considering a case study of the development of desalination capacity in Qatar. This case study provides the background that inspires the various models and the analysis that are used throughout the rest of the thesis.

3.1. Desalination

The success of water infrastructure relies on the careful management of physical infrastructure in the face of changing social and environmental conditions. This has always been the case of water infrastructure, from the earliest Mesopotamian canals to modern hydroelectric dams. Despite this long history and experience with managing water, however, as seen in Figure 3-1, water scarcity today is an issue that affects many areas of the world.

Figure 3-1 A Picture of Global Water Risk – Red indicates higher risk. Source: WRI.org
Despite the widespread prevalence of water problems, there is not a global water problem per se. Rather, there are many different kinds of challenges, the different combinations of which affect different regions in different ways. The increasing uncertainty in both the availability of and demand for water are perhaps the two most common contributors to water problems around the world. Changing climate patterns everywhere are affecting both the timing and quantity of rainfall and ice melt, fundamentally reshaping the availability of water. These changes are occurring in the face of increasing global populations and water demand.

Beyond these two broad global trends, however, the challenges associated with the provision of water vary from city to city and region to region. The availability of water depends to a large part on both the natural geological features of a particular region as well as man-made features like pipes and canals. The lack of water in a particular region could be as much a result of a lack of rainfall as it could be a result of poor maintenance. In some areas human-caused destruction of traditional recharge mechanisms, whether natural or man-made, has been a factor in reducing water availability. In other areas, industrial activities and poor water management practices have led to the deterioration of water quality, making it unsuitable for consumption. Just as a variety of factors lead to uncertainty with the supply of water, uncertainties in water demand can also arise for different reasons. In some regions the issue is not due population growth as much as it is due to changing the crop-mix or through increased industrial activities. All of these micro-trends interact with different local conditions including geology, institutions and even culture, to create a myriad of diverse challenges and water risks.

Because of the varied nature of the water problems around the world, approaches for managing water need to be tailored to the situation at hand. Some areas of the world have turned to complex capital-intensive approaches, like the construction of dams and water recycling facilities as a way of managing water supplies. Other areas have sought less capital-intensive approaches focused on institutional reforms. The experience of the last two decades points to the increased need for a

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1. The destruction of traditional temples in Chennai which traditionally also housed water reservoirs are thought to have contributed to the of the reduction of the recharge of the underground water aquifer (Ganesan, 2008)
2. Chennai, India and the Punjab region of Pakistan both present well-documented examples of the role of poor water-management on the deterioration of water quality and subsequent water scarcity. See Malik and Briscoe 2006 and Briscoe and Qamar 2008 for more information.
3. Two famous examples include Windhoek, Namibia and Singapore City, where recycled wastewater is mixed in with municipal drinking water.
4. The Gujarat region in India provides a good example whereby a restructuring of the electrical infrastructure, coupled with some economic development initiatives were used as a way of curbing groundwater pumping (Shah and Verma, 2008)
portfolio approach to managing water and this in turn has led to a shift in the water-management approach of global institutions including the World Bank (World Bank, 2003).

**Desalination Technology**

Desalination is an important tool in the broader water management portfolio. Desalinated water is relatively immune to changing environmental and social conditions compared to other sources of water. Desalination processes do not depend on rainfall nor are they affected by geology. The availability of water does not require changes to human consumption habits nor is it as susceptible to human pollution. This robustness and reliability, however, comes at a relatively high price in terms of cost per unit of water produced (2030 Water Resources Group, 2009).

At its most basic, desalination is a process that uses energy to remove impurities, namely salt, from water. Most desalination plants are designed to treat either seawater or saline groundwater. The desalination facilities themselves can take a wide number of forms, ranging from small units for the desalination of ground water for use in the immediate vicinity of the unit, to large desalination plants used for providing water to municipal water grids. There are three major components to a desalination plant: the intake/outfall, a pre-treatment unit and the processing unit itself.

![Figure 3-2 Global Desalination Capacity (94 million m^3/day). Data: Desaldata.com](image)

As shown in Figure 3-2, much of the world’s desalination infrastructure is located in the Gulf Cooperation Council (GCC), a group of six nations on the Arabian Peninsula. Commercial-scale desalination plants were first commercialized in the 1970’s. These early plants were based on thermal processes, Multi-Stage Flash (MSF) being the most widespread. Thermal processes apply heat to water in order to separate the water from the salt. Due to the high energy requirements
associated with the technology, the technology is considered to be prohibitively expensive (World Bank, 2004). The major exception is in the GCC, where the abundance of cheaply-produced oil and gas resources coupled with what are effectively energy subsidies have allowed the technology to be commercially viable. Today roughly 85% of all global MSF capacity is located in the GCC (Desaldata.com).

A shift in desalination technology came with the development and refinement of Reverse Osmosis (RO) desalination. Instead of relying on thermal processes, RO relies on the use of special membranes that can separate salt from highly-pressurized water. Because of its greater energy efficiency, RO delivers water at much lower cost than MSF (World Bank, 2004). As shown in Figure 3-3, this has led to a boom in the spread of RO desalination facilities over the last decade. Today RO makes up roughly three quarters of all desalination plants by capacity for all uses and 60% of seawater desalination plants (Desaldata.com).

![Figure 3-3 Global trends of desalination technology. Data: Desaldata.com](image)

**Design Considerations for a Reverse Osmosis Plant**

There are two general design approaches to RO design. The first, and the most common one, is the modular approach. Under this approach raw saline water first passes through a common intake and pre-treatment plant. The pre-treated water is then distributed to a number of desalination trains. Each train consists of pumps, membranes and heat recovery units, where impurities are separated from the raw water. A post-treatment unit can then be used if required to get the final product water to the required specifications. Brine is usually discharged through an outfall. The modular approach can achieve availabilities of up to 95% (Voutchkov, 2012).
For higher availabilities, plants have to be designed using a centralized, non-modular approach. Instead of the trains discussed above, three centers are built, one for pumps, one for membranes and one for heat recovery. This allows both for higher availability (>95%) as well as greater variations in water production rates to better match water demand scenarios (Voutchkov, 2012). Given their less modular nature, however, these designs are more difficult to expand.

The use of the modular approach allows for more flexibility in capacity expansion. Rather than having to conduct an intensive overhaul of the system, so long as space is available and the site has been sufficiently prepared, modular units can simply be added to an existing plant to expand capacity. Modular RO plants are usually built in self-contained process units of up to roughly 20,000 m$^3$/day in order to take advantage of economies of scale associated with the ready availability of off the shelf equipment (see Figure 3-4). These units contain the main RO membranes, pumps and heat exchangers. Both pre and post treatment units are also modular. These units are typically arranged in trains of up to a total capacity of 200,000 m$^3$/day. Anything larger than this results in operational complexities and so this is seen as the upper end for a single RO plant. Plant capacities beyond 200,000 m$^3$/day are achieved by constructing a new plant. It is common practice to design large plants with an intake that can accommodate future expansions sometimes by as much as 100% (Voutchkov, 2012).

![Figure 3-4 economies of scale. Data: Voutchkov 2011](image)

While incremental expansion of the capacity of desalination plants is possible, to date expansions tend to be on a much larger scale. The Fujairah 1 desalination plant in the UAE, for example, was designed to be expanded in a single large expansion. The original 170,000 m$^3$/day plant came
online in 2013 and a 136,000 m3/day phase expansion is planned for 2015 (Desalination.com, 2013). Hyflux’s TuasSpring RO plant in Singapore appears to be equipped with the provisions to allow for incremental, small-scale expansion (Wong, 2013); these expansions, however, have not yet occurred. There are a few examples of relatively small-scale expansions in Israel with the Asheklon, Hadera and Palmicham desalination plants. These expansions were incremental in size, ranging up to 20% of the base capacity (up to 70,000 m3/day). The Israeli plants are for the most part designed using the centralized, non-modular approach (Faigon et al., 2012, and Sauvet-Goichon, 2008); these expansions, therefore, were likely not modular and may have been intensive.

3.2 PARTNERSHIPS AND DESALINATION

There are two key participants in desalination projects, public agencies responsible for the provision of water and private firms that provide a variety of desalination-related services. The overall municipal water sector, which usually includes the distribution of water to the general population from many sources, is largely dominated by public agencies. While there are examples of successful private water providers, such as in England, Chile and Manila, private water companies serve a small portion of the world’s population. In 2007, public agencies made up over 90% of the total market as measured by the number of people served (Marin, 2009). Furthermore, the provision of water by the private sector has proven controversial, both because of the monopolistic nature of the market\(^5\) and due to a small number of high profile failures such as the case in Cochabamba, Bolivia\(^6\). Because desalination plants are largely used for the purpose of providing water for municipal purposes, as shown in Figure 3-5, the public sector is a significant player in the development of desalination projects and is typically the key project proponent responsible for awarding projects.

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\(^5\) The top two or three firms control anywhere from 50%-70% of the global water market. See OECD, 2003 and Lobina, 2005.

\(^6\) For an introduction to this controversial event, see the PBS documentary: Bolivia - Leasing the Rain
The private sector participants in desalination projects typically consist of specialty firms that have expertise in desalination-related engineering, development, construction and operations. Participants in the market for large-scale saltwater RO plants include Veolia, Hyflux, IDE, Degremont and Acciona, amongst others. These firms are large conglomerates that, either in-house or through coalitions, offer complete technical packages that include engineering design, construction and operations. The desalination market is only slightly more competitive than the overall private water market. While the largest five firms that provide Seawater RO (SWRO) plants only account for 38% of the total SWRO desalination capacity world-wide, they make up 50% of the large (>50,000 m3/day) SWRO plants.

**Figure 3-5 Seawater desalination Capacity by end costumer. Data: Desaldata.com**
PARTNERSHIPS AND DESALINATION
As seen in Figure 3-7, project partnerships between the public agencies and private firms can take many forms. The two ends of the spectrum are defined by the cases when either the public or private sector retains complete ownership and operations of the infrastructure asset. Any kind of partnership between the private and public sector to jointly operate the asset can in some sense be referred to as a private public partnership (PPP).

There are two main reasons why a public agency might choose to pursue PPP in the development of infrastructure projects. First of all the inclusion of private firms in an infrastructure project is thought to result in more efficient and therefore cheaper operations (Hallmans and Stenberg,
1999). Secondly, the use of PPP’s may lead to a reduction in the financing costs and can also lead to a reduction in public debt (Wolfs and Woodroffe, 2002). This latter option is a particularly enticing for public agencies with limited financial resources and is likely to be a main cause behind the use of PPP in the provision of water (Brenck et al., 2005).

An important caveat is that the appropriateness of PPP’s need to be considered on a case-by-case basis. While PPP’s can lead to better performance because of the closer integration of operations and design, governments with enough in-house experience can achieve the same results without relying on PPPs (Voutchov, 2012). Furthermore, public agencies may find themselves in a poor capacity to negotiate with large conglomerates and better off running the projects themselves even if they do so less efficiently (Lobina, 2005).

**PROJECT APPROACHES TYPICAL IN DESALINATION**

Despite this large variation in the approaches to partnership, partnerships typical to desalination projects can be grouped into two broad categories, Engineering-Procurement-Construction (EPC) and Build-Own-Operate-Transfer (BOOT). There no standard nomenclature to describe contract types and various sources may describe different partnership structures using different names. EPC contracts represent the traditional way in which infrastructure is developed. The public agency retains complete ownership of the desalination facilities. The role of the private sector in this case is to act as a service provider. The public agency contracts third parties for the actual engineering design, construction and sometimes even the operations of the facility. The public sector guarantees a payment to all private sector participants usually based on cost and with some allowance for a profit (Grimsey and Lewis, 2004).

BOOT contracts reflect a newer approach to developing desalination projects. In a BOOT contract the private firm’s role is to finance, design, build and operate the desalination plant. The public agency acts as a client that is paying the private firm for the provision of water. The private sector is compensated not on a cost basis, but rather on a performance basis; it either sells water directly or it receives an availability payment from the public agency based on the production of water (Weber and Alfen, 2010). Two general reimbursement approaches are used to pay the private sector, either a fixed price or a fixed return on capital. Theoretically both approaches should lead to the same result if the fixed price is adjusted on some temporal basis (Ian et al., 1996). Fundamentally both approaches tie the private firm’s income to the actual water demand. Broadly speaking, as shown in Figure 3-8, these contracts are used roughly equally to develop large desalination projects. Design-
build-operate (DBO) contracts are similar to EPC contracts except that the private firm also operates the plant.

An important distinction between these two types of contract lies in the way that they allocate risks and responsibilities between project participants. Three categories of responsibilities are of particular importance to our discussion:

- **Construction and Operations Risks**: This includes the risk of not completing the construction of the project on time, on budget and according to the agreed upon water quality and quantity. In addition these can include the risks of not completing the expansion of existing capacity on time or on budget.

- **Water Demand Risks**: Water demand risks refer to the chances of changes to the water demand or water price causing the plant to run at under capacity or resulting in a significant reduction in income from selling water. This is a particular concern where there are alternative sources of water that may be price competitive with desalinated water which can cause swings in both water demand and price.

- **Financial Risks**: Financial risks refer to the risks and challenges of raising financing for desalination projects.

Both EPC and BOOT contracts allocate all of the construction and operations risks to the private firm. The main differences between the contracts lie in how they allocate financial and water...
demand risks. The costs of municipal-scale desalination facilities are usually in the range of hundreds of millions of USD. Under an EPC contract the burden of raising the funding necessary to construct and operate the desalination project is borne by the public agency. The public agency can fund the project from government budgets or raise debt on the state’s balance sheet.

One of the main features of BOOT contracts, and one of its greatest selling points to public agencies, is that it shifts the burden of funding onto the private firm. Private firms typically seek to raise debt from any number of lending sources including banks. Rather than raise the debt against its own balance sheet, however, private firms under BOOT contracts typically raise non-recourse debt on the project itself. In case the project is not commercially successful and cannot pay back its debt, lenders can only make claims against the project. The private firm is not liable for any compensation to the lenders.

Along with financial responsibilities, however, BOOT contracts also shift water risks onto the private firm, at least in theory. Under EPC contracts, the private firms’ costs are guaranteed by the public agency regardless of the water demand. Construction costs are completely reimbursed to the private firm as they accrue, as are operations costs; the private firm bears no risk. Under BOOT contracts, however, part of the water demand risk is shifted to the private firm.

Shifting the risks associated with water demand creates a big challenge for raising finance. In the absence of recourse to company balance sheets and guaranteed repayment, as is the case with traditional loans, lenders are left with project revenue stream as the only source of repayment for their debt. The more risky that this source of revenue is, the higher the likely cost of raising debt (Voughtov, 2012). Given the large investment required to construct desalination projects, exposing the project’s income stream to water demand risk may not only raise the cost of finance, but might actually lead to the inability to finance the project at all (Wolfs and Woodroffe, 2002).

One of the ways in which the uncertainty surrounding project revenue streams is reduced is through the inclusion of capacity payments in the water purchase agreements associated with desalination projects. The water purchase agreement is one of the key elements of a BOOT contract. This agreement specifies the terms under which the private firm will be reimbursed for water production or sales. One of the main provisions of this contract is typically a capacity payment referred to as a take or pay clause. This capacity payment usually specifies a minimum amount of water sales that the public agency guarantees to the private firm reducing the amount of the water
demand risk on the project itself (Vouchkov, 2012). Capacity-plus-volume and fixed take or pay structures are the most commonly used capacity payment structures (Wolfs and Woodroffe, 2002.)

While a number of concerns have been raised regarding capacity payments, take or pay is today a typical part of most BOOT agreements. Variations on the BOOT contracts with take or pay clauses have been used for desalination projects throughout the world in both developing and developed nations. The Wonthaggi plant in Victoria, for example, uses a BOOT contract under which the local government pays both a fixed capacity payment and a variable one based on actual water consumption to the private firm. The desalination plant that is currently under development in Carlsbad, California is also a BOOT that uses a take-or-pay contract under which the San Diego County Water Authority has to purchase between 48,000 and 56,000 Acre Feet per year (AFY) of water at a price that ranges between 2290 and 2041 USD per AF. The Singapore Tuas Desalination Plant (Chowdhury, 2011) and both Hadera (Faigon et al., 2010) and Ashkelon (Sauvet-Gauchon, 2009) in Israel are BOOT plants with take or pay elements in their contracts. The Ashkelon desalination plant is a BOOT project run as a partnership between Veolia, IDE Technologies and Elran Infrastructure. It has a performance requirement for 110,000 million m3/yr of which the public authority has an obligation to purchase 100,000 million m3/yr. Abu Dhabi’s Al Taweelah’s water and power plant uses a BOOT structure that has both a capacity and variable payment element (Wade, 1999).

### 3.3 WATER AND THE ARABIAN PENINSULA

The oil-rich, water-scarce nations of the Gulf Cooperative Council (GCC), share similar water challenges, characterized by scarce natural water resources coupled with relatively large demand for water. These factors have led both to an over-extraction of natural water resources as well as the reliance on desalination for drinking water.

**Renewable Sources of Water**

The Arabian Peninsula is for the most part an arid desert. While the Southern and Western coasts of the Peninsula receive modest amounts of rainfall, the majority of the Peninsula receives a low annual rainfall ranging from 59 mm per annum in Saudi Arabia to a high of 125 in Oman (FAO Data,

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The relatively low rate of rainfall and high evaporation rates have led to a renewable supply of water that, with the exception of Oman, is not sufficient to meet the water needs of the region. As shown in Figure 3-9, the total regional demand for water outstrips the total renewable water supply by almost seven times.

**Figure 3-9 sustainability of water consumption. Data: Aquastat**

**WATER DEMAND**

As seen in Figure 3-10, while the average water consumption intensity per capita in the GCC is comparable to water consumption figures from some selected high-income countries like Japan and Norway, it is nearly four times the average consumption of neighboring Middle Eastern countries. While the demand breakdown varies from country to country, surprisingly for a region with low agricultural production, the largest source of water demand is agriculture, making up roughly 85% of the total regional water demand. Much of this demand is due to various agricultural policies that have been pursued throughout the GCC designed to improve food security (Al-Zubairi, 2008). These policies have included both the provision of agricultural subsidies as well as the free use of groundwater resources.
Figure 3-10 Water consumption in various countries. Data: Aquastat

As shown in Figure 3-12, the deficit in freshwater demand is met in three ways: non-renewable groundwater withdrawals, desalination and wastewater reuse. Groundwater is the largest source of water in the GCC, making up roughly 90% of the total water supply. This amounts to almost 75 million m³/day of water, or almost 6.5 times the renewable groundwater extraction rate. There are two concerns associated with this high level of groundwater extraction. First, extracting more groundwater than can be naturally replenished causes the ingress of saltwater into the
groundwater reservoirs, potentially leading to the long-term deterioration of the water quality in the reservoirs. Secondly, several countries in the region, including Saudi Arabia, have begun drilling into non-renewable sources of groundwater (Al-Zubairi, 2008), which are essentially fossil water trapped in deep reservoirs since the last ice-age. As seen in Figure 3-13, the unsustainable water extraction rates vary tremendously from country to country. This source of water is almost exclusively used for agriculture. Deterioration in water quality has already been observed across the Gulf (Al-Zubairi, 2008, and Aquastat, 2008) and concerns over the depletion of this resource have led certain countries, like Saudi Arabia, to reconsider their agricultural policy. 

![Figure 3-12: Sources of Water Supply for the GCC. Data: Aquastat](image)

*Figure 3-12: Sources of Water Supply for the GCC. Data: Aquastat*

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9 See the article: “Saudi Scraps Wheat Growing to Save Water.”
Non-agricultural water demand, including both municipal and industrial demand, is almost exclusively met by desalination. While RO technology has seen broad application around the world, there has been some resistance to the use of this technology in the Arabian Peninsula. The region is considered to be a bastion of thermal desalination technologies, benefiting from energy and extensive operations and design expertise. RO has been relatively slow to catch on in the region. The earlier versions of RO membranes were not suitable for use in the water conditions of the Persian Gulf, leading to failures and poor reliability (WorldBank, 2004). However recent developments of the membrane technology have overcome this challenge and as seen in Figure 3-14, there has been increased adoption of RO technology over the last decade.
Qatar is a small rapidly developing nation on the Arabian Peninsula. It is marked by having one of the world’s largest GDP per capita. This is a reflection of both its small population, approximately 2 million people as of 2014, and its large income based on oil and gas resources. Much of this wealth followed from the rise in oil prices in the early 2000’s and the development of the world’s largest LNG exporting cluster. Like the rest of the Arabian Peninsula, Qatar is a water scarce nation. It has no permanent bodies of surface water, a low annual average rainfall of 80 mm and limited fresh groundwater resources. At the same time, given its lack of water resources, the country has a high water demand, well over its natural renewable supply of water (Aquastat, 2008).

As shown in Figure 3-15 agriculture makes up almost the majority of the total water demand. As with the rest of the GCC, agricultural water demand is met exclusively through freshwater drawn from scarce groundwater resources (Figure 3-16). This results in a net extraction rate (mining) of 150 million m3 per year, almost three times the natural replenishment rate\(^\text{10}\). To date this has caused deterioration in groundwater quality and quantity resulting in the abandonment of farmland (Al Muraikhi, 2008).

\(^{10}\text{Mining refers to net aquifer extractions minus returns from rainfall and seepage back to the aquifer after application on farms (Aquastat, 2008).}\)
Qatar’s municipal water demand, which accounts for almost 40% of all water use, is entirely met through desalination from the Persian Gulf. Desalination capacity is entirely dominated by thermal processes, mainly Multi-Stage Flash (MSF). Qatar currently lags the region in terms of large-scale Reverse Osmosis (RO) capacity.
THE STRUCTURE OF THE QATARI WATER SYSTEM

There are two key players in the Qatari water system: Qatar General Electricity and Water Corporation (Kahramaa) and the Qatar Electricity and Water Company (QEWC). Kahramaa is responsible both for buying and distributing water and power from the private sector, as well as planning and tendering for new water and electricity capacity. QEWC is the main private sector player that sells water and power to Kahramaa. QEWC is roughly 40% owned by the government with the remainder of its shares traded on the Qatari stock exchange. All water and power generation facilities previously under ownership and operation of Kahramaa were transferred to QEWC over the last two decades as part of a national privatization drive. Furthermore QEWC is also a major shareholder in all desalination plants in Qatar.

Water Planning in Kahramaa

Water planning in Kahramaa occurs on a five year rolling basis. Water demand forecasts are made for five-year periods based on information provided by the General Secretariat for Development Planning (GSDP). The GSDP compiles all macro indicators including population forecasts, industrial activity, economic activity, etc. It then uses this information to come up with a set of scenarios for water demand. Kahramaa in turn translates these scenarios into probabilistic distributions (P90, P50, P10) and conducts its planning based on the P50 demand forecast. Forecasts of water supply are based on the assumption of that the water desalination system can operate at full capacity. If water demand is forecast to meet or exceed supply at the end of the five-year period, Kahramaa issues a tender for additional water generation capacity. The typical capacity expansion cycle takes five years from the point of tendering to the point of start-up and the capacity is expected to meet demand for 10 years.

Once Kahramaa decides that there is need for additional desalination capacity, it issues a tender for additional capacity, usually only specifying capacity and leaving the technology choice to the potential bidders. Kahramaa then evaluates the tenders based on both technical competence as well as a levelized cost per m3 of water for a 25 year contract. While the tenders are open to private sector bidding, the projects are usually constructed as part of a consortium that includes QEWC.

3.5 Uncertainties Affecting Desalination:

There are many sources of uncertainty that can influence the performance of a desalination plant.

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11 The information in this section is largely based on interviews with various representatives from both Qatari government agencies and Kahramaa
Key amongst these are the uncertainty in water conditions, technology and perhaps most importantly, demand for desalinated water. Desalination plants, and especially those that use RO technology, are highly sensitive to water conditions, including the level of the incoming seawaters’ salinity, temperature, biological matter and pollution. A typical practice for many large RO plants is the construction of a pilot plant (> 40,000 m3/day) for a period of up to six months to test water conditions and ensure that the desired performance can be met (Voutchkov, 2012). Changes to the water conditions can increase the costs of production either through increasing the need for energy to desalinate the water or by increasing the need to replace membranes due to fouling. Furthermore an increase in the level of pollutants in the incoming water might require the need for additional treatment of the water in order to meet drinking quality standards. The occurrence of oil spills, nuclear contamination and other extreme pollution of the water source, can even potentially lead to the complete shutdown of plant operations for a period of time.

In addition to its direct effect on the performance of desalination plants, water conditions may also indirectly affect plant performance due to environmental considerations. There are already some indications that the increased effluent discharges from desalination plants to the GCC may have an adverse impact on the marine ecosystem (Al-Barwani, 2008, and Daoud, 2012). This in turn could lead to potential disruptions to desalinate production in order to protect the environment.

Technology is a second source of uncertainty that can impact plant performance. Uncertainty in technology is related to the fact that future technology can lead to improved desalination performance. While desalination might be a mature technology as a whole, aspects of it are still experiencing rapid development. In particular there are constant improvements to the desalination membrane technologies. As mentioned earlier, the improvements in membranes were one of the key factors that allowed the deployment of RO in the GCC. Besides these performance improvements, changes to the technology can provide ways of ameliorating the negative impacts cause by deteriorating environmental conditions.

The greatest source of uncertainty related to desalination, however, is uncertainty in water demand. There are two general sources of variation in water demand, cyclical and noncyclical. Cyclical variations in desalinated water demand arise from changing diurnal or seasonal consumption patterns. These changes in consumption can be quite significant. Tourism-dependent economies, for example, can encounter an almost doubling of water demand during peak tourist seasons, as is the case in Gibraltar (Darton and Buckley, 2001). Even in less tourism-dependent
areas, however, there can be significant seasonal variations in water demand. The Hadera desalination plant in Israel for example, exhibits significant seasonal variations in water demand, which ranges from 9.65 M m3 per month in the winter season to 11.8 M m3 in the summer months (approximately a 20% variation) (Faigon et al., 2012). These same cyclical variations are also exhibited in the GCC. A desalination plant in Sharjah, an emirate in the UAE displays a 10% variation in demand over the year (Al Mulla et al., 2005). As part of the design of Taweelah desalination plant, another project in the UAE, a 20% reduction was expected during the winter months (Wade, 1999). While these variations are important to keep in mind, they are not uncertain and are therefore not considered further in terms of characterizing the uncertainty of Qatari water demand.

Non-cyclical water demand uncertainty is related to the growth of the underlying population and overall increases in the demand for water. This is a particular issue for Qatar. There are two major components to the desalinated water demand in Qatar: municipal drinking water and industrial demand. Industrial demand makes up roughly 10% of the total desalinated water demand. As part of their approval process, all new industrial activities must submit their projected water demand based on full capacity estimates to Kahramaan three years in advance of the desired water supply starting date. Approval to commence the construction and operations of the industrial facility is conditional on the availability of water to meet the demand. This portion of water demand has relatively low levels of uncertainty.

Demand for municipal drinking water, on the other hand, is anything but steady and predictable. This is mainly due to the nature of Qatar’s population and the patterns of population growth. Qatar’s population consists of two segments, Qatari nationals and expatriates. As can be seen in Figure 3-18, population has been steadily increasing since the 1960s with an average growth rate of 7.2%. Growth rates, however, are tremendously variable. Since 2000, growth rates have varied from almost 2% to 18%. Much of this growth and the variation are explained by the presence of temporary migrant labor in the construction industry, which makes up roughly 27% of the total population (Qatar Information Exchange). Due to the size of some of the projects, with individual construction projects employing the equivalent of 5% of the total population, single decisions on projects can actually have marked impacts on the nation’s population.
Figure 3-18 Historical data on population growth. Data: World Bank

Not only does the nation’s population growth exhibit high variability, but this variability is also highly unpredictable. Qatar is a small nation with tightly controlled borders. The issuance of work visas are tightly regulated and in theory should allow for some regulation in population growth. However the history of the expansion of water desalination capacity suggests that this is not the case. Water desalination capacity has not been able to keep up with the speed of growth. According to DesalData.com’s country profile on Qatar, most desalination projects in the last decade actually had to be constructed on a fast track basis in order to keep up with the unexpected increase in water demand. There were at least five major desalination projects that have come online over the last decade or so. As can be seen in Figure 3-19, these projects were spread in an ad-hoc manner over the decade.
The uncertainty surrounding population growth rates and their associated water demand is likely to continue in the near future. Much of the growth in population in Qatar is driven by the large investment in national infrastructure. This in turn is driven by the ballooning of the national GDP per capita over the last decade caused by the both the increase in the prices of energy as well as the expansion of the Qatari LNG sector. These infrastructure trends are likely to continue into the future (Ibrahim and Harrigan, 2012). Much of this infrastructure is related to preparations for hosting the FIFA 2022 World Cup which could draw enough spectators to cause a 10% increase in total population. Given the history of Qatar’s experience with water demand and the uncertainties surrounding the phasing of the expansion of the infrastructure, the variation and unpredictability of population growth in the next decade is still likely to cause large uncertainties in the demand for drinking water.
Chapter 4 **Flexible Approaches to Desalination**

Flexibility can help in the management of the kinds of uncertainty previously discussed. The chapter begins by considering a traditional, deterministic approach to the evaluation of an “inflexible” desalination project. Then same desalination project is evaluated using a stochastic approach. Finally, four alternative desalination design cases are identified, each with a different capacity expansion strategy. These designs are also evaluated using a stochastic approach and are then compared to the inflexible case. This chapter demonstrates the potential value that the use of flexible desalination designs can add to the desalination project.

### 4.1 Baseline Model

The first step of the analysis is to build a baseline model of the desalination plant. This model will serve as the base from which all further analysis occurs and is inspired by the development of a desalination plant in Qatar. There are three important aspects of the baseline model: water demand, technical specifications, and financial assumptions.

**Determining the Water Demand**

**Water Allocation Strategy:** The water allocation strategy assumes that new plants are marginal to the existing system. Under this strategy the entire system is fully supplied through commitments from other sources that cannot be reduced. Any new water desalination capacity is only used to meet water demand that is greater than the base water demand in 2015.

**Water Demand:** Based on the water allocation strategy, water demand is modeled using a probabilistic distribution. The overall demand for water is modeled by multiplying a water intensity factor by total population figures. The water intensity factor is found by dividing current municipal water consumption figures by the population. It is assumed that this factor remains constant for the life of the plant. In reality this factor is likely to drop with time given current government policies to try to reduce water consumption, but this effect is likely to be slight and so is ignored for this analysis.

Under this water demand model, population growth is the major source of uncertainty. Population growth rates are modeled by defining two independent probability distributions in @Risk, where each distribution represents a different portion of the population. The annual growth rate of the permanent population, which is assumed to consist of 750,000 people, is modeled using a normal distribution centered on 2% annual growth rate (Figure 4-1). The annual growth rate of the
migratory population, which is made up of 900,000 construction and other project related labor, is modeled using a uniform distribution of annual growth rates ranging from -3% to 12% (Figure 4-2). A uniform distribution is used to model the temporary population because of the tight relationship between this population and construction projects and the assumption that construction projects can start or end in any year.

![Comparison with Normal(2,2.8053834...)](image)

**Figure 4-1** Normal distribution for permanent population growth
Desalinated water demand is calculated as follows:

1. The Monte Carlo simulation samples a growth rate for every year of the plant’s operation from each of these two distributions.
2. The total subgroup population is calculated for every year based on growth from the previous year.
3. The total population is calculated by adding the two subgroups together.
4. Total water demand is calculated by multiplying total population by water intensity.
5. Marginal water demand is calculated by subtracting the base water demand (i.e. water demand in 2015) from the total water demand.

**TECHNICAL SPECIFICATIONS**

**The Scope of the Plant:** The plant is a stand-alone Reverse Osmosis desalination plant. The plant requires its own dedicated sea-water intake, pre-treatment and disposal system. The plant will tie in to the existing water distribution system and the electric grid and so does not require any additional distribution pipelines or electricity generation capacity.

**Plant Timelines:** Construction of the plant will take 12 months. This is perhaps slightly faster than average as average plant construction times typically range from 12-24 months (Voutchkov, 2012).
Construction is expected to start in the year 2015 and operations are expected to commence in year 2016.

**The Size of the Plant:** Based on the expected marginal water demand presented in Figure 4-3 and the discussion with Kahramaa regarding the use of the P50 water demand as the basis of desalination capacity-sizing, the plot area of the plant is be sized to allow an ultimate desalination capacity of 400,000 m³/day.

**Capital Costs:** Capital costs for the proposed desalination plant include intake and outfall costs, pretreatment costs and process costs amongst others as described in Table 4-1. The total capital costs of the desalination plant are approximately 215 million USD per train for a total cost of 430 million USD for the entire 400,000 m³/d capacity plant. All cost information is taken from DesalData's plant cost estimator for a 200,000 m³/day RO plant in Qatar.

**Table 4-1 Desalination Capital Costs**

<table>
<thead>
<tr>
<th>Intake / outfall</th>
<th>$17,229,310</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumps</td>
<td>$21,536,640</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>$18,306,140</td>
</tr>
<tr>
<td>Installation and services</td>
<td>$17,229,310</td>
</tr>
<tr>
<td>PVs</td>
<td>$3,230,500</td>
</tr>
<tr>
<td>Design and professional costs</td>
<td>$11,845,150</td>
</tr>
<tr>
<td>Membranes</td>
<td>$10,768,320</td>
</tr>
<tr>
<td>Piping/high alloy</td>
<td>$25,843,960</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>$39,842,780</td>
</tr>
<tr>
<td>Equipment and materials</td>
<td>$47,380,600</td>
</tr>
<tr>
<td>Legal and professional</td>
<td>$2,153,670</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$215,366,380</strong></td>
</tr>
</tbody>
</table>

**Operations Costs:** Operating costs have both a fixed and a variable component. Variable costs are calculated on an annual basis and are based on water volumes per day. These costs include chemical costs, membrane replacement, and brine disposal.
Fixed costs include labor, maintenance, environmental monitoring and other overhead costs. Fixed costs are incurred on an annual basis and are based on installed capacity regardless of utilization. All costs are based on information presented in Voutchkov 2012. Energy costs are calculated assuming an average RO plant efficiency of 3.1 kw per m3 of water produced. An average energy tariff of 0.06 USD/kWh is assumed.

**Table 4-2 Assumptions regarding operating costs**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Avg Cost (USD/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical (USD/m3)</td>
<td>0.05</td>
</tr>
<tr>
<td>Membrane Costs</td>
<td>0.045</td>
</tr>
<tr>
<td>Disposal</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td></td>
</tr>
<tr>
<td>Consumption (kw/m3)</td>
<td>3.1</td>
</tr>
<tr>
<td>Energy Tariff (USD/kWh)</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Fixed</strong></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>4%</td>
</tr>
<tr>
<td>Labor</td>
<td>0.03</td>
</tr>
<tr>
<td>Environmental monitoring</td>
<td>0.01</td>
</tr>
<tr>
<td>Other</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Financial Assumptions**

**Inflation:** Inflation is not included in this assessment. All values are real.

**Taxes:** A zero-percent tax rate is assumed.

**Discount Rates:** Discount rates are fixed at 10% for the purpose of the assessment. This assumption is tested as a sensitivity.

**Evaluation Period:** The plant is evaluated over a 20 year period.

4.2 Technical Context: Discounted Cash Flow Model

The first step of the analysis is to evaluate the baseline model described above under a purely technical, deterministic context. In order to do so, a deterministic water demand, based on the P50

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12 Energy tariffs in Qatar actually range from 0.07 to 0.15 DHS/kWh (0.02-0.04 USD/kWh). Industrial rates are at the lower end of this range. See http://www.km.com.qa/en/customer/pages/rateinformation.aspx
value of the stochastic distribution described in the baseline model, is used to size the plant capacity. As shown in Figure 4-3, the plant is sized for a 400,000 m$^3$/day capacity to be able to meet the expected water demand in 2025. It is important to note that in reality the plant would likely be sized according to some factor of the P50 water demand, but for simplicity, it is assumed that the P50 is used as is. In order to take advantage of economies of scale as discussed in Voutchkov 2012, the plant is designed as two identical trains of 200,000 m$^3$/day each. Both of these trains are built prior to the first year of operations. All capital costs are incurred in the first year of the project’s life. Operations costs are calculated by multiplying the expected water demand with the variable cost and by calculated the fixed costs as per the initial installed capacity.

**Figure 4-3 The expected value of the water demand**

As shown in Table 4-3, the PV of the total capital costs for the construction of this inflexible desalination plant are fixed at roughly 430 million USD. Operating costs, based on the water demand described earlier are equal to 477 million USD. The present value of the total costs is 908 million USD.

**Table 4-3: Capital and total costs of the Deterministic design approach (PV mil USD)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>$431</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>$477</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$908</td>
</tr>
</tbody>
</table>
4.3 Socio-Economic Context: Stochastic Models

The second step in the analysis is to analyze the same inflexible plant, but this time with consideration of the particular socio-economic context in which the plant operates. As described in the previous chapter, the water demand situation in Qatar is highly uncertain due to the socio-economic factors surrounding water demand. Rather than using a deterministic P50 estimate to predict water demand, a stochastic approach is used that considers the entire water demand distribution.

Figure 4-4 shows a comparison of the expected water demand used for the deterministic case and some sampled outputs of the simulated water demand. The simulated water demand is generated using the stochastic water model described earlier. As shown, the stochastic water demand can be completely under or over the expected water demand. As seen by the dashed orange line, the water demand can increase above the capacity of the plant. When this happens, the plant is not able to produce at the level of the water demand. The use of an average value for water demand, however, does not account for this limitation, and this in turn has an impact on the calculation of the operating costs.

![Figure 4-4 The Evolution of Water Demand Stochastic v Deterministic](image_url)

Figure 4-5 shows a comparison between the operating costs calculated under the deterministic approach and those calculated under the stochastic approach. For both approaches, the capital costs are the same. This is because of the inflexible nature of the plant, whereby the entire investment to build the desalination capacity is made in year one. The only source of variation between the two cases is due to the operations costs and in particular to the variable operating costs which include
energy. The deterministic approach, shown in blue, shows the operating costs to be fixed at almost 477 million USD. The stochastic approach, however, paints a different picture. The expected value of the stochastic approach is also roughly the same, 479 million USD, however, because of the different ways in which the water demand can evolve, variation in the total cost can be anywhere from 409 to 540 million USD with a 90% probability. This is equivalent to a variation of roughly plus or minus 14% compared to the deterministic case.

![Graph showing deterministic and stochastic operating costs for a RO plant](image)

**Figure 4-5 PV deterministic and stochastic operating costs for a RO plant**

Another important way in which stochastic analysis can help refine the deterministic one is in understanding the frequency with which water demand can exceed the plant’s installed capacity. As discussed earlier, plant designers expect the plant capacity to meet water demand needs over a ten year period. As shown in Figure 4-6, however, there is almost a 50% chance that water demand will exceed the plant’s capacity before ten years and an almost 10% chance that it will do so before seven years.
4.4 FLEXIBLE DESALINATION

The true value of considering the socio-economic context and using stochastic approaches for this case lies not in refining the evaluation of existing projects, but rather in helping project designers consider more flexible designs that are better able to deliver value in the face of uncertainty. Given that the major source of uncertainty being considered is that surrounding water demand, the key design flexibility required is flexibility in capacity, or expandability. Four flexible capacity expansion cases (“design cases”) are identified. Each of these cases describes a different way of expanding capacity relative to unfolding water demand. The cases are analyzed using a stochastic approach and the results of all the cases are compared to each other and the inflexible case considered earlier.

DESIGN ALTERNATIVES TO INFLEXIBLE DESALINATION:
Flexible design has the potential to add significant value to a desalination project. Expanding capacity as water demand increases allows project proponents to defer capital costs to the future and also reduces fixed operating costs. Three major aspects are considered in the formulation of the design cases: the initial installed desalination capacity, the size of the expansion tranche and the number of years over which desalination capacity for the purpose of making desalination expansion decisions. The design cases are analyzed using the same stochastic approach developed in the previous section.
1. **Phased:** The first design alternative uses a relatively conservative approach to flexibility. Half (200,000 m$^3$/d) of the plant capacity is built in year 1 and an expansion of 200,000 m$^3$/d occurs should the need arise based on a two-year forecast of water demand.

2. **Flexible I:** An initial plant of 160,000 m$^3$/day capacity is installed with adequate pre-investments to support expansion up to one desalination train of 200,000 m$^3$/day capacity. Expansions occur in tranches of 80,000 m$^3$/day based on a two-year forecast. Once expansion occurs beyond 200,000 m$^3$/d, another pre-investment is made for an additional 200,000 m$^3$/day train. This approach is intended to avoid high expansion frequencies.

3. **Flexible II:** This case is similar to Flexible I except that expansion occurs in tranches of 20,000 m$^3$/day as required to closely match a two-year forecast of water demand.

4. **Flexible III:** An initial plant size of 80,000 m$^3$/day is installed with adequate pre-investments to support expansion up to 200,000 m$^3$/day. Expansion occurs to closely match a one-year forecast. This case reflects the most flexible expansion approach considered in this analysis.

These design cases do not represent the total menu of potential designs. The purpose of the designs is not to define the entire scope of flexibility but rather to illustrate a spectrum of increasingly flexible designs in order to understand how this increase in flexibility influences project value.

**Table 4-4 Summary of design cases**

<table>
<thead>
<tr>
<th>Design</th>
<th>Initial Capacity</th>
<th>Expansion Tranche</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflexible (Base Case)</td>
<td>400,000 m$^3$/day (100%)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Phased</td>
<td>200,000 m$^3$/day (50%)</td>
<td>200,000 m$^3$/day (50%)</td>
<td>2 years</td>
</tr>
<tr>
<td>Flexible I</td>
<td>160,000 m$^3$/day (40%)</td>
<td>80,000 m$^3$/day (20%)</td>
<td>2 years</td>
</tr>
<tr>
<td>Flexible II</td>
<td>160,000 m$^3$/day (40%)</td>
<td>Any multiple of 20,000 m$^3$/day</td>
<td>2 years</td>
</tr>
<tr>
<td>Flexible III</td>
<td>80,000 m$^3$/day (20%)</td>
<td>Any multiple of 20,000 m$^3$/day</td>
<td>1 year</td>
</tr>
</tbody>
</table>
**Additional Assumptions Made Regarding the Flexible Design Cases**

**Pre-investment costs:** Based on discussions in Voutchkov 2012, the major component of the pre-investment cost is that related to civil works. Intake and outfalls can be included as either a pre-investment cost or as part of the expansion costs. Voutchkov suggests that including the intake and outfalls as part of the expansion results in greater economies of scale. The model assumes a pre-investment cost equivalent to 25% of the total capital costs; this figure includes civil work for a full capacity plant, and an assumed portion of various other costs (See Appendix A for further information).

**Expansion Timelines:** In the case of expansions, it is assumed that all expansions can occur within four months. This is in line with the discussion in the literature of potential expansion timelines (Darwish and Najem, 2005). The assumption of the investment timeline is an important one for the results in this case and will be explored as a sensitivity.

**Water Shortage:** Water shortages occur when the water demand in a particular year is greater than the installed desalination capacity. In order to be able to compare the different design cases to each other, it is important to characterize and compare the water shortage risks associated with each design case. For the purposes of the analysis in this section, the plot size of the plant is assumed to be limited to 400,000 m³/day. This places a hard upper limit on the total capacity expansion. Therefore in calculating water shortages the various design cases are only liable for providing water up to this limit. The results in this chapter only discuss the water shortage event that occurs to a plant during its lifetime. It is important to note, however, that any fines and penalties are levied on the basis of total water shortage as they occur.

**4.5 Performance Comparison**

Figure 4-7 shows how the distribution of PV of capital and total costs vary with the different design cases. The expected value of the capital costs decreases by up to 100 million USD with increasing flexibility. This result occurs only due to the delay in capital expenditure, as all of the cases ultimately build 400,000 m³/day of capacity over the 25-year period considered. The variability of the capital costs stay relatively constant with flexibility. Operations costs consist of variable and fixed costs; variable costs are a function of water demand and so are the same for all projects. Fixed costs, however, decrease as a function of installed capital. Overall, flexibility reduces total project costs by up to almost 20% or over 200 million USD.
Figure 4-7: The present value of capital and total costs of various design approaches

Figure 4-8 displays the results of the maximum water shortages associated with the different design cases. These values represent the maximum water shortage from a single water shortage event and not the total water shortage for each design case. The inflexible case by definition does not have any water shortages because the maximum demand that the desalination plant is exposed to is 400,000 m³/day. From a system-wide perspective, however, it is important to note that shortages can be expected even with an inflexible approach, because water demand can rise above 400,000 m³/day. The expected value and variability of the potential water shortages increase with flexibility. The expected shortage from a phased approach is roughly 1 million m³ and it goes up to 4.8 million for the most flexible case. This result is expected and reflects the fact that flexibility is geared towards building capacity more in line with actual demand. These potential shortages play an important role in the discussion of risk and the setting of fines and penalties and are discussed later.
Finally, Figure 4-9 shows the relative expected cost of the various design options in comparison with the base case. This graph represents the expected net value of pursuing flexibility. It shows that when considered at the level of the whole project, flexibility has the ability to decrease total costs anywhere from 10%-20%. As is explored in the next chapter, however, this analysis only considers flexibility in terms of its technical aspects.
### Table 4-5 Summary of Expected Results

<table>
<thead>
<tr>
<th>Project Summary</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs (mil USD)</td>
<td>$431</td>
<td>$360</td>
<td>$350</td>
<td>$340</td>
<td>$313</td>
</tr>
<tr>
<td>Total Costs (mil USD)</td>
<td>$910</td>
<td>$800</td>
<td>$777</td>
<td>$761</td>
<td>$714</td>
</tr>
<tr>
<td>Water Shortage (million m3)</td>
<td>-</td>
<td>1.00</td>
<td>0.59</td>
<td>1.38</td>
<td>4.77</td>
</tr>
</tbody>
</table>

#### 4.6 Sensitivity

In addition to analyzing the base case, a few sensitivities regarding the assumptions made are considered as part of the analysis. Two particular set of assumptions have a large impact on the results so far: assumptions about the length of time it takes to expand capacity in times of unexpected shortage, and the discount rate. Assumptions regarding the pre-investment amount are also tested; however, they appear not to have any significant impact on the total costs.

The biggest impact on the results is that of the discount rate. As seen in Figure 4-10, changing discount rates have a big impact on the actual savings as compared to the base case. The lower the discount rate, the less important time is as a factor in decision making and this makes flexibility less valuable. It is important to note, however, that even at a 4% discount rate, which is unrealistically low, flexibility can still provide up to 15% increase in value compared to the base case. The 10% discount factor chosen for the base case is typical of public sector analysis. The private sector is likely to use much higher discount rates that are driven by the costs associated with raising the capital for the project.
As discussed earlier, the duration of the expansion timelines is another important factor in determining the size of the potential water shortage. While the literature describes this duration as being relatively short, given the unexpected nature of the shortage and the issues associated with ordering expansion materials on short notice, this could in practice lead to increases to the maximum water shortage by 3-4 times (Figure 4-11) depending on the length of the actual expansion duration and the particular flexibility approach.

**Figure 4-10** The sensitivity of the expected project cost reduction to the discount factor.

**Figure 4-11** The sensitivity of the maximum water shortage to the expansion duration

The sensitivity of the performance of the various flexible designs with regards to assumptions about pre-investments is also tested. While there is potentially a minimum required pre-investment
to support the continuous expansion of desalination plants, namely related to civil works, designers have considerable freedom to choose their desired level of pre-investment. As shown in Figure 4-12, however, these assumptions have a negligible impact on the total project costs.

**Figure 4-12 Sensitivity of total costs to pre-investment assumptions**
Chapter 5 INSTITUTIONAL CONTEXT

The analysis in the previous chapter considers the effect of flexibility on the project as a whole. In reality neither of the two project participants mentioned in Chapter 3 makes decisions based on this overall project value. Rather each participant considers its own specific gains or losses. Just as a consideration of the socio-economic context allows the development and evaluation of different flexible expansion strategies, a consideration of the institutional context allows the evaluation of how the value from flexibility is distributed between the project participants. By exploring the contractual arrangements associated with desalination projects, this chapter shows how contractual terms can shape the preferences of each participant with regards to flexibility.

The chapter considers two broad partnership approaches, EPC and BOOT. Specific contractual scenarios are defined for each of these two broad approaches. A waterfall analysis evaluating the distribution of gains to each participant is conducted for each of the design cases under each contractual scenario. Finally the chapter looks at how these results might shape the preferences of the participant.

5.1 CONTRACTUAL CASES

The first step of the analysis is to identify a set of contracts for each partnership approach under which to evaluate the distribution of value. While there are many existing templates of both EPC and BOOT contracts, these templates have not been set up with expansion flexibility in mind. The main difference between flexible desalination and inflexible desalination, in terms of contracts, is that there is a mismatch between capacity and liability. Under inflexible desalination plants, the plant is expected to produce the amount of water in line with the plant’s ultimate nameplate capacity. At the same time the actual capacity of the plant is equal to the nameplate capacity. Under flexible designs the situation is different. While the plant is still liable to produce water according to its ultimate nameplate capacity, the actual installed capacity can be less than the nameplate capacity. The challenge is to consider different permutations of the many existing contract types to adequately reimburse the uncertain capacity expansion associated with the flexible design cases.

For EPC contracts this is a straight-forward exercise. Typical EPC contracts are either lump-sum or reimbursable. Lump-sum contracts limit the amount of payment that the private firm receives to a predetermined fixed-amount. Under this contract type, the public agency pays the same amount to the contractor regardless of actual costs. Because all flexible designs represent a 400,000 m3/day asset, albeit delivered at a different schedule, the lump-sum approach implies that the public agency
compensates the private firm the same amount regardless of the flexibility used. Of course there are capacity differences between the design cases due to the issue of water shortages; each design case represents a slight decrease in water availability over the lifetime of the plant. However, for the purpose of the evaluation it is assumed that this does not affect the price of the lump-sum contract. The issue of water shortages is taken up in more detail in the next chapter.

Reimbursable contracts, on the other hand, typically reimburse the private sector on the basis of the actual costs incurred due to the construction and operations of the project. The reimbursement typically also includes an additional profit component. Three reimbursable contracts are considered in the analysis: a cost-plus a fixed management fee, cost-plus percent and cost-plus-incentive payment. The incentive payments in this case are based on the percentage of capacity savings that the plant achieves and are included as a way to provide incentives for flexible designs.

<table>
<thead>
<tr>
<th>Table 5-1 Summary of EPC Contractual Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contract Type</strong></td>
</tr>
<tr>
<td><strong>Lump Sum</strong></td>
</tr>
<tr>
<td><strong>Cost plus Fixed Fee</strong></td>
</tr>
<tr>
<td><strong>Cost plus Percent</strong></td>
</tr>
<tr>
<td><strong>Cost plus Incentive</strong></td>
</tr>
</tbody>
</table>

Because of the need for capacity payments, BOOT contracts are slightly more complicated. As described earlier, besides reimbursement for water sales, capacity payments are an important aspect of BOOT partnerships. Typical capacity payments are made with some reference to the plant
capacity. The complication under conditions of flexibility, however, is whether or not this capacity should be the capacity for which it is liable or the one that is actually installed. The most obvious approach is to base capacity payments on the installed capacity. Doing so, however, limits ability of private firms to benefit from flexibility. For this reason a capacity payment based on a fixed capacity of 400,000 m³/day is also considered. In addition, as in the EPC approach, an incentive-based contract is also considered whereby the private firm is reimbursed on the basis of capacity saved. Finally a no take or pay contract is also considered just to understand the implications of that contractual scenario on the project economics.

Table 5-2 Summary of BOOT contract scenarios

<table>
<thead>
<tr>
<th>Capacity Payment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity</td>
<td>The private firm receives a payment for water sales and an additional capacity payment based on the difference between its installed capacity and actual water demand. For each period the firm makes total revenues equal to its installed capacity.</td>
</tr>
<tr>
<td>150% Installed</td>
<td>A permutation of the installed capacity contract where the private firm receives a capacity payment based on 150% of the installed capacity.</td>
</tr>
<tr>
<td>Fixed Capacity</td>
<td>The private firm receives total revenues equivalent to the ultimate 400,000 m³/day of capacity.</td>
</tr>
<tr>
<td>Capacity Savings</td>
<td>Another permutation of the installed capacity approach. Besides water sales and installed capacity, a firm receives an additional capacity payment based on the difference between the ultimate 400,000 m³/day capacity and the installed capacity.</td>
</tr>
<tr>
<td>No Take or Pay (NO TOP)</td>
<td>There is no capacity payment in the water purchase agreement. The private firm is completely exposed to the water demand.</td>
</tr>
</tbody>
</table>

Each of the BOOT contract scenarios are considered under two reimbursement schemes. The first is a fixed price scheme whereby the private firm receives a fixed price for all water production and capacity payments. The second scheme is a fixed return on capital scheme whereby the private firm receives a fixed expected IRR.

For all of the contract scenarios, no capacity payments are made during periods of water shortage. As described earlier, for all flexibility designs, there is a chance that water demand could increase beyond the installed desalination capacity. Capacity payments are withheld for the duration of the
time it takes to expand capacity in this situation. In a sense this effectively acts like a fine imposed for failing to meet water targets. The issue of levying additional fines due to water shortages is taken up in the next chapter.

5.3 Waterfall Analysis

The next step of the analysis is to create a waterfall distribution for each of the designs considered in the last chapter under each of the scenarios described above. The distribution of value between the two participants is an important driver behind each participant’s decision to adopt flexibility. The purpose of the waterfall analysis is to understand how the total gains to the desalination project from the implementation of flexibility are distributed between the project participants under each contract type. The public agency gains value by reducing its total expenditures, i.e. the sum of all of its payments to the private firm. The private firm gains value by increasing its NPV. In addition to these two parameters, the analysis also keeps track of returns on capital to the private firm. The aim of this analysis is to show the financial incentives for each participant to pursue flexibility under each contract scenario, pointing to the fact that the choice of contract can shape the adoption of flexibility.

Assumptions

Bidding Process: For all of the scenarios in this chapter it is assumed that a public water agency wants to build the desalination project discussed in the previous chapter. This agency can either pursue a traditional EPC approach or a BOOT approach. In either case the public agency makes a single request for proposals specifying the terms of a particular contract scenario as described in the previous section. The public agency explicitly makes an allowance to accommodate any desired capacity expansion strategy. Private firms respond with an offer in terms of a levelized cost for the particular contract scenario and a capacity expansion rule. For simplicity this chapter reports all of the result in net present value rather than levelized costs (levelized costs are simply the NPV divided by the total expected water output).

Comparing EPC and BOOT Contracts: An important additional assumption made in this analysis is that there is no inherent performance benefit that arises due to the type of contract used. As discussed in the literature, the nature of the private firms’ roles in BOOT contract can create greater incentives for the private sector to improve performance. This in turn actually can lead to performance improvements compared to other types of contracts such as EPC.
Because it is assumed that there are no differences in performance, the main considerations that the public agency is making when choosing between BOOT and EPC contracts are non-technical and non-performance based. Key amongst these considerations is likely to be the desire to raise financing without resorting to government balance sheets as well as other political and strategic considerations. The implications of this are that the public agency not interested in a performance comparison of EPC and BOOT contracts.

While a comparison between purely public procurement approaches and PPP approaches to the same project are performed by some government agencies, such a comparison is usually both complicated and questionable (Brenck et al., 2005). Furthermore additional factors like the desire for control of certain aspects of a project for political and strategic reasons as well as the capacity of a government agency to successfully administer a particular approach also play a role in selecting different contract types (Brenck et al., 2005).

Because of these reasons, performance is only considered on a relative basis; each of the flexible designs under each contractual scenario are only compared to the inflexible case under that specific contract scenario. For the purpose of scale, adjustments are made to ensure that all of the inflexible cases are equal one another.

**Fixed Prices for the BOOT contract:** The fixed prices for the BOOT contract are assumed to be constant in real terms throughout the life of the project. As described earlier, fixed price contracts in reality are typically adjusted throughout the life of the project through a series of renegotiations. The issue of renegotiations is taken up separately in the following chapter on behavioral responses to the waterfall distribution. The fixed price is set so that the inflexible cases for each contractual scenario match in terms of government expenditure, private NPV and expected IRR.

**The expected returns on capital:** The expected returns on capital to the private firm for BOOT contracts are relatively straightforward. IRR is used to calculate the expected returns. IRR makes sense in this context because it allows private firms to compare its potential returns in this desalination project against its own internal requirements for rates of return on equity. For EPC contracts, however, the situation is a little different. The private firm is not really making an investment. All costs are completely recovered on an annual basis. The decision being made here is not so much one related comparing various investments but rather one of comparing different service contracts. So instead of IRR, return on capital is calculated as the net present value divided by the total expenditures by the private firm.

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5.3 Expected Results

A total of twelve contract scenarios are analyzed. The detailed results of the BOOT fixed price are included to give an example of the results of the analysis. For the fixed IRR BOOT contracts and the EPA contracts, only a summary is given in the chapter while the details are included as part of the appendices.

**BOOT Fixed Price Approach**

**Installed capacity**

As described earlier, most capacity payments are based on some sort of fixed capacity and such an approach makes sense from the perspective of a desalination plant with a fixed capacity. The question, however, is how to translate this fixed capacity approach to a situation where the capacity of the desalination plant changes considerably with time. An initial response might be to limit capacity payments to the actual installed capacity. The idea that capacity payments are supposed to reimburse the private firm for installing capacity is logically linked to making that capacity tied to the actual capacity installed.

While this approach might be attractive from the perspective of the public agency, it severely reduces the private firm's NPV and expected returns on investments. As seen in Figure 5-1, this capacity payment structure channels most of the gains from flexibility towards the public sector, resulting in a reduction in public expenditure up to 36%. Increasing flexibility under this contract scenario, however, disadvantages the private firms because they are eligible for smaller capacity payments compared to the inflexible case. As seen in Table 5-3, increasing the flexibility of the design approach results in a significant reduction in NPV to the private firm. The expected IRR of the firms also decreases with increasing flexibility.
One way to improve the returns to the private firm is to increase the eligible capacity upon which capacity payments are made. Instead of using the actual installed capacity as a base, this contract scenario considers using 150% of the installed capacity. The installed capacity however is limited by the maximum capacity of the whole desalination plant, so that the firm is never eligible for a capacity payment higher than 400,000 m3/day. As seen in Figure 5-2, this results in a shift of the distribution of value towards the private sector. As seen in Table 5-4 this shift ensures that the private sector can achieve a positive NPV for a wider range of flexible designs and also raises its IRR by about 6 percentage points as compared to the installed take or pay structure. The general trends of the distribution, however, remain as they were under the installed capacity TOP. The distribution of value towards the private firm decreases with increasing flexibility. While this results in decreasing gains from flexibility with some of the more flexible options, both NPV and IRR remain positive and relatively high. With regards to the public sector gains this contract results in a reduction of roughly 100 million USD across all of the design options as compared to the installed
capacity case. The public sector, however, still has a potential gain of up to 25% by pursuing flexibility under this contract scenario.

![Waterfall graph for fixed price 150% installed capacity Contract](image)

**Figure 5.2 Waterfall graph for fixed price 150% installed capacity Contract**

**Table 5.4 Summary of expected results from 150% installed capacity Contract**

<table>
<thead>
<tr>
<th>150 Capacity</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,007</td>
<td>$913</td>
<td>$883</td>
<td>$861</td>
<td>$749</td>
</tr>
<tr>
<td>IRR</td>
<td>14%</td>
<td>17%</td>
<td>17%</td>
<td>17%</td>
<td>12%</td>
</tr>
<tr>
<td>NPV</td>
<td>$97</td>
<td>$116</td>
<td>$105</td>
<td>$100</td>
<td>$35</td>
</tr>
</tbody>
</table>

**Fixed Capacity**

Another potential contractual approach is to maintain a fixed capacity payment regardless of actual installed capacity. As shown in Table 5.5, this approach results in tremendous gains to the private firm with increasing flexibility. The NPV of the most flexible case is almost 1.5 times that of the inflexible case and the associated IRR is almost 50%. This contractual case, however, provides no incentives for the public agency. While the waterfall chart shows some increase in gains to the public sector, these gains are actually due to water shortages. During water shortages, more flexible designs are not able to produce as much water as the inflexible case and are therefore are eligible for fewer water and capacity payments.
**Figure 5-3 waterfall for fixed price, fixed capacity contract**

**Table 5-5 summary of expected results from fixed capacity contract**

<table>
<thead>
<tr>
<th>Fixed</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,007</td>
<td>$1,004</td>
<td>$1,004</td>
<td>$1,002</td>
<td>$967</td>
</tr>
<tr>
<td>IRR</td>
<td>14%</td>
<td>25%</td>
<td>30%</td>
<td>33%</td>
<td>48%</td>
</tr>
<tr>
<td>NPV</td>
<td>$97</td>
<td>$204</td>
<td>$228</td>
<td>$242</td>
<td>$254</td>
</tr>
</tbody>
</table>

**Capacity Savings**

The Capacity Savings approach seeks to create a hybrid between the two previous approaches, allowing both the private firm and the public agency to benefit from the capacity savings due to flexible designs. Under this approach the private firm receives a capacity payment based on installed capacity. Then in addition to this capacity payment, the private firm receives an incentive payment based on the capacity saved compared to the fixed capacity payment. In this case the incentive payment is 75% of the difference between the fixed capacity and the installed capacity.

While this may seem similar to the 150% capacity approach, the effects of using this incentive structure are markedly different in terms of the distribution of gains. As seen in Figure 5-4, the private sector receives increasing gains from flexibility. The private firm NPV goes up by up to almost 75%. The public agency also receives increasing gains with flexibility, although total expenditures only reduce by up to 12%. This approach essentially results in splitting the gains of the fixed capacity case between the private firm and the public agency. The gains to the private sector decrease slightly for the Flexible III design approach. This is due to the issues related to water shortages as described earlier.

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No Take or Pay

The final contract offers no capacity payments to the private firm. While capacity payments have been highlighted by the literature as a critical condition to ensure project finance, the situation with regards to desalination in the GCC is slightly different than those in other places. Given that there are no competing sources of water and therefore there is less of a chance of plants going idle, it is quite plausible that lenders may find this condition acceptable. A slight adjustment is made for the no take or pay structure. Instead of using a fixed water price of 0.85 USD/m³, a higher fixed price of 1.34 USD/m³ is used. This is in order to scale the inflexible no take or pay case to the inflexible cases for the other contractual cases. This price is still under the unsubsidized water price in Qatar equivalent to 2.37 USD/m³ (Mohtar and Darwish, 2012).

As seen in Figure 5-5, the no TOP contract does not result in any gains to the public sector. Because there is no capacity payment and the water demand distributions are the same for all of the design cases, the public sector pays the same amount regardless of the design option pursued. The only exception is that there is some gain because of water shortages during which the public agency both
pays for and receives less water. All of the potential gains from flexibility accrue to the private sector. The private sector stands to almost double its NPV and receive a return on capital of up to 20%. An interesting comparison can be made between this contractual case and the fixed capacity case, whereby in both these cases the public sector is indifferent between the design options and the private firm makes all of the gain. There are however important differences between these two cases in terms of the riskiness of the value distribution. These are taken up in the next chapter.

**Figure 5-5 waterfall for fixed price no take or pay**

**Table 5-7 summary of expected results for fixed price no take or pay**

<table>
<thead>
<tr>
<th>No Top</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,010</td>
<td>$1,008</td>
<td>$1,009</td>
<td>$1,009</td>
<td>$1,003</td>
</tr>
<tr>
<td>IRR</td>
<td>12%</td>
<td>16%</td>
<td>17%</td>
<td>18%</td>
<td>21%</td>
</tr>
<tr>
<td>NPV</td>
<td>$100</td>
<td>$206</td>
<td>$232</td>
<td>$248</td>
<td>$289</td>
</tr>
</tbody>
</table>

**Summary of BOOT Fixed Pay Contract Scenarios**

Figure 5-6 and Figure 5-7 show the gains to the public agency and the private firm from pursuing the various Fixed Price contract types. From the perspective of the public agency, the most value occurs through the use of the installed capacity approach. It is indifferent between the fixed capacity and the no take or pay approach on the basis of expected gains. From the private firm’s perspective, the greatest value accrues to it from the implementation of fixed and no take or pay approaches. Under the fixed pay BOOT approach, all contract scenarios with the exception of installed capacity have expected gains to the participants that could result in the adoption of flexibility.
BOOT Fixed Return on Capital Approach

In addition to the fixed price reimbursement approach, the same analyses are undertaken for the fixed IRR reimbursement approach. A summary of the expected returns to project participants are presented in Figure 5-8 and Figure 5-9. The detailed results can be found in Appendix B. In general the fixed IRR approach results in decreased expenditure for the public agency and decreased NPVs for the private firm under all cases, although the NPVs generally remain positive. In addition as seen in Figure 5-10 for the capacity savings and the fixed capacity cases, the water price falls below the
fixed price. These two cases also result in the greatest gains to the public agency. For the private firm, however, there are no gains from increasing flexibility.

**Figure 5-8 Summary waterfall of gains to public agency for Fixed IRR BOOT**

**Figure 5-9 Summary waterfall of gains to private firm for Fixed IRR BOOT**
Figure 5-10 Summary of Water Prices

EPC Contracts

Figure 5-11 and Figure 5-12 show a comparison of the expected gains for each of the design options under each of the four EPC contract scenarios. As can be seen, on the basis of expected revenue, the cost percent approach results in the greatest gains to the public agency, while the lump sum approach results in the greatest gains to the private firm. Also under all of these scenarios with the exception of the cost plus percent from the private firms’ perspective, the greater flexibility results either in greater gains or indifference. Detailed results can be found in Appendix C.

Figure 5-11 Summary Waterfall of Gains to Public Sector for EPC
The analysis so far has only considered the distribution of gains to the project participants on an expected value basis. The reality is that there is considerable uncertainty surrounding the returns discussed earlier. From the perspective of the private firm, this uncertainty can lead to opportunities to capture more value than expected, or it can expose the firm to losses. The situation is slightly different from the perspective of the public agency. Given that is not a profit maximizing firm, especially in the case of a budget-rich government like that in Qatar, the public agency is not solely driven by the desire to reduce costs. A perhaps equally if not more important consideration is the perception of the fairness of the contractual arrangement.
Figures 5-13 to 5-16 show the stochastic distribution of returns to the private firm for four of the contract scenarios under the BOOT Fixed Price approach. As can be seen, the variations in the gains to the private sector vary tremendously with the contract type pursued. For both the fixed and the capacity savings contract scenarios, the flexible option offers tremendous opportunity for up sides to the private sector, while not subjecting the firm to any downside. The variations in the returns under the no TOP contract are more limited; while this contract type does not expose the private firm from any significant downside risk, it does not offer the same upside potential as the fixed and capacity savings contracts. The 150% capacity contract, is perhaps the least preferred alternative from this perspective as it exposes the private firm to significant downside risk with no real upside.
opportunity. It is important to note, however, as shown in Figure 5-17, while there may be the potential for decreasing gains to the private firm following a more flexible design under the 150% contract strategy, it still maintains a positive NPV.

Figure 5-17 Private NPV of designs under 150% Capacity Scenario

Figure 5-18 to 5-21 show the gains to the public sector from the different contracts as a percentage of total gains. Under this metric, the public sector is less sensitive to the absolute gains or losses that might arise due to overall changes to the project conditions (water demand) so long as the public agency receives a fair share of the total gains. If the public sector can show that it is benefiting from the gains of flexibility, then it may matter less what the private sector gains are. As expected, the Fixed and the No TOP cases provide minimal returns to the public sector. Of the remaining two contracts, the Capacity Savings contract provides relatively non-variable and low gains to the public sector, whereas the 150% Installed Capacity contract provides much higher returns with greater variability.
In addition to the gains from flexibility, variations in return on capital are also considered. This is an important metric for both the private and the public participants. For the private firm, returns on capital represent an important consideration when making capital allocation decisions. While it is not necessarily the case that higher returns on capital are better, the private sector will certainly be concerned if the returns are lower than a certain threshold rate. From the perspective of public agency, the private firm’s returns represent another issue of fairness. Just as the public agency may want to ensure that it maintains a fair share of the gains from flexibility, so too might it want to ensure that the private firm does not make too high of a return on its investments.
As shown in Figures 5-22 to 5-25, both the expected IRRs and their potential variations are significantly different between the different contract types. Of particular concern to the public agency might be the Fixed Capacity and Capacity Savings contracts as they allow the private firm to receive IRR’s of up to 80% for the fixed capacity and 50% for the capacity savings under some of the more flexible designs.

**Figure 5-22 Private firm IRR from Fixed Capacity**  
**Figure 5-23 Private firm IRR from No TOP**  
**Figure 5-24 Private IRR from Capacity Savings**  
**Figure 5-25 Private IRR from 150% of Installed Capacity**
5.5 Discussion of Results

The choice of contractual arrangements can have a significant impact on shaping how the overall value from the implementation of flexibility gets distributed between the project participants. This is true both in terms of the expected gains by each of the participants as well as the variations in the returns. Some of the contracts give all of the gains from flexibility to one of the participants, sometimes at the expense of the other, while others divide the gains between the two participants. This distribution in turn can play a significant role in the preferences for each of the participants for the adoption of flexibility under each contract type.

The following table presents a summary of the contracts analyzed so far with an indication of how each contract type shapes the preference for the participant towards the adoption of flexibility. For the sake of simplicity this analysis is limited only to the BOOT Fixed Price contracts, as it is the most illustrative out of the three contract approaches. Blue represents a preference for flexible designs, green represents a preference for inflexible designs and grey represents a neutral position. Upside opportunities or downside risks for the private firm, and fairness risks for the public agency are included as comments. The ways in which the different preferences for flexibility and perceptions of risks under each contract type interplay in shaping the level of flexibility that is ultimately adopted are taken up in the next chapter.

### Table 5-8 Contract Scenario Ranking for Fixed Price BOOT Contracts

<table>
<thead>
<tr>
<th>Contract Scenario</th>
<th>Public</th>
<th>Private</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Capacity</td>
<td>Fairness Risk</td>
<td>Upside Opportunity</td>
</tr>
<tr>
<td>Installed Capacity</td>
<td>Blue</td>
<td>Green</td>
</tr>
<tr>
<td>150% Installed Capacity</td>
<td>Downside Risk</td>
<td>Yellow</td>
</tr>
<tr>
<td>Capacity Savings</td>
<td>Fairness Risk</td>
<td>Upside Opportunity</td>
</tr>
<tr>
<td>No Take or Pay</td>
<td>Yellow</td>
<td>Blue</td>
</tr>
</tbody>
</table>
Chapter 6 DISTRIBUTION OF RISK

The discussion in the previous chapter revolves around the role of contractual arrangements in distributing the gains from flexibility between the private and the public participants. The distribution of value, however, is not the only factor that shapes the adoption of flexible designs for a particular project. Equally important is the distribution of risks associated with each of the contract types and the design cases. This chapter expands the discussion in the last chapter to consider how different contractual arrangements distribute risks between project participants. The issue of how these risks actually influence the decision to adopt flexibility is considered in the next chapter.

6.1 The Scope of the Analysis

The previous chapter considers three different approaches to partnerships between public and private participants in a project, EPC, fixed price BOOT and fixed returns BOOT. The purpose of considering three different approaches was to demonstrate that there are vast differences in the distribution of returns depending on the selected contractual arrangement and the partnership approach. Rather than consider the ways in which behavioral effect all of the previously discussed contract types, and in order to better focus the discussion, the analysis in this chapter is limited to a consideration of fixed price BOOT contracts.

6.2 Risks

Even without considerations of flexible capacity expansions, large-scale infrastructure projects are inherently risky. As described earlier, such projects are prone to cost overruns, delays, under-utilization, political risks, and environmental risks. The extent to which these risks influence the preferences of project participants is context specific. Different public agencies and private firms have different abilities to manage different risks and so will react differently to the risks.

The analysis in this chapter focuses on three categories that are particularly relevant to flexible capacity expansions of desalination plants: expansion risk, water risk and renegotiations risks. In addition the previous chapter also considers the variations in the gains from flexibility and the associated upside potential and downside risks.

Water Risks

Water shortages are perhaps the biggest risk associated with flexible capacity expansions, particularly for public agencies. Ensuring the availability of water for the general public is the main
purpose behind the construction of desalination plants. As can be seen from Figure 4-8 (see Chapter 4), different designs can lead to different amounts of water shortage. These shortages arise from a short-term mismatch between supply and demand due to an unexpected increase in demand. As shown in the graph, the maximum shortages from single events increase with flexibility. Increasing capacity expansion flexibility inherently results in the introduction of a trade-off between ensuring the ability to produce enough water to meet water demand targets and saving capital. The more flexible the design, the more exposed it is to unexpected variations in the water demand. In this case expected shortages can result in an expected maximum water shortage of up to 5 million m$^3$ over the lifetime of a desalination plant under the most flexible design.

Concerned public agencies have three options at their disposal to mitigate the risks of water shortages. The first mitigation option is to accept the risks. The existence of a water shortage does not necessarily pose a threat to the availability of water for municipal consumption. Many regions have access to water storage capacity that can be used as a backup to offset short term water shortages. Qatar, for example, currently has a national water storage capacity of 2.67 million m$^3$ (Mohtar and Darwish, 2012), which is sufficient to accommodate potential water shortages associated with some of the flexible designs. The national water storage capacity is currently being expanded up to 15 million m$^3$ of water (Hyder Consulting, 2013). This future water storage capacity is large enough to accommodate even the P90 water shortages associated with the most flexible case. In addition, desalination plants are often able to produce more water than their nameplate capacity. Sorek, Wonthaggi and Ashkelon, three large RO desalination plants in the capacity range of 400-500 thousand m$^3$/day, produce between 10% and 15% more water than their nameplate capacity (Desalination.com, 2013).

Public agencies not comfortable with taking on all of the water shortage risks might choose to limit the adoption of flexibility by levying penalties to deter the private firms from pursuing “risky,” highly flexible designs. Such a penalty can be tied to using water from the national storage system so that private firms are charged for use of the stored water. For the case of Qatar, the price of water from the system could be set equal to 10 QR/m$^3$ (~ 2.75 USD/m$^3$), which is assumed to be the market price of water in Qatar based on the unsubsidized price that water distributors pay to private water producers in Qatar (Mohtar and Darwish, 2012). As seen in Figure 6-1 while this penalty would result in a disincentive for the private firm to pursue the most flexible designs under some contract types, it would still provide some incentives to pursue flexible designs under others.
Finally, if a public agency does not have enough capacity to support potential water shortfalls or trust in the ability to deliver water in times of water shortages, the only remaining option it has is to disallow flexible capacity expansion and require total desalination capacity to be built before the commencement of the project operations.

**Expansion Risks**

Expansion risks refer to the uncertainty regarding the price and duration of expanding the capacity of the desalination plants in order to meet increases in water demand. There are two kinds of capacity expansions: planned capacity expansions according to the flexible design rule and unplanned ones that occur due to unexpected short-term mismatches between available capacity and water demand. Under both of these expansions, there is a risk that both financing and construction may not be readily available, leading either to an increase in expansion costs or duration.

Private firms have four potential mitigation options for handling expansion risks. First of all they can acquire both finance and equipment in advance and store it until it is needed. While this approach ensures that both financing and equipment are available and the price at which it is available, it can lead to additional costs that may be expensive. Storing equipment and prefabricated units will incur warehousing costs, keeping construction workers idle incurs opportunity costs and raising financing incurs borrowing costs.
A second strategy is to enter into agreements with providers of construction services and finance to guarantee the availability of construction and finance when required. In return the construction and construction firms will likely demand an upfront amount for their promise, which may be additional to the cost of providing the service. Neither is the availability nor cost of such agreements known. Similar kinds of agreements are typically priced to be competitive with the price of the first option.

In addition to these two active approaches, the private firm has two passive approaches. It can either do nothing, taking on expansion risks as they arise, or it can avoid flexible design altogether.

The ability of a firm to pursue the different strategies depends largely on the characteristic of the firm itself. Many of the private sector firms involved in this market are large conglomerates that are integrated across much of the desalination value chain. Such firms may be in a good position to pursue the first strategy of storage because of their reduced storage costs and better access to capital on demand. Smaller firms might have to provide insurance or other kinds of coverage to ensure that it will be able to cover all of the costs of expansion as they arise. The particular strategy that is ultimately chosen needs to consider both the firms’ own capacity as well as the nature of the expansion risk itself.

Two proxies are used to model expansion risks: expansion frequency and the duration of the period over which expansions occur. As seen in Figure 6-2, the number of expansions varies according to the design case. The higher the number of expansions expected, the greater are the expansion risks. At the same time, the greater the variation in the frequency of expansions, the more difficult it is to manage the expansion risks. While a construction contract with three expansions is likely to be more expensive than a one-time expansion contract, a construction contract with an indeterminate number of expansions might not even be available. As expected the more flexible the design the higher the expansion risks and the more difficult they are to manage.
The second proxy for expansion risk is that the duration over which capacity expansions occur. This proxy is important given that firms need to know the duration over which they have to be able to ensure that there are enough resources to implement the expansion. Figure 6-3 shows the expected duration of the expansion process and the variations in that duration. On average the expected duration over which expansion takes place ranges from 4 to 8 years depending on the expansion flexibility. The variation for each of the design cases, however, is roughly 6 years. As in the first proxy, both considerations of the expected value and the variation in that value are important from the perspective of understanding the firms’ ability to manage this risk.
**Renegotiations Risk**

A final category of risk that can affect both the private and the public sector is the risk of renegotiations after a contract has been signed and the project is in operations. Renegotiations typically occur due to changes in the socio-economic conditions and can be undertaken by either participant. If water demand is consistently higher than expected and private firms are able to make windfall gains, the public agency might call for renegotiations to avoid social unrest that might arise from the perception that private firms are making too much money. Conversely, in the case of extended periods of low demand, private firms may call for renegotiations in case they are not making enough money to meet their expectations.

Surveys by Guasch (2004) and Cruz and Marques (2013) of over 1000 infrastructure projects in Latin America and the Caribbean found that the majority of the projects were renegotiated. The amount of renegotiations in the water and wastewater sector was particularly high; roughly 80% out of the 160 projects that were surveyed were renegotiated. The average time for the renegotiation occurred within 1.5 years of the contract award. Of these renegotiations roughly two-thirds were initiated by the private firm and the rest were either initiated by the public agency or by both parties. The results of the renegotiations are typically delays in infrastructure spending or tariff increases. In some cases, however, renegotiations can lead to extensive damages. As mentioned earlier, social unrest in Cochabamba in Bolivia in reaction to perceptions of a lack of fairness, led to the withdrawal of the international water consortium that had been awarded the local water supply contract\textsuperscript{13}. Similarly, low profits in Argentina, led to the abandonment of the Tucuman water and sanitation concession by the private firm (Guasch, 2005).

In order to determine the exposure of each design and contract case to renegotiations risks, a proxy to reflect the variations in profit from long-term profit expectations is used. This is calculated by averaging the first three years of the annual net-income to the private firm divided by the total water delivered for that year in order to calculate a profit per unit of water delivered. The first three years are used because this is the time period during which renegotiations typically occur. This value is compared to the average net income per unit of water produced over the lifetime of the project. If the annual margin that the private sector makes is particularly high, it may cause the public agency to seek a renegotiation. If it is particularly low then the either the public or the private sector might call for a renegotiation. There is of course no hard line for when renegotiations will happen. The purpose of the analysis is simply to observe the trends under each of the two

\textsuperscript{13} See the before-mentioned PBS Frontline documentary for more information
different contract scenario and comment on how different contracts may affect the relationship between flexibility and renegotiations.

Figure 6-4 and Figure 6-5 show the average profit per unit of water for the first three years of the life of the plant under the 150% installed capacity and the capacity savings contract. Under both contract scenarios, the project is exposed to renegotiations risks due to low profits under all of the flexible design cases. In addition, as can be seen from the large variation in the income per unit of water, the project is also exposed to renegotiations due to potential undue gains to the private firm. Under the 150% capacity contract scenario (Figure 6-4), however, this variation and the associated renegotiations risk, decreases with flexibility. For the capacity savings case (Figure 6-5), the variation and the renegotiations risk do not decrease with flexibility. Flexibility does not reduce the exposure to renegotiations due to perceived unfairness.

\[\text{Figure 6-4 Private 3-year average income per unit water produced for 150\% capacity contract}\]
One approach to managing the risks of renegotiations is to include clauses in the contract that formally allow for a renegotiation of key terms once upside or downside conditions occur. Such conditions are typically tied to some level of profit to the private firm (Guasch, 2004 and Cruz and Marques, 2013). In addition to triggering the renegotiation, the clauses can specify how the contract needs to be re-adjusted. This readjustment can include an adjustment in the tariff rate to achieve a certain rate of return for the private sector or an adjustment in the capacity payment to achieve a certain capacity-payment to water-sales ratio for the public agency. In this way value to either participant can be adjusted to enable the continued operations of the project should the need arise.

**Summary of Risks**

Table 6-1 shows a summary of the risks associated with the adoption of flexible designs under different contractual structures. Some of the risks, like those related to water shortages and expansion delays, are design-based. In general, these risks increase with flexibility. Other risks like the upside, downside and renegotiations risks are based on the contract itself. The effect of flexibility on these risks depends on the contract structure under consideration.
### Table 6-1 Summary of Risks

<table>
<thead>
<tr>
<th>Risk</th>
<th>Nature of Risk</th>
<th>Risk Holder</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expansion Frequency</td>
<td>Design-based</td>
<td>Private</td>
<td>Risks increase with flexibility</td>
</tr>
<tr>
<td>Expansion Duration</td>
<td>Design-based</td>
<td>Private</td>
<td>Risks increase with flexibility</td>
</tr>
<tr>
<td>Water Risks</td>
<td>Design-based</td>
<td>Public</td>
<td>Risks increase with flexibility</td>
</tr>
<tr>
<td>Upside Risk</td>
<td>Contract Based</td>
<td>Public</td>
<td>Mixed</td>
</tr>
<tr>
<td>Downside Risk</td>
<td>Contract Based</td>
<td>Private</td>
<td>Mixed</td>
</tr>
<tr>
<td>Renegotiation Risks</td>
<td>Contract-Based</td>
<td>Private and Public</td>
<td>Mixed</td>
</tr>
</tbody>
</table>

It is again important to note that this analysis only shows the relative magnitude of the probability of occurrence of the risk in question. There is, for example, a greater chance of public agency-led renegotiations due to the perceived unfairness of the returns to the private sector from flexible desalination under a capacity savings contract as opposed to a 150% capacity contract. The actual ways in which this increased chance ultimately shapes the decision-making of participants, however, is not deterministic; it depends to a large part on the specific ability of the participant to manage those risks and that participants’ appetite for that particular risk. The role of these risks on the actual decision-making is taken up in the following section.
Chapter 7 Interactions

So far the thesis has considered the role of the distribution of risks and gains to each of the participants in shaping their preferences for flexibility. While these preferences in turn shape how each of the participants makes decisions with regards to flexibility, the flexibility that is ultimately adopted depends on the interaction of the decisions made by the two participants. The final step in the analysis is to consider how the risks and gains shape the decisions made by each of the participants and how the interaction between the decisions shapes the outcome of the decision-making process.

7.1 A Model for Interactions
A simple game-theoretic model is used to evaluate how the interactions between each participants’ decision shapes the adoption of flexibility. There are two key decisions made by the participants, both of which are made during the bidding process: first the public agency chooses the terms of the contractual arrangements which it issues as part of the tender and then the private firm responds by choosing one of the design cases. The level of flexibility that is ultimately adopted will depend on the contract-design pair that results in the greatest gains to the public agency.

The purpose of the model is to understand the ultimate flexibility that will result from the interaction of these two steps and under different assumptions about the participant’s aversion to risks. To illustrate how the interactions occur, three contract scenarios are considered under three sets of assumptions regarding the risk-preferences of the participants. Because the public agency ultimately selects the contracts, the No Take-or-Pay and Fixed Capacity contracts are ignored as they do not add value to the public agency. The interactions are analyzed assuming first that both participants are risk-neutral, then that only the private firm is risk-neutral and finally that both participants are risk-averse.

Interactions with Risk-Neutral Participants
The situation is first considered where both project participants are risk-neutral. The public agency in this case is comfortable with using its water storage capacity to compensate for any water shortages and is not concerned with any fairness issues associated with the private firm making high returns. The private firm is a large integrated corporation that is able to manage the expansion risks associated with the project. Furthermore the private firm and the public agency have a long
history of working together and so are not concerned about any risks associated with renegotiations.

As discussed in Chapter 5, the highest possible gains to the public agency occur with the adoption of the most flexible design under the installed capacity contract. As shown Figure 7-1, this could result in the gains of over 350 million USD to the public agency. Under an installed capacity contract, however, the private firm maximizes its value by adopting an inflexible design. As indicated by the green square, in the case that the public agency proposes an installed capacity contract, the private firm will respond by proposing an inflexible design case, resulting in zero gains to both the participants and to the project as a whole.

![Figure 7-1 Interaction outcomes from Installed Capacity Contract](image)

**Figure 7-1 Interaction outcomes from Installed Capacity Contract**

The next step is to consider the interactions under the second-best contract from the perspective of the public agency. Under the 150% contract, the public agency has the potential to gain 250 million USD if the most flexible design case is pursued. As shown in Figure 7-2, the private firm maximizes its gains under this contract by pursuing a phased design approach. This results in a gain of roughly 90 million USD to the public agency and a total gain to both participants of 110 million USD.
Finally under the third-best contract, the Capacity Savings contract, the public agency has the potential to gain 120 million USD if the most flexible design case is adopted. As shown in Figure 7-3, under this contract, the private firm is indifferent between the two most flexible contracts on the basis of expected gains. However given that there are greater potential upsides in the most flexible case (Chapter 5), the private firm might prefer to choose the most flexible design. Doing so results in total gains to the system of almost 200 million USD.

While at a first glance, the public agency might have expected to maximize its value by pursuing the installed capacity contract, as a result of the interactions between the preferences of the two
participants, the public agency actually maximizes its gains by pursuing its third best contract, the capacity savings contract. This contract coincidentally also results in achieving the greatest total value to the system under the design cases considered. As is seen in the next section, however, this outcome is not always achieved.

**Interactions with risk-averse public agency**

The same situation described above is reconsidered under the assumption that the public agency is risk-averse. The public agency is concerned about water shortages because of a limited confidence in national water storage. It wants to avoid the adoption of capacity expansion rules that are too flexible in an effort to manage these water shortage risks. In order to do so, the public agency imposes the penalties described earlier. As before the private firm is risk-neutral.

The outcomes under the installed capacity case are the same as before. The private firm maximizes its value by pursuing an inflexible design resulting in no gains to either participant. As shown in Figure 7-8, under the 150% Capacity contract, the private firm still maximizes its gains by pursuing a phased design case. The gains to the public agency are roughly 100 million, slightly higher than before due to the additional gains from the fines. The total value to both participants is still 110 million USD.

**Figure 7-4 Interaction outcomes under a 150% Installed Capacity with Fines**

The situation under the Capacity Savings contract is different than it was earlier. As can be seen in Figure 7-5, with the imposition of fines, the private firm maximizes its gains by pursuing the second
most flexible design, rather than the most flexible design as earlier. This results in the gains to the public agency of roughly 75 million USD and a total gains to both participants of 150 million USD.

![Figure 7-5: Interactions outcomes under Capacity Savings Contract with Low Fines](image)

**Figure 7-5 Interactions outcomes under Capacity Savings Contract with Low Fines**

Under the conditions of a risk-averse public agency, the public agency maximizes its gains by pursuing a 150% Installed Capacity contract rather than a Capacity Savings contracts as was the case assuming a risk-neutral public agency. This results in the adoption of a phased design and total gains to both participants of only 110 million USD, much less than the total gains of 200 million achieved in the risk-neutral case. Furthermore, the total gains to the project by pursuing a 150% installed capacity are lower than those that could have been achieved by pursuing a Capacity Savings contract, however the public agency is better off under the 150% installed capacity contract.

**Interactions with both participants risk-averse**

Finally, the situation is considered where both project participants are risk-averse. It is assumed that while the private firm can manage the expansion risks associated with flexibility, it will only do so if it feels that the returns are high enough to justify these extra risks. Under these conditions the response of the private firm to the 150% installed capacity and Capacity Savings contracts considered earlier will be different. The phased design under the 150% installed capacity contract results in a low level of gains to the public firm, one that is susceptible to considerable downside risk (see Chapter 5). Because the private firm is risk-averse, these returns and their variability might not be sufficient incentive for it to consider taking on the expansion risks associated with the
phased approach; it may consider pursuing an inflexible design instead. As shown in Figure 7-6, such a decision does not result in any gains to either participant.

\[ \text{Figure 7-6 Interaction outcomes under 150\% installed capacity for risk averse participants} \]

Similarly, for the Capacity Savings contract scenario, the increasing risk-aversion of the private firm may lead it to pursue a less flexible design. Figure 7-8 shows the variations in the gains to the private sector under a Capacity Savings contract with fines. The private firm receives similar gains for most of the design cases. The additional gains from pursuing flexibility in this context may not be sufficient to offset the additional expansion risks associated with those designs. Instead of taking on the additional risks associated with the flexible design cases, the private firm might choose to pursue a less flexible design that carries a lower level of expansion risks. As shown in Figure 7-7, this would result in the adoption of a phased design approach, resulting in a public agency gain of 60 million USD and total gains of 110 million USD.
7.2 SUMMARY OF FINDINGS
The objective of the interaction analysis is not to predict the level of adopted flexibility under each contractual scenario, but rather to demonstrate that the choice of contractual arrangements can result in significant differences in the level of flexibility that is ultimately adopted. While the contracts themselves are only distributive in nature and do not change the total gains to the project from pursuing a given level of flexibility, the choice of contracts does influence the participants’ decisions to adopt flexibility. As can be seen in Table 7-1, because of this, the total gains to the
project under each of the contract structures can vary. Many of the potential gains to the public agency that are theoretically possible from the pursuit of flexibility may not be attainable because the contracts may not provide incentives that are commensurate with the level of perceived risks for the private firms to pursue those flexible designs. At the same time as shown by the summary of the interaction outcomes described in Table 7-2, the public agency will only choose those contract types that maximize its own gains from the project, further reducing the potential total gains to both participants. The ways in which the different contract types lead to different outcomes depends to a large extent both on how the contracts distribute the risks and values associated with the various design cases and the participants’ preferences for risk.

**Table 7-1 Summary of total potential project gains under Various Contract Types and Risk-Preferences**

<table>
<thead>
<tr>
<th>Contract Scenario</th>
<th>Risk Neutral (mil USD)</th>
<th>Risk Averse I (mil USD)</th>
<th>Risk Averse II (mil USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed</td>
<td>$0</td>
<td>$0</td>
<td>0</td>
</tr>
<tr>
<td>150% Installed</td>
<td>$112</td>
<td>$109</td>
<td>0</td>
</tr>
<tr>
<td>Capacity Savings</td>
<td>$196</td>
<td>$149</td>
<td>$111</td>
</tr>
</tbody>
</table>

**Table 7-2 Summary of Results of the Interactions**

<table>
<thead>
<tr>
<th>Public Gain Maximizing Contract</th>
<th>Risk Neutral</th>
<th>Risk Averse Public</th>
<th>Risk Averse Private and Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adopted Flexibility</td>
<td>Capacity</td>
<td>150%</td>
<td>Capacity</td>
</tr>
<tr>
<td>Public Gain (mil USD)</td>
<td>Savings</td>
<td>Installed</td>
<td>Savings</td>
</tr>
<tr>
<td>Total Gain (mil USD)</td>
<td>$122</td>
<td>$97</td>
<td>$60</td>
</tr>
</tbody>
</table>

One important caveat to the results in this chapter is that the public agencies can always attempt to force the private firm to adopt a certain flexible design. A number of issues might arise from pursuing this approach. First of all private firms, especially given their large integrated nature, are likely to be in a better position to manage the risks associated with flexibility than the public agency. Second, the public agency is not in a particularly good position to be able to monitor and enforce any particular set of expansion rules without resorting to invasive practices. The public agency, however, can still choose to pursue this approach. Doing so will require a reconsideration of some of the conclusions described in this chapter.
Chapter 8 CONCLUSIONS AND FURTHER WORK

The adoption of flexible design can add considerable value to infrastructure projects. The ability of project participants to do so, however, depends on the specific contractual arrangements between the two project participants. Different contractual arrangements result in different distributions of both the gains from flexibility as well as the risks from the adoption of flexibility between each of the project participants. The emergent risk-value profiles result in different preferences for the adoption of flexibility leading each of the participants making different decisions to adopt flexibility under each contract scenario. The interactions between the decisions results in the adoption of a level of flexibility that varies both with different contract types as well as according to each participant’s risk-preferences. While contractual arrangements only distributes the gains from flexibility between the project participants without adding value, because of the ways in which they can lead to decisions to the adoption of different levels of flexibility, the choice of contract structure can influence the ultimate gains to the project from flexibility.

The analysis does not identify an optimal contract structure that allows project participants to maximize the value of their projects. Rather it points to the fact that given their role in the adoption of flexibility and the associated gains to the project, project participants should evaluate the effects that different contractual arrangements might have on the decisions reached by both project participants to adopt flexibility in the particular context of their project.

The conclusions described in this thesis are preliminary; more than anything they point to the need for further work. The most obvious extension of the work presented thus far is to develop a more categorical understanding of the role of contracts on flexibility for different infrastructure types and in different project conditions. Various contextual considerations can affect the applicability of the results beyond the specific context of a small, rich developing nation located in the Arabian Peninsula. An important consideration is the nature of the uncertainty that a particular project faces. For the case of desalination projects, so long as the uncertainties surrounding the demand for desalinated water are high, flexibility can be expected to add value to the overall project. This uncertainty does not need to arise from changes in population, however, and can be the result of changes to climatic conditions or water demand patterns. Nor need the types of uncertainty be limited to those related to water demand. Infrastructure projects are prone to many kinds of uncertainties beyond water demand including those associated with construction and operating
costs, environment and technology. Flexibility has the potential to add value in the face of all of these uncertainties.

A second important consideration is the particular ability of the project participants to manage the various uncertainties. The availability of the necessary infrastructure to support flexibility, for example, is a particularly important factor. For regions with many alternative sources water, water shortages might be even less of an issue than as described in this thesis. Equally important as the presence of physical infrastructure is the presence of institutional infrastructure to support flexibility. The use of flexibility allows project proponents to modify the nature of the capacity expansion in response to changing input costs, water demand, technological developments and changing environmental conditions. In order to do so, however, the appropriate institutional framework needs to be in place that allows for the ability to monitor changing conditions and feed back information into the decision-making process. While the private firm may be in a better position to monitor some of these uncertainties, public agencies also play a role. The ability of governments to implement institutional reforms, including the implementation of water-demand reduction measures and the ability to use of groundwater reservoirs as back-up water supplies, have the potential to increase the gains from flexibility for the case already considered in this thesis.

Finally, the extent to which the results apply to other types of infrastructure projects may vary. As described earlier, there are a limited number of firms that currently develop seawater reverse osmosis plants. The number of firms that have the capacity to engage with flexible desalination plants in developing countries like Qatar might be even smaller still. While the different contract types should still result in a different distribution of both gains and risks, in more competitive bidding situations, the individual risk-preferences of firms might play a smaller role in the final level of adopted flexibility. Furthermore different types of infrastructure might have different restrictions with regards to flexible expansion that might limit or enhance the value of flexibility in those contexts.

In addition to a consideration of the applicability of the results, the research can also be extended by exploring different models for delivering flexible infrastructure. While there can be value gained from broadening the scope of engineering analysis to include institutional and socio-economic considerations, doing so raises important questions regarding the boundary between engineers and policy makers. The use of flexibility points to an important shift in the nature of the development of large infrastructure projects. It is no longer the case that large projects can be developed as self-
contained technical endeavors, solely under purview of technical experts. Flexibility requires the consideration of a broader set of issues. A more collaborative approach may be required both to identify the types of uncertainty that the project should strive to manage as well as to manage those uncertainties. While technical expertise can be broadened to accommodate the new analytical needs, the extent of the decision making required is arguably beyond the legitimate authority of technical experts. Instead managing the kinds of uncertainties that are relevant to large-scale infrastructure projects will require a combination of both technical expertise and value judgments. Given the public scope and the long lifetime of the projects, these value judgments ultimately need be informed by some sort of public policy. Furthermore, the ability to manage the uncertainty surrounding a project as time unfolds will necessarily require the cooperation with public bodies for a variety of purposes. Not only are public inputs important for the purposes of monitoring uncertainties in order to react in a timely manner, they are also important for managing adverse events as they arise. Collaboration across government agencies and between public and private stakeholders is important to delivering flexibility.

Finally, in addition to the static role of institutional capacity in supporting flexibility, the research can also be extended to consider a dynamic institutional environment. Given the pace of infrastructure development, institutional structures in many nations may not be compatible with the challenges associated with managing uncertainty. There will be many challenges facing the implementation of flexible infrastructure in those contexts. Unfortunately this is precisely the context in which many infrastructure projects are being pursued. Understanding the relationship between institutional regimes in states of flux and flexible infrastructure could result in the identification of policy measures to enable greater institutional capacity for flexibility and sustainable development.
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### Appendix A: Capital Cost Assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake / outfall</td>
<td>$17,229,310</td>
</tr>
<tr>
<td>Pumps</td>
<td>$21,536,640</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>$18,306,140</td>
</tr>
<tr>
<td>Installation and services</td>
<td>$17,229,310</td>
</tr>
<tr>
<td>PVs</td>
<td>$3,230,500</td>
</tr>
<tr>
<td>Design and professional costs</td>
<td>$11,845,150</td>
</tr>
<tr>
<td>Membranes</td>
<td>$10,768,320</td>
</tr>
<tr>
<td>Piping/high alloy</td>
<td>$25,843,960</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>$39,842,780</td>
</tr>
<tr>
<td>Equipment and materials</td>
<td>$47,380,600</td>
</tr>
<tr>
<td>Legal and professional</td>
<td>$2,153,670</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$215,366,380</strong></td>
</tr>
</tbody>
</table>

Table A - 1: Cost Breakdown for a 200,000 m³/day RO plant in Qatar (Desaldata.com)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Pre Investment</td>
<td>$39,842,780</td>
</tr>
<tr>
<td>Maximum Pre Investment</td>
<td>$100,145,370</td>
</tr>
<tr>
<td>Assumed Pre-Investment</td>
<td>$53,652,679</td>
</tr>
<tr>
<td>Percentage of Total</td>
<td>25%</td>
</tr>
</tbody>
</table>

Table A - 2: Pre-Investment Assumptions
APPENDIX B: FIXED IRR BOOT RESULTS

**Fixed Capacity TOP**
The fixed capacity contract is analyzed under the fixed IRR condition. As expected, this approach reverses the trends from the fixed price reimbursement approach. The public agency in this case makes increasing gains with flexibility. In addition to these gains, the price that the public sector has to pay for water decreases by up to almost 30% with increasing flexibility. These gains, however, come at the expense of the private firm which receives a smaller distribution of the gains with increasing flexibility. The private firm still makes a positive NPV for most of the design cases, but has no financial incentive to propose greater flexibility.

![Figure B - 1 Waterfall from Expected Gains from Fixed Capacity](image)

**Table B - 1 Summary Result of Fixed Capacity**

<table>
<thead>
<tr>
<th></th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,007</td>
<td>$831</td>
<td>$793</td>
<td>$776</td>
<td>$697</td>
</tr>
<tr>
<td>IRR</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>NPV</td>
<td>$97</td>
<td>$28</td>
<td>$17</td>
<td>$16</td>
<td>($17)</td>
</tr>
</tbody>
</table>

**Installed Capacity BOOT**
The fixed IRR reimbursement approach significantly improves the distributional effect of this payment structure for the private firm relative to the fixed fee approach. It also improves the NPV of the private firm, holding it relatively constant for the different flexibility approaches. While the
public agency still makes the bulk of the savings, this approach results in an increase in the price of water relative to the fixed price.

![Waterfall of Expected Gains (Mil USD NPV)](image)

**Figure B - 2 Waterfall for Expected Gains from Installed Capacity**

**Table B - 2 Summary of Expected Results for Fixed IRR Installed Take or Pay**

<table>
<thead>
<tr>
<th>Installed Capacity</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,007</td>
<td>$873</td>
<td>$856</td>
<td>$834</td>
<td>$796</td>
</tr>
<tr>
<td>IRR</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>NPV</td>
<td>$97</td>
<td>$74</td>
<td>$79</td>
<td>$74</td>
<td>$83</td>
</tr>
</tbody>
</table>

**150% Installed Capacity Boot**

The fixed IRR reimbursement structure results in a decrease in the NPV as compared both to the fixed price 150% capacity approach as well as the fixed IRR installed capacity approach. This NPV, however, is still relatively high, remaining roughly 50% of the inflexible case for all the flexible design cases. The price of water in this scenario remains roughly constant for all of the design cases.
**Figure B - 3 Waterfall of Expected Gains from 150 Capacity Case**

**Table B - 3 Summary Results of 150% Capacity**

<table>
<thead>
<tr>
<th>150 Capacity</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,007</td>
<td>$853</td>
<td>$833</td>
<td>$814</td>
<td>$768</td>
</tr>
<tr>
<td>IRR</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>NPV</td>
<td>$97</td>
<td>$52</td>
<td>$55</td>
<td>$53</td>
<td>$54</td>
</tr>
</tbody>
</table>

**Capacity Savings Boot**

The fixed IRR reimbursement approach results in a decrease in gains to the private sector with increasing flexibility. The NPV to the private sector is positive but only barely so, it is roughly only 25% of the inflexible case. The public agency continues to make the bulk of the gains from flexibility. The price of water for this case also remains roughly constant for all of the design cases.
**Figure B - 4 Waterfall from Expected Gains from Capacity Savings**

**Table B - 4 Summary Results of Capacity Savings**

<table>
<thead>
<tr>
<th>Savings</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,007</td>
<td>$841</td>
<td>$805</td>
<td>$786</td>
<td>$708</td>
</tr>
<tr>
<td>IRR</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>NPV</td>
<td>$97</td>
<td>$39</td>
<td>$28</td>
<td>$25</td>
<td>($5)</td>
</tr>
</tbody>
</table>

*No Take or Pay Boot*

While the no take or pay contract also follows the same distributional trends as the other fixed IRR contract scenarios, it does allow the private sector to maintain a relatively high NPV across all design cases, second only to the installed capacity scenario. For the public sector, the gains from this contract structure are low compared to the other contract scenarios. This scenario has the highest prices of water, but this is due to the adjustment made to scale this scenario to the other scenarios. The trend in water prices is to decrease with increasing flexibility.
**Figure B - 5 waterfall of expected gains from no take or pay**

**Table B - 5 summary results of no take or pay**

<table>
<thead>
<tr>
<th>No Top</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,010</td>
<td>$873</td>
<td>$844</td>
<td>$829</td>
<td>$771</td>
</tr>
<tr>
<td>IRR</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>NPV</td>
<td>$100</td>
<td>$72</td>
<td>$67</td>
<td>$67</td>
<td>$57</td>
</tr>
</tbody>
</table>
APPENDIX C: EPC CONTRACTS

EPC LUMP SUM

The first EPC contractual approach calls for the payment of a fixed sum equivalent to the
deterministic expected total cost of a 400,000 m3/day desalination plant. Under this scenario, the
public agency is in essence simply paying the private firm a fixed amount. By giving the private firm
the freedom to phase the expansion however it pleases, it essentially gives complete freedom to the
private firm to maximize value. Figure C-1 shows the result of the waterfall analysis for the lump
sum EPC approach. The graph shows the relative gain from the adoption of the design approach
relative to the inflexible case for each participant. As is expected, under a lump sum approach, the
government is indifferent in terms of expenditure between the various options and the private
sector captures all of the gains from the adoption of flexibility. In addition to the distribution of
gains, the expected return on capital to the private sector is also graphed. In line with the
increasingly high NPVs, the returns on capital increase by up to a factor of three with increasing
flexibility, reaching a potential high point of 45%. The consequences of this high return on capital as
well as the underlying risk distribution for all of the contract scenarios is discussed in detail in the
next chapter.

Figure C - 1 waterfall diagram showing distribution of expected gains from a lump sum approach
Table C - Summary of results of waterfall analysis for lump sum epc scenario (PV mil USD)

<table>
<thead>
<tr>
<th>Lump Sum</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,008</td>
<td>$1,008</td>
<td>$1,008</td>
<td>$1,008</td>
<td>$1,008</td>
</tr>
<tr>
<td>Private NPV</td>
<td>$98</td>
<td>$208</td>
<td>$230</td>
<td>$247</td>
<td>$294</td>
</tr>
<tr>
<td>Returns On Capital</td>
<td>11.0%</td>
<td>28.5%</td>
<td>31.7%</td>
<td>34.5%</td>
<td>44.2%</td>
</tr>
</tbody>
</table>

**EPC Cost Plus Fee**

Whereas in the lump sum approach the public agency was made indifferent in terms of expected gains, the fixed fee approach makes the private firm indifferent from the perspective of gains. Figure C-2 shows the waterfall chart for the cost plus fixed fee approach. In terms of the distribution of gains this approach results in an almost inverse distribution of gains as compared to the lump sum approach. In this case the NPV that goes to the private sector is fixed, while the government makes all of the gains from flexibility, which amount up to approximately 20%. However, given that the private sector makes a smaller investment as flexibility increases, the private sectors return on capital increases with flexibility. These returns, however, are in the range of 10-15%, much lower than the 40% plus IRR of the lump sum case. In addition because of the decrease in total government expenditure, the cost per unit of water to the public sector decreases with increasing flexibility.

![Waterfall Chart](image)

**Figure C-2** Waterfall chart showing the distribution of gains from flexibility to project participants
Table C - 2Summary expected distribution of value for cost plus fee (mil USD NPV)

<table>
<thead>
<tr>
<th></th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,010</td>
<td>$900</td>
<td>$878</td>
<td>$862</td>
<td>$814</td>
</tr>
<tr>
<td>Private NPV</td>
<td>$100</td>
<td>$100</td>
<td>$100</td>
<td>$100</td>
<td>$100</td>
</tr>
<tr>
<td>Returns On Capital</td>
<td>11.0%</td>
<td>12.8%</td>
<td>13.1%</td>
<td>13.3%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

EPC Cost Plus Percent

Instead of offering a fixed fee on top of costs, the cost plus percent approach pays the private firm an additional percentage of cost as a profit payment. As can be seen in Figure C-3, this scenario results in fixing the returns on capital to the private firm. While the actual private sector NPV remains positive for all of the design scenarios, the NPV decreases with increasing flexibility. The more value that the flexibility delivers to the project, the smaller the share of that value that the private sector receives. The public sector on the other hand receives increasing gains from the distribution of value.

Figure C - 3 Waterfall chart showing the distribution of value from cost plus percent

Table C - 3Summary of the expected distribution of value for cost plus percent (mil USD PV)

<table>
<thead>
<tr>
<th>Cost Plus</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$994</td>
<td>$873</td>
<td>$840</td>
<td>$817</td>
<td>$759</td>
</tr>
<tr>
<td>Private NPV</td>
<td>$97</td>
<td>$86</td>
<td>$82</td>
<td>$80</td>
<td>$74</td>
</tr>
<tr>
<td>Returns On Capital</td>
<td>10.9%</td>
<td>10.9%</td>
<td>10.9%</td>
<td>10.9%</td>
<td>10.9%</td>
</tr>
</tbody>
</table>
**EPC Cost Plus Incentive**

The cost plus incentive contract essentially splits the gains from the project between the public and the private participants almost on an equal basis. Both private and public participants receive increasing gains from the implementation of flexibility. The gains to the private sector are considerably less than the gains it would receive from the lump sum approach and the gains from the public sector less than those from the fixed fee or the cost plus percent approach. The returns on capital to the private sector are high in this case, going up to 30%.

![Figure C - 4 Waterfall chart showing the distribution from flexibility for cost plus percent](image)

**Table C - 4 Summary of the expected distribution of value for cost plus incentive (mil USD PV)**

<table>
<thead>
<tr>
<th>Savings Sharing</th>
<th>Inflexible</th>
<th>Phased</th>
<th>Flexible I</th>
<th>Flexible II</th>
<th>Flexible III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov Expenditure</td>
<td>$1,010</td>
<td>$958</td>
<td>$947</td>
<td>$939</td>
<td>$917</td>
</tr>
<tr>
<td>Private NPV</td>
<td>$100</td>
<td>$157</td>
<td>$169</td>
<td>$178</td>
<td>$203</td>
</tr>
<tr>
<td>Returns On Capital</td>
<td>11.0%</td>
<td>20.8%</td>
<td>22.6%</td>
<td>24.2%</td>
<td>29.7%</td>
</tr>
</tbody>
</table>
**APPENDIX D: SAMPLE SPREADSHEETS**

**FIGURE D - 1 Calculation of Performance of a Flexible Design Case for first five years of operations (Flexible I in this case)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity</td>
<td>160000</td>
<td>160000</td>
<td>160000</td>
<td>240000</td>
<td>240000</td>
<td>240000</td>
</tr>
<tr>
<td>Water Demand Forecast</td>
<td>87471.39138</td>
<td>153969.2105</td>
<td>188271.9083</td>
<td>175647.2542</td>
<td>151075.5027</td>
<td>166161.6103</td>
</tr>
<tr>
<td>Expansion Check</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Additional Capacity Required</td>
<td>0</td>
<td>0</td>
<td>28271.90826</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of tranches required</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Existing Preinvestments</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Check if additional pre-investment required</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PreInvestment Counter</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Investment</td>
<td>$430,732,760</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulative Capital</td>
<td>$183,023,640</td>
<td>$183,023,640</td>
<td>$301,361,799</td>
<td>$301,361,799</td>
<td>$301,361,799</td>
<td>$301,361,799</td>
</tr>
</tbody>
</table>

**Project Expenditure**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed OM</td>
<td>$0</td>
<td>$12,576,946</td>
<td>$17,310,472</td>
<td>$19,938,472</td>
<td>$19,938,472</td>
<td>$19,938,472</td>
</tr>
<tr>
<td>Variable OM</td>
<td>$0</td>
<td>$3,376,035</td>
<td>$4,171,186</td>
<td>$3,965,909</td>
<td>$4,960,623</td>
<td>$5,549,293</td>
</tr>
<tr>
<td>Energy</td>
<td>-</td>
<td>5,708,569</td>
<td>7,053,096</td>
<td>6,705,992</td>
<td>8,387,963</td>
<td>9,383,350</td>
</tr>
</tbody>
</table>

**PV Expenses**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Capital Expense</td>
<td>$341,450,609</td>
<td>$183,023,639.72</td>
<td>$0</td>
<td>$97,800,132</td>
<td>$0</td>
<td>$0.00</td>
</tr>
<tr>
<td>PV OM</td>
<td>$397,963,558</td>
<td>$19,692,318</td>
<td>$23,582,441</td>
<td>$22,998,026</td>
<td>$22,735,509</td>
<td>$21,652,219</td>
</tr>
<tr>
<td>Total Expense</td>
<td>$739,414,167</td>
<td>$183,023,640</td>
<td>$19,692,318</td>
<td>$121,382,572</td>
<td>$22,998,026</td>
<td>$22,735,509</td>
</tr>
</tbody>
</table>
**Figure D - 2 Sample Calculation of the distribution of value due to a particular contract scenario (Capacity Savings Contract in this case)**

**Take Or Pay Calculations**

<table>
<thead>
<tr>
<th>Installed Capacity Basis</th>
<th>160000</th>
<th>160000</th>
<th>160000</th>
<th>240000</th>
<th>240000</th>
<th>240000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take Or Pay</td>
<td>$596,579,832</td>
<td>$0</td>
<td>$75,661,103</td>
<td>$69,805,906</td>
<td>$77,230,488</td>
<td>$69,905,773</td>
</tr>
</tbody>
</table>

**Fine Calculations**

<table>
<thead>
<tr>
<th>PV TP</th>
<th>$382,916,696</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Fine</td>
<td>$0</td>
</tr>
</tbody>
</table>

**BOT Contracts**

<table>
<thead>
<tr>
<th>Installed Capacity Basis</th>
<th>340000</th>
<th>340000</th>
<th>340000</th>
<th>360000</th>
<th>360000</th>
<th>360000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take Or Pay</td>
<td>$596,579,832</td>
<td>$0</td>
<td>$75,661,103</td>
<td>$69,805,906</td>
<td>$77,230,488</td>
<td>$69,905,773</td>
</tr>
</tbody>
</table>

**Private Sector Income**

<table>
<thead>
<tr>
<th>Installed Capacity Basis</th>
<th>160000</th>
<th>160000</th>
<th>160000</th>
<th>240000</th>
<th>240000</th>
<th>240000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take Or Pay</td>
<td>$596,579,832</td>
<td>$0</td>
<td>$75,661,103</td>
<td>$69,805,906</td>
<td>$77,230,488</td>
<td>$69,905,773</td>
</tr>
</tbody>
</table>

**Public Expenditure on BOT**

<table>
<thead>
<tr>
<th>Installed Capacity Basis</th>
<th>340000</th>
<th>340000</th>
<th>340000</th>
<th>360000</th>
<th>360000</th>
<th>360000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take Or Pay</td>
<td>$596,579,832</td>
<td>$0</td>
<td>$75,661,103</td>
<td>$69,805,906</td>
<td>$77,230,488</td>
<td>$69,905,773</td>
</tr>
</tbody>
</table>

**Figure D - 3 Sample calculation of risks**

<table>
<thead>
<tr>
<th>Project Risks</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of Expansion</td>
<td>14</td>
</tr>
<tr>
<td>Expansion Duration</td>
<td>14</td>
</tr>
<tr>
<td>Exposure</td>
<td>($183,023,640)</td>
</tr>
<tr>
<td>IRR</td>
<td>24%</td>
</tr>
<tr>
<td>NPV</td>
<td>$194,297,579</td>
</tr>
<tr>
<td>Undiscounted NI</td>
<td>($183,023,640)</td>
</tr>
<tr>
<td>Payback Period</td>
<td>4</td>
</tr>
<tr>
<td>Shortage</td>
<td>5957739.868</td>
</tr>
<tr>
<td>Total Water shortage</td>
<td>5957739.868</td>
</tr>
<tr>
<td>Profit as percentage of average</td>
<td>52.6%</td>
</tr>
<tr>
<td>Capacity/Sales</td>
<td>3.376956429</td>
</tr>
</tbody>
</table>