ECONOMIC ANALYSES OF POLICIES FOR HOUSEHOLD WATER SERVICES IN METRO MANILA

By

Albert E. Lamberte

A thesis submitted for the degree of Doctor of Philosophy

The Australian National University

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Declaration of Authorship

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Abstract

The Philippine Government privatised water services in Metro Manila, the National Capital Region (NCR) of the Philippines, in 1997, dividing the service areas between two water concessionaires—with Manila Water servicing the East Zone and Maynilad covering the West Zone. Since the privatisation, the water services have improved markedly. However, the increases in household population and water connections have resulted in increased water demand, putting pressure on the principal water supply sourced from the Angat Dam. In order to ration scarce water supplies, the water concessionaires have imposed timed water disruptions. The Philippine Government plans to augment water storage by building the Kaliwa Dam and passing on the investment cost to water users.

This thesis provides economic analyses of the social welfare implications of two measures to address water scarcity in Metro Manila, namely, price-measure water-demand management and the proposed water supply augmentation. Both measures are dependent on the sensitivity of households to changes in water prices. Thus, the thesis estimates household water-demand elasticities post-privatisation of the water services in Metro Manila. The results suggest that households in the East Zone are less sensitive to changes in water prices than households in the West Zone, which can be attributed to the different performances of the two concessionaires. The results also suggest that other household characteristics, such as household head gender, household head marital status, household head age, and the household type are endogenous variables that have statistically significant influence on water demand, aside from the family size and income that existing literature has considered.

The thesis considers using the risk-adjusted user cost (RAUC) as an alternative to water rationing in times of water scarcity. This pricing instrument estimates the households' willingness-to-pay to avoid water restrictions and allows households to consume water undisrupted, despite the declining water levels in Angat Dam. The findings suggest that given the current conditions in Metro Manila, households do not require a RAUC. The findings of the sensitivity analyses, however, suggest that if: (i) the Kaliwa Dam is not operational by 2025; and (ii) the concessionaires achieve their goal of 100 per cent service connections for all households in Metro Manila; and (iii) extreme dry weather events occur, then the RAUC would increase the social surplus, or the social net benefit, of Metro Manila households.

To determine the optimal time at which the Kaliwa Dam should be operationalised, a dynamic optimisation model was constructed especially for this thesis. It shows that the optimal time to operationalise the Kaliwa Dam is 2042. The results of the sensitivity analyses further suggest that the optimal time is sensitive to different household growth rates and the very low water inflows scenario from the Angat Dam but is insensitive to the changes in social discount rates. The Philippine Government currently plans to have this dam operational by 2025, but the model indicates that this is premature and will result in social losses.

Overall, the thesis provides valuable insights for policymakers who are considering either a water-demand management approach or supply augmentation for managing an urban water supply system.

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The series of lockdowns put in place by both the Australian Government and the Philippine Government to stem the spread of the SARS-CoV-2 had made it impossible for me to go back to the ANU campus after I completed my fieldwork in the Philippines. However, with the unqualified endorsement from my supervisors, the ANU and the Australia Awards allowed me to continue working on my thesis remotely in the Philippines while the COVID-19 pandemic was raging. I am grateful to Dr. Megan Poore and Ms. Tracy McRae for providing me with the support and all the information I need to be able to work remotely during the pandemic. Heartfelt thanks also go to the Away Team for making me feel like I was in the CSPP-ANU while working on my thesis remotely in the Philippines.

My co-faculty members at the School of Economics (SOE) at De La Salle University (DLSU)-Manila have been supportive ever since I first started teaching at the School and throughout my PhD candidature at the CSPP-ANU. I am grateful to them, most especially Professor Marites Tiongco, who while Dean of the School, had encouraged me to apply for the Australia Awards and the PhD program at Crawford.

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I would like to thank my family, the source of my inspiration, strength, and emotional and moral support. My father, Mario, sounded like a broken record for incessantly reminding me to stick to my thesis topic even if the water at the Angat Dam runs dry. I came to understand why he avoided my many attempts to discuss my research with him, and why he kept on refusing to read several drafts of my seminar papers until after I completed my thesis. My late mother, Tata, who was an exemplary teacher and researcher at the DLSU, inspired me to switch from practicing my profession as a civil engineer to become an educator and researcher, following in her footsteps. She encouraged me to pursue a graduate degree so that I could continue the work she started at the DLSU. She even convinced my father not to inform me about her critical condition just so I would not be distracted from my studies. I always feel her love, care, and protection every single day. My sister, Lisa, gave me ample tutorial lessons on how to survive well in a foreign university whose faculty, students, and administrative staff come from different social and cultural backgrounds and academic disciplines.

And lastly, but most importantly, I would like to thank the Almighty God for bringing me into this world, for answering my prayers, and now for giving me the opportunity to share my talents with my fellow men and women.

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List of acronyms and abbreviations

ACT	Australian Capital Territory
ADB	Asian Development Bank
ADR	appropriate discount rate
AIDS	Almost Ideal Demand System
AMRIS	Angat-Maasin River Irrigation System
BOT	Build-operate-transfer
CEEC	China Energy Engineering Corporation
CMS	cubic metres per second
COA	Commission on Audit
CPI	consumer price index
CSDM	combined stochastic and deterministic modelling
cu.m.	cubic metre
DBM	Department of Budget and Management
DMA	District metering areas
DMZ	demand monitoring zone
DOF	Department of Finance
DOH	Department of Health
DPWH	Department of Public Works and Highways
DTI	Department of Trade and Industry
EIRR	economic internal rate of return
EMB	Environmental Management Bureau
EPA	Extraordinary price adjustment
FCDA	foreign currency differential adjustment
FIES	Family Income and Expenditure Survey
GLQM	Gaussian Legendre quadrature method
GPOBA	Global Partnership on Output-Based Aid
IBT	increasing block tariffs
ICC	Investment Coordination Committee
IP	Indigenous people
JICA	Japan International Cooperation Agency
km	kilometres
LGU	Local Government Units
m	metres
MC	marginal cost
MCM	million cubic metres
MLD	million litres per day
MROC	marginal resource opportunity cost
MWCI	Manila Water Company, Inc.
MWSI	Maynilad Water Services, Inc.
MWSS	Metropolitan Waterworks and Sewerage System
NAPOCOR	National Power Corporation
NCR	National Capital Region
NEDA	National Economic Development Authority
NEDA-ICC	National Economic Development Authority - Investment Coordination Committee
NIA	National Irrigation Authority
NPV	net present value

NRW	non-revenue water
NWCA	National Water Crisis Act
NWRB	National Water Resources Board
ODA	official development assistance
OLS	Ordinary Least Squares
PAGASA	Philippine Atmospheric, Geophysical, and Astronomical Services Administration
PIDS	Philippine Institute for Development Studies
Php	Philippine Peso
PPP	public-private partnership
PSA	Philippine Statistical Authority
PSI	pounds per square inch
QUAIDS	Quadratic Almost Ideal Demand System
RA	Republic Act
RAUC	risk-adjusted user cost
SCBA	social cost-benefit analysis
SDDP	stochastic dual dynamic model
SDP	stochastic dynamic programming
SDR	social discount rate
UTCE	University of Tokyo Civil Engineering
VAT	value-added tax
WAC	water abstraction charge
WQAP	Water Quality Association of the Philippines, Inc.
WTP	willingness-to-pay
WSC	water service charge

Chapter 1

Introduction

I. Rationale of the thesis

The water services in Metro Manila, the National Capital Region (NCR) of the Philippines, was privatised in 1997 to improve their efficiency in providing water services to customers. The region was divided into two concession areas—the East Zone and the West Zone—with each one assigned to the winning bidder. The Metropolitan Waterworks and Sewerage Systems (MWSS), a government-owned corporation that used to run the water system in Metro Manila, was assigned the task of regulating the two private concessionaires.

Since the water services market was privatised in Metro Manila, the water services have improved in terms of the increase in the number of household connections and the reduction in non-water revenue. Non-revenue water (NRW) is attributed to both structural (i.e., leaks in pipelines, measurement errors in meters, and illegal connections) and non-structural factors (i.e., water theft). Nevertheless, the region experiences intermittent water supply interruptions, which, typically, occur during the summer months when the water level at the Angat Dam, the main source of water for the region and nearby agricultural areas, dips below the 180-metres minimum operating level and approaches the 160-metres critical level. The 160-metre critical level is to be observed to preserve the structural integrity of the Angat Dam and the flora and fauna in the dam's watershed. Further, this prevents the change in the water quality and keeps the natural hydrograph of the dam (Wang et al. 2020, Ehsani et al. 2017). When the water level falls below the minimum operating level, the National Water Resources Board (NWRB) reduces the volumetric flows, which lowers water pressure and results in service interruptions for domestic water use.

In an important report, the Metropolitan Waterworks and Sewerage Systems (2012) observed that, beginning in 2025, the water demand at the existing water tariff would exceed the available storage in Angat Dam, which is the main source of raw water for the region. In response, the Philippine Government, through the National Economic and Development Authority (NEDA) Board, approved in 2014 the proposal of MWSS to construct a new water source, the Kaliwa Dam, whereby households would shoulder the cost of investment under a public-private partnership (PPP) scheme. According to the Environmental Management

Bureau (EMB 2014), the main use of the Kaliwa Dam is to ensure water security by increasing the raw water supply purely to meet the future domestic water demand of Metro Manila. Moreover, constructing the dam will reduce the dependence of the region on the Kaliwa Dam.

The construction of the Kaliwa Dam was originally supposed to start in 2016 and be completed in 2020. When the Duterte administration assumed office in the mid-2016, it shifted its policy of financing public infrastructures, from PPP to official development assistance (ODA). This caused a delay in implementing the Kaliwa Dam project. In 2018, the government approved the ODA financing scheme in the form of a soft loan from the People's Republic of China (PRC) through its government-owned bank. The construction was supposed to start in 2019 and be completed in 2025. This plan was delayed by the Commission on Audit (COA) that highlighted some legal issues to the construction of the dam, which include, among others, (i) the foreign contractor's lack of significant experience in constructing dams over the last 20 years, (ii) the forced displacement of indigenous peoples, and (iii) the soft loan that will be provided by one of China's government-owned banks (Commission on Audit 2019). COA also flagged MWSS for issuing a notice to the contractor to proceed with the project in November 2019 despite the company's failure to show proof that it had complied with the preconditions set by the Department of Environment and Natural Resources (DENR) under an environmental compliance certificate issued in October 2019 (Commission on Audit 2020).

Both water concessionaires had earlier expressed their concerns with the uncertainty in the timing of the operationalisation of the Kaliwa Dam should water demand exceed available supply according to MWSS' projection (Manila Water 2017, Maynilad 2017). This raises two fundamental questions. First, considering MWSS' projection of water shortage in 2025 and uncertainty in augmenting the water supply for Metro Manila, what approach should the regulator and concessionaires adopt to manage the situation wherein water demand exceeds supply should the new water storage not yet be operationalised? Second, is the operationalisation of the Kaliwa Dam in 2025, as planned by the government, the optimal time for its commencement? This thesis is motivated by the need to provide evidence-based answers to those questions. The principle is to avoid making policy decisions that will have substantial negative welfare implications.

II. Statement of the problem

The worsening problems due to surface water scarcity have prompted policymakers worldwide to examine appropriate strategies to respond to water supply challenges. To manage households' consumption of water, one strategy is to impose non-price demand management policies, such as meter testing and replacement programs, social conservation incentive and disincentive programs, and water restrictions on certain water uses (Dziegielewski 2003). A common approach is to impose water restrictions, usually on outdoor or leisure use of water. Supply augmentation is an alternative but, typically, this approach requires large investments for infrastructure, such as dams or reservoirs. Funding these investments by water users requires the establishment of a water tariff that, typically, includes a fixed and variable or volumetric price associated with water use. When building the additional water supply and storage facilities has become a necessity, water tariffs can be formulated to finance the investment partly or fully. Given that the water tariff affects water demand, it should be fully integrated into the optimal timing of water supply augmentation (Grafton et al. 2020). Therefore, it becomes necessary to determine the optimal timing of making these additional storages operational, so as to maximise net social benefits from the water services after accounting for all economic costs and benefits.

In the case of the water services market in Metro Manila, the MWSS reduces the volumetric flows for domestic water use during periods when the water level of the Angat Dam falls below the critical level, so as to avoid risks to future water supply. This approach results in lowering the water pressures that flow to households and the two concessionaires have chosen to impose timed water disruptions in their respective service areas as a result. This was done to maintain the required pressure allocated to the water users in some unaffected areas. Such a disruption to services, however, reduces the reliability of water services and contravenes the concession agreement—which requires both Manila Water and Maynilad, the two private concessionaires, to provide a 24/7 undisrupted and reliable water supply. One key economic problem also arises if the water pressure for consumers is reduced. A lower water supply to households leads to a decrease in the consumer surplus, which is the additional value that water users realise from consuming the water services of both concessionaires. Hence, there is a need to explore an alternative demand management approach that would avoid or reduce to a minimum the negative impact on the consumers' welfare.

By 2022, both water concessionaires are expected to provide all households in their respective concession areas connection to their water supply systems. This is a challenging task, especially if the population continues to grow at an annual rate of 1.66 per cent for the Manila Water concession area, and 3.62 per cent for the Maynilad concession area (Manila Water 2017, Maynilad 2017).

Supply augmentation can relax supply constraints, but the cost of investing in a new water storage—whether through a PPP or an ODA financing scheme—will still be borne by households in the form of higher water tariff. Under the concession agreement, increases in water tariffs by the concessionaires are allowed, but this is subject to the approval of the MWSS. In their rate-rebasing exercise conducted in 2018, Maynilad and Manila Water had already included the cost of investment of the Kaliwa Dam in their respective proposed tariffs. Consequently, this will affect the consumer surplus. If this happens, building the Kaliwa Dam too early reduces the consumer surplus. Consequently, analytical tools are needed to determine the optimal timing for operationalising the Kaliwa Dam.

III. Research questions

Given that both water-demand management and supply augmentation have significant effects on the social welfare of households in Metro Manila, the research questions of this thesis are as follows:

1. **To what extent are households in the two concession areas sensitive to changes in water tariffs?**
2. **If price is used as a water-demand management tool, instead of using water interruptions and reduced water pressure, how much would households additionally pay to have their water consumption undisrupted with the current climate and existing water storage in the Angat Dam?**
3. **If the national government proceeds with water supply augmentation by building the Kaliwa Dam, when is the optimal time for such augmentation?**

IV. Research objectives

The general objective of this thesis is to provide economic analyses relating to the implications for social welfare of both price-measure water-demand management and the proposed water supply augmentation. More specifically, the thesis attempts to:

1. **Estimate the household water-demand elasticities, which measures the sensitivity of households to price changes, for each concession area, after the privatisation of the water services in Metro Manila;**
2. **Explore the use of alternative water-demand management with a dynamic scarcity pricing and measure the willingness-to-pay of households to avoid water restrictions; and**
3. **Determine dynamically the optimal timing for operationalising the Kaliwa Dam to avoid social welfare losses from building the infrastructure prematurely.**

The social welfare effects of water-demand management instruments and supply augmentation are dependent on several factors, such as (i) the household water-demand elasticities on the water services, (ii) the pricing mechanism that adapts to changes in weather, and (iii) the timing of the construction of an additional water source.

Pricing instruments are dependent on the sensitivity of the households to changes in water prices. Thus, Chapter 4 estimates the household water-demand elasticities to determine whether households in the two concession areas differ in the extent of their sensitivity to price changes. Using the estimated elasticities, Chapter 5 computes the dynamic scarcity premium that households must pay to have their water use undisrupted with the ongoing climatic change and the decline in water levels in Angat Dam. Chapter 6 focuses on the supply augmentation to meet the households' demand for water. More specifically, it estimates the optimal timing for operationalising the Kaliwa Dam using a dynamic stochastic model.

V. Contributions of this thesis

This thesis contributes to the existing literature on water services by using an integrated approach that considers both demand and supply factors to demonstrate how the welfare of households in a region could be improved by alternative policies. Specifically, the thesis considers the price elasticities of household water demand to estimate the welfare scarcity price. This scarcity price is the households' willingness-to-pay to avoid water restrictions—such that their water consumption would not be disrupted despite the declining water levels in an existing water storage. This thesis also estimates the point in time when the net present-value benefits exceed the costs, both social and economic, of an additional water storage reservoir, like the Kaliwa Dam.

Studies on demand systems offer insights useful for policymaking, especially for essential goods and services dominated by monopolists or a small number of suppliers. Yet, such studies are lacking especially in developing economies like the Philippines for various reasons, including lack of data. This thesis partly fills up this lacuna by estimating the households' demand for water in a regime when the water services is 'privatised'.

VI. Thesis structure

This thesis examines the welfare effects from the perspectives of demand- and supply-driven approaches following the four major objectives. It consists of seven chapters. Aside from this introductory chapter, Chapter 2 discusses the background of the water services in Metro Manila to provide context to the analytical chapters, Chapter 3 summarises the related literature that examine demand and supply methods in analysing different urban water systems, and three analytical chapters. Chapters 4 and 5 are the analytical chapters focused on the demand-side analysis. On the other hand, chapter 6 applies methods to analyse the supply-side. The three analytical chapters' analyses and results are comprehensively discussed to achieve the main objective of this thesis. Chapter 7 summarises the key findings and discusses the policy implications as well as potential areas for further research. Table 1.1 presents a summary of the thesis structure and framework for each chapter.

Table 1.1: Thesis structure and framework for each chapter

Chapter	Research questions	Structure and contents of each chapter
1	What are the main objectives and motivations of the thesis?	Presents the thesis' rationale, statement of the problem, research questions, the main objectives, and the contribution to the existing literature.
2	What is the current setting of the water services in Metro Manila and why is the structure unique?	Provides a background of the water services in Metro Manila: • Presents the history of the water services, the water governance structure, the rationale for privatising it, and the current operating water services. • Discusses the issues being addressed during the privatisation, such as the water tariffs and non-revenue water. • Analyses the factors that led to the different performance of the two concessionaires during the initial years of the privatisation. • Introduces the current challenges facing the water services, which include the planned supply augmentation project, specifically the building of the Kaliwa Dam; rate-rebasing issues; and regulator's and concessionaires' methods of managing water supply.
3	What are the methods used to examine optimal pricing policies and optimal timing for key infrastructures in urban water systems?	Discusses existing literatures and presents the proposed decision-making framework for water-demand management and supply augmentation that the thesis follows. The studies reviewed are categorised as follows: • **Increasing block tariffs (IBTs).** These studies deal with IBTs, as a pricing policy in different water services around the world and the issue whether IBTs can address both efficiency and equity concerns. • **Water-demand estimations**. These studies estimate water-demand elasticities using various econometric techniques, such as ordinary least squares, two-stage least-squares, two-step Heckman, discrete-continuous approach, multinomial logit, and Quadratic AIDS model. • **Dynamic programming models**. These studies develop dynamic programming models for determining optimal timing, investment, and pricing policies of water supply augmentation.
4	To what extent are households in Metro Manila sensitive to changes in water tariffs?	Using the framework of the IBT structure, the Almost Ideal Demand System (AIDS) model, and the Family Income and Expenditure Survey (FIES) databases, the chapter: • Estimates the water-demand elasticities of households in the two concession areas in Metro Manila using the methodology—the AIDS model. • Determines whether other household characteristics, aside from family income and household size, are endogenous to the household water consumption.
5	If price is used as a water-demand management tool, instead of water interruptions and reduced water pressure and scarce water supply, how much would households additionally pay to have their water consumption undisrupted with the ongoing climatic change and existing water storage in the Angat Dam?	Using the frameworks of the user cost (Boland 1992, Renzetti 1992), the water balance equation and the RAUC (Chu and Grafton 2019), this chapter • Estimates the scarcity price that households must pay when water levels are declining from the current source, which is the Angat Dam, given the current climate conditions. • Evaluates the scarcity price that households must pay to postpone the construction of the Kaliwa Dam.
6	If the national government proceeds with water storage augmentation by building the Kaliwa Dam, when is the optimal time for such augmentation?	Using the framework of the economics of water supply augmentation (Grafton et al. 2015), this chapter • Estimates the optimal time for operationalising the Kaliwa Dam using the estimated price elasticities of demand for water from the concessionaires in Chapter 4 and the price elasticities of demand for vended water in Appendix 6. • Compares the estimation of the optimal time using the public-private partnership (PPP) and the official development assistance (ODA) financing schemes to see which of the two policies maximises the social welfare benefits. • Conducts various sensitivity analyses, including changing the discount rate for the investment cost, household growth rates, and weather scenarios; and an analysis on prematurely operationalising the Kaliwa Dam.
7	What are the conclusions and policy implications of examining the water services in the Philippines?	Provides a summary of the key questions, approaches, and key findings in chapters 2–6; and discusses some policy implications as well as potential areas for further research.

Chapter 2

Background of the water services in Metro Manila

This chapter presents the history and the current situation of the water services in Metro Manila, Philippines. This chapter is structured as follows: The first section presents the history and the current operational system of the water services. The second section deals with the issues that were addressed during the privatisation of the water services. The third section examines the factors that influenced the outcome of the concessionaires' operations after privatisation. The fourth and final section discusses the challenges currently faced by the water concessionaires and the regulator.

I. History and the current operational system of the water services in Metro Manila

History of the water services in Metro Manila: Privatising to address government failure

The Angat Dam, which is part of the Angat-Ipo-La Mesa dam system, was constructed to provide water supply to Metro Manila and the surrounding provinces. The dam is situated 30 kilometres (km) northeast of the nation's capital and provides approximately 4 million cubic metres (MCM) of water per day, which constitutes 98 per cent of the capital's water supply. The dam was constructed in 1964 to 1967 and became operational in 1968 as a multi-purpose dam that combines urban water supply, irrigation, and hydropower generation. The national government awarded the water rights to the National Water Resources Board (NWRB) and the water services were centrally controlled by the state. The NWRB still manages the allocation of raw or untreated water in the Angat Dam, and this includes the competing uses of water supply, irrigation, and hydropower.

In June 1971*, Republic Act 6271* (RA 6271) established the Metropolitan Waterworks and Sewerage System (MWSS) as a government-owned, autonomous public utility corporation. The corporation provided and managed the water supply and sewerage services in Metro Manila as well as in the province of Rizal and some areas of Cavite. This allowed the government to centrally control and manage the water supply through the MWSS. However, in the late 1980s and early 1990s, MWSS failed to improve the water services in the region. According to the Asian Development Bank (ADB 2008), the water services in Metro Manila during the 1990s, before its privatisation, was one of the worst among major Asian cities (see Table 2.1). The water services barely expanded despite rapid industrialisation and high population growth. The MWSS encountered two operational problems that prevented it from improving the water infrastructure. These were the (i) high levels of non-revenue water (NRW), and (ii) high levels of accounts receivable.[1] These structural and non-structural issues contributed to the unsuccessful delivery of the water services. In addition, only 60 per cent of the population in Metro Manila were connected to MWSS and received water supply for only 12 hours or less per day. Thus, MWSS failed to perform its mandated task of improving the water services in Metro Manila.

Table 2.1: Selected Asian cities and water services, 1996

City	Population (millions)	GDP per capita (US$)	Coverage (%)	Non-revenue water (%)	Accounts receivable (months)	Tariff ($/cu. m.)
Bangkok	9.0	3,815	82	38	2.0	0.31
Beijing	7.4	862	100	8	0.1	0.05
Colombo	0.6	863	58	51	3.2	0.14
Delhi	8.4	544	86	44	4.5	0.03
Dhaka	3.4	320	42	51	11.0	0.09
Hanoi	3.5	328	76	71	0.1	0.11
Hong Kong	6.4	30,809	100	36	4.0	0.56
Jakarta	9.1	575	27	53	1.0	0.61
Karachi	9.3	1,448	70	40	16.8	0.09
Kuala Lumpur	1.1	586	100	36	0.5	0.34
Manila	11.0	5,952	67	58	6.0	0.23
Taipei	2.6	12,709	99	37	1.7	0.39

Source: ADB (2008).

One of the contributing problems is the complex water management in the Philippines due to the complex interlinkages among the different local and national agencies. Elazegui (2004) points out that water management in the Philippines involves various agencies both at the national and local levels (see Figure 2.1). Overlaps in the designated responsibilities between national and local agencies and the weak interagency linkages and coordination have weakened the ability of the agencies to perform their mandated tasks in water management.

Political factor could have also affected the performance of MWSS. The MWSS Administrator was appointed by the President and served at his/her pleasure. The experience and management

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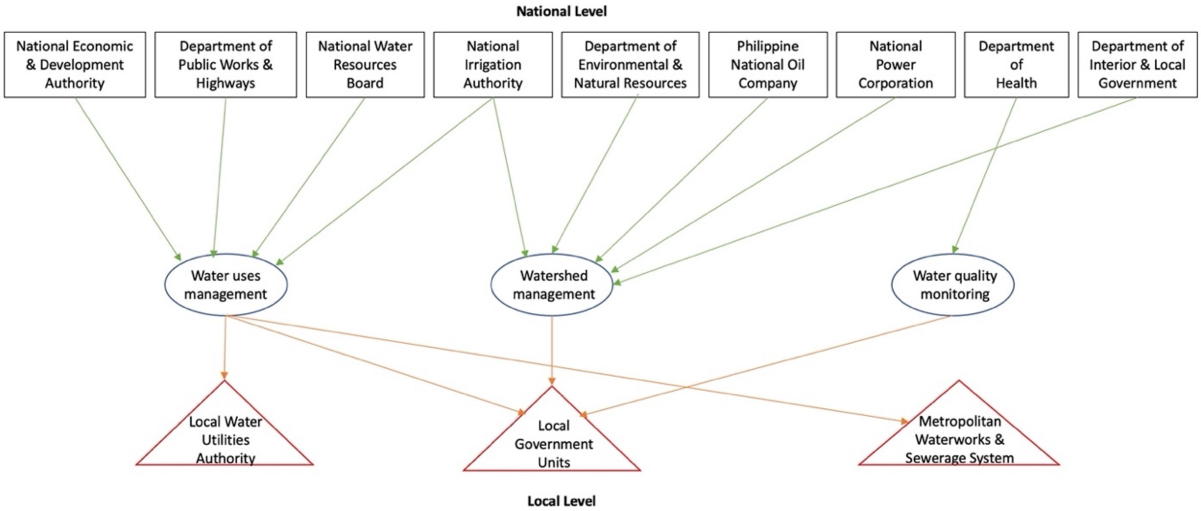
[1] Non-revenue water is attributed to leaks in pipelines, measurement errors in metres, illegal connections, and water thefts.

skills of political appointees need not be the primary consideration in choosing an administrator. This prevented the professionalisation of the MWSS top management.

Figure 2.1: Major institutions involved in water resource governance in the Philippines



Source: Elazegui (2004).

Realising that centrally managing the water services did not improve the water services, the national government passed the *National Water Crisis Act* (NWCA) in 1995 (Chia et al. 2007). The Act declared that Metro Manila was in water crisis and that employing a public-private partnership (PPP) to improve water services was a necessary step forward. Consequently, the water services were privatised under the Act. The NWCA sought to improve the water services to consumers by raising the operating efficiency of the current water infrastructure and expanding the coverage of the services. The NWCA also enabled the national government to seek assistance from the private sector for the provision of financial, operational, and human resources. It also criminalised water theft as a means of reducing NRW.[2]

The NWCA retained the MWSS as a government agency and gave it the responsibility of regulating the water services. The NWCA further allowed MWSS to reorganise itself to better manage water services. The MWSS introduced two separate offices under their agency, which are the: (i) MWSS regulatory office, which monitors the performance of the concessionaires; and the (ii) MWSS corporate office, which oversees the overall administration and expansion of the water services. Lastly, the NWCA divided Metro Manila into the East Zone and the West Zone (see Figure 2.2). Dividing Metro Manila into two zones gave MWSS more leverage in

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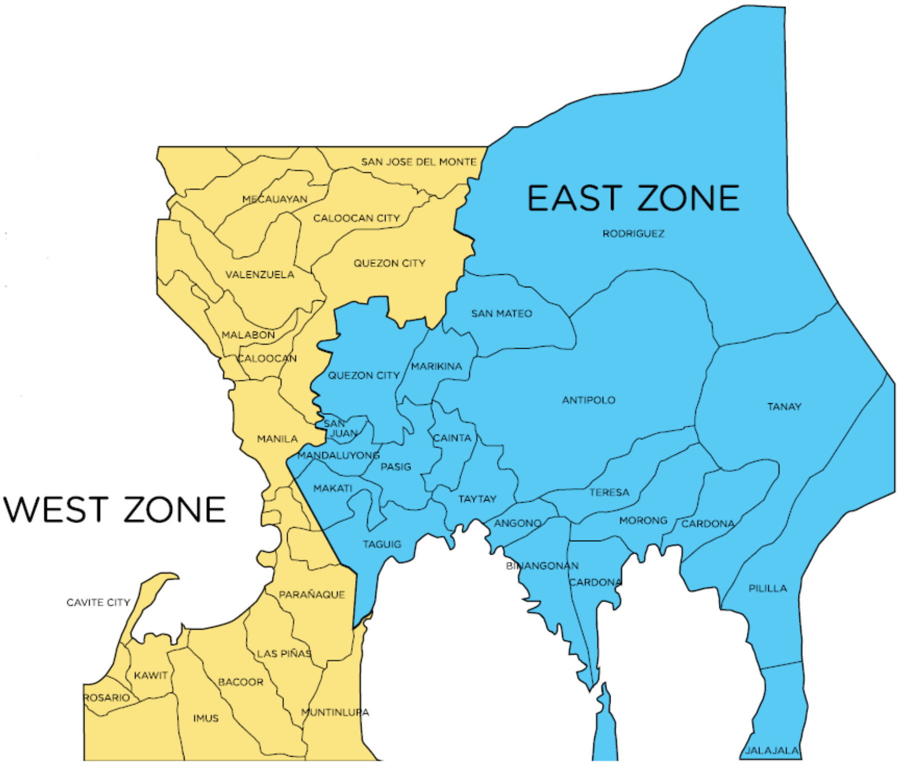
[2] Such acts include the illegal tapping of water, tampering with water meters, stealing of meters, and unauthorised selling of water coming from water connections.

its negotiations with the two private concessionaires, provided benchmarking comparisons between the two zones, and serving as a safety net with the operation of two separate zones. However, if one of the concessionaires were to have financial constraints and problems, the other could take over the management and operations temporarily—with the regulator's approval. This was intended to ensure that water services continue without any interruption.

Figure 2.2: The West and East Zones



Source: Manila Water (2017).

Manila Water operates the East Zone concession area while Maynilad covers the West Zone. The concession agreement, which was also established through the NWCA, identifies the deliverables, agreements, and conditions that the MWSS and both concessionaires agreed during the concession period. In the agreement, the water concessionaires are required to meet the targets of increased service coverage, better water quality, and the reduction of NRW. These targets are achieved by allowing both Manila Water and Maynilad to increase or adjust their respective tariffs. The concession agreement identifies three acceptable grounds for tariff adjustments: (i) inflation, (ii) extraordinary price adjustment (EPA), and (iii) rate rebasing. The MWSS allows the adjustment of prices according to changes in the consumer price index (CPI), as well as to recoup the sudden financial effects of certain events that concessionaires have not anticipated (i.e., changes in laws and regulations). Rate rebasing is conducted every 5 years.

This is to allow concessionaires to reap efficiency gains and, at the same time, share such benefits with the consumers. In addition, the concessionaires adopted the increasing block tariff (IBT) pricing structure that the MWSS had implement since the late 1980s.

During the early years of its privatisation, the water services encountered many challenges that impeded the realisation of the benefits from the new regulatory regime. The El Niño phenomenon and the Asian financial crisis happened simultaneously in 1997, the year when the concession rights were allocated to Maynilad and Manila Water. The El Niño phenomenon caused a drought in the country, which made it difficult for concessionaires to draw water from the Angat Dam. Meanwhile, the Asian financial crisis led to the devaluation of the Philippine peso, which resulted in the doubling of the MWSS's debt service burden. This, in turn, increased the financial obligation of Maynilad and Manila Water because one of the provisions in the concession agreement was that the debt service of MWSS would be paid from the concession fees.

In meeting these challenges, both concessionaires explored different management strategies to meet the concession targets. Manila Water was more successful in reaping the benefits of privatising the water services compared to Maynilad. Although Manila Water started with a low bidding price, the concessionaire was able to reduce the NRW from 58 per cent in 1997 to 25 per cent in 2005. It also posted positive profits from tariff revenues by 1999. Consequently, Manila Water was able to start the improvements in its water infrastructure earlier than Maynilad. The success is attributed to its decentralised management framework. Decentralising the management of the water systems in the East Zone allowed it to pinpoint specific areas that have significant NRW and respond to these accordingly. This contributed to the significant decrease in NRW and, in 2016, Manila Water (2017) reported that NRW was down to 12 per cent. In contrast, Maynilad decided to centrally manage the water management and operations in the West Zone. This led to the increase in the NRW from 58 per cent in 1997 to 69 per cent in 2003. Thus, it failed to deliver the targets set by the concession agreement. Consequently, it filed for bankruptcy in 2003, which prompted the MWSS to abrogate its concession rights. The regulator handled the operations of Maynilad up until 2005 when it awarded the concession rights for the West Zone to a new partnership of the Metro Pacific and Investment and the DMCI Holdings. Under this new management, Maynilad adopted the decentralised management framework of Manila Water. As a result, NRW significantly declined from 69 per cent in 2005 to 30 per cent in 2016, and the company was able to post positive net income as well as improve the water infrastructure in the West Zone.

Operational system of the water services after privatisation

The Angat Dam, which has been operational since 1968, has a total capacity of 850 million cubic metres (MCM) and received an annual rainfall of 3,089 millimetres (mm) from 2010–2019. The NWRB, the highest body that manages and regulates all water resources and services in the Philippines, including the Angat Dam, decides on the allocation of Angat Dam's water to different users. The normal operating level of the Angat Dam is 180 metres and above, while the critical level is 160 metres. The water level should not fall below the critical level to preserve the flora and fauna in the Angat watershed, as well as conserve the structural integrity of the concrete dam. Regulating the flow of water results in the alteration of the dam's natural hydrograph that secures a reliable source of water for the various needs of humans and the environment (Ehsani et al. 2017). Whenever the water level of the dam falls below 180 metres, the NWRB reduces the flow of water from the dam and changes the water allocations to different users, including flows going to MWSS for the households in Metro Manila.

The National Power Corporation (NAPOCOR) measures both the inflows and outflows of the Angat Dam. In its study, the World Bank (2012) pointed out that the outflows from Angat Dam include the consumptive water use, irrigation water use, and environmental flows. The environmental flow is the water provided within a river to maintain ecosystems. The NWRB allocates 46 cubic metres per second (cu.m./s) for MWSS concession areas in Metro Manila and 40 cu.m./s to Angat-Maasim River Irrigation System (AMRIS) for irrigation purposes (see Figure 2.3).[3] Although it allocates 1.9 cu.m./s to the province of Bulacan, it has not strictly enforced it. The NWRB estimates that the environmental flow is 1.9 cu.m./s. In total, the current actual maximum water use from the Angat Dam is limited to an outflow of 72.9 cu.m./s. Table 2.2 shows the water allocation in the Angat-Umiray dam system.

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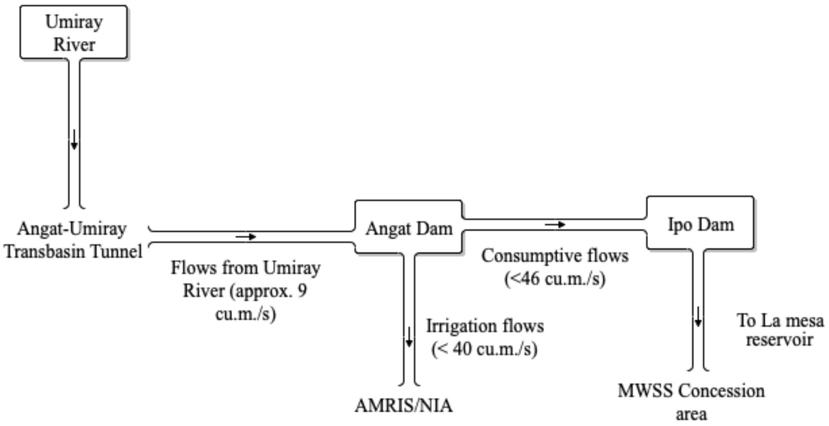
[3] The flows are, as much as possible, maintained for 24 hours each day for the whole year.

Figure 2.3: Angat-Umiray water supply system



AMRIS = Angat-Maasim River Irrigation System, MWSS = Metropolitan Waterworks and Sewerage System, NIA = National Irrigation Administration.
Sources: MWSS and author's interpretation.

Table 2.2: Water allocation in the Angat-Umiray water supply system as approved by NWRB

Water user	**Allocation in volume**	**Description**
AMRIS	40.0 cu.m./s	Allocation can be reduced to 25 cu.m./s in cases where the subtracted flows of 15 cu.m./s is allocated to MWSS in times of underutilisation.
MWSS	46 cu.m./s	This includes the 20.1 cu.m./s flows from Angat Dam, the 10. cu.m./s from Umiray Dam, and the additional 15 cu.m. cu.m./s from the conditional allocation from AMRIS.
Environmental flows	1.9 cu.m./s	This is equivalent to 10% of the dependable flows for the quasi-natural condition.
Bulacan province	1.9 cu.m./s	Not yet fully utilised.
Total	89.8 cu.m./s	The maximum flows are 89.9 cu.m./s, but the maximum current water use is 72.9 cu.m./s.

AMRIS = Angat-Maasim River Irrigation System, MWSS = Metropolitan Waterworks and Sewerage System, NWRB = National Water Resources Board.
Source: World Bank (2012).

II. Issues addressed during privatisation

Issues on water tariffs

The MWSS' pricing policy of the water services was a huge challenge before privatisation. The agency has adopted an increasing block tariff (IBT) since 1989 as it was widely used as the main pricing policy for water services in developing countries. IBT is a form of a volumetric component tariff that comprises of the first block–which is the social or lifeline block–and succeeding blocks where the price per unit of water consumption increases. The lifeline block is set below the marginal cost for affordability purposes (Monteiro and Roseta-Palma 2011) and that the higher blocks are assumed to cover the full cost of providing the water services. IBTs allow water utility managers to recover costs as well as accumulate capital investment (Boland and Whittington 2000). The MWSS had set the tariffs exceptionally low for households but doubled it for industrial and commercial users because the objective of the agency's tariff structure was to only recover the cost of water production and not use the tariff revenues for further expansion of its services. The MWSS received substantial direct subsidies from the national government, which were intended for its investment programme of expanding the water infrastructure. Tariffs imposed on connected households were Php5.50 (US$0.23) per cu.m. and Php8.50 (US$0.35) per cu.m. if also connected to the sewerage service.[4] Yet, by the end of 1996, only 60 per cent of the households were connected to the services despite the reasonable prices.[5] MWSS was unable to recover its operating costs in water production due to the low price and the unwillingness of consumers to pay for water and sewerage services.

IBTs are designed to discourage people from consuming too much water, while being beneficial to poor households. The tariffs imposed at the first block is set below the marginal cost of providing water to make it affordable for low-income consumers (Boland and Whittington 2000). The tariffs increase in succeeding higher blocks. David and Inocencio (1998), who examined the IBTs pricing policy of the water services in Metro Manila before privatisation, found that the tariff set on the first block was prohibitively high because it covered the cost of having a water connection to the system of MWSS. This is because households pay the full price of the connection whether they consume 10 cu.m. or less and this is built into the first-tier price. Consequently, the authors concluded that in the pricing policy, poorer households paid a higher average price for water compared to the other households (see Table 2.3). In 1995, the average price of water was Php36.38 (US$0.88) per cu.m. for households in the lowest income class, but this was only Php7.14 per cu.m. (US$0.17) for households with the highest income. The authors estimated that the poor households, on average, consume 6 cu.m. while the wealthier households use about 90 cu.m. of water.

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[4] Using 1995 average exchange rate.

[5] David and Inocencio (1998) show that for the first 10 cu.m., the cost of water in Metro Manila is US$1.44, as compared to US$1.57 in Bangkok, US$1.72 in Jakarta, and US$3.26 in Singapore.

Table 2.3: Average price, water consumption, and the ratio of water consumption to income by household income class in Metro Manila, 1995

Income class	Average price (Php/cu.m.)	Water consumption (cu.m. per household)	% of water bill to income
Under ₱30,000	36.38	6.0	8.2
₱30,000–₱39,999	15.89	14.3	4.4
₱40,000–₱59,999	15.88	18.4	4.2
₱60,000–₱99,999	15.92	19.5	2.9
₱100,000–₱149,999	13.94	26.0	2.2
₱150,000–₱199,999	9.16	32.0	1.6
₱200,000–₱249,999	5.94	38.5	1.4
₱250,000–₱449,999	8.04	36.1	0.8
₱500,000–₱749,999	6.04	63.9	0.8
₱750,000–₱999,999	9.27	71.4	0.8
₱1,000,000 & above	7.14	90.2	0.6

Source: David and Inocencio (1998).

The privatisation deal was scheduled in January 1997, and a competitive bidding process ensued to also address the equity problem of the water tariffs that the MWSS has set. Affordability of water service was one of the main concerns of the concession agreement. Thus, all bidders submitted their respective proposed water tariffs lower than that set by MWSS. Four consortia submitted their bids for the West and East Zones (see Table 2.4). At the end of the bidding process, the concession rights were awarded to Maynilad for the West Zone, a joint venture of Suez and Benpres Holdings; and to Manila Water, a joint venture of Ayala, United Utilities, and Bechtel for the East Zone.

Table 2.4: Tariff bids of all bidding participants

	East Zone		West Zone	
	Tariff bid (in Php)	Percentage of prior tariff (in %)	Tariff bid (in Php)	Percentage of prior tariff (in %)
Ayala-United (Manila Water)	2.32	26.40	2.51	28.60
Aboitiz-CGE	5.21	62.90	4.99	56.90
Metro Pacific-Anglian	5.66	64.50	5.87	66.90
Benpres-Lyonnais (Maynilad)	6.13	69.80	4.97	56.60
Pre-privatisation	8.78		8.78	

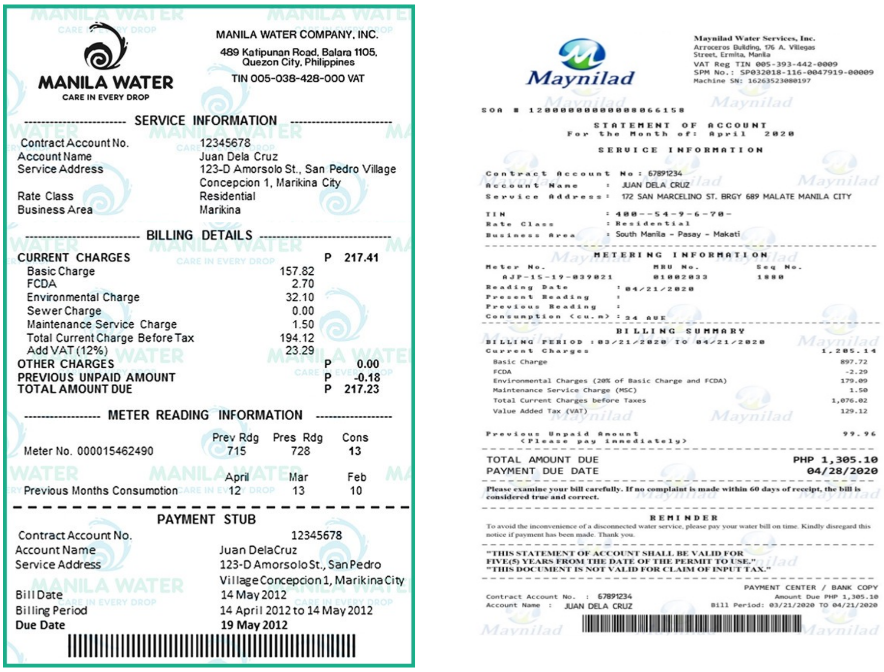
Source: Chia et al. (2007).

Equation 2.1 below shows the computation of the water tariffs that households pay on a monthly basis after the privatisation of the water services.

$$Water\ tariff = (basic\ charge + FCDA + environmental\ charge + sewer\ charge + maintenance\ service\ charge) + VAT \qquad Eq. 2.1$$

The tariff consists of the basic charge, the foreign currency differential adjustment (FCDA), an environmental charge, sewer charge, maintenance service charge, and the value-added tax (VAT), which are all in nominal and in Philippine peso terms. The basic charge covers the operating and maintenance costs as well as the improvements and expansion of the water supply distribution networks and water treatment facilities responsible for supplying water to the end users. The maintenance service charge only consists of the maintenance of the installed water meter per water user. The FCDA accounts for the variation of the Philippine peso against other countries' currencies, as both concessionaires have foreign investors. The sewer charge is based on the water user's basic charge and is generally 0 per cent, except for communities and other establishments that have sewer connections, in which case, they pay an additional 30 per cent of the basic charge. Lastly, the total cost of all cost components is subject to an additional 12 per cent VAT. Figure 2.4 shows the sample billing statements from both Manila Water and Maynilad, which households receive monthly.

Figure 2.4: Sample billing statements of Manila Water and Maynilad



MANILA WATER
CARE IN EVERY DROP

MANILA WATER COMPANY, INC.
489 Katipunan Road, Balara 1105,
Quezon City, Philippines
TIN 005-038-428-000 VAT

SERVICE INFORMATION

Contract Account No.	12345678
Account Name	Juan Dela Cruz
Service Address	123-D Amorsolo St., San Pedro Village Concepcion 1, Marikina City
Rate Class	Residential
Business Area	Marikina

BILLING DETAILS

CURRENT CHARGES		P	217.41
Basic Charge	157.82		
FCDA	2.70		
Environmental Charge	32.10		
Sewer Charge	0.00		
Maintenance Service Charge	1.50		
Total Current Charge Before Tax	194.12		
Add VAT (12%)	23.29		
OTHER CHARGES		P	0.00
PREVIOUS UNPAID AMOUNT		P	-0.18
TOTAL AMOUNT DUE		P	217.23

METER READING INFORMATION

	Prev Rdg	Pres Rdg	Cons
Meter No. 000015462490	715	728	13

	April	Mar	Feb
Previous Months Consumotion	12	13	10

PAYMENT STUB

Contract Account No.	12345678
Account Name	Juan DelaCruz
Service Address	123-D Amorsolo St., San Pedro Village Concepcion 1, Marikina City
Bill Date	14 May 2012
Billing Period	14 April 2012 to 14 May 2012
Due Date	**19 May 2012**

Maynilad

Maynilad Water Services, Inc.
Arroceros Building, 176 A. Villegas
Street, Ermita, Manila
VAT Reg TIN 005-393-442-0009
SPM No.: SP032018-116-0047919-00009
Machine SN: 16263523080197

SOA # 1200000000000008066158

STATEMENT OF ACCOUNT
For the Month of: April 2020

SERVICE INFORMATION

Contract Account No : 67891234
Account Name : JUAN DELA CRUZ
Service Address : 172 SAN MARCELINO ST. BRGY 689 MALATE MANILA CITY

TIN : 400--54-9-6-70-
Rate Class : Residential
Business Area : South Manila - Pasay - Makati

METERING INFORMATION

Meter No.	MRU No.	Seq No.
AJP-15-19-039021	01002033	1880

Reading Date : 04/21/2020
Present Reading :
Previous Reading :
Consumption (cu.m) : 34 AVE

BILLING SUMMARY

BILLING PERIOD : 03/21/2020 TO 04/21/2020

Current Charges	1,205.14
Basic Charge	897.72
FCDA	-2.29
Environmental Charges (20% of Basic Charge and FCDA)	179.09
Maintenance Service Charge (MSC)	1.50
Total Current Charges before Taxes	1,076.02
Value Added Tax (VAT)	129.12
Previous Unpaid Amount (Please pay immediately)	99.96

TOTAL AMOUNT DUE	PHP 1,305.10
PAYMENT DUE DATE	04/28/2020

Please examine your bill carefully. If no complaint is made within 60 days of receipt, the bill is considered true and correct.

REMINDER

To avoid the inconvenience of a disconnected water service, please pay your water bill on time. Kindly disregard this notice if payment has been made. Thank you.

"THIS STATEMENT OF ACCOUNT SHALL BE VALID FOR FIVE(5) YEARS FROM THE DATE OF THE PERMIT TO USE."
"THIS DOCUMENT IS NOT VALID FOR CLAIM OF INPUT TAX."

PAYMENT CENTER / BANK COPY
Contract Account No. : 67891234
Account Name : JUAN DELA CRUZ
Amount Due PHP 1,305.10
Bill Period: 03/21/2020 TO 04/21/2020

Sources: Manila Water https://www.manilawater.com/customer/bill-information and Maynilad <https://www.mayniladwater.com.ph/how-to-read-your-water-bill/>.

The tariffs set by Manila Water and Maynilad were found to be exceptionally low as compared to the previous tariffs of MWSS and were met with criticisms from the public and from policymakers. Fabella (2006) argues that "Low price is no consolation when the service is not available when needed or is unusable when available." (p.4). Further, Wu and Malaluan (2008) state that the low tariff bids reflected both the inefficiency in MWSS and the private sector's confidence. The concessionaires, as per the concession agreement, could increase tariffs in the subsequent years. The increase in tariffs was due to the FCDA and the appropriate discount rate (ADR).[6] The FCDA allowed the concessionaires to recover from their foreign currency losses at an accelerated rate (Wu and Malaluan 2008). The ADR, on the other hand, significantly increased during the rate-rebasing process in 2002. The Asian financial crisis in 1997 and the persistent water supply problems due to the El Niño phenomenon further increased the financial obligations of the concessionaires. Targets for the expansion and reduction of NRW had to be adjusted downwards so that both Maynilad and Manila Water could reduce their capital expenditure requirement. Although the tariffs started significantly lower, the sharp increases in subsequent years caused controversies and disagreements from the general public. Table 2.5 below shows the history of the tariff increases from pre-privatisation to post-privatisation.

Table 2.5: History of the base tariff rates at pre- and post-privatisation in nominal terms (in Php per cu.m.)

	Average base tariff		Average all-in tariff*	
	Manila Water	Maynilad	Manila Water	Maynilad
Pre-privatisation	8.56		8.78	
Post-privatisation				
1997/1998	2.32	4.96	4.02	7.21
1999	2.61	5.8	4.37	8.23
2000	2.78	6.13	4.55	8.63
2001	2.95	6.58	4.78	9.17
2002	4.51	11.39	9.37	19.92
2003	10.06	11.39	13.38	19.92
2004	10.40	11.39	14.00	19.92
2005	13.95	19.72	18.55	30.19
2006	14.94	21.21	19.73	32.34

*All-in tariff = base tariff + CERA (currency exchange rate adjustment) + FCDA + environmental charge (EC) + VAT (value-added tax)
Source: Wu and Malaluan (2008).

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[6] According to Manila Water (2017), the ADR is based on the parameters: (i) reference instrument for the cost of equity; (ii) the market risk premium; (iii) the reference instrument for the cost of debt; (iv) gearing ratio; (v) asset beta; and (v) credit spread. Currently, the ADR of both concessionaires is 12 per cent at fixed nominal discount rate.

Non-revenue water issues

One of the major problems when MWSS managed the water services centrally was the high NRW, which was attributed to both structural and non-structural issues. Structural issues include physical water losses from leaks in pipelines and commercial losses caused by water theft, illegal connections, measurement errors in meters, and billing inefficiencies. The average water bill collection period was 6.5 months in 1980 but improved to 5.9 months in 1988. Notably, government agencies and large companies did not pay their bill on time (ADB 2008). Moreover, some government agencies colluded with households by allowing the latter to attach illegal hose connections and charged them connection fee and a monthly fixed charge. Many households had also found a way to connect water pipes in public vacant lands where no meters were installed.

The high NRW prevented MWSS from raising financial resources to improve the reliability of water supply to the consumers. David and Inocencio (1998) reported that only less than 60 per cent of the households with access to the water services of MWSS received water 24 hours a day, 7 days a week. Of this 60 per cent, 30 per cent of households had access to water services for fewer than 12 hours a day. The NRW contributed to the low water pressure that consumers experienced. Among those connected, 40 per cent experienced low water pressures, while 48 per cent had moderate water pressure. Only 12 per cent of households had high water pressures.

Non-structural issues, such as the political and social unrest during the 1980s,[7] led to the degradation and neglect of the operation and maintenance activities of MWSS. The MWSS was also criticised as being highly inefficient (Chia et al. 2007). It employed about 15,000 people, making the working ratio of employees to water supply connections to 9.8:10,000. Meanwhile, the country's Southeast Asian neighbours, such as Bangkok (Thailand), Jakarta (Indonesia) and Singapore had a working ratio of 4.6, 7.7, and 2.0 staff per 10,000 connections, respectively. Moreover, the customers' low willingness to pay and the low tariff revenues did not give MWSS the opportunity to upgrade its offices and facilities.

Unable to upgrade its facilities, MWSS was not able to address the rising NRW problem, which led to the water crisis. Faced with both structural and non-structural problems, the NRW of the

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[7] Filipinos started to oppose the Marcos administration, which led to violent political demonstrations and killings.

water services stood at 58 per cent by 1996. Thus, ADB (2008) described the water services in Metro Manila as one of the worst in the Southeast Asian region in the 1990s.

One of the key objectives in the concession agreement during the privatisation of the water services was to further reduce NRW to increase the provision and reliability of water services. Concessionaires were given the freedom to design their own corporate governance, financial management, and operations management frameworks that tackled the reduction of NRW. Since the 1997 privatisation, the NRW has been significantly reduced due to the concessionaires' efforts to improve the water infrastructure in Metro Manila. Many of the old water infrastructures, including pipelines and pumping stations, were replaced with newer and larger water mainlines.[8] Water availability has greatly improved as households have access to water 24 hours a day, 7 days a week. The water pressure also increased from 7 pounds per square inch (PSI) or approximately 10,850 pounds per m^2 (before privatisation) to between 16 to 20.13 PSI, or 24,800 to 31,202 pounds per m^2 (Maynilad 2017, Manila Water 2017). Finally, NRW declined significantly from 58 per cent to 12 per cent in the East Zone and from 69 per cent to 30 per cent in the West Zone.

Water theft was also criminalised under the concession agreement, which contributed to the significant decrease in the number of households connecting illegally. Both concessionaires introduced their respective 'water for community' programmes that provided poor and highly dense informal communities affordable water services. These initiatives contributed to the decline in water theft incidences in many low-income areas as poor households and those in highly dense areas were provided affordable water service connections through bulk or shared meters.

III. Factors that influenced the outcome of the concessionaires' operations

The decision to privatise the water services in Metro Manila was met with criticism. Critics claimed that privatising water services would produce undesirable results. Public benefits of water services are supposedly incompatible with the private sector's objective to maximise profits (Estache and Rossi 2002). According to Scanlon et al. (2004), privatising water services would limit water access as a basic right of the poor, since water prices will be determined by

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[8] The old MWSS pipelines consisted of substandard polyvinyl chloride (PVC) pipes. The concessionaires replaced these pipes with high-density polyethylene (HDPE) pipes, which are less prone to corrosion and leakage.

the monopolies arising from privatisation. Another problem that Esterin and Pelletier (2018) point out is that developing countries that attempt to privatise water services have faced difficulty in implementing the change in the market structure.

Wu and Malaluan (2008) point out that the failure of privatising water services in other countries is attributed to not having a concrete transformation framework. According to them, the success of a privatisation lies in the transformation of the ownership structure and organisation within the company. The authors highlight three factors that are important for privatisation to succeed: (i) corporate governance, (ii) financial management, and (iii) operations management. These three are discussed below.

Corporate governance

One unique feature of corporate governance in the Philippines is the existence of a small number of family conglomerates that control 17 per cent of the nations' market capitalisation (Wu and Malaluan 2008). Of the three largest family conglomerates, two of these are the Lopez and the Ayala groups—both of which were awarded with concession rights. However, the corporate decision on who to employ for their services and consultancies was different for each family. Both had no experience in operating water services, but each adopted a different approach. Maynilad, which was then owned by the Lopez group, contracted the Suez Lynnaise des Eaux of France (Suez, from here onward) and the Benpres Holdings Corporation and their subsidiaries or affiliates for services and consultancies. This, in turn, resulted in higher operation costs because both Suez and Benpres Holdings Corporation employed many subcontractors that increased the cost of wages and operation.

By comparison, Manila Water contracted companies affiliated with the Ayala Corporation. This brought the costs of operation to 75 per cent less than that of Maynilad. Also, the corporate decision to repair first the outdated water supply networks and leaks was recognised as one of the company's successful practices (Wu and Malaluan 2008). This was in contrast with Maynilad's decision to upgrade its facilities and equipment first rather than improve the water mains and reduce leaks in its concession area.

Financial management

The second factor that influenced the performance of both concessionaires is their financial management. This is an important factor because the time of privatisation coincided with the

1997 Asian financial crisis. In its first 5 years of operation since 1997, Manila Water focused on borrowing small-size loans, ranging from US$20 million to US$67 million, from several local banks. The company also significantly decreased its capital expenditure to protect itself from financial risks. The decision led to impressive positive profits as early as 1999 and this increased significantly in 2002. In contrast, Maynilad decided to borrow a total of US$350 million for its capital expenditure from the Asian Development Bank (ADB), the European Investment Bank, and from a group of foreign commercial banks. Due to the Asian financial crisis, Maynilad had a difficult time borrowing a large amount. It secured approval for only US$100 million bridging loan, which was insufficient for Maynilad to mount swift responses to repair the water mains. Consequently, its NRW increased since the start of its operation in 1997. In March 2003, the company defaulted on its bridging loan. Other long-term loans ceased as well.

Operations management

After the privatisation, both concessionaires inherited an organisational structure that resembled a centralised management, which is common for state-owned utility companies (Wu and Malaluan 2008). This included employees and capital goods that were previously under the MWSS. Manila Water took this opportunity to develop strategies built on the following principles: (i) a corporate culture that is focused on honesty, (ii) efficient performance and customer service, (iii) clear chain of responsibility by decentralising the decision-making process, (iv) working procedures that promote better communication and cooperation, and (v) an outcome-based reward system (Wu and Malaluan 2008). The company retained the previous employees of MWSS and gave them key positions. It also invested heavily on improving human capital by sending veteran employees abroad for training. In contrast, Maynilad retained the centralised operational management of MWSS, gave key positions to most of the employees from Benpres Holdings and its subsidiaries who had little to no experience in the water sector, and gave lower positions to those who were retained from the MWSS (Chia et al. 2007). Moreover, it did not make substantial investments to improve human capital. The difference in operational management approaches between the two concessionaires resulted in different experiences after the privatisation.

Manila Water was able to achieve the targets set by the concession agreement within the first 5 years of its operation since 1997. This success is attributed to the introduction of the territory management framework to reduce NRW first (Rivera 2014, Chia et al. 2007, and Wu and

Malaluan 2008).[9] The territory management system partitioned the East Zone into seven business areas to make operations more manageable. These business areas were further divided into 43 operational districts called demand monitoring zones (DMZs), with each zone managing approximately 10,000 water connections. Each DMZ manages several district metering areas (DMAs) that have 500–1,000 connections. Teams within the DMZs are responsible for customer services, monitoring, control of NRW, and new service deployment. The clear delineation of work responsibilities contributed to the reduction in NRW as well as better customer management. Within less than a decade since privatisation, NRW was significantly reduced from 58 per cent to 37 per cent. In the East Zone, NRW has been reduced and maintained at 12 per cent since 2015 (Manila Water 2017). Wu and Malaluan (2008) attribute these successes to the (i) territory management, and (ii) '*Tubig para sa Barangay*' or 'water for the community' programme.

The '*Tubig para sa barangay*' programme focused on delivering water services to poor areas, informal settlements, and highly dense communities. Rivera (2014) reports that this programme introduced better financing options through staggered connection fees, sharing of costs among residents, and average water rates for bulk metered connections. Moreover, connection charges to poor households were waived through a subsidy that Manila Water obtained from the World Bank through the Global Partnership on Output-Based Aid (GPOBA) programme in 2007. The company introduced the bulk metered system where 2−5 households share one connection. The cost is split between them depending on the individual household's water consumption. The head of the community is given the responsibility to distribute water accordingly as well as monitor the water meters installed to ensure no incidences of water theft. Manila Water (2017) reported that their programme has reached 850,000 individuals in poor communities that had access to their water services. In 2017, this concessionaire services 94 per cent of the total household population of the East Zone.

As noted earlier, many of those in key positions at Maynilad had no experience in the water sector and one of its partners, the Suez, was allocated the management positions (Chia et al. 2007, Wu and Malaluan 2008). Those in key positions ruled in favour of proceeding with a system-wide approach in tackling the NRW. The University of Tokyo-Civil Engineering Ltd (UTCE) and Japan PFI Association (2005) reported that although the company had spent

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[9] This is to achieve the third strategy of Manila Water, which is to create a clear chain of responsibility by decentralising the decision-making process.

billions for laying new pipes, it only released a report that identified significant leaks in the system in 2000. This was a result of the company's inability to launch a centralised monitoring plan to identify the leakages in the system due to the system-wide management approach (Wu and Malaluan 2008, UTCE and Japan PFI Association 2003).

Maynilad also launched the '*Bayan Tubig*' programme, which is similar to Manila Water's water for the community programme. However, it became the main source of the increase in NRW due to its faulty implementation (Chia et al. 2007, UTCE Ltd and Japan PFI Association 2003, Wu and Malaluan 2008). Individual connections were placed in the vicinity of the households instead of a bulk meter. This gave unconnected households the opportunity to illegally tap into the system before the water reached the meter of the connected households. There were also cases where connected households tampered with their own connections by reconnecting their pipes before the meter itself. This resulted in higher NRW, prompting Maynilad to halt the programme due to the financial difficulties brought about by the design of providing water to poor communities (Wu and Malaluan 2008).

When the new partnership, the Metro Pacific Investment and DMCI Holdings, took over the concession rights for the West Zone in 2005, it adopted the territory management of Manila Water. It created 12 business areas in three business districts (North, Central, and South) to monitor, review, and evaluate the performance of, and to achieve the goals set by, the concession agreement. In 2016, the company introduced the district metered areas (DMAs), which was based on the territory management of Manila Water. The NRW significantly declined—from 69 per cent in 2004 down to 30 per cent in 2016. All these improvements were attributed to the adoption of the decentralised management of Manila Water. In 2017, Maynilad serviced only 75.8 per cent of the total household population in the West Zone.

IV. Current challenges in the water services

Kaliwa Dam project and controversy

Brief description and specifications of the Kaliwa Dam project

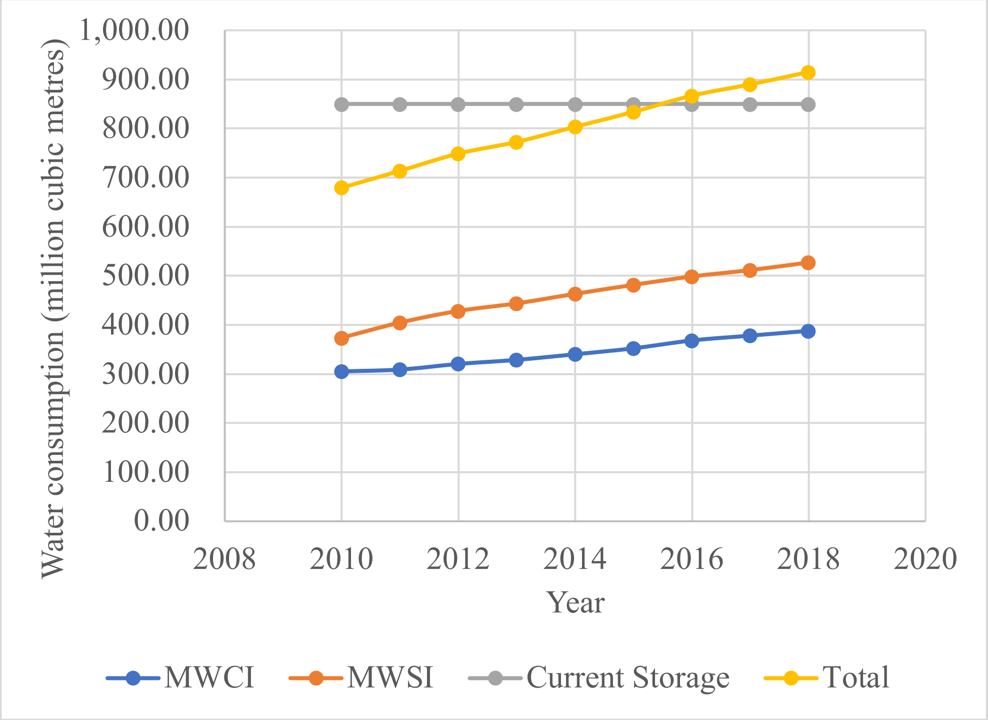
Water demand in Metro Manila has been increasing in the last decade due to the region's increasing population and economic activities (see Table 2.6 and Figure 2.5). There have also been years when the water level declined below the 160 metres critical level during the summer months of the Philippines (see Figure 2.6). At times of water scarcity, the regulator and the two concessionaires resort to demand management to avoid reaching the critical volume level in the Angat Dam by reducing the flows from Angat Dam.[10] This has resulted in timed water disruptions as well as campaigns in water savings. The Environmental Management Bureau report (EMB 2014) claims that current water supply will be insufficient to satisfy water demand in Metro Manila starting in 2025 (see Table 2.7).

Table 2.6: Total water consumption for MWCI and MWSI, 2010–2018, in MCM

Year	MWCI	MWSI
2010	305.32	373.84
2011	309.05	404.73
2012	320.43	428.42
2013	328.81	443.85
2014	340.18	463.24
2015	352.30	481.53
2016	368.31	498.60
2017	378.16	511.66
2018	387.93	527.15

MWSI = Maynilad Water Services, Inc.; MWCI = Manila Water Company, Inc.
Sources: Manila Water and Maynilad.

Figure 2.5: Total household water consumption in Metro Manila, 2010–2018



MWSI = Maynilad Water Services, Inc.; MWCI = Manila Water Company, Inc.
Sources: Manila Water and Maynilad.

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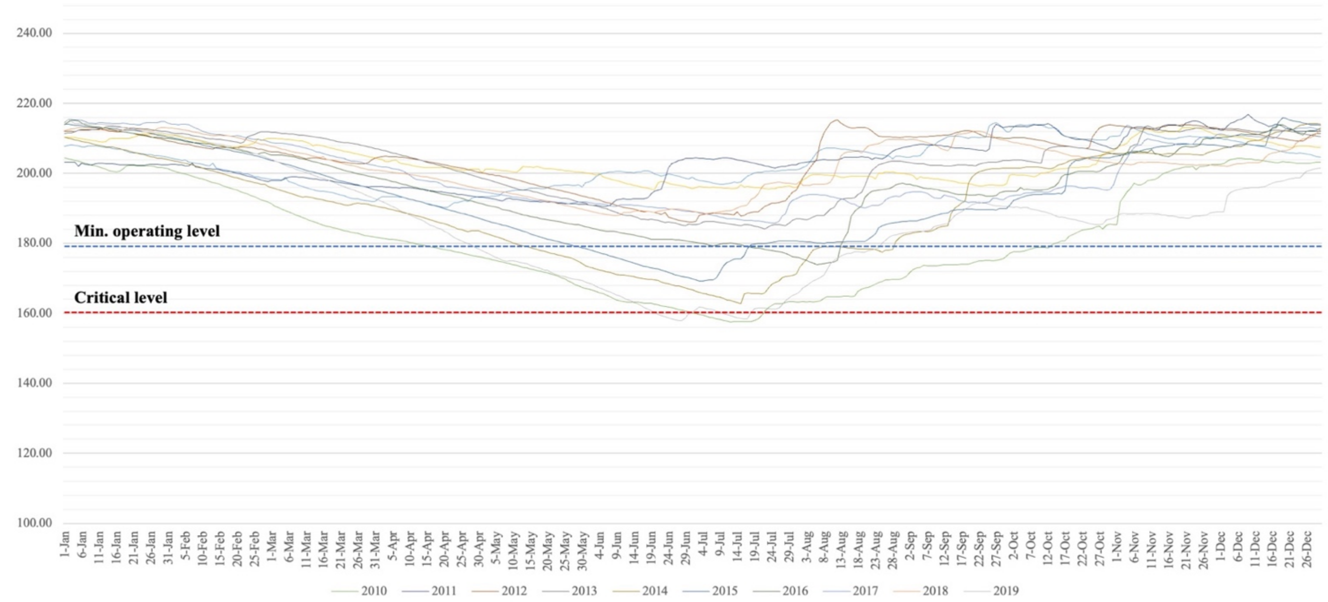
[10] According to Dziegielewski (2003), any policy that can potentially reduce the water use by households may be considered a demand management measure. This includes the decline in water flows and timed water disruptions.

Figure 2.6: Daily recorded water levels (metres) in Angat Dam, 2010–2019



Source: NAPOCOR (data obtained upon request)

Table 2.7: Water-supply demand projections for Metro Manila, 2013–2037

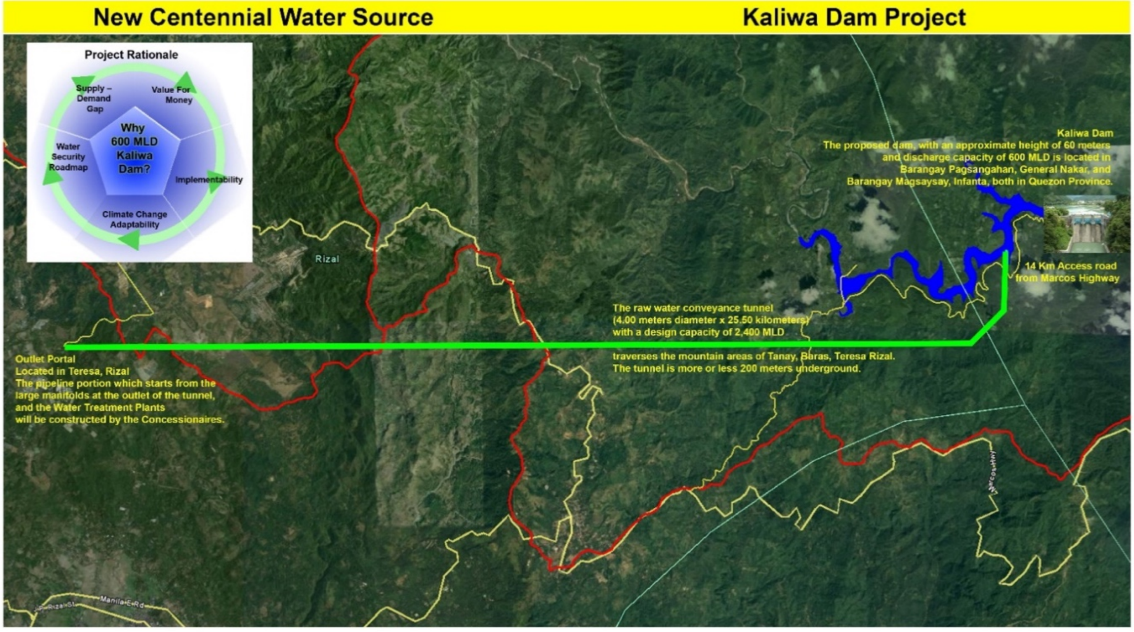
Year	Water demand (MLD)	Existing supply (MLD)	Surplus/deficit (MLD)
2013	3,264	4,132	868
2020	3,892	4,132	240
2025	4,322	4,132	–190
2030	4,947	4,132	–1,496
2035	5,628	4,132	–1,496
2037	5,896	4,132	–1,654

MLD = millions of litres per day.
Source: Environmental Management Bureau (2014).

In 2014, the national government approved the construction of the new water source, the Kaliwa Dam, in response to the growing water demand in the Metro Manila (EMB 2014). This is part of the 2011–2016 Philippine Development Plan (PDP). The Kaliwa Dam, which will be situated in the municipality of Infanta, Quezon Province, will increase the raw water supply and is intended to increase water security and meet future water demand in Metro Manila and nearby provinces. The goal is for the Kaliwa Dam to reduce Metro Manila’s dependency on the outflows from Angat Dam. Moreover, the project promotes the creation of a more effective watershed management plan to meet the goals of sustainable conservation, protection, and rehabilitation of critical watersheds.

The absolute volume of the Kaliwa Dam would be approximately 57 million cu.m. (MCM) in storage, with a discharge capacity of 600 MLD. The current size of the Angat Dam, on the other hand, is 850 MCM and has a discharge capacity of 1,460 MLD. The project has the following components: (i) a 60-metre (m) high dam with intake and appurtenant structures, (ii) a water conveyance tunnel, 27.7 kilometres (km) in length and 4 m in diameter, (iii) resettlement for those displaced by the project, and (iv) access roads to be built by the Department of Public Works and Highways (DPWH). The 27.7 km conveyance tunnel has a maximum capacity of 2,400 MLD in preparation for the complete construction of the Laiban Dam in the upstream.[11] It ends at the outlet portal located in Teresa, Rizal Province. The pipeline portion starts from the large manifolds at the outlet of the tunnel. The water treatment plants will be constructed by the concessionaires. Following the currently approved financing scheme, the construction period runs from 2019–2023, with a planning horizon of 50 years. In the Aquino administration, the economic analyses considered the integrated dam system that included both the Laiban and the Kaliwa Dam. However, the Duterte administration decided not to push through with the construction of the Laiban Dam because it would potentially displace 4,800 families. Instead, the administration has focused its efforts on the Kaliwa Dam (Nicolas 2019). Figure 2.7 shows the schematic diagram of the project.

Figure 2.7: Kaliwa Dam Project conveyance proposal



Source: MWSS website <http://mwss.gov.ph/projects/new-centennial-water-source-kaliwa-dam-project/>.

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[11] The Laiban Dam is part of the Centennial Water Project. Once its construction is completed, it will discharge water to the Kaliwa Dam. Its capacity can reach up to 1,800 MLD. Combining the water conveyance from Laiban and Kaliwa dams, the total water capacity of the dam system will be 2,400 MLD.

Economic costs

The original idea was to finance the construction of the project through a public-private partnership (PPP) funding scheme. However, the current Philippine administration opted to seek official development assistance (ODA) to fund this project. The total construction cost of the dam and the conveyance tunnel is approximately Php12.19 billion (US$253.57 million[12]) under the ODA financing scheme. Further details of the construction cost as well as the environmental and social costs are not available due to confidentiality reasons with the current contractor. Thus, this thesis includes the original details that the Environmental Management Bureau (EMB) provided under the PPP-funded scheme.

Under the PPP funding scheme, the project's estimated total cost would be Php18.50 billion, (US$413.20 million). Of the total cost, 80 per cent (Php15 billion or US$335 million) is the local component while 20 per cent (Php3.5 billion or US$78.2 million) is the foreign exchange cost. EMB (2014) estimates that the economic life of the dam works, conveyance structure, and civil engineering works is from 50 to 100 years. The breakdown of the costs under the PPP funding scheme is shown in Table 2.8.

Table 2.8: Cost breakdown for the Kaliwa Dam under a PPP funding scheme

Component	**Cost (Php billion)**
Development costs	0.10
Cost of project financing	3.73
Construction costs	
Kaliwa Dam	4.03
Conveyance structure	8.21
Land acquisition and resettlement costs	1.97
Investment phasing costs	0.46
Total	**18.50**

Source: Environmental Management Bureau (2014).

Social costs (under a PPP financing scheme)

The social costs for the current construction plans using the ODA funding scheme are not publicly available due to the confidentiality agreement between the national government and the China Energy Engineering Corporation (CEEC). Thus, the report of the EMB (2014) is the basis for the social costs in the analysis.

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[12] Using the 2014 exchange rate since planning started in 2014: US$1 = Php44.78.

According to EMB (2014), constructing the Kaliwa Dam displaces and affects 1,465 households in the area. Changes in resource access and utilisation, land use, social and community networks, and other policy changes disturb 424 households in Barangays Magsaysay and Pagsanghan. Moreover, flooding events and possible dam failure could have an impact on 1,041 households in Barangay Daraitan. In addition, 56 indigenous peoples (IP) households are indirectly affected by the construction, while 284 IP households are exposed to the risk of flooding and possible dam failure. Table 2.9 summarises the number of affected households during the construction of the dam.

Table 2.9: Number of households affected by construction of the Kaliwa Dam

Barangay	No. of households
Daraitan	1,041
Magsaysay	191
Pagsanghan	233
Total	**1,465**

Source: Environmental Management Bureau (2014).

The EMB (2014) expects that it will cost Php1.97 billion (approximately US$44 million) for the total land acquisition and the cost of resettling the households. The cost includes the following: (i) replacement cost for impacted infrastructures; (ii) land loss; (iii) agricultural tree and crop losses; (iv) timber tree losses; and (v) losses from lost livelihood, including those from ecotourism.

Economic analysis (social cost-benefit analysis)

The EMB (2014) provides a social cost-benefit analysis (SCBA). The Kaliwa Dam is part of an integrated dam system, together with the Laiban Dam. Thus, the SCBA examines if the integrated dam system is economically sound based on several indicators.[13]

The EMB (2014) estimates that the economic internal rate of return (EIRR) of the integrated dam system is 21.4 per cent, which exceeds the 15 per cent social discount rate set by the National Economic Development Authority (NEDA). The Kaliwa Dam specifically has an EIRR of 16.8 per cent (see Table 2.10). Over a 100-year period, EMB (2014) assesses that the economic net present value (NPV) of the infrastructure is approximately Php4.37 billion (US$97.6 million). If that is correct, this analysis implies that the public can expect that the

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[13] In the executive summary reported by EMB (2014), it is only the New Centennial Water Source-Kaliwa Dam Project that is examined. The planning for the Laiban Dam would have originally been carried out after the construction of the Kaliwa Dam.

benefits realised from the project are significantly higher than the economic costs over the economic useful life of 100 years. Benefits of the project include the following: (i) water security, (ii) incremental water consumption, (iii) reduction in death rates due to water-related issues, (iv) better health and hygiene of consumers, (v) more savings due to reduced purchases of commercially available drinking water, (vi) ability to substitute for the irrigation water from Angat Dam, and (vii) benefits to fisheries and preservation and improvements of ecosystems in the watershed.

Table 2.10: Economic indicators for the Kaliwa Dam

Economic indicators for the Kaliwa Dam	
Economic internal rate of return (IRR)	16.8%
Economic net present value (ENPV)	Php4.37 billion
Benefit-cost ratio (BCR)	1.165
Social discount rate (SDR)	15%

Source: Environmental Management Bureau (2014).

Financing scheme

The ODA provided by the government of the People's Republic of China covers 85 per cent of the total cost of the project, payable over 50 years. The two concessionaires shoulder the remaining 15 per cent of the cost, equally divided between them, using water tariff collections from consumers.[14] MWSS does not provide more details regarding the cost of the construction of the Kaliwa Dam. However, EMB (2014) and the previous MWSS administration provided more details regarding the financing under the previously planned PPP funding scheme.

For the payment scheme under PPP, consumers would shoulder the cost of the project, following the 'users-pay' principle. Payments for the project consist of fixed annual amortisation payments to cover the cost of construction and financing of the Kaliwa Dam and the 27.7 km conveyance tunnel. A specific account will be created by MWSS for the amortisation payments to the project proponent (see Figure 2.8). This will lead to increases in

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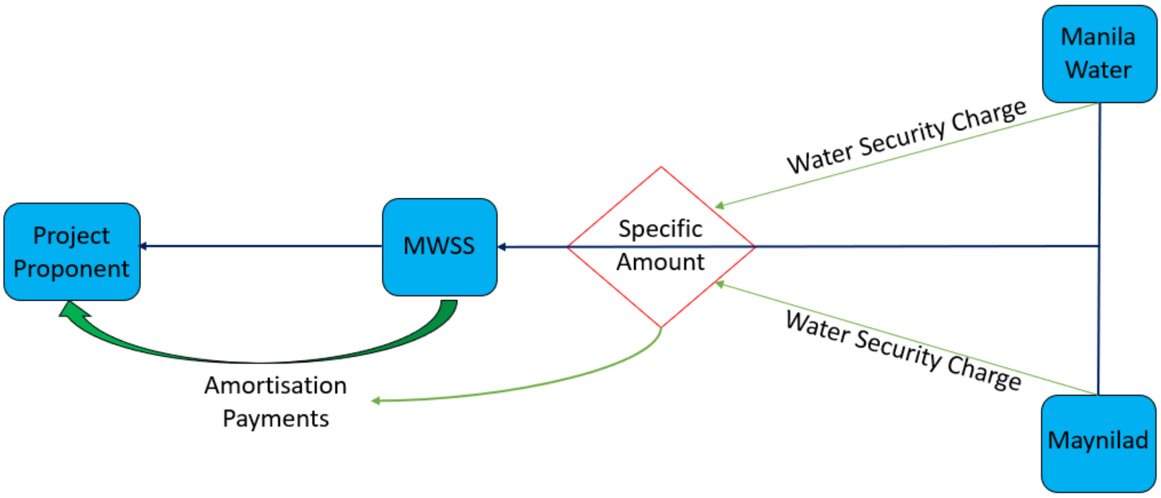
[14] Future interest payments and amortisation of such ODA will eventually be shouldered by all water consumers in the East and West Zones. An example of this is the Metro Manila Subway Project which is funded by a Japanese ODA. Repayment of the loan will be based on the project's cash-flow generation and secured on the basis of the project's assets alone <https://www.globaltradealert.org/intervention/62018/trade-finance/japan-jica-oda-loan-agreement-to-the-philippines-for-japanese-sourced-infrastructure-assistance>

water tariffs imposed by the concessionaires. Both Maynilad (2017) and Manila Water (2017) proposed their respective incremental increases in the tariffs—to be imposed on consumers—to cover the cost of the project during the 2018–2022 rate-rebasing exercise. Table 2.11 shows the schedule of tariff increases of Manila Water from 2018 to 2022. Maynilad (2017) only reports that the rebasing tariff adjustments is 29.63 per cent, or a total of Php9.69 per cu.m. adjustment, which will be arbitrarily spread from 2018–2022.

Figure 2.8: Payment scheme for the Kaliwa Dam based on a PPP proposal



Source: MWSS website <http://www.mwss.gov.ph/wp-content/uploads/NCWSP-Invest-Water-PH-1.pdf>.

Table 2.11: Proposed tariff increases for consumers serviced by Manila Water, 2018–2022

Charging year	Rate adjustment (%)	Equivalent amount of increase (Php)
2018	7.72	1.93
2019	7.16	1.93
2020	6.69	1.93
2021	6.27	1.93
2022	5.90	1.93

Source: Manila Water (2017).

Controversies

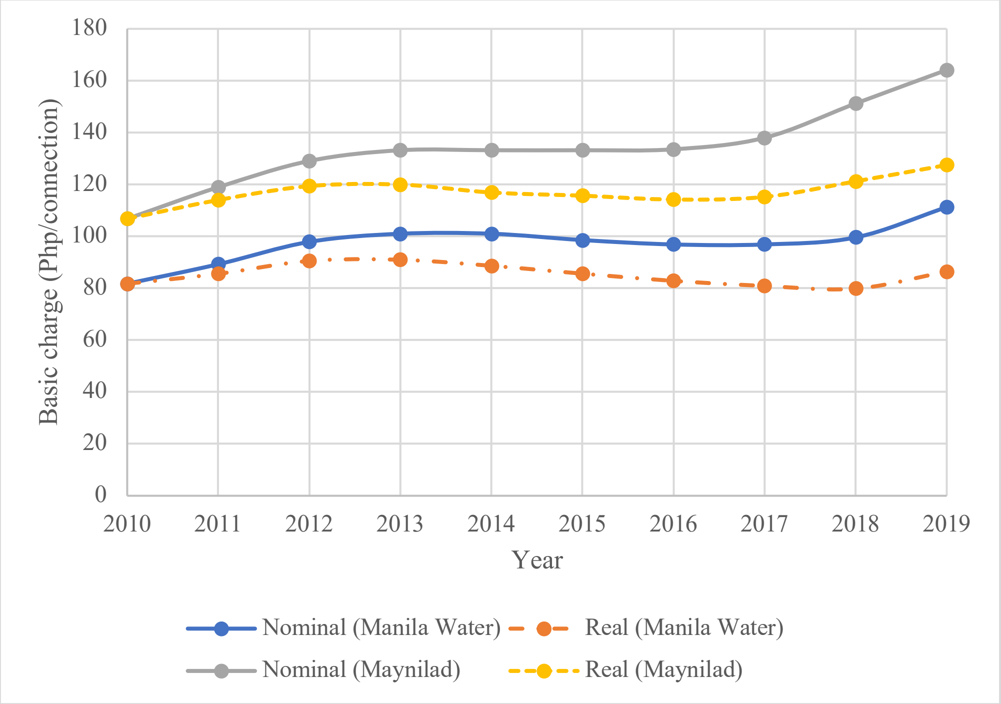
The Department of Finance (DOF 2019) reports that utilising the ODA from the People's Republic of China—instead of a PPP—will benefit Filipinos more with a cheaper project and financing costs. It is reported that the project would only cost US$283.5 million if ODA financing is used compared to US$365.6 million under the PPP financing scheme. Although the ODA has a relatively lower cost, the project has been criticised by the public. The construction plans of the China Energy Engineering Corporation (CEEC), the company that won the bid for the project, has been opposed by various institutions. Green (2019) reports that the construction plans had an interest rate of 2 per cent per year and involve the destruction of rare flora and fauna. Moreover, the Dumagats and Remontados indigenous peoples living around the area of the construction site will be displaced during the construction of the dam. Realising these problems, an Osaka-based Japanese firm, the Global Utility Development Corporation, submitted an unsolicited bid. The company's plan had a smaller 7-metre dam that has lower environmental impact, but a higher cost of US$410 million. The annual interest rate is lower at 1.25 per cent. Ultimately, the current administration decided on contracting the Chinese company due to its lower cost and its faster implementation.

The Commission on Audit (COA), however, reported that the bidding process as well as the choosing of the winning company had several irregularities (Marcelo 2019). The technical working group of the MWSS did not follow the proper bidding and vetting procedures when the contract was awarded to the CEEC last December 2018. The COA found that MWSS shortlisted three Chinese firms, including CEEC, despite not having met the pre-qualification requirements. Specifically, all firms failed to indicate in their bids if they had substantial experience in the design, engineering, and construction works for dams and other water infrastructures in the last 20 years. In addition, it was discovered that the CEEC deployed technical equipment and conducted preliminary activities at the site without authorisation to proceed from the MWSS and from other agencies concerned. Lastly, COA stated that the loan agreement between the Philippine Government and the China Eximbank was ineffective. Key requirements were not submitted to the COA, such as environmental compliance certificate; a letter of guarantee from the Bangko Sentral of the Philippines, the country's central bank; and the approval from the National Commission of Indigenous Peoples, were not submitted to the COA.

Rate rebasing

The rate rebasing, which happens every 5 years, gives the concessionaires the opportunity to submit their business and expansion plans for the subsequent 5 years. This means that 2003, 2008, 2013, 2018, and 2023 are the years for which both Manila Water and Maynilad are required to submit their business plans to justify the adjustments in their respective water tariffs. As stated in the concession agreement, both concessionaires can increase their water tariffs based on the proposed expansion plans they have indicated in the rate rebasing. However, this has been a source of contention among the stakeholders that include the regulator and the public. For example, an arbitration case was filed by the concessionaires against MWSS in the international courts last 2012, which lasted until 2015, because the regulator did not approve the water tariff increases and, instead, asked Maynilad and Manila Water to lower their respective tariffs. In 2017, Maynilad won the arbitration case and demanded the MWSS and the national government to pay approximately US$66.5 million as reimbursement for the long delay in tariff increases that constrained the concessionaire from expanding and improving its water services. On the other hand, Manila Water lost the case and was ordered by MWSS to reduce water tariffs by almost 6 per cent annually from 2013 to 2017. Figure 2.9 shows the nominal and real basic charge of the concessionaires from 2010 to 2019.

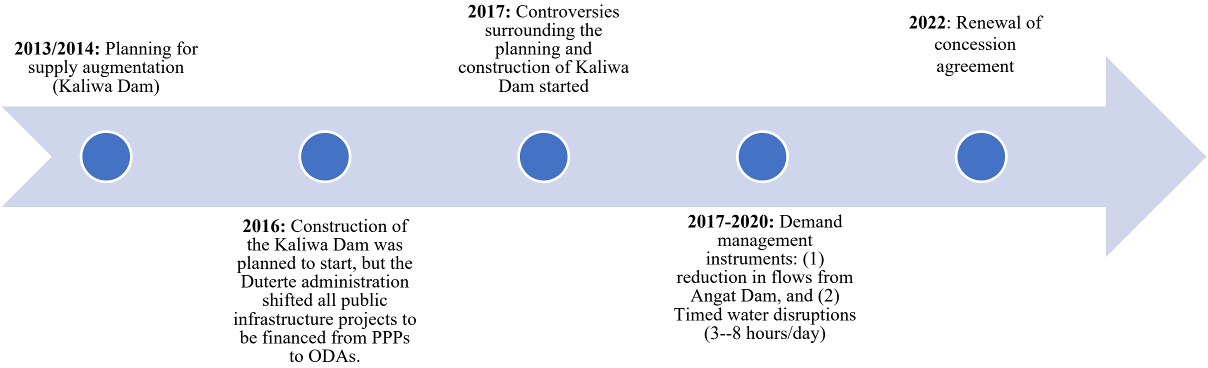
Figure 2.9: Nominal and real basic charge of the concessionaires, 2010–2019[a]



[a] Most of the data were taken at the start of the year. There are years when the water tariffs changed within the year. However, for simplicity and consistency of purposes, the author considers the tariff changes implemented for January of each year.
Sources: Manila Water, Maynilad, PSA, media press releases, and author’s calculations.

The tariff increases proposed by the concessionaires in their rate rebasing include the cost of capital investment for the Kaliwa Dam project. Although both Maynilad and Manila Water did not disclose the exact percentages, part of the revenues from tariff collections covers the cost of investing in the Kaliwa Dam project. This was agreed upon with the previous Aquino administration when the project was approved in 2012 and that the dam’s construction was due to start in 2016. However, with the change in financing policy of the Duterte administration, the concessionaires' involvement in the decision making for future water infrastructure became limited. This deviates from the signed concession agreement, which stipulates that all stakeholders of the water services—including the concessionaires and the public—will be involved in the decision making of the management and financing of all major water infrastructures in the concession areas. This change will also have implications in the proposed tariff increases for the 2018–2022 rate-rebasing plans that the concessionaires have submitted. Figure 2.10 summarises the events that took place from 2013 to 2020.

Figure 2.10: Timeline of events, 2013–2020



Sources: Various media press releases, MWSS, Maynilad, and Manila Water.

Penalties due to non-compliance to wastewater targets

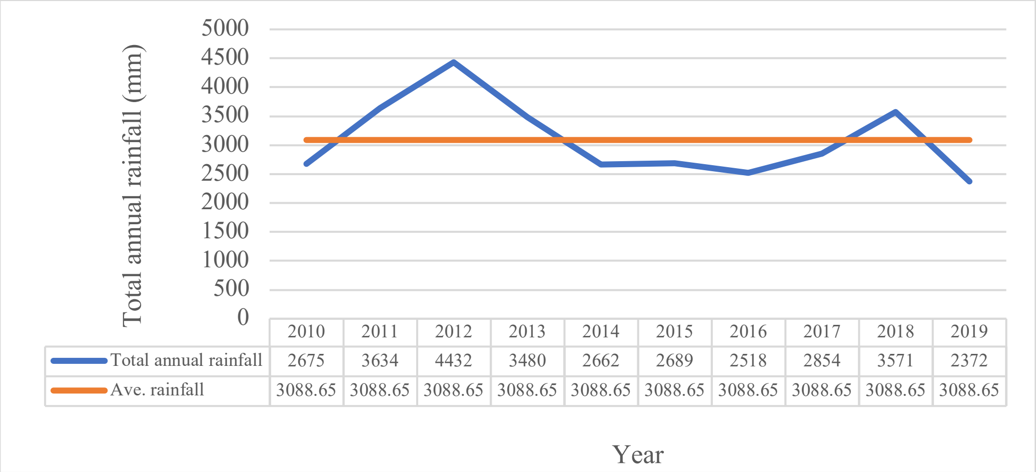
Manila Water abruptly stopped its water services for all its customers in March 2019, which caused great inconvenience to the consumers in the East Zone. The concessionaire claimed that this was attributable to the low water supply in the Angat Dam and in the La Mesa Reservoir, which was caused by the El Niño phenomenon. The Philippine Atmospheric, Geophysical, and Astronomical Services (PAGASA) and MWSS did not believe such claim. Although the dams were operating at critically low levels, this was due to both El Niño and the increase in water withdrawal by concessionaires to meet the increasing water demand in the past few years. As previously discussed, the concessionaires and the regulator may resort to supply management by reducing the flows from Angat Dam, which also inconvenience the public. MWSS decided to impose sanctions on Manila Water due to its actions. The concessionaire then admitted that it did violate its service obligation.

Another issue that is currently faced in the provision of water services is the Supreme Court (SC) of the Philippines' decision to impose large penalties on both MWSS and the concessionaires. In August 2019, the SC ruled that MWSS, Maynilad, and Manila Water did not fulfil their obligation to build sufficient wastewater treatment plants. Part of the Philippine *Clean Water Act of 2004* states that these agencies are mandated to build wastewater treatment plants to improve the quality of water in rivers and creeks around Metro Manila. The SC fined Maynilad and MWSS US$17.7 million, and US$17.7 for Manila Water and MWSS separately, for failure to put up these treatment facilities (Patag 2019). Due to the imposed penalty, Manila Water reported that consumers in the East Zone should anticipate a Php26.70 per cu.m., or a 780 per cent water rate hike, arising from an increase in water tariffs, which will be staggered over the next few months (Simeon 2019).

Managing the supply of water in Metro Manila by altering flows from Angat Dam

Precipitation contributes to the recharging of the surface water supply in the Angat Dam. The observed rainfall in the region from 2010 to 2019 averaged 3,089 mm per year (see Figure 2.11).[15] During the years 2011, 2012, 2017, and 2018, the Philippines experienced La Niña; thus, there had been frequent rainfall events during this period. However, during 2013–2016, and in 2019, the country experienced the El Niño phenomenon, making rainfall events less frequent. The exception was in 2018 when the rainfall was above the mean rainfall due to the typhoon Mangkhut that directly hit Metro Manila in September 2018.

Figure 2.11: Total annual and average rainfall in Science Garden, Quezon City, 2010–2019



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total annual rainfall	2675	3634	4432	3480	2662	2689	2518	2854	3571	2372
Ave. rainfall	3088.65	3088.65	3088.65	3088.65	3088.65	3088.65	3088.65	3088.65	3088.65	3088.65

Sources: Philippine Atmospheric, Geophysical and Astronomical Services Administrations (PAGASA) and author's calculations.

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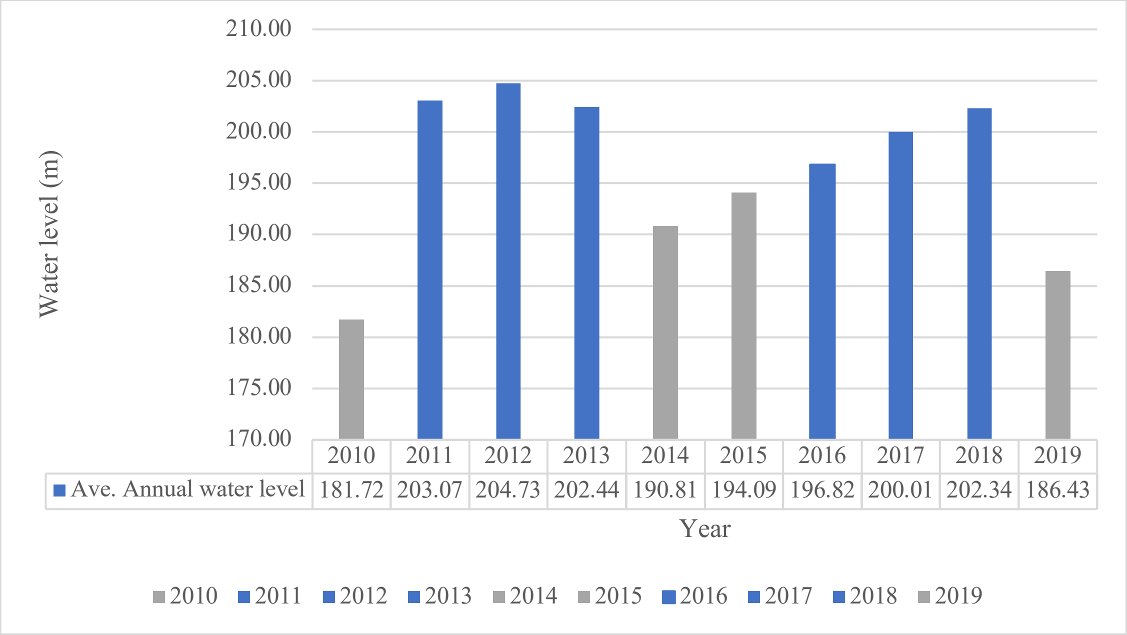
[15] PAGASA does not have a rainfall station at the location of the dam. According to the agency, they use the data from the Science Garden located in Quezon City, Metro Manila to measure the rainfall at the dam.

Figure 2.12 shows the average annual water levels at Angat Dam from 2010 to 2019. The El Niño phenomenon caused a decline in the annual storage levels in the Angat Dam, reaching as low as 181.77 metres in 2010. On the other hand, the La Niña event was able to recharge the water levels in Angat Dam. Nevertheless, it is observed that rainfall events during the La Niña were not able to sustain the 212-metre operating water levels in the dam.

Figure 2.12 Average water levels in Angat Dam, 2010–2019



Sources: PAGASA and author’s calculations.

Whenever the water level at the Angat Dam falls below the critical level, the regulator, MWSS, and the concessionaires impose water restrictions in the form of reduction in flows. The surface water level in Angat Dam has been declining due to the less frequent rainfall and decreased flows from the Umiray River to recharge the water levels in the dam.[16] Moreover, the consumptive flows for the MWSS concession area have been below the 46 cu.m./s allocation (see Figure 2.13). The total water demand in the region, however, has increased due to the increasing population and service connections done by the concessionaires. The regulator and concessionaires, therefore, resorted to water supply management to mitigate the increasing surface water scarcity—by reducing flows from Angat Dam and introducing scheduled rotational disruptions of water services.

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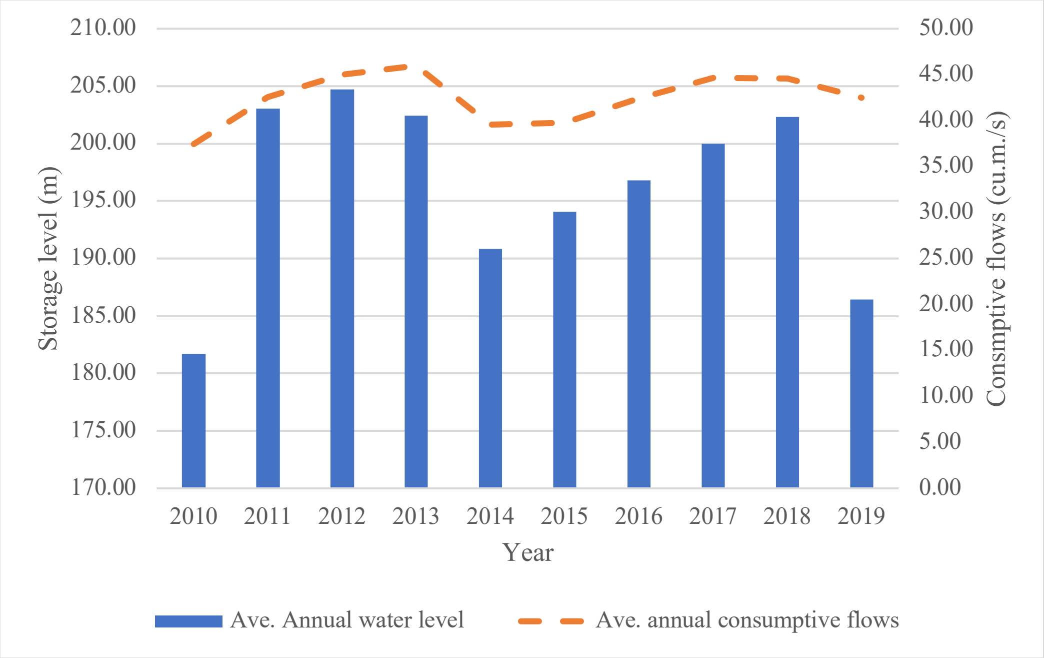
[16] According to the daily water level data from the National Power Corporation (NAPOCOR) from 2010 to 2019 and JICA (2013).

Figure 2.13 Annual average storage levels and average consumptive flows in Angat Dam, 2010–2019



Sources: PAGASA, NAPOCOR, and author's calculations.

In response to the declining water levels in Angat Dam, the MWSS reduced the allocative flows for domestic water use from the dam in 2018. The first stage in the water restriction involved the reduction in the water flows from 48 cu.m./s to 46 cu.m./s, which is equivalent to a 4 per cent reduction in flows. During this stage, the water level was observed to be at 168.96 metres, which is approximately 11 metres below the minimum operating water level and 43 metres less than the normal water level of 212 metres. This resulted in the reduction in the discharge capacity from 1,460 to 1,168 MCM.[17] The decrease in the allocation to the concessionaires caused a decline in household water consumption by 2 per cent.[18] In the second stage of the restriction, the flows were further reduced from 46 cu.m./s to 40 cu.m./s, which is equivalent to approximately 13 per cent reduction in flows, or 17 per cent reduction from the original flows. At this stage, the water level was observed to be at 160.71 metres, which is 24.2 per cent less than the base level. This resulted in the reduction in discharge capacity to 1,106.68 MCM. The further decrease in the allocation to the two concessionaires caused a reduction in household water consumption by 5 per cent.[19]

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[17] See Appendix 1 for the computation of the estimated volume.
[18] This was done by comparing the water consumption of July 2018 and July 2019.
[19] This is arrived at by comparing the water consumption of August 2019 with that of August 2018.

MWSS allocates 60 per cent of the surface water supply in Angat Dam to Maynilad, and 40 per cent to Manila Water. This means that Maynilad is allocated a maximum of 876 MCM/year of discharge capacity of water supply for the West Zone, while Manila Water is given a maximum of 584 MCM/year of discharge capacity of water supply. This thesis translates the reduction in flows mentioned in the previous paragraph into the allocation of the concessionaires. Table 2.12 shows the translated values for the critical level, and the first and second stages of water restrictions. Also included is the water level at which the Angat Dam is at its minimum operating level of 160 metres.[20]

Table 2.12 Translated volumes of Maynilad and Manila Water during the critical levels of the water restrictions, July to August 2018

Restriction	Water level (m)	% of total capacity	Flow (cu.m./s)	Maynilad allocation discharge capacity (MCM/year)	Manila Water allocation discharge capacity (MCM/year)
Minimum Operating Level	180.00	85.0	48	744.60	496.40
First stage	168.96	80.0	46	700.80	467.20
Second stage	160.70	75.8	40	664.01	442.67
Critical level	160.00	75.5	36	661.38	440.92

Source: Author's calculations.
MCM = million cubic metres.

Re-allocating water from irrigation to domestic water use

The NWRB allocates the water flows coming from Angat Dam to multiple uses. The government agency may change these allocations depending on the water level at Angat Dam, provided that it adheres to Article 22 of the Water Code of the Philippines, which states that allocation for municipal and domestic use shall have a priority right over all the other uses of water.[21] Furthermore, Article 23 of the same code states that if there are competing water uses, the priorities of water use may be altered on grounds of greater beneficial use. According to Libisch-Lehner et al. (2019), when the water level in Angat Dam is within the operating zone, or water level is higher than 180 metres and is translated to have a volume of 247 MCM, the water demand for irrigation and domestic purposes are met. However, if the water level declines to the drought zone, wherein the water levels are between 160 metres and 180 metres,

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[20] The NWRB has set this minimum water level since the Angat watershed is declared a protected area to preserve the natural habitat and the flora and fauna.

[21] Presidential Decree No. 1067, s. 1976.

which translates to 113 MCM in volume, the irrigation water supply is immediately halted to favour water use in Metro Manila. Based on this legal framework, the NWRB reallocates 15 cu.m./s of the irrigation flows for consumptive flows in times when the AMRIS does not fully utilise the water allocation. Gutierrez et al. (2019) point out that due to problems brought about by increasing water scarcity and extreme variability in climate, farmers must adjust their planting window throughout the year when water is more available for irrigation. Table 2.13 shows some instances when the NWRB changed the allocation for irrigation.

Table 2.13: Recent events of water reallocation by NWRB

Date	Allocation change	Justification	Source
1 May 2019	AMRIS: 10 cu.m./s	Start of harvesting season and decline in water level due to El Niño	Cabuenas (2018)
19 November 2019	MWSS: 40 cu.m./s AMRIS: 16 cu.m./s	Decline in the water level in Angat Dam	Ruiz (2019)
20 January 2020	MWSS: 42 cu.m./s AMRIS: 20 cu.m./s	Increase in the water level in Angat Dam	Siytangco (2019)
21 April 2020	MWSS: 46 cu.m./s AMRIS: 15 cu.m./s	Preventive measures against the COVID-19 pandemic and support to the government's program of food security during the lockdown	NWRB (2020)
October 2020	MWSS: 44 cu.m./s AMRIS: 25 cu.m./s	Current water storage is 3 metres below 180 metres	Lagare (2020)

AMRIS = Angat-Maasim River Irrigation System, MWSS = Metropolitan Waterworks and Sewerage System, NWRB = National Water Resources Board.
Sources: NWRB media releases.

Chapter 3

Examining water urban systems and the decision framework for managing water demand and augmenting water supply

This chapter examines the literature relating to urban water systems. It includes studies that (i) estimate the water-demand elasticities for water services in urban areas, (ii) discuss and identify the optimal pricing policies, and (iii) present methods of determining the optimal time to build a new water infrastructure. These studies guided the analyses in estimating the household water-demand elasticities in the two concession areas in Metro Manila, Philippines after water supply services were privatised.

This chapter is structured as follows. The first section discusses increasing block tariffs (IBTs) as the main pricing policy used in different urban areas around the world. The second section highlights the methodologies in estimating water-demand elasticities, which includes analyses of the equity issues. The third section presents the dynamic optimal pricing models in urban water systems. This section also includes a discussion on dynamic optimal timing models that determine the optimal time to construct a water infrastructure. The last section discusses the decision-making framework in managing water demand and in augmenting the water supply.

I. Increasing block tariffs as a main pricing policy

There are two possible instruments that policymakers can choose when it comes to designing the water tariffs, namely, a flat charge and a volumetric price. According to Grafton et al. (2020), decision makers tend to choose an instrument where charges or subsidies imposed on consumers are independent from their water consumption; another alternative is to impose a water tariff that includes volumetric charge. Typically, water tariffs include a flat charge that allows the water utility to have stable revenue streams despite the varying water demand for a specific period. Volumetric pricing, as part of a water tariff, can be in a form of uniform or variable volumetric pricing. Uniform volumetric pricing imposes a uniform rate for all customers regardless of their patterns of consumption and seasonal changes. A variable volumetric pricing allows differential rates based on the volume that was consumed, the season, the time of water use or household characteristics. The most common form of variable volumetric price is the IBT, and its objective is to provide incentives to conserve water. Many countries have adopted IBT in their water pricing.

In theory, IBTs are designed to achieve both efficiency gains for the water suppliers and equity gains for the consumers and the general public (Munasinghe 1990, Boland and Whittington 2000). IBTs ensure that users with higher water consumption face a higher volumetric price for additional water use than at lower levels of water use. IBTs seek to discourage high water consumption because of the high volumetric price imposed on higher consumption blocks.

The IBT is a specific form of a volumetric component of the tariff (Boland and Whittington 2000). The price of the first block is normally set below the marginal cost as it is intended for low-income households (Monteiro and Roseta-Palma 2011). Odwori and Wakhungu (2018) highlight that the first block is called the social or lifeline block as it is based on the essential minimum consumption of households. The lifeline or social block is assumed to be limited to consumers consuming water for drinking, washing, bathing, or flushing the toilets. Other water users with high water consumption subsidise the cost of providing water to low water users at the initial block. The prices set on the higher blocks are also intended to finance the full cost of water services. Thus, the pricing policy forms a cross-subsidisation wherein higher income or wealthier households with greater water use pay the costs for their own higher water use and also cover the cost of accessing water for low-income households.

The reality of IBTs is that poorer households generally have larger family sizes. Thus, as Grafton et al. (2020) point out, a possible and unintended consequence of IBTs is that those with higher water consumption, regardless of income class, pay a higher volumetric price than those with low water consumption. This is despite the fact that the per-capita water consumption of larger water consumers is below the overall per-capita level of water use in the community (Grafton et al. 2020). Importantly, the differences in prices imposed on consumers result in different marginal values for water across users. Thus, IBTs do not promote the efficient allocation of water across different users (Chu and Grafton 2019).

Dalhuisen et al. (2003) and Epsey et al. (1997) compare the different pricing structures and provide insights on how pricing policies can influence the water-demand elasticity estimations. Although their methods are almost similar, Dalhuisen et al. (2003) point out two observations that Epsey et al. (1997) had missed. The first observation is that if there were subsistence requirements, price and income elasticities are non-constant. Price elasticities tend to increase with income for goods that have relatively high subsistence requirements. Such is the case for water as it is a necessity and has a high subsistence requirement for households. The second observation is that if the pricing structure follows a block tariff, price and income elasticities become non-constant due to discontinuity in the pricing structure. This is attributed to the sudden jumps in the marginal prices that households are faced with, resulting to kinks in the budget line. The authors conclude that IBTs make residential water demand more price elastic due to the jumps in marginal prices, and that prices are determined endogenously.

II. Water-demand estimation and equity issues of increasing block tariffs

Water-demand estimation

Empirical works on water-demand estimation suggest that, typically, demand for water services is price inelastic (Rizaiza 1991, Crane 1994, David and Inocencio 1998, Strand and Walker 2005, Nauges and Strand 2007, Nagues and van den Berg 2009, Di Cosmo 2011). Households perceive that water is necessary for their sustenance and for daily domestic activities. Nevertheless, some studies suggest otherwise—that water demand is price-elastic (Hewitt and Hanemann 1995, Rietveld et al. 2000, Klassert et al. 2018). Most of these studies highlight that when IBTs are employed as the main pricing policy in the water services, households make an economic decision when using water since water consumption determines the price. Therefore, households are faced with endogenously determined prices and IBTs violate the classical consumer maximisation problem.

Early empirical studies by Rizaiza (1991) use ordinary least squares (OLS) to estimate water demand in Saudi Arabia, as for Crane (1994) for Indonesia. Rizaiza (1991) includes annual residential water usage per household, family size, family income, average annual temperature, educational attainment of the head of household, a dummy variable as an indicator for the presence of a garden in a household, and lastly, a dummy variable as indicator for the presence of household sewer or septic tank as control variables. Crane (1993) makes use of household monthly income, time spent collecting water, distance to hydrant, purchase from hydrant, time to commute to work, household size, age of household head, years in the house, tenant type, floor area, type of toilet, reservoir capacity, and a dummy for urban or rural as control variables. Estimates of both studies suggest that water demand for public water networks is generally price-inelastic, with values ranging from –0.60 to –0.78. Both studies consider that households have other alternative water sources, given that not all households in both countries are connected to the piped water supply. The elasticities for alternative sources range from –0.40 to –0.48. The empirical analyses observe that if IBTs are used as the pricing policy, OLS estimates may be biased and inconsistent. Arbues et al. (2003) further argue that IBTs will produce endogenously determined prices based on quantity demanded, causing simultaneity problems and conclude that demand simultaneity and the discontinuity of IBTs may invalidate the OLS estimates.

To remedy the simultaneity and endogeneity problems from IBTs and circumvent the problems of biased and inconsistent OLS estimates, studies have introduced alternative methods of demand estimation. Studies on water demand use: (i) the Quasi-Almost Ideal Demand System in Di Cosmo (2010); (ii) two-stage least squares (2SLS) in David and Inocencio (1998) and Strand and Walker (2005); (iii) two-step Heckman approach in Nauges and van den Berg (2009); and (iv) discrete-continuous approach in Rietveld et al. (2000), Klassert et al. (2018), and Hewitt and Hanemann (1995) to address and consider the endogeneity issues in water-demand estimations.

Demand estimation methods seek to estimate a demand equation that can reflect the actual demand of individuals or households. Most models use linear expenditure systems because the expenditure is expected to be linearly related to household demand. Deaton and Muellbauer (1980) introduce the Almost Ideal Demand System (AIDS) that uses a first-order binary approximation. The AIDS model adheres to the five important characteristics of demand: (i) it satisfies the axioms of choice; (ii) it aggregates perfectly over consumers without invoking parallel linear Engel curves; (iii) the functional form should be consistent with available expenditure data of households; (iv) it is easier to estimate, given its non-linear estimation procedure; and (v) restrictions on homogeneity and symmetry restrictions can be tested using linear restrictions on fixed parameters.

An extension of the AIDS model, the Quadratic Almost Ideal Demand System (QUAIDS), was proposed by Banks et al. (1997). QUAIDS is based on the estimation method of Seemingly Unrelated Regression (SUR). QUAIDS is represented by a quadratic logarithmic in the income term to assume that the Engel curve is non-linear. Many applications of the AIDS model include, among others, the demand estimation for milk, beer, and tobacco consumption in Turkey (Sahinli and Ozcelik 2016); all goods of Japanese households (Mizobuchi and Tanizaki 2013); and some goods identified in the consumer price index (CPI) basket of Poland (Gostkowski 2018).

Di Cosmo (2011) is the only empirical study that uses the Quadratic AIDS (QUAIDS) model in water demand, with estimation for drinking water in different regions in Italy. Regional fixed effects were included in the study because water service concessionaires operate at the municipal level. Southern regions in Italy also have arid weather conditions as compared to those in the northern regions. Di Cosmo (2011) also investigates the link of consumption behaviour between types of households (i.e., the presence of children and/or senior citizens), and price increases of water as well as other goods. Water-demand elasticity of households across Italy is estimated to be –0.23, while cross-price elasticity between water and other goods is almost zero. This is attributed to water having a small expenditure share in the overall household expenditure but is still considered as a necessary service. Households with children have water-demand elasticities ranging from –0.14 to –0.18 with income elasticities ranging from 0.40 to 0.43. Older households have a water-demand elasticity of –0.36 and an income elasticity of 0.46. From these results, Di Cosmo (2011) suggests that households in the southern regions have higher elasticities due to the drier weather. The higher elasticities in these regions are due to the higher pass-through costs; thus, the concessionaires impose higher tariffs. Regional and household demographic characteristics also have a strong influence on water-demand elasticities.

David and Inocencio (1998) use the 2SLS model to estimate water-demand elasticity in Metro Manila, Philippines while Strand and Walker (2005) use the same for Central American cities. The 2SLS model can address the problems of simultaneity and endogeneity in prices given the increasing block tariff pricing policy in the market. David and Inocencio (1998) estimate the price equation at the first stage, and the second stage predicts the price based on the explanatory variables, which includes the household size, distance from water source, dummy variable to indicate if they are connected to the MWSS pipelines, variables that describe water quality, type of household, a dummy variable to indicate whether they have booster pumps, a dummy variable if the household is connected to a sewer service, the number of supply hours, and the educational attainment of the household respondent. They estimate that while the demand for piped water is –0.2, the number of households in their sample that are connected to the water system is too small. Estimates for the vended water have a price elasticity that is –2.1. The authors justify that the high responsiveness of water demand to price changes is attributed to the high dependence of low-income households on vended water. Strand and Walker (2005) find almost the same results as David and Inocencio (1998). The authors include the marginal water price, the average water price, and a set of household characteristics. Although water demand is generally price inelastic for households that are connected to piped water, those that rely on non-tap sources have higher price elasticity estimates.

In many developing countries, water supply services are often under-priced, especially for domestic use. Nauges and van den Berg (2009) consider the inclusion of cost recovery in water policies in the piped and non-piped water systems in Sri Lanka. Piped and non-piped water systems are essential as they help predict the possible effects on household water demand as well as the welfare effects of water tariff changes. Using the two-step Heckman approach, the authors identify the factors that would affect the water-demand elasticities of both piped and non-piped water in Sri Lanka. The authors point out that because of the complexity of IBTs, households react to the average price and not to the marginal price. Households that have both water sources have an elasticity of –0.37, while those who are fully dependent on piped water have an elasticity of –0.15. For households that are not connected and have their own water source, the estimated price elasticity is –0.44. The authors find that non-piped water is identified as an inferior good, as it is inversely related to household income, albeit the result is not significant. The authors conclude that there is some evidence on the substitutability between water sources for both piped and non-piped consumers.

Possible shifts in the distribution of consumers among the price blocks can result in problems in misspecification of the water-demand estimation. To capture the discrete and discontinuous nature of household responses to block pricing, Burtless and Hausman (1978) introduce a model that uses a two-stage probit model or the Discrete-Continuous approach. Hewitt and Hanemann (1995), Rietveld et al. (2000), and Klassert et al. (2018) use this approach in estimating the water demand for Texas in the United States, Salatiga City in Indonesia, and Jordan, respectively. The studies find that it is possible that water-demand elasticities are price elastic, especially at the higher price blocks. Hewitt and Hanemann (1995) estimate that the water-demand elasticity for piped water ranges from –1.57 to 1.63 for households in Texas. Rietveld et al. (2000) estimate that household water-demand elasticity is –1.2. The results of Klassert et al. (2018) show that water-demand elasticities range from 0 to –1.445. In using the discrete-choice model, the authors allow the inclusion of both economic and non-economic factors, where variation in behaviour is influenced by price, income, and other factors, such as various socio-demographic variables. The most important household characteristic influencing demand is the household size, yet policymakers do not, in general, account for the household size in deciding on the size of the blocks in IBTs. Thus, the pricing structure is regressive for low-income households that have large family sizes.

Dalhuisen et al. (2003) and Sebri (2014) compare the methods used in water-demand estimation regardless of the pricing structure. Using 100 studies with 638 price elasticities, Sebri (2014) finds that price elasticities range from –3.054 to –0.002 while income elasticities can have values between –0.440 to 1.560. The analysis did not consider studies with positive price elasticities. Dalhuisen et al. (2003) suggest that household size greatly influences the water-demand elasticity of households, which has been highlighted by multiple empirical studies. Household size elasticity, a variable that measures the significance and impact of household size in IBTs, is included as a control variable in the analysis. Results suggest that both income and household size variables induce negative and statistically significant effects on the price elasticity estimates. They also influence the water-demand elasticity to be more price-elastic. Household elasticities are found to be 0.273 for developing nations and 0.484 for developed countries. Families in low-income countries do not significantly increase their water consumption when a new household member is added, thus, they have lower household elasticities compared to rich countries.

This thesis uses the AIDS model for household water-demand estimation. To test for robustness of the results, the 2SLS and the QUAIDS models were also employed. The Two-Step Heckman and the Discrete-Continuous approach are not used in the robustness checks because these methods assume that household water consumption is exogenously given and that the average price is being estimated. In the case of this thesis, both household water consumption and the average price is endogenously determined based on the household expenditure on water.

There have been several studies of the water services in Metro Manila, but they are mostly concerned with the political aspect of the water governance problems (e.g., Elazegui 2004 and Coxhead 2004). After privatisation, the number of households connecting to the water services of the two concessionaires increased substantially due to the improved delivery of water services. Despite the substantial increase in the number of households being connected to the piped water supply, there are still many households that use alternative water sources. This is due to households experiencing either financial constraints or frequent disruption of water services. Water services are disrupted not only during extreme weather events but also on regular days due to, for example, breakdown of equipment. Water tariffs of both concessionaires have been increasing annually to cover the costs of investment. Thus, a need to estimate water-demand elasticities after the privatisation of the water services.

Table 3.1: Selected water-demand estimations

Authors	Country	Pricing structure	Method	Water service providers	Water-demand elasticity
Rizaiza (1991)	Saudi Arabia	IBT	OLS	National Water Company & private concessionaires	–0.40 to –0.78
Crane (1994)	Jakarta, Indonesia	IBT	OLS	Municipal water authority	–0.48 to –0.60
Hewitt & Hanemann (1995)	Texas	IBT	Discrete-Continuous approach	Public Utility Commission of Texas	–1.57 to –1.63
Rietveld et al. (2000)	Salatiga, Indonesia	IBT	Discrete-Continuous approach	Regional water companies	–1.2
Klassert et al. (2017)	Jordan	IBT	Discrete-Continuous approach	Water Authority of Jordan, 3 water utilities	0 to –1.445
David and Inocencio (1998)	Manila, Philippines	IBT	2SLS	MWSS (Government-owned and controlled corporation)	–0.5 to –2.1
Strand and Walker (2005)	Central America	IBT	2SLS	Community, municipal, regional, national	–0.17 to –0.37
Nauges & Strand (2007)	El Salvador & Honduras	Varied	Multinomial Logit Model	Government, private and municipal concessionaires, deep wells, public wells	–0.4 to –0.7
Nauges and van den Berg (2009)	Sri Lanka	IBT	Two-step Heckman	Private wells, national water Supply & Drainage Board	–0.15 to –0.44
Di Cosmo (2011)	Italy	Fixed fee + capped variable component	Quadratic AIDS	Municipal-level water concessionaire	–0.14 to –0.36

Source: Author.

Equity issues in increasing block tariffs (IBTs)

Most water services adopt IBTs as the main pricing policy. (Whittington 1992, Boland and Whittington 2000, Rietveld et al. 2000, Dahan and Nisan 2007, Odwori and Wakhungu 2018). The pricing block structure imposes penalties to consumers that have high water consumption and are represented through the high marginal prices imposed on the higher blocks. The use of IBTs as the main pricing policy to improve equity among consumers is dependent on how strong the positive correlation is between water use and household income (Agathe and Billings

1987). IBTs work on the assumption that high-income households use more water than low-income households. Agathe and Billings (1987) also observe that in IBTs, water is also subjected to diminishing marginal utility. In other words, high-income households have a smaller marginal utility when consuming water to the last unit as compared to low-income households. The ideal rate structure, therefore, follows an increasing price function and each rate of increase is matched to the rate of decline of the consumer's marginal utility of income (Agathe and Billings 1987). For any progressive water tariff structure, water-demand price elasticities are high and a price increase would result in a proportionately larger decrease in water use.

IBTs impose higher prices at higher blocks on the assumption that high-income households or high-volume water users can afford to pay. Martinez-Espeñera (2003) finds that there is a high positive correlation between household income and water use. The payment from high-income households, as well as industrial and commercial establishments, subsidises low-income households' access to water services. Due to the high marginal prices set at higher price blocks, IBTs also promote water conservation as higher marginal prices discourage households from unnecessary use of water. Prices at the higher blocks are also matched with the rising marginal costs of extracting and delivering water to households. Maddock and Castaño (1991) point out that IBTs can also reduce the risk of diseases in poor communities. This is because the positive externality created from the cross-subsidy allows poor families to consume safe and potable water. Thus, IBTs are more equitable and explicitly redistributive (Maddock and Castaño 1991).

There are, however, different views. Boland and Whittington (2000) argue that the structure of IBTs prohibits water utility managers from achieving the equity objective. One of the problems in the design of IBTs is the setting of the price and the size of the lifeline block. The price of the first block, or the 'lifeline block', is set below the marginal cost but prices in the higher blocks are equated with their corresponding marginal costs. Limiting or adjusting the price and the size of the lifeline block is nearly impossible as water utility managers face political and social pressures. Households prefer the size of the first block to be as large as possible so that water prices are kept low. However, setting it too large to keep the prices low will have serious negative consequences on the water utilities' business because they may not be able to recover their cost, thereby discouraging them from making additional investments in the future. The second problem of IBTs is that the complexity leads to non-transparency issues pertaining to the average and marginal prices that each household pays. The jumps in each price block may confuse water users, making it difficult for them to know the actual price they are paying per unit of water consumption.

Relationship between water demand and household characteristics

Most of the empirical studies concentrate on the differences in elasticities of family sizes, income classes, and geographical location, noting that there are only a few empirical studies that discuss the influence of other household characteristics, apart from family size, on water demand. Nevertheless, it is important to investigate which household characteristics influence water demand because domestic water use also varies depending on households' socio-demographic factors (March and Sauri 2010). This section discusses the few existing empirical works that examine the water demand and that take into consideration different household characteristics.

Corbella and Pujol (2009) argue that non-price factors, or socio-demographic characteristics of households, have significant influence on water demand. Household size is a significant factor that can affect water consumption in different ways. Due to the demographic transition occurring in developed countries, the changing demographic structure and ways of living can have two implications. The authors point out that economies of scale on water consumption could not be generally achieved in small households. Thus, the increasing number of small households promotes a more inefficient water use. Another factor that affects water demand is the age structure of the population. Older generations tend to use more water because they spend more time being at home and doing household chores. Older household members may also have more water-saving awareness because they generally have lower income and thus are more vulnerable to increases in water prices. Lastly, the authors point out that only a few studies examine the relationship between gender and domestic water use. In developing countries, women-headed households tend to use more water because they carry out more household chores and emphasise good hygiene practices. Thus, including these non-price determinants in water-demand estimations is important, especially in addressing the equity issues surrounding different water pricing policies.

March and Sauri (2010) examine which household characteristics significantly affect water demand in Barcelona. The changes in development patterns and socio-demographic structures in Barcelona influence the household water use and management. The authors use the OLS model in estimating domestic water consumption. The OLS model is a stepwise regression to avoid overlapping problems between explicative factors (March and Sauri 2010). Their results suggest that household size and the aging rate of households are not overall statistically significant. However, both are highly negatively correlated and significant with each other. As the population ages, the household size in the community becomes smaller. On the other hand, the results for households living in suburban areas indicate that household size partly explains the difference in domestic water consumption between suburban municipalities. In particular, smaller households contribute to higher domestic water consumption. The differences in the aging rate explain why there is the divergence of household water use patterns among suburban municipalities. The authors mention, however, that both household size and aging rate become significant in explaining water use in low-density cities only.

Aside from being the only empirical work that uses the AIDS model to estimate water-demand elasticities, Di Cosmo (2011) examines the influence of household age and marital status on water demand. She estimated the water-demand elasticities in households with (i) old couples (i.e., above 65); (ii) young couples (i.e., below 65 years old); (iii) young couples with one child; and (iv) young couples with two children. The differences in water-demand elasticities of young couples with or without children are small, with estimated elasticities ranging between –0.14 to –0.18. On the other hand, older couples are more price-elastic and have an elasticity of –0.36. Di Cosmo (2011) argues that older couples are more sensitive to price changes because they have a fixed income, which may be lower than that of younger couples. They also have more time for housekeeping activities. Older couples also have higher income elasticities as compared to younger couples. The income elasticity of households with senior couples is 0.46, while younger couples have elasticities ranging from 0.40 to 0.43. Based on the results, the author concludes that water tariff changes will affect senior citizens more intensely than other age groups.

Mazzanti and Montini (2006) and Musolesi and Nosvelli (2007) estimate the water demand in Italy by including the share of old households in the total population. The studies obtain contradictory results regarding the significance of the influence of this factor on water demand. Mazzanti and Montini (2006) use a log-linear model when estimating the water demand with the inclusion of household size, population, population density, and population age in the explanatory factors. The authors argue that adding these factors will ascertain the robustness of price and income elasticities across the different specifications and explore further the determinants of water demand. Their results show that households with residents who are above 64 years old have insignificant influence on water demand. Musolesi and Nosvelli (2007) also examine the effect on water demand of communities that have higher levels of senior citizens. Using a dynamic autoregressive log-linear model and the generalised method of moments, their results suggest that the share of the population aged more than 65 years old has a significant influence on household water demand, which is in contrast to the results obtained by Mazzanti and Montini (2006). Both studies, however, agree that communities with more senior households will have lower water consumption.

Schleich and Hillenbrand (2009) empirically analyse the impact of social determinants on the per-capita water demand in Germany. Aside from income and household size, their study includes the effects of population age, share of wells, and housing patterns. The authors note that German regulations require that water and sewerage price cover the total costs and that consumers are faced with average costs rather than marginal cost prices. This causes prices to be endogenously determined, which may give rise to simultaneity problems. To address these problems, the authors use the single equation OLS model and instrumental-variable procedures. The structural equations that the authors specify is a log-log and the semi-log models to estimate the elasticities. The dependent variable in the OLS equation is the water consumption, while the independent variables include the (i) price (total price of both water and sewage), (ii) income, (iii) household size, (iv) age (average age of the population), (v) presence of wells, (vi) type of household (single family or extended), (vii) rainfall, (viii) temperature, and (ix) regional dummies. In the first stage, the instrumental variables that the authors use are the natural logarithm of population and population density. The authors argue that these variables capture the inherent scale of economies in capital costs for pipe networks as well as business operations (i.e., billing and water quality testing). The results of their analysis indicate that as people age, water consumption increases because older people spend more time at home and doing more household chores. Access to wells results in a decrease in household water demand from the water utility companies. Although not statistically significant, the authors find that single-family houses have higher water consumption. The authors point out that on average, single-family houses are most likely to have individual and private metering as compared to those with multi-family dwellings.

Morakinyo et al. (2015) and Abebaw et al. (2010) examine the influence of gender differential on the access to drinking water sources in Nigeria, Senegal, and Ethiopia. Morakinyo et al.

(2015) estimate the likelihood of a household to connect to a better drinking water source, using a binary logistic regression. Their results suggest the likelihood that female-headed households will seek better drinking water sources is 1.17 times than that of male-headed families. Abebaw et al. (2010) estimate the differential effect of a head of household's gender on water demand using an OLS regression at the first stage. They point out that simultaneity and endogeneity problems could arise from such a model because households choose to stay with the unimproved source knowing that connecting to an improved source requires to travel for long distances to the facilities, which reduces household productivity, and higher user fees. To remedy this problem, the Abebaw et al. (2010) construct a bivariate probit model to test and control for possible endogeneity problems. Their findings are consistent with those of Morakinyo et al. (2015). Women are tasked to fetch water and are in charge of domestic chores. As heads of households and decision makers, investing in an improved water source would be better than fetching water. Females, typically, are more risk-averse than males, hence, they tend to increase household water consumption to minimise waterborne illnesses. Both studies suggest that household gender introduces a differential impact when it comes to water demand.

Briand et al. (2009) examine which household characteristics can influence the change in water use in Dakar, Senegal. Using the approach of Heckman (1976) and the probit model, the authors measure the change in water use given a change in obtaining a tap connection for previously unconnected households. The estimation of water demand includes household characteristics, such as household size, head of household education level, household marital status (widowed or not), head of household occupation, and characteristics of the house (i.e., number of rooms, appliances, equipment, and materials). The distance of the household from the stand post of the water service is included in the analysis to account for the quality of service provided. The results suggest that aside from income, the household size and household members' opportunity cost of time and expected health benefits from having a tap connection increases the probability of connecting to the water services. It also follows that once families have tap water connection, their water consumption consequently increases.

An important observation that can be drawn from the existing empirical studies is that most of the equity analysis investigates only whether the cross-subsidisation of the high-income households to low-income households is happening. In the regression analyses of these empirical works, family size and income have been identified as two of the household characteristics that influence water demand. Many of these studies suggest that larger families, regardless of whether they are low or high-income, pay more for water consumption. In addition, not all low-income households have low water use and not all high-income households are large water users (Agathe and Billings 1987). The implication is that large low-income families end up subsidising those with low water consumption.

A much deeper analysis of the equity issue needs to be carried out by examining in detail the influence of different household characteristics on water demand. The equity issue, in the context of water prices, has two dimensions—(i) horizontal equity, and (ii) vertical equity (Donkor 2010). Horizontal equity describes the situation wherein people in similar situations are assumed to be treated equally. This dimension assumes that households with equal water consumption are expected to pay equal monthly bills given that they have individual connections. Vertical equity, on the other hand, focuses on the differences in treatment of people in different economic situations to reduce inequalities. The inequality may be due to the different household characteristics, aside from family size, that influence water demand. Such analysis can yield more robust estimates of price and income elasticities and, at the same, can help in identifying which household groups would be more intensively affected by the changes in water prices.

Lastly, Chu and Grafton (2019) state that households with lower water demand elasticities have less flexibility to reduce their water use when there is a price increase. Therefore, any increase in water prices will have a significant impact on households with lower demand elasticities. Identifying which types of households have lower demand elasticities can provide policymakers with a firmer basis for formulating more effective water pricing policies to address the equity issue.

III. Dynamic programming models

Seminal works on dynamic programming models for urban water systems

Scarato's (1969) work forms the basis of many dynamic programming models to determine the optimal capacity to be considered in different urban water systems. This work presents a time-capacity expansion model, which uses a general minimum cost technique to determine the optimal time and size component of expansion to meet a water-demand growth rate. The objective function of the model is to minimise the cost of the capacity expansion that can meet a linearly increasing water demand over time. Scarato (1969) imposes five conditions in his model, as follows: (i) deterministic linearly increasing demand, (ii) constant economies of scale over time, (iii) continuous discount factor over time, (iv) infinite penalty costs, and (v) infinite planning horizon. The additional capacity considered by Scarato (1969) follows a step-wise function to represent the increase in capacity for each planned phase. For any measured construction time, the total discounted cost is the sum of the cost of the additional capacity and all future discounted costs. To simplify the analysis, Scarato (1969) assumes that the water revenues are the same, regardless of the size of the treatment plant, and that water sales are independent of the capacity. The capacity expansion satisfies the total projected demand.

Scarato (1969) extends his model to water treatment plants that require heavy capital investment costs. He observes that solving for the actual capacity for water treatment plants requires rigorous processes and analyses. Water treatment plants, in particular, require in-line processes that involve the analysis of each component in the facility (i.e., pumping, flocculation, sedimentation, filtration, chemical treatment, and storage). His method is to, first, solve for the optimum capacity expansion that needs current and reliable cost data, which are usually compiled in unusable datasets. Second, the optimal expansion is sensitive to the increase in demand that is specific to the facility being planned. Thus, the design capacity must be set individually for each separable system component, such that each part is designed to meet future demand based on the partial cost function for each specific system component. Changing a parameter for a component alters the whole cost function of the expansion of the water treatment plant. Hence, it is possible that the parameters can be different for each construction period. To be able to bypass these complications, Scarato (1969) suggests establishing the initial design size and the timing specifications after quantitatively analysing the effects of economies of scale and cost of capital under conditions of growth.

Another key contribution using the cost function in dynamic programming modelling is by Riordan (1971), who focuses on determining the optimal investment of a publicly owned or regulated monopolistic enterprise. Riordan (1971) observes in Scarato's (1969) paper that the long-run average cost (LAC) and long-run marginal cost (LMC), typically, change for each time period especially when the capacity expansion is undertaken in stages. Given the growth and demand characteristics of the population, all schedules can be optimal but would lead to different cost curves. LMCs will also be different for each stage especially if the planning horizon follows an addition-to-existing approach. This approach would lead to higher variable production costs than the installation of a completely new plant, and thus, the assumed LMCs of the previous curves are not the actual long-run curves. Riordan (1971), therefore, proposes a general model for the investment-pricing problem. His model has the following assumptions: (i) the monopolistic enterprise of interest is considered to be publicly owned or regulated; and (ii) the plant undergoes no physical or functional obsolescence, and the economies of scale will be observed with the additional plant; thus, it is desirable to invest in large discrete additions to its capacity. The decision problem has the following four components: (i) policy; (ii) demand; (iii) technology and costs of production; and (iv) initial conditions, such as initial pricing and initial supply and demand conditions. Equity is not considered in the model and the price alone reflects the water use of the households, as Riordan (1971) assumes that the monopolistic enterprise, in this case the water utility, can either be publicly owned or regulated. Thus, the assumption that the enterprise maximises economic efficiency holds, and that the price is set equal to the short-run marginal cost and that it is equal for all consumers.

Riordan (1971) highlights some disadvantages in his model. Firstly, it fails to explicitly handle the different components that constitute a system's capacity. For example, water supply systems include the transmission, treatment, and distribution in the system, and all must be included simultaneously in the estimation of an overall optimal investment plan. Secondly, the assumption of complete certainty regarding supply and demand conditions may not hold true. Lastly, the assumption that the price can continuously vary to ensure that the marginal willingness-to-pay (WTP) is equal to the short-run marginal cost (SRMC) fails to reflect the finite and discrete nature of a consumer's ability to decide based on the institutional and physical environment.

Solving the model requires breaking the capacity and the price into discrete annual steps. Using Riordan’s (1971) case study, the results suggest that the inclusion of administrative constraints increases consumers’ net benefits when compared to the average cost pricing. However, the increase is small in percentage terms and relatively insignificant on a per-capita basis. The administrative constraints that impose a limit on the rate of price change and cost recovery are more realistic, but the economic benefits obtained by optimum pricing and capacity expansion are reduced and have only marginal improvements over average cost pricing.

The model of Dandy et al. (1984) is one of the first dynamic programming models that recognises the interaction between demand and supply. With the assumption that a water utility supplies water to a growing community, the model determines an annual water price and the optimal timing to expand the water supply system given a discrete planning horizon. The maximisation problem is subject to five constraints, as follows: (i) water withdrawal cannot exceed capacity, (ii) the plant operates perpetually, (iii) there is a certain acceptable price range within a particular year, (iv) the annual price change must be within the acceptable limits, and (v) the revenues should be able to cover the financial costs. Administrative constraints, such as limiting the price change and stream of revenues of the water utility, account for the presence of the regulator. The state variables are the system capacity and the price in each year to determine the maximum net present value (NPV) for a given year. Using a forward-moving discrete dynamic programming algorithm, the model estimates the optimal policy where the water price covers the investment for the operations of the existing water supply system.

Stochastic dynamic programming models for determining optimal timing, investment, and pricing policies

This subsection discusses studies that use stochastic dynamic programming (SDP) models to determine the optimal investment in water infrastructures and optimal pricing policies in different urban water systems. Grafton et al. (2014) present two studies that use SDP models to evaluate whether it is efficient to build a desalination plant in Sydney, Australia. Hughes et al. (2009) introduce an SDP model that examines both demand and supply side in determining if either demand management or supply augmentation, or a mixture of both, gives the best policy outcome. Lastly, Chu and Grafton (2019) present an analysis using an SDP model that considers the risk-adjusted user cost (RAUC).

SDP models can determine the optimal time to build a major water infrastructure that maximises social benefits and minimises social costs. Grafton et al. (2014) use an SDP model, following a numerical simulation, to estimate the welfare losses generated from the premature construction of the desalination plant in Sydney, Australia. The objective function of their model is to maximise the expected present value of the total aggregate social surplus from the household water consumption over a time horizon of 100 years. The model is subject to an operational constraint, which is the minimum amount of real net revenue that the water utility obtains from tariff collections. In addition, the stream of revenues should be sufficient to cover the fixed costs and depreciation. The Sydney dam storage is treated as the state variable. Since water storage cannot be completely depleted, the model takes the minimum storage available at a particular time, *t*, that depends on the inflows, the current stock of water supplied to the households, the environmental flows, and the evaporation rate. The authors present two scenarios: (i) a baseline scenario that includes the current water supply at the dam and an option for a backstop technology, and (ii) the addition of a desalination plant. The dynamic optimisation problem uses a numerical simulation in three stages. The first stage solves for the value function by starting at the end point of the planned lifetime of the plant, at $t = 100$, using the standard value-function-iteration algorithm for a stationary Bellman equation. Once the value function at $t = 100$ is solved, the second stage solves for the time-dependent Bellman equation using the backward induction procedure to obtain the annualised value function during the planning horizon. The last stage concludes with two value functions at $t = 0$.

Grafton et al. (2014) include sensitivity analyses with varying discount rates and the longevity of the plant in terms of water pricing and water supply augmentation. If the plant's operational life is longer and the discount rate is low, the net benefit of the plant increases, assuming that construction cost is fixed. If the operational life of the plant is short and the discount rate is small, it will reduce the desirability of the desalination plant. The results suggest that having 2 per cent, 5 per cent, and 8 per cent discount rates will still yield negative NPVs if the operational life is set at 50 years. If the operational life is set at 70 years or more, the 2 per cent discount rate achieves a positive NPV under a medium, drier weather scenario. On the other hand, the NPV will become positive if the discount rate is 2 per cent and the operational life of the plant is set at 100 years. Given the results, the authors conclude that the desalination plant was prematurely built, unless the discount rate is set very low and that the lifetime is set for a longer period.

Another study by Grafton et al. (2015) employs the same SDP model with some adjustments in the parameters. Grafton et al. (2015) apply the SDP model to the desalination plant in Sydney, Australia to examine the optimal time to operationalise the plant. Further, they examine the potential social losses considering that the plant was built in 2010. First, the discount rate is set to 3 per cent. Second, the capital cost of the newly constructed desalination plant that has an additional capacity of 250 millilitre (ML) per day is A$1.92 billion while the cost of adding 250 ML/day—to have a total additional 500 ML/day—is A$1.02 billion. Lastly, the inflow data for a 90 year-period is influenced by the weather uncertainties. The authors also use the 30-, 50-, and 70-year operational life assumptions to determine the optimal time to expand the capacity to 500 ML/day. They also examine the different inflow scenarios since weather plays a big factor in the inflows to the dam. The results suggest that expanding the capacity of the plant should happen 20 years after its construction during the driest weather conditions. Under wetter conditions, expanding the capacity by 250 ML/day should be implemented during the mid-century or beyond. This is on the assumption that the plant remains operational beyond the planning period. The results further suggest that if the weather situation is drier, which means there will be lower inflows as well as a longer operational life, the supply augmentation should be carried out sooner.

Hughes et al. (2009) investigate the water services of the Australian Capital Territory (ACT) region in Australia. In Australia, water restrictions impose high inconvenience costs to households and significantly high enforcement costs to the water utilities. The study demonstrates the nature of optimal price (demand management) and investment (supply augmentation) policies instead of the usual analysis in forecasting the economic impacts of changes in urban water policies using an SDP model. The authors first model the water-demand equation, which is a function of the inflows, a demand equation constant, seasonal parameters, inflow parameter, long-term growth parameters, and the season. The supply side is a function of the difference of the storage levels at the current time, together with the inflows, and the storage losses and the quantity supplied.

The model of Hughes et al. (2009) includes a penalty in instances when the water supply is not able to meet the essential water demand. The objective function is the expected discounted sum of the computed market surplus, less the cost of the new investment and the penalty. The analysis has two scenarios: (i) a rain-dependent scenario—which assumes the construction of a new reservoir or dam, and (ii) a rain-independent scenario—which assumes there is water recycling. The study finds that there are substantial differences in both scenarios. Water utilities in the ACT region are more likely to adopt an approach in which delaying the investment is a definite option, due to higher costs, until a substantial decline in storage level occurs. The continuous demand growth, increasing supply augmentation costs, and the impacts of climate change are driving the long-term trends towards the increasing urban water scarcity.

Chu and Grafton (2019) introduce a dynamic marginal cost pricing model, the risk-adjusted-user-cost (RAUC), which allows the flexibility for the effect of current consumption on future water storage. The RAUC is an economic cost that arises when facing an uncertain water supply. Water use today imposes a consequent risk to future consumers; thus, the RAUC considers both supply and demand as risks. Supply risks can come from the magnitude and frequency of risk events that influence future water supply (i.e., variations in temperature and precipitation, and shutdowns due to water quality problems). Demand risks, on the other hand, consider the level of risk aversion of consumers to water restrictions. Consumers with low price elasticities are more risk-averse because they have less flexibility in reducing their water use when water prices increase. Consequently, they have a higher WTP to avoid any water restriction. Higher price elasticities also imply that consumers are less risk averse. This is because consumers can be more flexible in their water use when water prices change. Including the RAUC in the dynamic water pricing accounts for the current marginal costs associated with supply. The user cost associated with the reduction in water storages from current water use is also incorporated in the model. With the RAUC, a more efficient and dynamic water pricing under risk enables water utility managers to promote water conservation. Furthermore, it mitigates or eliminates possible future water restrictions.

Chu and Grafton (2019) apply the RAUC dynamic pricing model to analyse the pricing policy of the water services in the ACT. The pricing policy in the ACT is unique as it is one of the very few locations that include scarcity price. This price component is the water abstraction charge (WAC). However, the WAC does not include the RAUC; thus, it is not a dynamically optimal method for water pricing. The authors suggest that efficient water pricing is one that does not uniformly charge all water users at the same rate. Large water users pay a high price despite constant extraction and treatment costs of water because they generate different risk-adjusted implicit marginal costs (Chu and Grafton 2019). If water utilities impose higher user cost during supply shortages, it can adversely affect the low-income but large households. They suggest the following three ways to mitigate these adverse effects: (i) reduce or eliminate the fixed supply charge, especially for the poorer households; (ii) apply a free allowance of water where the user cost is not included in the water bill; or (iii) introduce water rebates for the poorer households, coming from the redistribution of revenues. Important assumptions in implementing the dynamic water pricing with the RAUC are (i) all households have individual water meters, (ii) households are charged volumetrically based on the amount of water they use, and (iii) households have perfect information on the volumetric price.

Stochastic dynamic programming models for determining optimal operation rules in different urban water systems

This subsection reviews the studies that use the SDP models, and other extensions, to determine the optimal operating policy for different urban water systems. Perera and Codner (1998) introduce methods to circumvent the dimensionality problem as well as to improve the computational speed of SDP models. While Liang et al. (1996) examine the trade-offs between hydropower and water supply using a stochastic and deterministic model, Tilmant and Keman (2007) evaluate the trade-offs of allocating water between hydropower and irrigation using a stochastic dual dynamic model (SDDP). Both studies examined the Upper Colorado River in Colorado, USA. Mortazavi et al. (2012) use a multi-objective SDP model to determine how altering water flows influence environmental flows and how it affects the ecosystems downstream in Sydney, Australia. Lastly, Macian-Sorribes et al. (2015) introduce a hydro-economic model that estimates the marginal opportunity resource cost of the Mijares River basin in Spain.

SDPs can potentially be the best method in generating the optimal operating rules in urban water systems. However, SDPs suffer from the ‘curse of dimensionality’, a problem that arises when there are multiple reservoirs present in the urban water system. Multiple reservoirs require multiple state variables to represent each reservoir. Therefore, the analyses involve more computational time and memory requirements. To address this problem, Perera and Codner (1998) modify the SDP model by aggregating all reservoirs into one big reservoir. Streamflow, which are the inflows and outflows, are stochastic in nature, and these form a multivariate probability distribution. The authors suggest adopting an SDP model that makes use of the computationally efficient Gaussian Legendre quadrature method (GLQM) to estimate the conditional probabilities of the streamflow. Discretising state variables, both storage and inflows, gives a specific number of states for both storage and inflows. In solving their model, the annual volumetric reliability—ratio of total volume supplied over a given length of time to the total volume of water demanded over the same period—is set as the objective function. The objective function is subject to the following constraints: (i) the water release cannot exceed the maximum discharge that the storage can handle; (ii) the discharge in storage cannot exceed the maximum storage of any reservoir; (iii) the total discharge should be less than the total storage; (iv) the discharge cannot exceed the total water demand for a specific stage; and (v) the total outflow, which is the difference between the storage and demand, should not exceed the capacity.

Perera and Codner (1998) introduce two methods that improve the computational efficiency of the SDP. One method assumes that there is a cross correlation of stream flows among reservoirs. This assumption eliminates the need to consider stream flows that are unlikely to occur. This is a common scenario in most reservoir systems where there is a strong cross-correlation between stream flows at various locations in the system.[1] The other method is the corridor approach, which eliminates the need to consider the infeasible storage volume combinations in the previous stage during the computation of the objective function (Perera and Codner 1998). Using a hypothetical water system of three reservoirs, the authors verify these methods, assumptions, and the GLQM. The two methods significantly reduce the computing time to determine the optimal operation for a multiple reservoir urban water supply system.

Many water basins provide both hydroelectric power and water supply for urban areas but have conflicting objectives. Liang et al. (1996) introduce a multi-objective model with two objectives to meet both hydroelectric power and reliable water supply in the Upper Colorado River basin. The first objective is to maximise the reliability of both annual water supply and hydropower generation given the constraints from the reservoir operation. Water supply is given priority due to the laws surrounding the river basin in the region. The second objective is to maximise the long-term average performance of potential hydropower production. The two-objective reservoir operation problem is difficult to solve because of its probabilistic and deterministic objective functions. The authors use both the constraint method and the method of combined stochastic and deterministic modelling (CSDM) and compare both estimations to identify the best water allocation policy. The constraint method allows the reformulation of the two-objective to a one-objective SDP, wherein the state vector describes the current water volume in the reservoir and the volume of inflow. To avoid the curse of dimensionality, the authors aggregate the reservoirs in the analysis. Using the CSDM, the optimal release policy gives the best long-term average performance for hydropower production. Unfortunately, this fails to satisfy the requirement for a reliable annual water supply. The authors propose two deterministic steps to avoid this problem: (i) compute the current monthly release, and (ii)

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[1] This happens since the outflow of one reservoir becomes the inflow of another.

select the release for the current month. By following these steps, Liang et al. (1996) are able to achieve both targets for the water supply and the hydropower.

Another study that examines the trade-offs of allocating water between different sectors is by Tilmant and Keman (2007). They use an SDDP model to investigate the trade-offs between the objective of the agricultural and the energy sectors in the multi-reservoir system in the Euphrates-Tigris River basin in Turkey. The study involves the allocation of water to produce hydroelectricity and irrigation. In their model, the volume of water in the reservoirs and the previous inflows are considered as the state variables that are used to describe the system's status. Each decision stage solves for the trade-off between allocating water to hydroelectricity and to irrigation. It also estimates the trade-offs between consuming water now or saving it for future use, whichever yields the higher value for water. The decision for the optimal policy for the allocation of water relies on where the current costs and future costs are minimised. To identify the best policy, the SDDP presents the following two phases: (i) a backward phase that identifies the lower bound of the allocation, and (ii) a forward phase that identifies the upper bound of the allocation. Both phases undergo iterations until there is a convergence between the backward and the forward phases. The authors conclude that allocating water to the agricultural sector will be more beneficial than to the urban water system. Despite increasing the number of hydropower plants, allocating water to the energy sector will be more costly, rather than being beneficial. Instead, the reallocation will be beneficial to the agricultural sector. The objectives of maximising water security are in conflict with minimising the cost, as well as environmental impacts.

Mortazavi et al. (2012) introduce a multi-objective optimisation approach that identifies the trade-offs among the conflicting objectives, taking into account environmental impacts. The study examines the trade-offs between allocating water for urban water and preserving environmental flows in the Wollondilly River in Sydney, Australia. The authors present three primary objectives, which are to: (i) minimise the frequency of water restrictions; (ii) minimise the present worth cost, which is the sum of capital (i.e., new infrastructure) and discounted expected operating costs, and the costs of the unplanned shortfalls; and (iii) minimise the environmental stress. Minimising the environmental damage mitigates the adverse effects on the ecosystem due to altered flows of water. Their model has several decision variables, each representing different pumps, plants, and flows in the water supply system. Given the results of the study, Mortazavi et al. (2012) conclude that the failure to optimise the mix of operational and infrastructure decisions, the failure to allow for high-return periodic droughts, and the failure to explore trade-offs will lead to inferior Pareto solutions. They also highlight the importance of ‘soft’ constraints (i.e., environmental flow constraints). Excluding these constraints in the optimisation models will run the risk of missing potentially good solutions while examining the trade-offs between domestic water supply and environmental flows to preserve the ecological balance.

Macian-Sorribes et al. (2015) use a hydro-economic model that considers the marginal resource opportunity cost (MROC) for the Mijares River basin in Spain. The authors define the MROC as “the benefits that would have been obtained at a specific time and space with the condition that the resource is available at that specific time and space and is increased by one unit” (p.3926). To account for uncertainty in the optimisation process, the authors pair their model with an SDP. The MROC can be estimated by both numerical simulation and a Lagrange multiplier optimisation approach associated with the mass-balance equation for the given place and time. The analysis involves the following steps: (i) defining the main pricing policy features; (ii) developing the hydro-economic stochastic programming model for the system; (iii) determining the MROC (marginal water values) time series at the reference nodes (i.e., main reservoirs); (iv) aggregating/disaggregating the MROC time series to calculate the aggregated MROC values; (v) developing the statistical analysis over the aggregated MROC values to obtain their cumulative probability distribution; (vi) building different scenarios from the cumulative probability values, obtaining the aggregated MROC values of the system state values, obtaining the system states associated with the characteristic values, and summarising all possible state values associated with each characteristic value that represents the steps; and (vii) defining several step-pricing policies.

Macian-Sorribes et al. (2015) highlight five important findings from their analysis. First is that SDP is a useful tool for estimating optimal policies and MROC time series to determine the overall performance of the optimisation policies that can assess pricing policies. Second, the pricing policies can enhance the system's global economic efficiency since they establish a relationship between the system state, storages and inflows, and water price based on the marginal value of water in a reservoir. Third, the participatory framework processes help define the features and characteristics of pricing policies. Fourth, the methodology they present considers a pricing policy that is efficient by incorporating administrative cost, environmental costs, and other social objectives. Lastly, the pricing policy they propose can be one of the economic instruments that can implement adaptable individual decisions to collective goals and achieve both social and environmental targets in managing water resource systems.

Ways forward

The water supply system in Metro Manila is primarily dependent on the water supply from the Angat Dam. Groundwater is also used as a secondary source and provides 2.1 percent of the total water supply in the region (JICA 2013). Both water sources are recharged through rainfall or precipitation. Water levels in dams are recharged through surface water run-offs, while groundwater is replenished through percolation of surface run-off into the ground. All of these are governed by the hydrologic cycle. However, climate change has greatly affected precipitation. Kundzewicz et al. (2008) claim that there will be a decrease in the reliability of surface water supply because of the higher variation of temporal flows from increase precipitation variability and the reduced low flows during the summer months. This, in turn, affects the available water supply that can be allocated to urban areas not only for one period but for different time periods.

The studies discussed above highlight the importance of analysing urban water systems dynamically. In the Metro Manila case, the dynamic analyses start out by estimating the household water-demand elasticities to identify the sensitivity of the households to the current pricing policy and to tariff increases. The water-demand elasticities are applied because the water services in Metro Manila were privatised and the number of connected households has increased since the start of the concession period in 1997. Estimating the price elasticities gives insights on the overall dependence of the domestic water users on their respective concessionaires.

The next step in the dynamic analysis is to identify the optimal pricing policy for water-demand management and the optimal timing for constructing a water infrastructure. Water inflows and outflows influence the availability of water supply in reservoirs across different time periods. Determining the optimal operation policy, pricing policy, and investment policy helps policymakers to maximise the water allocation between its competing uses, across long time periods. To determine these policies, one approach is to augment water supply, or another is to use water-demand management instruments. Such approaches, if analysed dynamically, minimise the welfare loss from either restricting water supply or from prematurely constructing a water infrastructure.

Urban areas around the world either impose water-demand management and/or augment water supply to address the problem of increasing water scarcity. The Philippine Government planned to augment the water supply in Metro Manila by the construction of the Kaliwa Dam. When completed, the dam will add 600 million litres per day (MLD) to the existing water supply to meet the growing demand for water in the country's capital region. The project, however, faces criticisms from the public. Aside from the legal constraints as discussed in Chapter 1, the cost of investment is passed on to water users, which the public perceives in a negative way. As an alternative to increased water supply, the concessionaires have resorted to reducing the water flows coming from the Angat Dam to conserve water at times of scarcity. This approach has reduced the consumer surplus of the water users as there has been a significant reduction in water consumption.

Dynamic efficiency analysis of the pricing instrument is, thus, also needed. A pricing instrument, such as a scarcity price or premium that Chu and Grafton (2019) introduce, can reduce the potential loss in consumer welfare as compared to imposing water restrictions. The dynamic analysis also provides insights on the best policy approach—whether to impose water-demand management instruments or to augment water supply—to address the persistent water scarcity problem in Metro Manila.

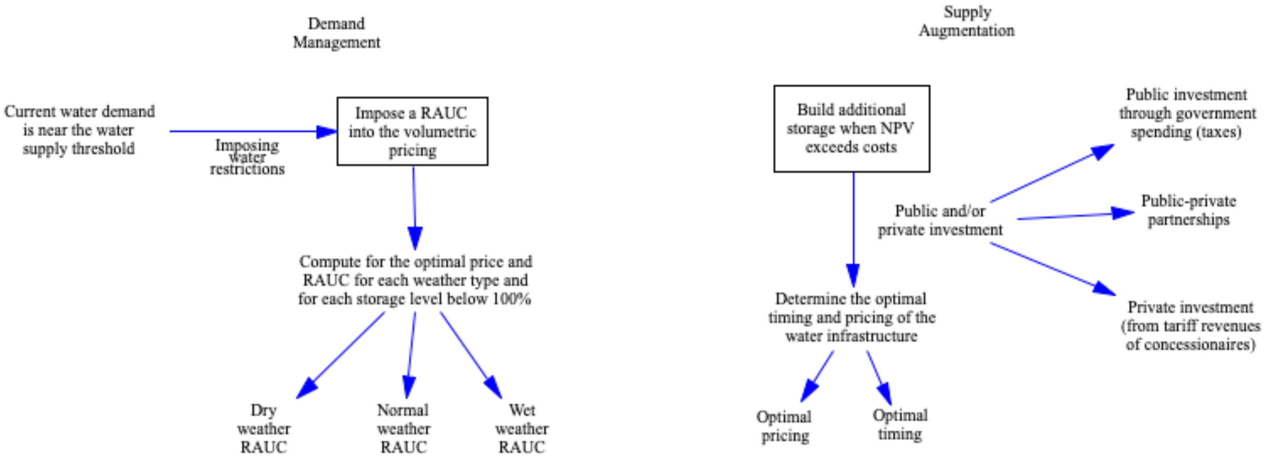
IV. Decision-making framework for managing water demand and augmenting water supply

To address water scarcity, water utilities can either employ the water-demand management approach or water supply augmentation, or both. While supply augmentation requires intensive costs and investment, the water-demand measures can be implemented when the regulator and/or concessionaires delay the construction of an additional water infrastructure. If the construction of a water infrastructure is delayed, the volumetric price should include a scarcity water price, or the RAUC, which is imposed on water users in situations when water supply becomes more scarce (Chu and Grafton 2019). A higher temporary volumetric price imposes additional costs to households, which runs counter to the policy incorporated in the current water concession agreement in Metro Manila—to keep water prices low and affordable. On the other hand, constructing an additional water infrastructure prematurely can result in social welfare losses. Thus, deciding whether to impose a scarcity price or to proceed with the building of a new water storage facility entails a deeper understanding of its trade-offs. Figure

3.1 introduces the decision-making framework that is applicable if the current capacity exceeds current water demand and when the critical scarcity levels of the water resource is reached.

When the current storage system is insufficient to meet current demand for a particular resource, or when the storage for the resource is already at its critical level, this prompts decision makers to: (i) impose a scarcity price, which is the RAUC, when storage levels are declining; (ii) build an additional infrastructure; or (iii) ration the water. Although surface water supply is a renewable resource, increasing water demand as well as the decline in the significant amounts of rainfall can lead to a decline in the current storage levels of dams. The short-term response is to impose water restrictions and the RAUC as an additional cost to water users. On the other hand, the long-term response is to build an additional water infrastructure, which requires significant public or private investment, if the net present value (NPV) exceeds the cost for such investment

Figure 3.1: Decision-making framework for managing water demand and augmenting supply



Source: Author.

Imposing water restrictions, such as reducing water inflows and implementing timed water disruptions, or a RAUC, is seen as a short-term solution, but with long-term benefits. It mitigates the increasing water scarcity by limiting households' water consumption. Furthermore, it decreases the rate at which surface water levels in dams decline, while allowing rainfall and net inflows to recharge water storages. However, resorting to such actions introduces risks to the water consumption of the households.

The RAUC represents the user-pay principle—that is, households that face higher risk and higher rate in their willingness-to-pay will face higher RAUCs and higher volumetric prices. As water levels in storages decline, the RAUC increases as supplying water becomes more costly and poses an increasing risk to the availability of water in the future. Volumetric prices that include the RAUC are seen to be the highest when the storage level has already reached the critical threshold (Chu and Grafton 2020). It is to be expected then that the RAUC is highest during the dry weather as water levels are at the lowest, compared to those during normal and wet weather. Thus, the regulator and concessionaires should have the flexibility to change the RAUC—depending on the dam's water level.

An alternative way to address the increasing water scarcity, which is a long-term solution, is to invest in a new water infrastructure. This is costly and requires public and/or private investments. The financial resources to build an additional water storage facility may come from the public, private, or both public and private sectors. With public investment, the national government finances the construction of the new water storage facility using tax revenues. A private investment follows the user-pay principle in which water users who will directly benefit from the additional water storage will have to pay higher water tariffs to defray the cost of constructing the new dam. Under a public-private partnership (PPP) arrangement, large-scale projects can be financed by both the public and the private sector, or in some cases the private sector alone. Most PPPs in the Philippines are under a build-operate-transfer (BOT) contract, in which the government grants a concession to a private company to finance, build, and operate the project for a period of time to recoup its investment with a profit. After the concession period, the private company transfers the control of the asset to the government.

Chapter 4

A household water-demand estimation and analysis of the post-privatisation water services market in Metro Manila, Philippines

This chapter estimates the water-demand elasticities in Metro Manila after privatisation using the Almost Ideal Demand System (AIDS) model. The estimated elasticities provide insights on the extent of the households' dependence on the water services of their respective concessionaires.

The first section of the chapter discusses the theoretical framework of the demand for water, specifically for increasing block tariffs (IBTs) as well as the AIDS model. The second section describes the data, the model specifications, and the methodology. The third section discusses the results of the estimation. The last section makes some concluding remarks.

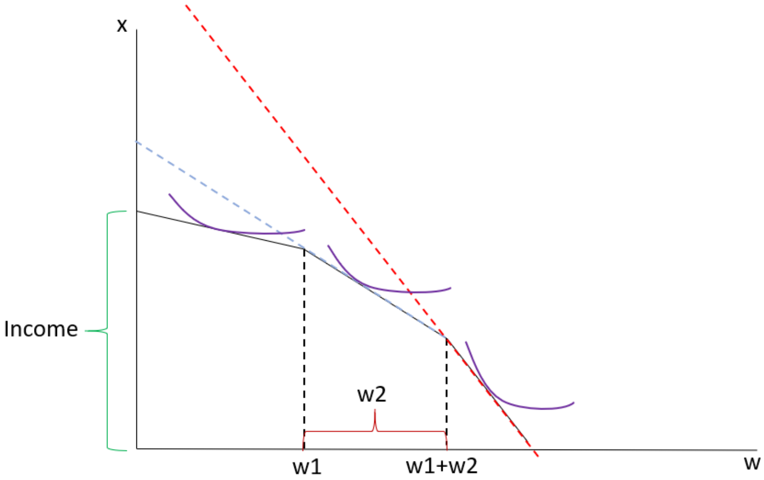
I. Theoretical framework

Demand for water under IBTs

Water services using IBTs, or any form of progressive pricing structure, have special consequences in terms of economic theory and econometric estimation (Rietveld et al. 2000). Instead of a linear and convex budget set, consumers are faced with a piecewise-linear budget set because of the 'jumps' in the prices for each block under the structure of IBTs. The discussions of the water demand under IBTs draw on the studies of Dahan and Nisan (2007) and Rietveld et al. (2000).

Let us suppose that we have a representative household that maximises its utility. The household has an income, represented as Y, and faces a piecewise-linear budget set given in Figure 4.1. The household utility comes from consuming water, w, and a composite good, x. The price of the composite good is normalised to 1 to make the analysis simpler.

Figure 4.1: Piecewise-linear convex budget set of the household



Source: Dahan and Nisan (2007).

In Figure 4.1, the household faces three increasing blocks with each block having its own marginal price and block size. The price of each *i*th block is defined as p_i and that the size of each block is denoted as w_i. The household budget constraint has three different equations:

$$Y = p_1 w + x \qquad if\ w < w_1 \qquad Eq. 4.1$$

$$Y + (p_2 - p_1)w_1 = p_2 w + x \qquad if\ w_1 < w < w_1 + w_2 \qquad Eq. 4.2$$

$$Y + (p_3 - p_2)w_2 + (p_3 - p_1)w_1 = p_3 w + x \qquad if\ w > w_1 + w_2 \qquad Eq. 4.3$$

Households are located within one of the price blocks or at any of the kinks as illustrated in Figure 4.1. The water demand of each household is determined by its preferences for water as well as the household size. It is expected that households with larger family sizes, as well as those with shared metered connections, will have higher water demand than those with smaller family sizes, all else equal. Such households are pushed to the higher price blocks unless the size of each block is related to household size. Rietveld et al. (2000) and Dahan and Nisan (2007) highlight the fact that the economies of scale (i.e., household size) are a key factor in shaping the demand for water. Furthermore, IBTs influence households to have a non-conventional reaction to price changes. Households will only be affected once there are price changes in the block to which they belong to and the distribution of households along the water consumption continuum heavily influences the magnitude of the price elasticity (Dahan and Nisan 2007).

Households in Metro Manila face an increasing 9-block tariff structure that the Metropolitan Waterworks and Sewerage System (MWSS) has implemented since the late 1980s. Both

Maynilad and Manila Water—the two water concessionaires—have adopted such IBTs after privatisation, and this was the pricing structure that MWSS had been using since the water services started in Metro Manila. There are about four sharp increases between the first block and the last block. The number of blocks is one of the highest among countries that have adopted the IBTs (see Table 4.1).[1] This means that households in Metro Manila face a very complex water tariff system set by the MWSS. Instead of the three kinks as shown in the example above, consumers in the region will have nine kinks in the budget set.

Table 4.1: Countries and the number of blocks in their respective IBT structures

Country	Number of blocks in IBT
Saudi Arabia	5
Salatiga, Indonesia	4
Manila, Philippines	9
Jordan	7
La Paz, Bolivia	4
Ho Chi Minh, Vietnam	3
Jerusalem	3

IBT = increasing block tariffs.
Source: Rizaiza (1991), Rietveld et al. (2000), David and Inocencio (1998), Klassert et al. (2018), Dahan and Nisan (2007)

The Almost Ideal Demand System (AIDS) model

The water-demand elasticities, both own price and cross-price elasticities, are estimated using the AIDS model. Deaton and Muellbauer (1980) introduced the AIDS model, and it has been extensively used in various demand estimation and analyses for many goods. According to Blanciforti and Green (1983), the AIDS model provides the first and second order for a demand system equation. Furthermore, the demand estimations of households are based on the axioms of choice. It states that households can be perfectly aggregated without the assumption of parallel linear Engel curves. One of its best features is that the functional form is consistent with the household budget. Many countries, including the Philippines, have made their respective household or family expenditure datasets publicly available.

Most demand estimation models use non-linear estimation methods, but these produce less than ideal results (Deaton and Muellbauer 1980). The AIDS model employs the transcendental logarithmic (translog) function and allows for the imposition of restrictions. Restrictions, such as homogeneity and symmetry, can be tested when using the AIDS model. The general form

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[1] This number of blocks was established before the MWSS started managing the water services in Metro Manila.

of the AIDS model considers that the budget shares of each good are a function of prices and utility. This thesis uses the AIDS to estimate the household water-demand elasticities. It employs the Quadratic Almost Ideal Demand System (QUAIDS) and the two-stage least squares (2SLS) model to check for robustness of the AIDS's results.

The cost function of a representative household is given in *Equation 4.4*:

$$\ln c(p,u) = [(1-u)lna(p) + ulnb(p)] \qquad Eq. 4.4$$

The representation of the preferences is called the *PIGLOG* class, and that *Equation 4.4* is the cost or expenditure function[2]. Utility, u, lies between 0 (subsistence) and 1 (bliss); we can regard $a(p)$ and $b(p)$, which are positive linearly homogeneous functions, as the costs for subsistence and bliss, respectively.[3] The expenditure function defines the minimum expenditure that the representative household needs to reach a utility level at specific price levels, and is denoted as *c(p,u)*. Utility is given as *u* and *p* is the price vector for all goods. Deaton and Muellbauer (1980) proposed that the specifications for *lna(p)* and *lnb(p)* can be expressed in *Equations 4.5 and 4.6*, respectively, as follows:

$$lna(p) = a_i + \sum_k^K \alpha_k lnp_k + \frac{1}{2}\sum_k^K \sum_j^J \gamma_{kj}^* lnp_k lnp_j \qquad Eq. 4.5$$

$$lnb(p) = lna(p) + \beta_0 \prod_k^K p_k^{\beta_k} \qquad Eq. 4.6$$

The last term in *Equation 4.5* captures the interaction between the prices of different goods. Combining *Equations 4.5* and *4.6* into *Equation 4.4* yields the basic specification of the almost ideal demand system, as shown below:

$$\ln c(p,u) = \alpha_0 + \sum_k^K \alpha_k lnp_k + \frac{1}{2}\sum_k^K \sum_j^J \gamma_{kj}^* lnp_k lnp_j + \beta_0 \prod_k^K p_k^{\beta_k} u \qquad Eq. 4.7$$

Deaton and Muellbauer (1980) highlight that the cost function, $\ln c(p,u)$, is linearly homogenous in prices if it follows the restrictions of homogeneity, symmetry, and additivity. The demand functions can be derived by obtaining the budget share of a good *i*, w_i, thus:

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[2] PIGLOG stands for price-independent generalised linear preferences.

[3] A 'bliss point' is the amount of consumption that maximises the individual's utility for a particular good or service. Any point beyond the bliss point will make the consumer less satisfied.

$$\frac{\partial lnc(u,p)}{\partial lnp_i} = \frac{p_i q_i}{c(u,p)} = w_i \qquad Eq. 4.8$$

Combining *Equation 4.7* and *4.8* yields:

$$w_i = \alpha_i + \sum_{j}^{J} \gamma_{ij} lnp_j + \beta_i \beta_0 \prod_{k}^{K} p_k^{\beta_k} u \qquad Eq. 4.9$$

Where,

$$\gamma_{ij} = \frac{1}{2}\left(\gamma_{ij}^* + \gamma_{ji}^*\right) \qquad Eq. 4.10$$

Assuming there is a utility-maximising consumer, the total expenditure *x* is equal to $c(u, p)$. This equality can be inverted so that utility, *u*, is a function of *p* and *x*, which is the indirect utility function. Undertaking this transformation for *Equation 4.7* and substituting it in *Equation 4.9* yields the budget shares as a function of *p* and *x* and gives the AIDS demand functions in the following budget share form, as follows:

$$w_i = \alpha_i + \sum_{j}^{J} \gamma_{ij}\, lnp_j + \beta_i \ln\left(\frac{x}{P}\right) \qquad Eq. 4.11$$

Where the price, P, is defined as the stone price index, thus:

$$\ln P = \alpha_0 + \sum_{k}^{K} \alpha_k lnp_k + \frac{1}{2} \sum_{j}^{J} \sum_{k}^{K} \gamma_{kj} lnp_k lnp_j \qquad Eq. 4.12$$

The restrictions of the parameters in *Equations 4.7 and 4.10* imply that:

$$\sum_{i=1}^{n} \alpha_i = 1, \quad \sum_{i=1}^{n} \gamma_{ij} = 0, \quad \sum_{i=1}^{n} \beta_i = 0 \qquad Eq. 4.13$$

$$\sum_{j=1}^{J} \gamma_{ij} = 0 \qquad Eq. 4.14$$

$$\gamma_{ij} = \gamma_{ji} \qquad Eq. 4.15$$

$$\sum w_i = 1 \qquad Eq. 4.16$$

Holding the restrictions in *Equations 4.13, 4.14,* and *4.15*, *Equation 4.11* is a representation of a system of demand functions that add up to total expenditure in *Equation 4.16*. These demand functions are homogeneous of degree zero in prices and income and satisfy the additivity constraint and the Slutsky symmetry restriction.[4]

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[4] Since the model starts out with a cost function, the Hessian matrix of the cost function should be a symmetric matrix.

The AIDS model is interpreted in this manner: In the absence of changes in relative prices and 'real' expenditure $\left({}^{x}/_{P}\right)$, the budget shares are constant, and this is, typically, the starting point for predictions using the model (Deaton and Muellbauer 1980). The changes in relative prices are represented through the terms γ_{ij}. Holding $\left({}^{x}/_{P}\right)$ constant, each γ_{ij} represents 100 times the effect on the budget share of the *i*th good should there be a 1 per cent increase in the price of the *j*th good. The changes in real expenditure are represented by the β_i coefficients. These coefficients add up to zero and are positive for luxury goods and negative for necessities.

To calculate the elasticities, Asche and Wessels (1997) propose the following equations for the Marshallian (uncompensated) elasticity, Hicksian (compensated) elasticity, and the income elasticity for AIDS models, in *Equations 4.17, 4.18*, and *4.19* respectively:

$$\varepsilon_{ij}^{u} = \left(\frac{\gamma_{ij}}{w_i}\right) - \delta_{ij} - \left(\frac{\beta_i}{w_i}\right)\left(\alpha_j + \sum_{j}^{J} \gamma_{ij}\, lnp_j\right) \qquad Eq.4.17$$

$$\varepsilon_{ij}^{c} = -\delta_{ij} + \frac{\gamma_{ij}}{w_i} + w_j \qquad Eq.4.18$$

$$\eta_i = 1 + \frac{\beta_i}{w_i} \qquad Eq.4.19$$

The term δ is known as the Kronecker delta.[5]

In this thesis, the budget shares of water, electricity, food and non-alcoholic beverages, and other goods are considered. The share of water expenditure is expected to be small relative to the total household expenditure, so the cross-price elasticities and effects are expected to be small. It should be noted that the share of water expenditure in this thesis is the household expenditure on water supply, which is the expenditure of households to the services provided by both concessionaires.

II. Data description, model specification, and methodology

Study area and dataset

Metro Manila, also known as the National Capital Region (NCR), has a more comprehensive and structured water services as compared to other provinces and metro cities in the Philippines. It is divided into four districts. Table 4.2 shows the cities for each district and

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[5] This is a mathematical function that has two variables, usually non-negative integers. The function is 1 if the variables are equal, and 0 if otherwise.

coverage of each concessionaire.[6] Table 4.3 shows the distribution of Family Income and Expenditure Survey (FIES) sample households in Metro Manila—by concessionaire and by year.[7]

This thesis uses the cross-sectional data from the FIES of the Philippines in the years 2009, 2012, and 2015.[8] Only the FIES sample households living in Metro Manila are included in the demand estimation as this thesis focuses on this region only. The FIES sample consists of 4,285 households in 2009, 4,323 in 2012, and 4,130 in 2015.

Table 4.2: Metro Manila's districts and cities

District	Cities	Concessionaire
Capital District (District 1)	Manila	Maynilad
Eastern Manila District (District 2)	Mandaluyong	Manila Water
	Marikina	Manila Water
	Pasig	Manila Water
	Quezon City	Manila Water
	San Juan	Manila Water
Northern Manila CAMANAVA (District 3)	Caloocan	Maynilad
	Malabon	Maynilad
	Navotas	Maynilad
	Valenzuela	Maynilad
Southern Manila District (District 4)	Las Piñas	Maynilad
	Makati	Manila Water
	Muntinlupa	Maynilad
	Parañaque	Maynilad
	Pasay	Maynilad
	Pateros	Manila Water
	Taguig	Manila Water

Source: Maynilad (2017) and Manila Water (2017).

Table 4.3: Distribution of households in Metro Manila, by concessionaire and by year

	2009	2012	2015
Maynilad	2,570 (59.08%)	2,641 (60.40%)	2,492 (61.44%)
Manila Water	1,715 (40.02%)	1,682 (39.60%)	1,638 (38.56%)
Total	4,285	4,323	4,130

Sources: FIES of the Philippine Statistical Authority and the author.

The cross-section dataset is unbalanced due to the varying number of household samples being surveyed by the Philippine Statistical Authority (PSA). Table 4.4 shows the summary of the

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[6] See Figure 2.2 in Chapter 2 for the areas of responsibilities for each concessionaire.

[7] See Appendix 4, section A4.1 for a description of the sampling design of the FIES.

[8] FIES is conducted every 3 years.

descriptive statistics of the sample households for each year. Appendix 1 shows the water tariffs that each concessionaire imposes for the years 2009, 2012, and 2015. Appendix 2 explains how the price that each household pays is determined endogenously from the total water expenditure.

Table 4.4: Summary of descriptive statistics (mean values)

Variable	2009	2012	2015
No. of sample households, Metro Manila	4,285	4,323	4,130
Income decile	7.76	7.39	7.38
Family size	4.60	4.55	4.57
Total income[a]	358,650.70	377,550.20	420,855.00
Total expenditure[a]	310,784.90	322,437.00	347,585.70
Total water supply expenditure[a]	4,765.36	5,710.71	6,088.92
Monthly water supply consumption[b]	27.46	24.36	27.52
Total electricity expenditure[a]	40,827.37	42,982.10	22,709.86
Total expenditure on food & non-alcoholic beverages[a]	116,474.60	122,914.90	131,549.80
Total expenditure on other goods[a]	82,919.09	151,772.30	150,803.10
Share of water supply expenditure	0.02	0.02	0.02
Share of electricity expenditure	0.13	0.13	0.07
Share of food & non-alcoholic beverages expenditure	0.44	0.44	0.43
Share of other goods expenditure	0.24	0.42	0.44

[a] In current Philippine peso of current year.

[b] In cubic metres (cu.m.).

Source: FIES of the Philippine Statistical Authority.

Model specification

The thesis adopts *Equation 4.11* as the main model specification to estimate the long-run water demand, with the addition of the household characteristic variables at the intercept (see *Equation 4.20*). Thus,

$$w_i = \left(\alpha_i + \sum d_z\right) + \sum_j^J \gamma_{ij}\, lnp_j + \beta_i \ln\left(\frac{x}{P}\right) \qquad Eq.4.20$$

The expenditure share, w_i, is estimated using the household control variables, d_z, the vector of prices, p_j, the price aggregator, P, the total expenditure, x, and the changes in relative prices, γ_{ij}. The empirical specification in *Equation 4.20* satisfies the homogeneity, symmetry, and additivity constraints when estimating *Equation 4.20*. Constraints are imposed to correctly estimate the elasticities. The analysis employs the Stata syntax of Lecocq and Robin (2015) in estimating AIDS models. This is to allow endogenous regressors in the model in cases when the water services follow the IBTs as the main pricing model.

This thesis computes for the long-run elasticities using the method of Asche and Wessels (1997), wherein both compensated and uncompensated elasticities are computed. This thesis examines two cases in estimating the household demand and income elasticities for water services. Case A estimates the elasticities that consider only the control variables, such as family size, district, water source, and the year. The existing literature suggests that aside from income, family size influences the demand for the water services of water utilities. The district dummy variables control for the geographical location for each household, as shown in Table 4.2.[9] The water source dummy variable categorises if the household's water source is from a private or a shared source. This is because there are communities in Metro Manila that have shared meters as a result of the concessionaires' program to provide water services to the poor and those in highly dense communities. Lastly, the year dummy controls for the time factor as the pooled cross-section data use the FIES from the years 2009, 2012, and 2015.

Case B estimates the elasticities that include the head of household's gender (Morakinyo et al. 2015, Abebaw et al. 2010); (ii) household head's age (Corbella and Pujol 2009, March and Sauri 2010, Di Cosmo 2011, Mazzanti and Montini 2006, Musolesi and Nosvelli 2007, Schleich and Hillenbrand 2009); (iii) household head's marital status (Di Cosmo 2011, Briand et al. 2009); and (iv) household type. These are aside from the family size, district, water source, and year dummy variables. This is to investigate further if these household characteristics are endogenous to the household water consumption and if adding these variables will have a significant change in the values of the demand and income elasticities. Table 4.5 shows the variables included in the analyses. Appendix 3 shows the descriptive statistics per household characteristic under each concessionaire.

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[9] District dummies were generated individually since there are four districts, hence, four categories. District 4 was not included to avoid the dummy variable problem and multicollinearity.

Table 4.5: Variables in the regression

Variable	Name	Description
w_i	Expenditure share of good i	Expenditure share of good i (water, electricity, food and non-alcoholic beverage, other goods)
famsize	Family size	Household or family size of each household
$d_{district}$	District dummy	The district where the household belongs to (District 1–4); each district is being served by either of the concessionaires.[a]
$d_{watsrce}$	Type of water source dummy	Households' main water supply source (private =1; shared = 0)
HH_gend	Household head's gender dummy	Gender of the household head (male = 1; female = 0)
HH_age	Household head's age dummy	Age of the household head (senior = 1; non-senior = 0)
HH_ms	Household head's marital status dummy	Household head's marital status (single, married, widowed, separated/divorce, annulled, unknown)[b]
HH_type	Type of household dummy	Type of household (single, extended, two or more)[c]
d_{year}	Year dummy	Assigned dummy variables for each year to account for time fixed-effects[d]
P_j	Vector of prices	Vector of prices of the different goods considered
P	Price aggregator	Stone Price Index
x	Total expenditure	Household's total expenditure on all goods
γ_{ij}	Changes in relative prices	Estimated coefficients for the changes in relative prices between two goods

[a] District dummies were generated for each district. In the regression for households serviced by Maynilad, District 4 was not included in the model to avoid the dummy variable and multicollinearity. Similarly, District 4 was also not included in the analysis for the household demand for Manila Water to avoid the same problems.

[b] Dummy variables were created for each marital status category. In the analysis for the households under Maynilad, the separated/divorced dummy variable was dropped to avoid multicollinearity and the dummy variable problem. On the other hand, in the analysis for the households under Manila Water, the widowed dummy variable was dropped to avoid multicollinearity and the dummy variable. The latter does not have any annulled or unknown in the sample. The annulled and unknown marital status were not included since there were only four observations.

[C] Dummy variables were created for each household type variable. In the regression, the two or more household types were not included because there are only 54 observations.

d In generating individual dummy variables for each year, 2015 was excluded and not included in the regression to avoid the dummy variable and multicollinearity problems.

Source: Author.

Limitations of the AIDS model

The methodology and the AIDS model have limitations in the analysis. The first limitation is that there will be endogeneity issues given the dataset being utilised. In particular, the dataset provides only the expenditure of households and not the households' water consumption. However, water consumed is a function of the prices of water and total household expenditure. Thus,

$$q_{water} = f(p_{water}, \mathrm{x}) \qquad Eq. 4.21$$

In this thesis, the water supply expenditure and the IBTs from each concessionaire are given. Consequently, the quantity of water is derived by using the pricing table of the concessionaires as well as the expenditure of each household. The endogeneity arises due to the variable q_{water} being derived from the expenditure and the price of water. Control variables (see model specification in the previous section) are included in the model to control and to mitigate the endogeneity problem.

The other limitation is that the AIDS model will yield different estimates depending on how the dataset is aggregated. Aggregated household data raise questions on the aggregation properties of such demand models. In particular, estimates could vary depending on how aggregated or disaggregated the dataset is and that the AIDS model yield estimates based on the average values. Thus, consideration should be given to the aggregation properties that reflect the extent to which the demand estimates closely resemble or represent the underlying preference structure of interest (Holt and Goodwin 2009). Furthermore, the preference structure of the specified model will reflect a representative consumer that is defined at the average values of prices and income (Holt and Goodwin 2009).

AIDS modelling in Stata

Many econometric programmers have attempted to introduce syntax that simplifies the programming language of complicated models such as AIDS and QUAIDS. Poi (2012) introduces a syntax in Stata that simplifies the programming language for QUAIDS estimation that has been extensively used by many empirical studies. It allows for the inclusion of demographic variables as well as the estimation of expenditure and price elasticities using the developed post-estimation tools. However, Lecocq and Robin (2015) raise several issues on the QUAIDS model of Poi (2012). Firstly, it does not allow the programmer to handle endogeneity problems. This is especially important as endogeneity issues are, typically, found in demand system models (Lecoq and Robin 2015). In other words, it is possible that variables at the right-hand side of the equation—typically, prices and total expenditure—are correlated with the error terms for each share equation. An example used by Lecocq and Robin (2015) to illustrate this is on total household expenditure. Total household expenditure is the sum of all expenditures of all goods i, while each expenditure of a good i is endogenous. Thus, both total expenditure and the expenditure on the other good j can be expected to be both endogenous. Pitarakis and Tridimas (1999) and Thompson (2004) reinforce the argument of Lecocq and Robin (2015) as these empirical analyses and consider total expenditure to be an endogenous variable in their demand estimation.

Given the discussions, this thesis makes use of the AIDSILLS command, which computes for the own-price and cross-price elasticities developed by Lecocq and Robin (2015). The model tests for the endogeneity of prices and total expenditure and can be controlled using linear techniques. The model's structure allows for an unconstrained or constrained model to test if the restrictions of homogeneity and/or symmetry hold.

III. Results and discussions

The econometric analysis estimates the households' water-demand elasticities using the AIDS model. Tests for endogeneity using the syntax of Lecocq and Robin (2015) suggest that there is endogeneity. Endogeneity issues can also arise as households determine the average price of water based on their water consumption, owing to the structure of IBTs (Arbues et al. 2003). The natural logarithm of income is used as an instrumental variable to control for endogeneity. The tests suggest that the null hypothesis for exogeneity can be rejected at the 5 per cent level, and that income is a good instrument. The final test is whether the homogeneity symmetry constraints were imposed to correctly evaluate water-demand elasticities.

This thesis adopts the computation for elasticities introduced by Asche and Wessels (1997). All elasticities describe the household's demand for the water services for either of the concessionaire, and not water as a good itself. To test for the robustness of the results, the QUAIDS and the 2SLS models were used. The results of the QUAIDS regression are close to the AIDS, but the model does not converge to zero and full details are given in Appendix 4.

In the discussions of results, a comparison of the estimated elasticities of the 'with' and 'without' the additional household characteristics is undertaken, first, to examine if such household characteristics have significant influence collectively on the overall household water demand. Then, the estimated demand elasticities of each of the household characteristics are examined, such as the (i) household head's gender, (ii) household head's age (senior and non-senior), (iii) household head's marital status, and (iv) household type.

Comparison of baseline elasticities: 'With' and 'without' household characteristics

The results from Table 4.6 show the own-price, cross-price, and income elasticities for both cases A and B. The estimated water-demand elasticities suggest that households serviced by Maynilad are more price-elastic than those serviced by Manila Water. Although the estimates are higher compared to the estimates of David and Inocencio (1998) prior to privatisation, the values are within the range of Dalhuisen et al. (2003) and Sebri (2014).[10]

It is noticeable that the inclusion of the other household characteristics alters the estimated own-price elasticities. The decrease in the own-price elasticity indicates that the included characteristics are endogenous variables and that they significantly influence water demand. The own-price elasticities of Case B for Maynilad are less than 1, although they still appear to be more sensitive to price changes in water tariffs compared to those serviced by Manila Water. Thus, the demand for water in both concessionaires are price-inelastic, which is to be expected of goods considered as necessities.

Table 4.6: Comparing the estimated elasticities: 'with' and 'without' additional household characteristics

	Case A: Without additional household characteristics					Case B: With additional household characteristics				
	Maynilad			**Manila Water**		**Maynilad**			**Manila Water**	
	District 1	**District 3**	**District 4**	**District 2**	**District 4**	**District 1**	**District 3**	**District 4**	**District 2**	**District 4**
ε_{wat}	−1.011***	−1.012***	−1.012***	−0.763***	−0.765***	−0.993***	−0.994***	−0.993***	−0.717***	−0.721***
	(0.011)	*(0.011)*	*(0.011)*	*(0.018)*	*(0.019)*	*(0.011)*	*(0.011)*	*(0.012)*	*(0.019)*	*(0.02)*
$\varepsilon_{wat/elec}$	0.036***	0.038***	0.035***	0.034***	0.032***	0.058***	0.063***	0.056***	0.065***	0.060***
	(0.004)	*(0.005)*	*(0.004)*	*(0.008)*	*(0.007)*	*(0.004)*	*(0.005)*	*(0.004)*	*(0.008)*	*(0.007)*
$\varepsilon_{wat/food}$	−0.003	−0.003	−0.003	−0.006	−0.006	−0.003	−0.004	−0.004	−0.011**	−0.012**
	(0.002)	*(0.002)*	*(0.002)*	*(0.004)*	*(0.004)*	*(0.002)*	*(0.002)*	*(0.002)*	*(0.004)*	*(0.004)*
$\varepsilon_{wat/othgds}$	−0.006	−0.005	−0.006	−0.013**	−0.013**	−0.013***	−0.012***	−0.012***	−0.018***	−0.017***
	(0.003)	*(0.003)*	*(0.003)*	*(0.005)*	*(0.004)*	*(0.003)*	*(0.003)*	*(0.003)*	*(0.005)*	*(0.005)*
ε_{income}	0.601***	0.585***	0.571***	0.666***	0.670***	0.630***	0.615***	0.603***	0.617***	0.622***
	(0.014)	*(0.014)*	*(0.015)*	*(0.016)*	*(0.017)*	*(0.016)*	*(0.017)*	*(0.017)*	*(0.019)*	*(0.02)*
N	1,746	2,922	3,035	4,325	710	1,746	2,922	3,035	4,325	710

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.
NOTE: Italicised values are std. errors.
Source: Author's calculations.

The differences in the demand elasticities highlight the gaps in the delivery of water services between Maynilad and Manila Water. One factor that is attributed to the gap is the difference in the non-revenue water (NRW) in the water supply systems of each concessionaire (see Table 4.7).

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[10] Manila Water provided data on the monthly average household consumption of water from 2010 to 2019. Data show that the monthly average household consumption of water declined from 27.79 cu.m. to 24.26 during this period. This coincided with the upward adjustments in the residential water tariff of Manila Water from 2009 to 2019 as shown in Appendix Tables A1.1 to A1.4. In other words, household demand for water is sensitive to tariff changes. This supports the high price elasticities found in this thesis.

Table 4.7: Approximate non-revenue water of Maynilad and Manila Water, 2012–2016

	2012	2013	2014	2015	2016
Maynilad	43%	39%	34%	31%	30%
Manila Water	11%	12%	11%	11%	11%

Sources: Maynilad (2017) and Manila Water (2017).

A higher NRW—due to persistent physical leaks and water theft in the water supply system—results in lower water pressure and further affects the available volume of water. Manila Water's lower NRW is attributed to the company's decentralised operational practices, specifically the territory management program as discussed in Chapter 2. This enabled the concessionaire to make substantial capital investments as early as 2 years after the privatisation. This also led to the significant improvement in the water supply pipes, as well as human capital in the company, which paid off in the succeeding years. As Manila Water expanded its water services, households became more dependent on its water services due to the increased reliability in water pressure and 24/7 availability of supply.

Due to the difficulties that Maynilad faced after privatisation, NRW started to decline only after a few more years (see Table 4.7). Maynilad (2017) reports that the high NRW in the West Zone is a result of persistent incidences of water theft, illegal connections, measurement errors from reading meters, and billing inefficiencies. The response of the households to the high NRW in the West Zone is to use alternative water sources to meet their water demands (see Table 4.8). Based on the household sample, there are significantly more households under Maynilad that are still dependent on water vendors.

Table 4.8 Water supply sources of households, 2015

Type of connection	Manila Water		Maynilad		Total	
	Number of households	% of households	Number of households	% of households	Number of households	% of households
Own use, faucet, community water system	1,594	86.02%	1,640	74.28%	3,234	79.62%
Shared, faucet, community water system	201	10.85%	350	15.85%	551	13.56%
Own use, tubed/piped deep well	1	0.05%	5	0.23%	6	0.15%
Shared, tubed/piped deep well	13	0.70%	25	1.13%	38	0.94%
Tubed/piped shallow well	2	0.11%	0	0.00%	2	0.05%
Dug well	1	0.05%	7	0.32%	8	0.20%
Water vendors (vended water)	38	2.05%	170	7.70%	209	5.15%
Others	3	0.16%	11	0.50%	14	0.34%

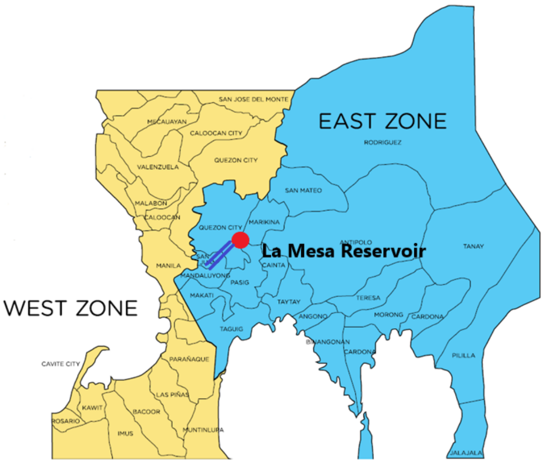
Sources: FIES (2015) of the Philippine Statistical Authority and author.

Influence of geographical location to elasticities

Aside from the higher NRW in the West Zone, which is Maynilad's concession area, it is also located farther from the water supply source. The La Mesa Dam and Reservoir, which is a holding dam that holds water from the Angat Dam, is situated in the East Zone, which is Manila Water's concession area. Servicing the West Zone requires a higher pass-through system, which leads to higher costs and tariffs imposed on households. Manila Water (2017) also claims that their tariffs are 30 per cent lower than that of Maynilad (see Appendix 1). Figure 4.2 shows the location of the La Mesa Dam and Reservoir, where water from the Angat Dam is stored and distributed to Metro Manila.

To provide the water demand in the southern cities, Maynilad uses an inland lake, the Laguna Lake, as an additional water source. This is approximately 2 per cent of the total supply available. The inland lake acts as a reservoir and provides water to the cities of Muntinlupa, Parañaque, and Las Piñas but Maynilad (2017) reports that the water quality of Laguna Lake is unpredictable. This is attributed to the algal blooms and backflow of saline water from Manila Bay to the inland lake, which causes variable water quality that may result in higher costs for both the households and to the concessionaire. These result in frequent water service interruptions by Maynilad for a time, since water quality has been affected. These water interruptions cause disruption in the water supply distributed in the southern cities of Metro Manila; thus, many people have no access to the water services and have to resort to purchasing water supply from other sources such as water vendors, specifically water refilling stations. Consequently, cities in District 4, particularly Parañaque, Las Piñas, and Muntinlupa, have high water-demand elasticities.

Figure 4.2: Location of La Mesa Dam and Reservoir



Source: Manila Water (2017).

Household characteristics and elasticities

Water-demand elasticities by gender of household heads

Studies that examine equity issues often concentrate their analysis on the differential impacts on household size and income on water demand. However, Morakinyo et al. (2015) and Abebaw et al. (2010) also highlight that the gender of the household head influences water consumption. Both authors conclude that households with female heads are more likely to choose to connect to an improved water source. In addition, women have more roles in the decision making in the consumption of goods, including water, at the household level (Nauges and Whittington 2009).

None of the existing studies empirically verify if there are differences in the water-demand elasticities between households with male and female heads. Differences in demand elasticities between these two types of households indicate the role that gender plays in water demand. Thus, quantifying the differential impacts can aid in identifying whether gender equity issues arise when changes in water prices occur. The estimate price and income elasticities[11] are shown in Table 4.9.

Table 4.9: Estimated water demand and income elasticities for households with male and female heads

	Maynilad						**Manila Water**			
	District 1		**District 3**		**District 4**		**District 2**		**District 4**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
ε_{wat}	–0.993***	–0.993***	–0.994***	–0.994***	–0.994***	–0.993***	–0.715***	–0.724***	–0.718***	–0.730***
	(0.011)	*(0.011)*	*(0.012)*	*(0.011)*	*(0.012)*	*(0.012)*	*(0.019)*	*(0.019)*	*(0.020)*	*(0.019)*
ε_{income}	0.632***	0.627***	0.612***	0.622***	0.604***	0.599***	0.613***	0.626***	0.618***	0.634***
	(0.016)	*(0.017)*	*(0.017)*	*(0.017)*	*(0.017)*	*(0.018)*	*(0.019)*	*(0.019)*	*(0.020)*	*(0.019)*

* $p<0.05$, ** $p<0.01$, *** $p<0.001$
NOTE: Italicised values are std. errors.
Source: Author's calculations.

The estimates suggest that the water-demand elasticity is similar for both types (male and female) of households. Specifically, the results indicate that the gender of household heads in the Maynilad concession area is not a distinguishing factor when it comes to measuring the degree of the responsiveness of households' demand for water with respect to water price changes. Nevertheless, with respect to income, the degree of the responsiveness of their

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[11] The cross-price elasticities were not indicated in Table 4.9 as it is similar with the estimates shown in the previous section in comparing the model on 'without' and 'with' the household characteristics.

demand to water changes varies according to household heads' gender. Under the Maynilad concession area, the income elasticities for households with male heads are marginally higher than those with female heads in District 1 and 4 but the reverse is true for District 3. Under the Manila Water concession area, the income elasticity for households with male heads is marginally lower than those with female heads in both District 2 and 4.

Water demand for households with female heads appears to be more price-elastic than households with male heads, serviced by Manila Water. Income elasticities are also higher for households with female heads as compared to their male counterparts. In other words, the demand for water among households with female heads is more responsive with respect to income changes than households that are headed by males. Ojeda- De La Cruz et al. (2016) suggest that women have higher water consumption because they spend more time at home and take the lead in household activities that require the use of water indoors and outdoors. Morakinyo et al. (2015) also find that having a female as the household head increases the likelihood of getting water from improved sources. Overall, for the Manila Water concession area, water demand among households with female heads is more sensitive to both price and income changes—compared to households with male heads.

Following the discussion of Chu and Grafton (2019), while households with female heads may be more sensitive to price changes, they are also less risk-averse and have a lower willingness-to-pay to avoid demand management policies imposed by the concessionaires. Consequently, water restrictions and/or price increases would encourage female-headed households to shift more quickly to using alternative sources than male-headed households.

Water-demand elasticity by age of household heads

Di Cosmo (2011) points out that older households are more sensitive to price changes in water services than younger households. Estimating the elasticities would show whether older households do, indeed, behave similarly or differently from younger households insofar as demand for water is concerned. To examine this issue, the sample households are divided into non-senior (young) and senior (old) households. Table 4.10 shows the estimated elasticities of non-senior and senior households.

Table 4.10: Estimated water-demand elasticities of non-senior and senior households

	Maynilad						Manila Water			
	District 1		District 3		District 4		District 2		District 4	
	Non-Senior	Senior	Non-Senior	Senior	Non-Senior	Senior	Non-Senior	Senior	Non-Senior	Senior
ε_{wat}	–0.993***	–0.993***	–0.994***	–0.994***	–0.994***	–0.993***	–0.716***	–0.723***	–0.719***	–0.728***
	(0.011)	*(0.011)*	*(0.012)*	*(0.011)*	*(0.012)*	*(0.012)*	*(0.019)*	*(0.019)*	*(0.020)*	*(0.019)*
ε_{income}	0.628***	0.637***	0.611***	0.630***	0.606***	0.593***	0.615***	0.626***	0.619***	0.633***
	(0.016)	*(0.016)*	*(0.017)*	*(0.016)*	*(0.017)*	*(0.018)*	*(0.019)*	*(0.019)*	*(0.020)*	*(0.019)*

* $p<0.05$, ** $p<0.01$, *** $p<0.001$
NOTE: Italicised values are std. errors.
Source: Author's calculations.

The estimated water-demand elasticities of senior and non-senior households serviced by Maynilad are very similar, suggesting that both group of households behave similarly with respect to changes in water prices. On income elasticities, senior households in districts 1 and 3 have higher income-elasticities than younger households, but the opposite is true in the case of households in District 4.

Among senior households, the demand for water appears to be more sensitive to price changes than in non-senior households in both districts 2 and 4. Price changes affect senior households' water consumption, and this is consistent with the findings of Di Cosmo (2011). Following the discussion of Chu and Grafton (2019), non-senior households may be more risk-averse to demand management policies such that a price increase will affect the younger households more compared with older households, given their increased willingness-to-pay to avoid adjusting their water consumption. Senior households' demand for water is also more sensitive to income changes than that of non-senior households. These results indicate that changes in water prices will have slightly more impact on older households than younger households.

Water-demand elasticities by marital status of household heads

The influence of the household heads' marital status on water demand has not been explored in any of the existing empirical studies. Di Cosmo (2011) provides water-demand elasticity estimates for older couples, and younger couples that are with and without children only. To examine the impact of marital status of the head of household on water demand, this chapter estimates the water-demand elasticities for household heads who are single, married, widowed, and separated/divorced. Table 4.11 shows the elasticity estimates for households in the Maynilad and Manila Water concession areas by district.

The estimates suggest that there are almost no differential impacts on water demand that can be observed among households headed by either single, married, widowed, or separated/divorced persons in the West Zone. In the case of income elasticities, however, the results are different. The degree of responsiveness on the demand for water varies among households headed by single, married, widowed, and separated/divorced persons. Among the households served by Maynilad, a certain pattern in all three districts emerges—that is, households headed by single persons are the least income-elastic while households headed by widowed persons are the most income-elastic, except in the case of District 4.

The differences, although marginal, are observed among the four groups of households serviced by Manila Water. A consistent pattern emerges in both districts 2 and 4. For example, the demand for water among households headed by a person with single status is the least responsive to price changes, while households headed by persons with a widow status are the most sensitive. These results suggest that an increase in the water prices of Manila Water will affect households headed by single persons more intensely than households having a married, widowed, or separated/divorced person as a household head. The same pattern is observed when it comes to income elasticities. The demand for water in households headed by persons with single status is the least sensitive to income changes, while households with widowed persons as heads are the most sensitive to income changes in both districts 2 and 4.

Although they have lower water-demand elasticities, households with single persons as a head are the most risk-averse to water disruptions compared to the other groups. On the other hand, the other groups of households are less risk-averse to water restrictions. They are more flexible to adjusting their consumption or even to finding alternative sources of water to meet their water demand.

Table 4.11a Estimated water-demand elasticities for household heads that are single, married, widowed, or separated/divorced (Maynilad)

	District 1				District 3				District 4			
	Single	**Married**	**Widowed**	**Separated/ divorced**	**Single**	**Married**	**Widowed**	**Separated/ Divorce**	**Single**	**Married**	**Widowed**	**Separated/ divorced**
ε_{wat}	–0.993***	–0.993***	–0.994***	–0.994***	–0.995***	–0.994***	–0.994***	–0.994***	–0.993***	–0.993***	–0.993***	–0.994***
	(0.012)	*(0.011)*	*(0.011)*	*(0.011)*	*(0.012)*	*(0.012)*	*(0.011)*	*(0.011)*	*(0.013)*	*(0.012)*	*(0.012)*	*(0.011)*
ε_{income}	0.584***	0.632***	0.645***	0.634***	0.607***	0.609***	0.643***	0.624***	0.558***	0.603***	0.612***	0.636***
	(0.022)	*(0.016)*	*(0.016)*	*(0.016)*	*(0.019)*	*(0.017)*	*(0.016)*	*(0.019)*	*(0.023)*	*(0.017)*	*(0.018)*	*(0.019)*

* p<0.05, ** p<0.01, *** p<0.001
NOTE: Italicised values are std. errors.
Source: Author.

Table 4.11b Estimated water-demand elasticities for household heads that are single, married, widowed, or separated/divorced (Manila Water)

	District 2				District 4			
	Single	**Married**	**Widowed**	**Separated/ divorced**	**Single**	**Married**	**Widowed**	**Separated/ divorced**
ε_{wat}	–0.690***	–0.718***	–0.730***	–0.710***	–0.691***	–0.721***	–0.739***	–0.709***
	(0.023)	*(0.019)*	*(0.019)*	*(0.022)*	*(0.023)*	*(0.020)*	*(0.019)*	*(0.023)*
ε_{income}	0.580***	0.618***	0.634***	0.606***	0.581***	0.623***	0.647***	0.606***
	(0.024)	*(0.019)*	*(0.019)*	*(0.023)*	*(0.026)*	*(0.020)*	*(0.019)*	*(0.025)*

* p<0.05, ** p<0.01, *** p<0.001
NOTE: Italicised values are std. errors.
Source: Author.

Water-demand elasticities by household type

Although previous studies suggest that family size has a significant impact on water demand (Rizaiza 1991, Hewitt and Hanemann 1995, David and Inocencio 1998, Rietveld et al. 2000, Dalhuisen et al. 2003, Strand and Walker 2005, Klassert et al. 2018), none has ever examined the influence of the type of household on water demand. Thus, this thesis attempts to estimate water-demand elasticities of single and extended families.[12] Table 4.12 shows the estimated own-price and income elasticities based on the household type for each district.

Table 4.12 Estimated water-demand elasticities, by household type

	Maynilad						**Manila Water**			
	District 1		**District 3**		**District 4**		**District 2**		**District 4**	
	Single family	**Extended**	**Single family**	**Extended**	**Single family**	**Extended**	**Single family**	**Extended**	**Single family**	**Extended**
ε_{wat}	–0.994***	–0.993***	–0.994***	–0.993***	–0.994***	–0.993***	–0.715***	–0.723***	–0.720***	–0.722***
	(0.011)	*(0.011)*	*(0.011)*	*(0.011)*	*(0.012)*	*(0.012)*	*(0.019)*	*(0.019)*	*(0.020)*	*(0.020)*
ε_{income}	0.625***	0.642***	0.613***	0.619***	0.600***	0.608***	0.613***	0.626***	0.621***	0.625***
	(0.017)	*(0.016)*	*(0.017)*	*(0.017)*	*(0.017)*	*(0.017)*	*(0.019)*	*(0.019)*	*(0.020)*	*(0.020)*

* $p<0.05$, ** $p<0.01$, *** $p<0.001$
NOTE: Italicised values are std. errors.
Source: Author.

For households serviced by Maynilad, the water-demand elasticity estimates show that there are almost no differences for both single and extended families. However, some difference in income elasticities between these two types of households can be observed. Extended families exhibit higher income elasticities as compared to single families.

As with the previous analyses, marginal differential impacts on the different types of households are observed among those in the East Zone. Although the differences are minimal, extended families have slightly higher price elasticities than single families. The same can be observed with respect to the estimated income elasticities—that is, extended families have higher income elasticities than single families.

Cross-elasticities and income elasticities

Cross-price elasticities, with respect to water demand, are price-inelastic for electricity, food and non-alcoholic beverages, and other goods. Food, non-alcoholic beverages and other goods have negative cross-price elasticities, which means that these are complementary goods with

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[12] Note that households with two or more families are not considered since there are too few observations in the sample.

the water services. Electricity has a positive cross-price elasticity, which means that it is a substitute for water services. However, this is not an *a priori* expectation since Maas et al. (2019) find that residential water and electricity are complements because they are jointly used for household activities. The results suggest that there will be minimal changes to the demand of both goods if there are price changes since cross-price elasticity is significantly price-inelastic. This is attributed to the lower share of water services—which is just 2 per cent of the total household expenditure. Electricity has an expenditure share of 6–13 per cent while food and non-alcoholic beverage make up more than 40 per cent of the total household expenditure.

Income elasticities, with respect to water demand, show that water is income-inelastic. Changes in income level will produce less than proportional changes in water expenditure. Estimated income elasticities are higher for households serviced by Maynilad than those by Manila Water. According to Dalhuisen et al. (2003), IBTs influence water-demand elasticity to be more price-elastic but lower income-elasticitc, noting that this thesis' income elasticities are higher than the 0.3 income elasticity estimates of David and Inocencio (1998). Nauges and Whittington (2009) also report that, typically, the income elasticity ranges between 0.1 and 0.3 for households in developing countries. The differences in the estimated elasticities could be attributed to the type of models used for the estimation of elasticities. This thesis used the AIDS model specification whereas David and Inocencio (1998) and Nauges and Whittington (2009) used OLS and 2SLS models, respectively.[13]

Synthesis on the differential impacts of other household characteristics on water-demand elasticity

The results indicate that other household characteristics, such as household head gender, household head marital status, household head age, and household head type, are endogenous and can influence water demand and income elasticities. Households with different socioeconomic levels will have differential impacts on the water demand. Thus, investigating into how the different household characteristics influence own-price, cross-price, and income elasticities will help address equity issues arising from water price decisions.

The impacts of the other household characteristics on water demand are different for the two concessionaires. The differences in water-demand elasticities among the different types of

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[13] As mentioned in Chapter 3, both models do not address the endogeneity issues when the water pricing structure follows an IBT.

households are much more pronounced for consumers serviced by Manila Water compared to those under Maynilad. Households in the East Zone under Manila Water have lower price elasticities. The differential impacts from the changes in the water price will be more evident among the various household characteristics. On the other hand, households in the West Zone are less dependent on the services of Maynilad.

Households serviced by Manila Water are more risk-averse to any disruption in their water consumption. Given that households in the East Zone have a relatively price-inelastic response to water demand, they have a higher willingness-to-pay to avoid water restrictions or any type of demand management policy. Price increases, therefore, will have more impact on the households serviced by Manila Water as compared to those serviced by Maynilad due to households' higher willingness-to-pay.

IV. Conclusion

The privatisation of the water services in Metro Manila was intended to improve the water supply and distribution in the region. Manila Water and Maynilad were able to significantly improve and expand the water services in Metro Manila. The thesis finds that the households appear to have different responses to the privatisation, and this is mainly due to the varying industry performance of the concessionaires. Households serviced by Manila Water are more price-inelastic, with elasticity estimates ranging from –0.717 to –0.721. This may be due to the company's better performance in supplying reliable water pressure and services because of low NRW, thus, resulting in water users being more dependent on the services. On the other hand, households serviced by Maynilad are more price-elastic, with estimates ranging from –0.993 to –0.994, due to the high NRW and higher pass-through costs, given that the West Zone is located farther from the water source.

The decline in the estimated elasticities in case B demonstrates that the inclusion of household characteristics, such as the household's head gender, marital status and age, and the household type, improve the precision of estimating household water-demand elasticities. Nauges and Thomas (2000) highlight that it is important to include the household characteristics as explanatory factors to improve the robustness of price and income elasticity estimates and to explore other non-price water-demand determinants. It is to be noted, however, that the results suggest that there are only marginal differences in the estimated water-demand elasticities among the different types of households.

Chapter 5

Analysing the dynamic optimal pricing policy of the water services in Metro Manila, Philippines

This chapter determines whether adding a scarcity price to the water services in Metro Manila is socially beneficial, by using the risk-adjusted user cost (RAUC) model as a water-demand management instrument. This chapter is structured as follows: The first section explains the framework and the alternative water-demand management instrument—the RAUC model. The second section provides the parameterisation of the rainfall, net inflows, water use, weather, and the water-demand function. The third section summarises the parameters and discusses the dynamic solution technique. The fourth section presents and discusses the results of the simulation analyses as well as some sensitivity analyses. The last section provides the conclusion.

I. Concept of user cost, water balance equation, and the RAUC

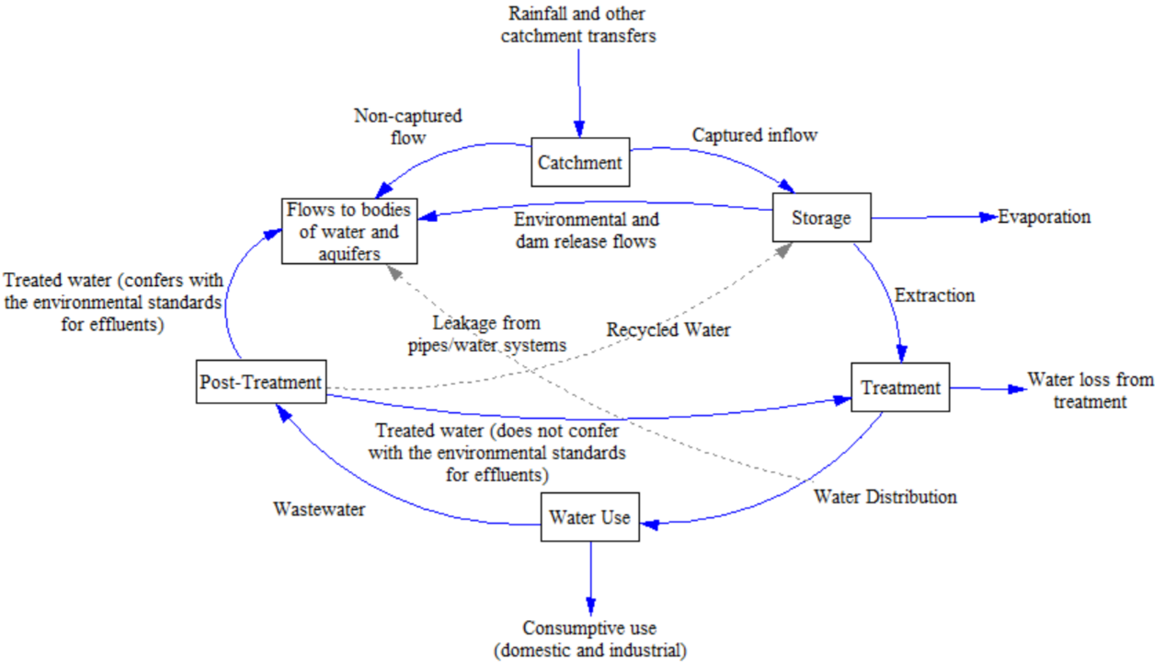
This section deals first with the concept of the user cost in an urban water system setting. Next, it discusses the dynamic optimal pricing model, which is based on the RAUC model of Chu and Grafton (2021) but with some modifications to consider the particular setting of the water services system in Metro Manila.

User cost of urban water

The design of a water tariff should reflect the costs of providing urban water to consumers. Boland (1993) highlights that urban water pricing aims to balance the objectives of economic efficiency, fairness, equity, revenue sufficiency, and net revenue stability. Many countries use increasing block tariffs (IBTs), which is a form of volumetric pricing, to achieve these objectives. Renzetti (1992), however, argues that understanding how the user cost is derived from the urban water supply system is the key to designing a water tariff structure that achieves the objectives proposed by Boland (1993). Understanding the user cost is best achieved by examining the key flows and stocks that are involved in an urban water supply (Chu and Grafton 2019 and Grafton et al. 2020).

Figure 5.1 highlights the interaction between the water cycle and the urban water systems, which is important in determining the user cost. It begins with the water cycle and how precipitation, or rainfall, generates inflows that recharge surface water in storages. Water in these storages, however, is depleted due to greater outflows—such as evaporation, environmental run-offs and flows, and extraction for water use—than inflows. Water for human consumption goes through several water-treatment processes so that its quality meets the minimum safety standards for consumptive domestic use before it is distributed. During water distribution, losses are expected due to leakages within the water supply distribution network. A portion of the water consumed goes back to the water supply system and is treated once again. Following standards for water quality for effluents, water utilities release the newly treated water to augment water storages if the water quality meets the standards for consumptive use. Part of the treated water that does not meet water quality for consumptive use is released to bodies of water.

Figure 5.1: Key flows and stocks in an urban water supply



Source: Adopted from Chu and Grafton (2019).

The current setup of the urban water supply system in Metro Manila, which is also discussed in Chapter 2, differs from the water system described above. Metro Manila's water requirement is serviced by two private concessionaires—Manila Water, which covers the East Zone and Maynilad, for the West Zone. The Metropolitan Waterworks and Sewerage System (MWSS) controls the outflows coming from Angat Dam that are intended for Metro Manila.[1] The National Water Resource Board (NWRB) decides the allocation of raw or untreated water in

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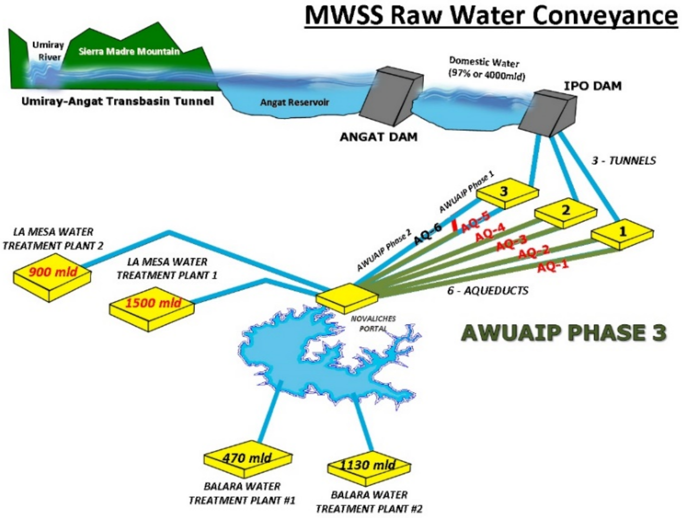
[1] However, it is the National Power Corporation (NAPOCOR) that oversees the management of the Angat Dam.

the Angat Dam to various competing uses such as for urban water supply, irrigation, and hydropower. The agency is guided by the Philippine Water Code when deciding on the outflows allocated to the different uses. It may negotiate with the NWRB when it comes to water flows from the Angat Dam allocated for Metro Manila especially during periods tightness in water supply. The outflows are then directed to and stored at the La Mesa reservoir. Raw water from the La Mesa Reservoir goes to four treatment plants. The La Mesa treatment plant, which is divided into two plants, is for the West Zone, while the Balara treatment plant, which is also divided into two plants, is for the East Zone. It is to be noted that rainfall events throughout the year are the only source for augmenting or recharging the surface water in the Umiray River and at the Angat Dam. Both concessionaires still lack adequate water recycling or sewer treatment infrastructure. Thus, recycled or post-treated sewage water is not returned to the current water storage. Figure 5.2 shows the water supply system of the region.

Figure 5.2: MWSS raw water conveyance system



Source: Metropolitan Waterworks and Sewerage System (MWSS).

The user costs of urban water supply have two major components: (i) an explicit cost; and (ii) an implicit cost. James and Pollock (1988) identify the explicit cost as the extraction cost while the implicit cost is the scarcity value of water. The extraction cost consists of all the costs to ensure that water can be distributed for consumptive use. It includes the operational costs for pumping water and water storage, administration costs, and costs for the treatment of sewerage (Renzetti and Kushner 2004). The scarcity value of water represents the opportunity cost of not allocating or extracting water for other uses. Chu and Grafton (2019) point out that the scarcity value of water is also the economic user cost of water supply.

Grafton et al. (2014) argue that incorporating the user cost in volumetric prices can lead to better water use policies, which can postpone the unnecessarily high costs of supply augmentation. Any investment and costs made today for future water storages will be imposed on the consumers today up to a specific planning period. Thus, there is a need to determine the dynamic optimal user cost that provides the most benefit for water users and ensure that such benefits exceed the costly investment in augmenting water supply. In addition, the optimal user cost can avoid stringent water restrictions in the long-term (Chu and Grafton 2019).

The RAUC model as a demand management instrument

Water consumption today imposes a significant impact on future consumption, thus increasing the risk for future water users. As water consumption increases today, water supply at the storage is gradually depleted. Consequently, there is a risk that the future water supply could become insufficient, especially when future demand exceeds the available supply. This imbalance between supply and demand influences the existing price and that may, in turn, result in water rationing. In this case, a user cost can be added in to the current water pricing model to avoid the expected welfare costs in the future arising from insufficient water supply.

Demand management instruments are utilised to lessen the risks in supply and demand when there is increasing water scarcity. Variability in rainfall, temperature, and other weather-related factors can induce a risk on water supply and water quality. Demand risks arise when households react towards demand management policies, including water restrictions, that are imposed on them by water utilities. Through the price elasticity of water demand, the behaviour, or the level of risk-aversion of households towards any disruptions to their water consumption can be measured. Water users with low price elasticities are risk-averse to any demand management instrument that will alter their water consumption. This is due to their high dependence on their water usage and to their water connection to the water utility (Chu and Grafton 2019). By contrast, consumers in Metro Manila with higher price elasticities are inferred to have a relatively low risk-aversion. Although they are dependent to a large extent on the piped water connection, they also have alternative water sources which they utilise during water supply disruptions.

Although supply augmentation can further lessen the risk of future water storage, the current situation in Metro Manila may require a demand management instrument to address the current scarcity problem in Angat Dam. A demand management instrument that this thesis explores, which incorporates the RAUC in the dynamic water pricing, allows the representation of the scarcity of water due to the uncertainties of future supply and demand. In this sense, the dynamic water pricing includes the user cost that is linked with the decline in water supply due to the current water demand (Chu and Grafton 2019).

The discussion of the model first starts out with the constraint, which is based on the water balance equation. The water balance equation shows the relationship between the water inflow and outflow balance, which was discussed in the previous section. *Equation 5.1* presents the water balance equation of the urban water supply in Metro Manila. It is to be noted that there is no provision for recycled water because it is not a feature of the current water supply system in Metro Manila. Table 5.1 describes the parameters in *Equation 5.1*.

$$S_{t+1} = \min\{S_t + I(W_t) - N_t \times (M + \min(Q(S_t), q(p_t|W_t)), \bar{S}\} \qquad Eq. 5.1$$

Table 5.1: Parameters of the constraint

Parameter	Description
S_t	Storage level at Angat Dam at time *t*
$\bar{S}$	Maximum discharge capacity; 1,460 million cubic metres/year (MCM/year)[2]
$I(W_t)$	Net inflow (gross inflow less the environmental outflows and the irrigation water flows)
W_t	Weather type (dry, normal, and wet)
$Q(S_t)$	Discretionary quantity restriction per household due to the reduction in flows
$q(p_t|W_t)$	Discretionary demand for water per household
N_t	Household population in each concession area (one user is considered to be one household)
M	Essential water use per household

Source: Author.

The model estimates the social surplus, which includes the consumer and the producer surplus. The social surplus changes if water-demand management instruments, such as water restrictions, are imposed. *Equation 5.2* derives the social surplus equation, where $p(q|W_t)$ is the per-household inverse demand function and the c_t is the average cost of supplying water. In cases wherein the profit of the supplier is zero, due to a regulatory body that sets the average cost of the monopolist water supplier to the price enough to cover its costs, the consumer surplus becomes equal to the social surplus (Chu and Grafton 2021). Alternatively, Chu and Grafton (2021) state that the regulator can set a price below the average production cost to be able to subsidise water users. This case considers the situation in which there is a transfer from

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[2] The concessionaires and the regulator report the capacity of the Angat Dam in terms of its discharge capacity. Thus, this will be adopted in the parameters and estimation for consistency.

the government revenues to the monopolist water supplier. The cost of supplying water is taken as the price of the block or tier where the average water consumption per capita is located.[3]

$$CS(p, W_t, N_t) = N_t \left(\int_{0}^{(\min(Q(S_t), q(p_t|W_t))} p(q|W_t)dq - c_t \times (\min(Q(S_t), q(p_t|W_t)) \right) \qquad Eq. 5.2$$

To analyse the dynamic water pricing problem, the thesis estimates the scarcity premium that maximises the expected social surplus for a specific time horizon. Pricing decisions consider the current storage level, weather, population, and uncertainty of future weather conditions (Chu and Grafton 2021). The dynamic water pricing problem, which is the pricing decision, is formally given in *Equation 5.3*.

$$p^*(S_t, W_t, N_t) = argmax_{<p>} \sum_{0}^{T-1} \left(\frac{1}{1+\rho}\right)^t CS(p, W_t, N_t) \qquad Eq. 5.3$$

In mathematics, $argmax$ refers to the inputs, or the arguments, where the output of functions is as large as possible. To solve for the pricing decision, $p^*(S_t, W_t, N_t)$, *Equation 5.3* is subject to the water balance equation given in *Equation 5.1*. The $p^*(S_t, W_t, N_t)$ is the price, at time *t*, that considers the social surplus of the current and future generations of water users. The discounted expected social surplus is maximised over a specific planning period. In this case, the analysis involves maximising the social surplus dynamically over a 100-year planning period, which is the expected life span of Angat Dam.

The model also includes the RAUC as part of the pricing decision. The RAUC is one of the three components in the cost of water supply. The other two components are the (i) explicit marginal cost of supplying water, and (ii) implicit opportunity cost from the reduction in environmental flows to bodies of water and aquifers due to domestic water use. The RAUC is defined in *Equation 5.4* below.

$$RAUC(S_t, W_t, N_t) = p^*(S_t, W_t, N_t) - c_t \qquad Eq. 5.4$$

In summary, the inclusion of the RAUC in the pricing model derives an efficient and dynamic water price. The RAUC represents a premium that is dependent on the current water supply, current and future water demand, and possible variations in future water supply. Changes in

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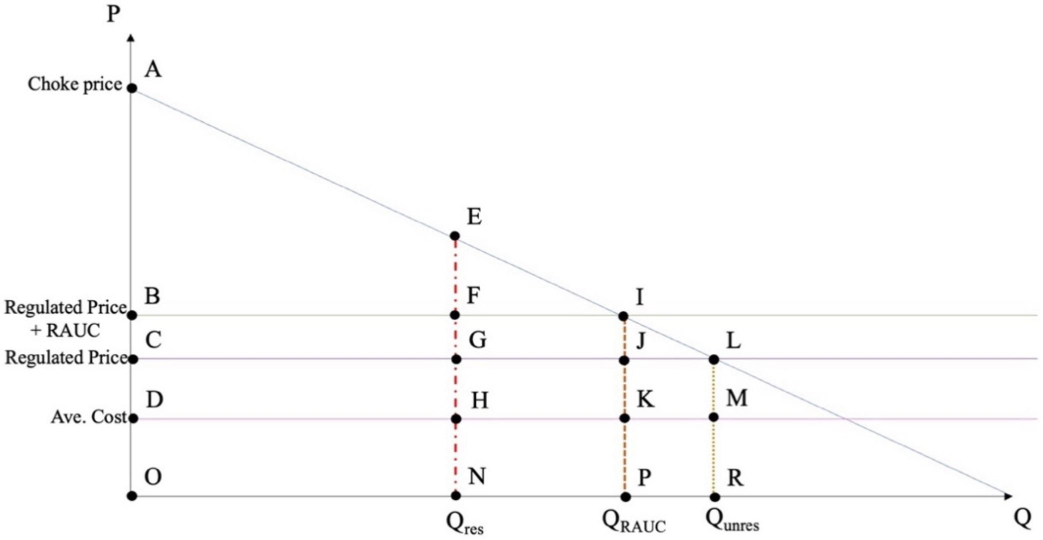
[3] Appendix 2, section A2.2 discusses in detail how the cost of supplying water to the households is determined. Although the utilities may have more sophisticated way to calculate the costs of supplying water in tariff setting, however, such information is not available to the public.

inflows are most likely due to sudden changes in rainfall and other risks associated with water storages. Imposing higher volumetric prices with the RAUC during water shortages promotes water conservation. The RAUC may also eliminate the need to impose future water restrictions, thereby avoiding substantial welfare losses from water restrictions.

Economic welfare analysis of water restrictions vs. RAUC

Water-demand management instruments include both pricing and non-pricing methods. The most common non-pricing method is imposing water restrictions or restricting the discretionary water consumption of households. Pricing methods include increasing the water tariffs or introducing the RAUC, when water levels in water storages are declining. Figure 5.3 shows how water-demand management changes social surplus.

Figure 5.3: Economic welfare impacts of water restrictions vs. RAUC



Adopted from: Chu and Grafton (2021).

In Figure 5.3, the regulated price is set above the average production cost. In the case of Metro Manila, where concessionaires and the regulator follow the IBTs, this thesis assumes that the regulated price is above the average production cost. This is because the IBTs are used to allow the concessionaires to have a constant stream of revenues.

Suppose that we have a downward sloping demand curve for discretionary water, which is represented by the line A-E-I-L. If the water consumption is unrestricted, households will consume water at the amount Q_{unres}. In this case, the total consumer surplus is represented by the area of the triangle A-L-C. As for the surplus of the water concessionaires, the producer surplus is represented by the area of the rectangle C-L-M-D.

If water restrictions are imposed due to the water level decline in the water storage, the economic welfare will change. The quantity of water demanded will significantly decrease from Q_{unres} to Q_{res}. The consumer surplus is now represented as the area of the trapezoid A-E-G-C. Water users will lose an amount of welfare from the water restrictions that is equivalent to an area of triangle E-L-G. Consequently, the water concessionaires' producer surplus will also be reduced to area C-G-H-D. The producers will lose producer surplus that is represented by area G-L-M-H. This reduction in the producers' welfare is due to the loss in potential tariff revenues since households will be consuming significantly less as compared to the unrestricted case. Therefore, the water restriction will result in a deadweight loss that is represented by the area E-L-M-H.

II. Setting of the thesis and weather patterns in Angat Dam

This thesis focusses on the Angat Dam, which provides the water supply in Metro Manila. As noted in Chapter 2, weather factors affect the water levels in the Angat Dam. Bagtasa (2019) notes that the average rainfall *increased* by 77.99 millimetres (mm) per decade in the region, and the mean temperature also increases by 0.12°C per decade.[4]

To investigate further the decline in water levels, this thesis examines the water inflow and outflow balance in the Angat Dam and computes the net inflows. The net inflows are calculated as the difference between the gross inflows, which are the recorded inflows, and the non-consumptive flows, which, in this thesis, include the flows for irrigation uses and the environmental flows. On days when the total recorded outflows fall below 47.9 cubic meters per second (cu.m./s), the allocation to irrigation is set to zero while environmental and consumptive domestic flows are maintained at 1.9 cu.m./s and 46.9 cu.m./s, respectively.[5] This is because irrigation water is not necessarily needed daily, whereas consumptive domestic

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[4] Bagtasa (2019) observed the rainfall and temperature of Metro Manila from 1901 to 2018.

[5] The opportunity costs, as indicated in p.5-6, are already part of the water pricing imposed on the concessionaires to the households (please see also Chapter 2, figure 2.10, p. 2-10 for the sample billing). There might be demand function for both irrigation and environment flow requirement, and marginal costs for reallocating water to residential uses can be increasing as more water is reallocated. However, lack of data can prevent a researcher from estimating a demand function for both irrigation and environmental flows. Since the passage of Republic Act No. 10969 on 2 February 2018, all farmers with only eight and below hectares of lands are exempted from paying irrigation service fees. Due to the implementation of the land reform law, most farmers in the country own less than 8 hectares. Thus, this can complicate the estimation of a demand function for irrigation water. There is also no available information on environmental flows. The thesis used data on environmental flows by the World Bank (2012). In the analysis, the environmental flows are held constant.

water use is required to meet the daily water demand in Metro Manila.[6] Table 5.2 shows the recorded annual rainfall, gross inflows, non-consumptive flows, consumptive domestic flows, net inflows, and Angat Dam capacity from 2010 to 2019, while Figure 5.4 shows the relationship between rainfall and net inflows.

The correlation coefficient between rainfall and net inflows is 0.4186, indicating that as rainfall increases, net inflows are also likely to increase. It is to be noted that the inflows into the Angat Dam do not only come from rainfall, but also from flows from the Umiray River system, which is located at the upstream, 13 kilometres to the eastern side of the dam (see Figure 5.2). The amount of water flows from the Umiray River though also depends on the weather.

Table 5.2: Total rainfall and net inflow, 2010–2019

Year	Rainfall (mm)	Gross inflows (MCM/year)[a]	Non-consumptive flows (MCM/year)	Consumptive domestic flows (MCM/year)	Net inflows (MCM/year)	Angat Dam discharge capacity (MCM/year)
2010	2,675	1,429.4	381.6	1,216.3	1,018.8	1460
2011	3,634	2,951.3	1,327.6	1,382.0	1,576.3	1460
2012	4,432	2,537.4	1,154.5	1,462.5	2,402.7	1460
2013	3,480	2,670.9	1,227.7	1,493.8	2,531.5	1460
2014	2,662	1,937.8	642.5	1,283.4	1,828.7	1460
2015	2,689	2,001.3	572.2	1,290.5	1,892.7	1460
2016	2,518	2,118.6	738.9	1,375.4	2004.0	1460
2017	2,854	2,693.7	1,323.8	1,449.6	2,561.0	1460
2018	3,571	2,281.6	812.5	1,449.5	2,159.3	1460
2019	2,372	1,835.7	664.5	1,379.2	1,727.2	1460

MCM = million cubic metre, mm = millimetre.
[a] This is million cubic metres (MCM) per year, converted from cubic metres per second.
Sources: PAGASA and author's calculations.

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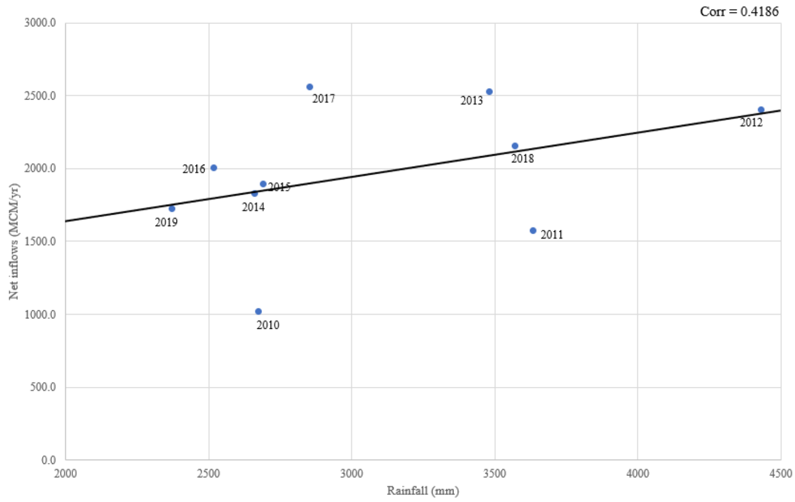
[6] The World Bank (2012) showed some months when no water was allocated for irrigation purposes. Under the National Water Resources Board's (NWRB) protocol in the release of water from Angat Dam, water releases for irrigation needs in Bulacan and Pampanga will be temporarily halted or reduced once the dam's level falls below its 180-metre minimum normal operating level, giving high priority to domestic water supply for Metro Manila. This has no significant impact on rice production because this happens during off-planting season or near harvesting period.

Figure 5.4: Rainfall and net inflows, 2010–2019



MCM = million cubic metre, mm = millimetre.
Sources: PAGASA and author’s calculations.

The thesis also investigates how household water consumption is related to rainfall, net inflows, and water basic charges in Metro Manila.[7] Manila Water, which covers the East Zone, has provided data on the average annual water consumption per water user. This thesis uses these data to represent the household water consumption in Metro Manila.[8] Table 5.3 presents the average annual water consumption per household from 2010 to 2019, while Figure 5.5 shows the correlation between rainfall and average water consumption per water user. Figure 5.6 shows the correlation between average water consumption per household and net inflows.

As shown from Table 5.3, the average annual household consumption of water from the concessionaires has generally declined during the period 2010–2019.[9] This can be attributed to the increase in the number of households connected to the water services. The computed correlation coefficient between the average annual consumption per user and rainfall is 0.2717, indicating a positive, albeit weak, relationship between the two variables. This is because the Angat Dam also receives water from the Umiray River. On the other hand, the correlation between the average annual consumption per household and net inflows is –0.4994, indicating an inverse, albeit weak, relationship between the average water consumption per water use and net inflows.

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[7] In this thesis, the terms ‘household’ and ‘water user’ are interchangeable.
[8] Maynilad refused to share the same dataset to this author.
[9] The average annual water consumption per household data were provided by Manila Water.

Table 5.3: Annual rainfall, average annual consumption per household, and net inflows, 2010–2019

Year	Rainfall (mm)	Ave. annual water consumption per household (cubic metre/year)	Net inflow (MCM/year)
2010	2,675.1	333.51	1,018.8
2011	3,633.7	322.62	1,576.3
2012	4,431.7	313.12	2,402.7
2013	3,479.6	313.22	2,531.5
2014	2,661.5	314.58	1,828.7
2015	2,689.4	301.30	1,892.7
2016	2,518.0	306.09	2,004.0
2017	2,853.7	302.27	2,561.0
2018	3,571.4	305.30	2,159.3
2019	2,372.4	291.66	1,727.2

MCM = million cubic metre, mm = millimetre
Sources: PAGASA, Manila Water and author's calculations.

Figure 5.5: Rainfall and average water consumption per household per year, 2010–2019

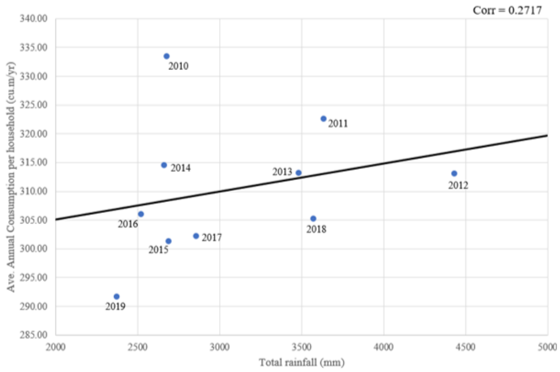
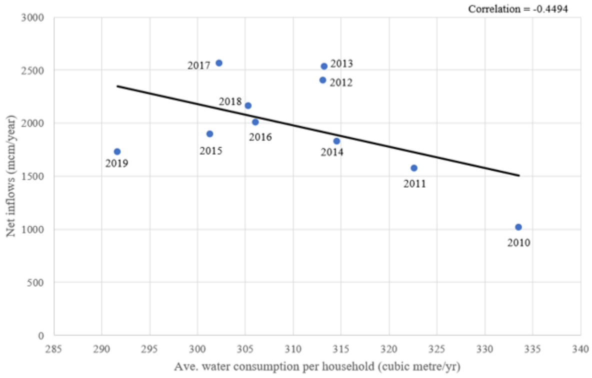


Figure 5.6: Average water consumption per household and net inflows, 2010–2019



MCM = million cubic metres.
Sources: PAGASA, NAPOCOR, Manila Water, and author's calculations.

As shown in Table 5.3, the average annual household consumption of water from the concessionaires has generally declined during the period 2010–2019. The computed correlation coefficient between the average annual consumption per user and rainfall is 0.2717, indicating a positive, albeit weak, relationship between the two variables. This is because the Angat Dam also receives water from the Umiray River.

III. Parameters

This section discusses the parameters used in the estimation of the RAUC. In estimating the RAUC, the weather variability that influences the demand for water and the net inflows are taken into account. Solving for the scarcity price also considers the current water-demand instruments that the regulator and the concessionaires impose in Metro Manila as well as the social discount rate that the Philippine Government follows.

Weather, water use, and the net inflows

The Philippines has two seasons—the wet and dry seasons. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) further classifies the weather of the country into four types of a dry and wet season.[10] Metro Manila's weather is classified as Type 1, which means that there are two pronounced seasons. The dry season lasts from November to April and the wet season for the rest of the year, with the maximum rain period occurring from June to September. The total annual rainfall in the region for the period 2010–2019 ranged from 2,372 mm to 4,432 mm (see Figure 2.11 in Chapter 2). The weather is divided into three equal intervals—dry, normal, and wet. The wet season includes the months when the country experiences the maximum rain period for each year. The average rainfall values are 2,628 mm during the dry season, 3,562 mm during the normal season, and 4,432 mm during the wet season. This gives probabilistic weather values of 0.6 for dry, 0.3 for normal, and 0.1 for the wet weather.

Based on the data provided by PAGASA, this thesis estimates the average net inflow corresponding to each type of weather. The estimated average total net inflow is 1,838.7 million cubic metres (MCM) per year for the dry weather, 2,089.0 MCM for normal weather, and 2,402.7 MCM for the wet weather. Without any water restriction, the average annual water uses in Metro Manila is 308 cubic metres (cu.m.) for dry weather, 314 cu.m. for normal weather, and 313 cu.m. for wet weather. The discretionary water use is arrived at by subtracting the essential water use or tier-1 use from the average annual water use. Thus, the discretionary water consumption during dry weather is 188 cu.m., 194 cu.m. for normal weather, and 193 cu.m. for wet weather. It appears that the discretionary water quantity for the normal and wet weather are only 1.8 and 1.6 per cent, respectively, more than that of the dry weather. This

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[10] Type 1: Two pronounced seasons—dry from November to April, and wet during the rest of the year with maximum rain period from June to September; Type 2: No dry season with a very pronounced rain period from December to February and there is not a single dry month; Type 3: No pronounced maximum rain period with a dry season only lasting from December to February or March to May; Type 4: Rainfall is evenly distributed throughout the year and has no dry season.

suggests that water consumption of households in Metro Manila does not vary significantly with the type of weather.[11]

Demand function for discretionary water

Following Chu and Grafton (2021), this thesis calibrates the model with the demand function for the discretionary water. The demand for discretionary water is a function of the water price. *Equation 5.5* shows the demand equation for discretionary water.

$$q(p^0|W) = b^w - m^w p^0 \qquad Eq. 5.5$$

The intercept, b^w, and the slope, m^w, depend on the weather. The price elasticity of demand is taken as the first derivative of *Equation 5.5* with respect to the price, considering the total demand for water, which is the sum of the discretionary water use, $q(p^0|W)$, and essential water use, M. *Equation 5.6* shows the price elasticity of demand for the household water consumption.

$$\varepsilon = -\frac{\partial q(p^0|W) + M}{\partial p} x \frac{p^0}{q(p^0|W) + M} = \frac{m^w}{b^w - m^w p^0 + M} \qquad Eq. 5.6$$

The intercept and the slope of the demand equation are estimated using the observed price and quantities for discretionary water and from using *Equations 5.5* and *5.6*.[12] The dataset used in estimating the household water-demand elasticities comprises the households' expenditure on water and other goods that are drawn from the Family Income and Expenditure Survey (FIES). As discussed in Chapter 4, the households of the two concession areas have different estimated water-demand elasticities. Specifically, the estimated water-demand elasticities of households serviced by Maynilad range from –0.993 to –0.994, while those of households serviced by Manila Water range from –0.717 to –0.721. Thus, the estimated intercepts and the slopes of the demand equation differ in these two concession areas.

Reduction in flows as supply management

As discussed in Chapter 2, the decline in water levels prompted the concessionaires and the regulator to reduce the flows coming from the Angat Dam. This supply management is undertaken when water level falls below the operating level of 180 metres to avoid falling it

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[11] Inocencio et al. (2002) estimated that Filipinos' maximum consumption for basic use—which includes drinking, personal hygiene, sanitation, cooking and kitchen, and laundry—is 246.78 litres per capita per day. This translates to 0.248 cu.m per capita per day or 88.8 cu.m. per capita per year.

[12] The estimated elasticities from Chapter 4 are used, specifically the elasticities that include the other household characteristics.

further below the 160–metre critical level. As mentioned in Chapter 2, the MWSS prevents the water level from going down below 160 metres to preserve the flora and fauna in the Angat watershed, keep the structural integrity of the dam, and maintain the water quality in the Angat Dam. In 2019, there were two observed stages in the reduction in flows. The first stage was when water level reached 168.98 metres, the flows were reduced to 46 cu.m./s, and the total discharge capacity declined to 1,168 MCM/year. The reduction in the flows resulted in a decreased household water consumption of 2 per cent. The second stage was when the water level was at 160.71 metres and the total remaining storage was 1,106.68 MCM/year. The flows were further reduced and caused a 5 per cent decline in household water consumption.

Social discount rates

The social discount rates (SDRs) set in the parameters are based on the rates set by the cabinet-level Investment Coordination Committee (ICC) for the evaluation of all major capital projects. The current SDR is set at 10 per cent, which was lowered from 15 per cent since September 2016.[13]

Summary of parameters to estimate the RAUC and the solution technique

In estimating the RAUC, the thesis uses the parameters introduced in the previous section to examine whether the RAUC, as a form of a demand management instrument, can be imposed on water users in Metro Manila given that the Kaliwa Dam has *not* been built as an additional water supply source. Estimating the RAUC shows that the current water tariff, where the water levels are declining but water demand is increasing, needs a scarcity pricing or premium to help ensure the availability of water for future use in the absence of supply augmentation.

The planning horizon is specified at 100 years starting from 2019. The SDR, ρ, is set at 15 per cent, which is based on the report of EMB (2014).[14] This is consistent with the literature indicating that in developing countries, the SDRs vary from 7.3 to 15 per cent (Zhuang et al. 2007 and Gurluk 2016). The sensitivity analyses to be performed later, however, use lower SDRs, specifically 10 per cent and 5.2 per cent. The number of domestic billed water users serviced by Manila Water at the base year is 1,311,066 and is expected to grow at 1.66 per cent

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[13] See Appendix 5, section A5.1, for a discussion of SDR determination and the reasons why SDRs in developing countries are higher than those in developed countries.

[14] Note that this happened before the SDR was reduced from 15 per cent to 10 per cent.

per year.[15] The number of billed water users serviced by Maynilad in 2019 is 1,325,171 and is expected to grow at 3.62 per cent annually.[16] Table 5.4 shows the values of the parameters drawn from different sources, as well as the author's calculations.

The analysis considers two water storages that depend on the water allocation of the water supply to Maynilad and Manila Water. This accounts for the concessionaires having different water prices and the households in these two concession areas having different estimated demand elasticities. The dynamic optimisation problem, as shown in *Equation 5.2*, uses the parameters shown in Table 5.4 and solves the RAUC using the optimality principle of Bellman (1957). The numerical approximation method is used since the dynamic optimisation problem yields a non-closed-form solution. The RAUCs at different storage levels in Angat Dam are calibrated to the specified parameters of the current water services in Metro Manila.

Table 5.4: Summary of values for each parameter

Description	Notations	Values	Sources
Storage capacity	$\bar{S}$	876 MCM/year (Maynilad allocation of Angat Dam), 584 MCM/year (Manila Water allocation of Angat Dam)	MWSS
Weather distribution	$Prob(W = dry, normal, wet)$	0.6, 0.3, 0.1	Approximated data from PAGASA
Average net inflow for each weather [a]	$I(W)$	Maynilad: 1,103.2 MCM/year (dry), 1,253.4 MCM/year (normal), 1,441.6 MCM/year (wet) Manila Water: 735.5 MCM/year (dry), 835.6 MCM/year (normal), 961.1 MCM/year (wet)	Approximated data from NAPOCOR & PAGASA
Essential (tier-1) use per water user	M	120 cu.m./year	Estimated from data and water tariff schedules
Price elasticity of water demand	ε	Maynilad: –0.994 (Districts 1 & 4), –0.993 (District 3) Manila Water: –0.717 (District 2), –0.721 (District 4)	Estimated using the AIDS model (Chapter 4)
An observed price and quantity	$p^0, q(p^0 \vert W = dry)$	Maynilad: Php38.09/cu.m. Manila Water: Php24.33/cu.m.; 188.66 cubic meter/water user	Estimated from data
Breakeven average cost	c	Maynilad: Php38.09/cu.m. Manila Water: Php24.33/cu.m.	Estimated from data and from IBT of the water services
Weather-varying ratio for water use	$\frac{q(p \vert W = normal)}{q(p \vert W = dry)}$ $\frac{q(p \vert W = wet)}{q(p \vert W = dry)}$	1.018, 1.016	Estimated from data
Reduction in flows impacts	$Q(S_t)$	$Q(677.43) = 0.98q(p^0 \vert W = dry)$ $Q(644.36) = 0.95q(p^0 \vert W = dry)$	Estimated from data
Discount rate	ρ	15%	Investment Coordination Committee (ICC)
Planning time	T	100 years	Environmental Management Bureau (EMB 2014)
Number of water users (using 2019 as the base year $t = 0$)	N_t	N_0 *for Maynilad*: 1,346,741 , growing at 3.62% per year; N_0 *for Manila Water*: 1,311,066, growing at 1.66% per year	Maynilad and Manila Water

IBT = increasing block tariff, MCM = million cubic metres.

[a] The total net inflows are divided according to the allocation of the water supply to Manila Water and Maynilad.

Sources: Author, Manila Water, and various government agencies.

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[15] This is based on the actual data provided by Manila Water.

[16] This is based on the figures reported by Maynilad in its 2017 Business Plan for 2018 to 2019.

The RAUC is calculated at intervals of 2.5 percentage points in reference to the storage levels that trigger the water restrictions, which the regulator imposes (i.e., 75%, 77.50% of the storage capacity, and so on). Piece-wise linear functions are used to estimate the value of the RAUC between these points. The RAUC is computed as the difference between the estimated optimal prices for each weather and the current cost of supplying water.

The dynamic water pricing problem accounts for the weather variability as changes in rainfall influence the remaining water capacity in the Angat Dam. Table 5.5 summarises the estimated impact of climate change on rainfall in Metro Manila. The data came from PAGASA's 2036-2065 projected seasonal change in total rainfall, compared to the 1971-2000. PAGASA uses two climate change scenarios, namely, RCP 4.5 and RCP 8.5.[17] There is a wide variation in the projected total rainfall in the region for the two scenarios—that is, the region experiences less rain in the drier years and considerably more rain during the wet years.

Table 5.5: Projected average annual rainfall during 2036–2065, compared to the 1971–2000 period

Years (period)	Unit	DJF	MAM	JJA	SON	ANNUAL
Observed (1971_2000)	mm	107.5	198.5	1170.2	758.7	2234.9
Projected (2036_2050)						
Moderate emissions (RCP 4.5)						
Lower bound (<10 per centile)	mm	107.3	199.8	920.8	676.4	1,904.3
		–0.1%	0.70%	–21.30%	–10.80%	–14.8%
Median (50 per centile)	mm	126.5	212.2	1,051.6	713.5	2,103.8
		17.7%	6.9%	–10.10%	–6.00%	–5.9%
Upper bound (90 per centile)	mm	167.1	246.9	1,165.2	817.2	2,396.4
		55.5%	25.70%	–0.40%	7.7	7.2%
High emissions (RCP 8.5)						
Lower bound (<10 per centile)	mm	110.4	184.2	970.9	698.1	1963.6
		2.70%	–7.20%	–17.00%	-8.00%	–12.1%
Median (50 per centile)	mm	137.4	208.1	1098.5	788.3	2232.3
		27.8	4.80%	–6.10%	3.90%	–0.1%
Upper bound (90 per centile)	mm	164.9	237.9	1260.5	909.4	2572.7
		53.40%	19.80%	7.70%	19.90%	15.1%

mm = millimetre.
NOTES: (i) DFJ = December, January, February; (ii) MAM = March, April, May; (iii) JJA = June, July, August; and (iv) SON = September, October, November.
Source: PAGASA.

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[17] Representative Concentration Pathway (RCP) is a measure adopted by the Intergovernmental Panel on Climate Change (IPCC). It is used to predict future weather climate based on the greenhouse gas concentration trajectories. RCP 4.5 means that the radiative forcing is 4.5 watts per square metre, while RCP 8.5 means 8.5 watts per square metre.

IV. Results and discussions

Using the parameters described in Section 3, the dynamic optimisation of *Equation 5.2* is solved to calculate the RAUC. This section discusses the results from the estimations of the base case scenario and the sensitivity analyses.

Estimating the RAUC and factors affecting the RAUC

This thesis computes for the RAUC given the current situation in which MWSS receives water from the Angat Dam for the households in Metro Manila. The thesis computes for the optimal prices for each weather type. The RAUC is computed separately for each district under each concessionaire because the household water-demand elasticities are different for each district. The estimated optimal prices and the RAUC are shown in Tables 5.6 and 5.7.

Table 5.6: RAUC of household in the East Zone (Manila Water), in Php per cu.m.

Discharge capacity (MCM/year)	**District 2: Elasticity = –0.717**						**District 2: Elasticity = –0.721**					
	Optimal prices			**RAUC**			**Optimal prices**			**RAUC**		
	Dry	**Normal**	**Wet**	**Dry**	**Normal**	**Wet**	**Dry**	**Normal**	**Wet**	**Dry**	**Normal**	**Wet**
438.00	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
526.60	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
467.20	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
481.80	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
496.40	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
511.00	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
525.60	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
540.20	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
554.80	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
569.40	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00
584.00	24.33	24.33	24.33	0.00	0.00	0.00	24.33	24.33	24.33	0.00	0.00	0.00

RAUC = risk-adjusted user cost.
Source: PAGASA, Manila Water, and author's calculations.

Table 5.7: RAUC of household in the West Zone (Maynilad), in Php per cu.m.

Discharge capacity (MCM/year)	Optimal prices			RAUC			Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
639.48	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
661.38	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
683.28	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
705.18	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
727.08	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
748.98	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
770.88	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
792.78	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
814.68	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
836.58	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00
858.48	32.06	32.06	32.06	0.00	0.00	0.00	32.06	32.06	32.06	0.00	0.00	0.00

RAUC = risk-adjusted user cost.
Source: PAGASA, Manila Water, and author's calculations.

Results show that the estimated RAUC is zero for all households in Metro Manila. It suggests that the current water tariffs imposed on households do not require a scarcity price despite the increasing water scarcity problem from the Angat Dam. There are three factors that can explain these results.

First factor: Net inflows are higher than consumptive flows

The first factor is that the net inflows are significantly higher than the consumptive flows. The estimated average water consumption per household per year is 291.66 cu.m., which translates to 812.6 MCM per year for the whole of Metro Manila. By comparison, the net inflow coming from the Angat Dam during the dry season is estimated at 1,838.7 MCM per year. The current household water consumption is just 44.19 per cent of the total inflows during the dry season. Thus, the water consumption is only 39.59 per cent of the total inflows during the normal season and 34.35 per cent during the wet season (see Figure 5.7). This means that the net inflows to recharge the water supply in the Angat Dam were significantly larger during the period 2010–2019. Although there were periods of dry spells throughout the year, typically during the summer months, the region received sufficient rainfall during the wet season to meet the water-demand requirement.[18]

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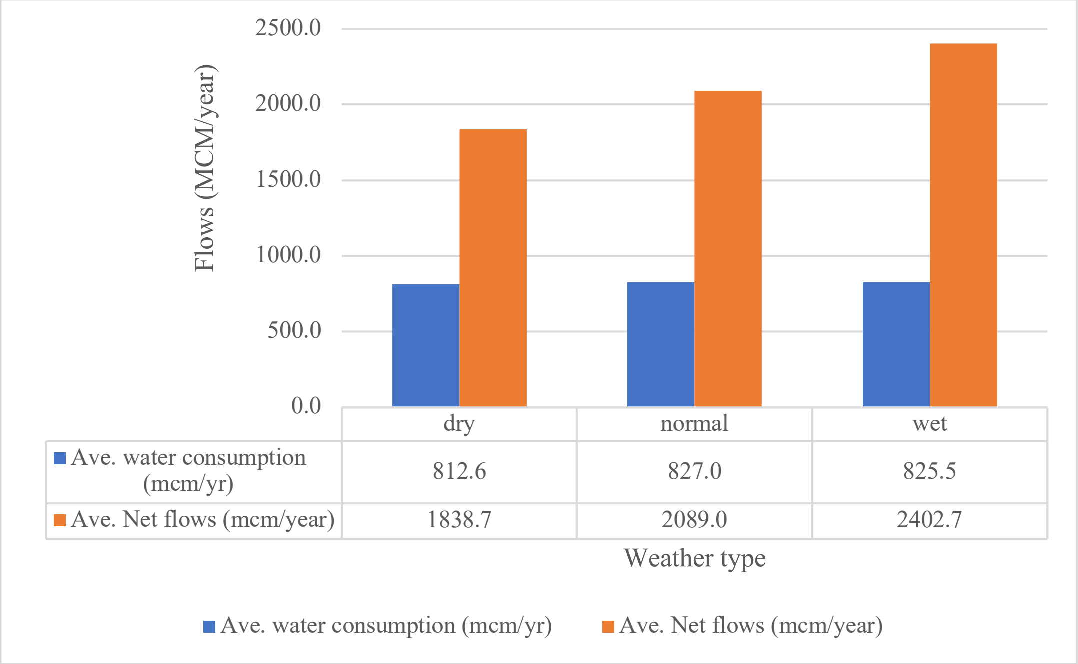
[18] This is explained in Chapter 2, section 4.

Figure 5.7: Average annual consumptive and net flows



MCM = million cubic metres.
Source: Author's calculations.

Second factor: High water-demand elasticities and social discount rates

The second factor is that the demand elasticities of households and the social discount rates are high. Households in the East Zone have price demand elasticities ranging from –0.717 to –0.721, while those in the West Zone have demand elasticities ranging from –0.993 to –0.994. This means that the households are generally less risk-averse towards avoiding water restrictions. This is consistent with the findings of Chu and Grafton (2019). This is because households have access to alternative water sources, such as water refilling stations and groundwater, despite maintaining the water connection of the concessionaires. In times of a reduction in the water supply, households will use the alternative sources to meet their water demand.[19] In this case, households are not willing to pay an additional premium if water restrictions are imposed to retain the same level of water consumption. In addition, the social discount rate of households is high at 15 per cent. As shown in *Equation 5.3*, the optimal price depends on the discounted consumer surplus. Higher social discount rates reduce the amount of RAUC since the costs of future risks decline (Chu and Grafton 2019).

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[19] See Appendix 5, section A5.2, for further explanation on the water refilling stations and groundwater usage in Metro Manila.

Third factor: Adjustability of water allocation for irrigation purposes

The last factor that can explain why the RAUC is zero in the current situation is the adjustability of the water allocation for irrigation purposes. Based on *Equation 5.1*, the net inflows are dependent on the adjustment to the allocation of water for irrigation purposes. Seasonal water use by the households in Metro Manila is affected by the share of the irrigation water supply. However, by following the guidance provided by the Water Code, this problem is being minimised by reducing the share of irrigation water supply and increasing the share of water for consumptive use whenever the water at the Angat Dam reaches a critical level. Thus, any adjustment in the allocation for irrigation water will influence the flows that are allocated for water use in Metro Manila.

The NWRB adjusts the allocation of water from Angat Dam for irrigation purposes depending on the planting season and the consumptive water use for Metro Manila. The water allocation for irrigation purposes is pegged at a maximum flow of 40 cu.m./s, which includes 15 cu.m./s of conditional water use (World Bank 2012). The conditional use, however, is reallocated for water use in Metro Manila given that the Angat-Maasim River Irrigation System (AMRIS) does not need the 15 cu.m./s flows for irrigation activities noting that farms need more water only during planting season.[20]

The allocated flows for irrigation, however, are observed to be generally declining over the past decade (see Figure 5.8). The reduction in the allocated volume for irrigation water is brought about by the increasing consumptive water demand in Metro Manila. In allocating water supply, the NWRB gives priority Metro Manila to abide by the Water Code of the Philippines. More specifically, the NWRB is mandated to divert water flows for irrigation purposes and give the highest water allocation to domestic and municipal use in times of water scarcity. Gutierrez et al. (2019) point out that due to problems brought about by increasing water scarcity and extreme variability in climate, farmers adjust their planting window throughout the year when water is more available for irrigation. As shown in Figure 5.8, the volume of water for consumptive flows barely reached the allocated flows of 46 cu.m./s for MWSS. Thus, the NWRB realises the need to reallocate some of the flows for irrigation purposes to the MWSS's concession area.

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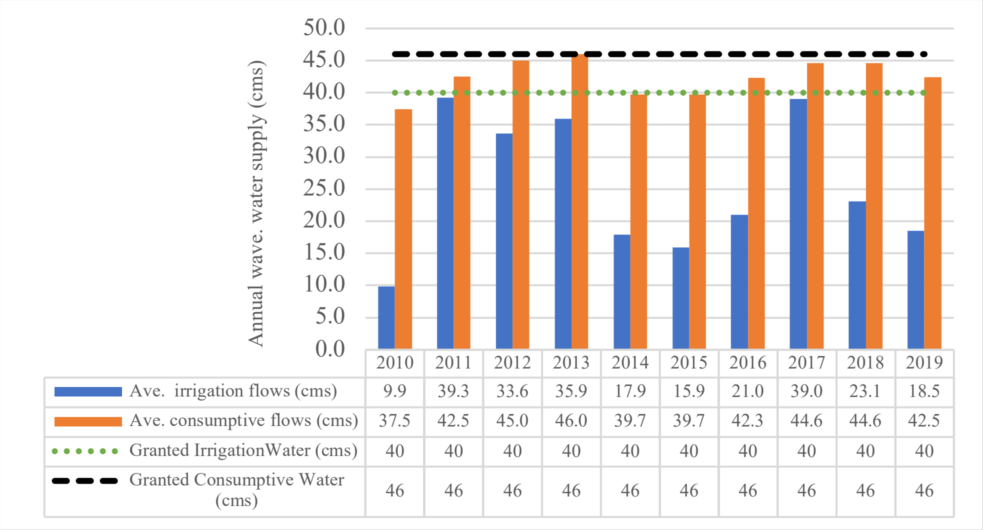
[20] See Appendix 5, section A5.3 for further details on the planting season in the Philippines.

Figure 5.8: Average annual flows for consumptive and irrigation water, 2010–2019



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
🟦 Ave. irrigation flows (cms)	9.9	39.3	33.6	35.9	17.9	15.9	21.0	39.0	23.1	18.5
🟧 Ave. consumptive flows (cms)	37.5	42.5	45.0	46.0	39.7	39.7	42.3	44.6	44.6	42.5
•••••• Granted IrrigationWater (cms)	40	40	40	40	40	40	40	40	40	40
▬ ▬ ▬ Granted Consumptive Water (cms)	46	46	46	46	46	46	46	46	46	46

cu.m./s = cubic metres per second
Sources: NAPOCOR and author's calculations.

Sensitivity analyses

This thesis performs three sensitivity analyses to consider a scenario in which the Kaliwa Dam is not operational by 2025. The first sensitivity analysis estimates the RAUC of the current situation but using different social discount rates. The second sensitivity analysis estimates the RAUC given the possibility of an extreme dry spell in 2023 and beyond. The last sensitivity analysis considers the situation in which all households in Metro Manila have a metered connection to the water services of the two concessionaires in 2023 and beyond.

Sensitivity analysis on social discount rates

As mentioned by Chu and Grafton (2021), the RAUC is dependent on the social discount rate since this thesis also considers future costs, which must be converted to the present value. There are two other social discount rates that are examined in this sensitivity analysis. The first discount rate is set at 10 per cent, which the ICC has imposed for all major capital projects (MCPs) of the government since September 30, 2016. The second discount rate is based on the daily average Philippine 10-year government bond from 2010 to 2020, which is at 5.20 per cent—to be consistent with the methodology of Chu and Grafton (2021).[21] The estimated RAUCs, given the different social discount rates, are shown in Tables 5.8 and 5.9.[22]

Table 5.8a: Estimated RAUC using the 10 per cent SDR for the East Zone, in Php per cu.m.

Discharge capacity (MCM/year)	Manila Water					
	Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet
438.00	24.33	24.33	24.33	0.00	0.00	0.00
526.60	24.33	24.33	24.33	0.00	0.00	0.00
467.20	24.33	24.33	24.33	0.00	0.00	0.00
481.80	24.33	24.33	24.33	0.00	0.00	0.00
496.40	24.33	24.33	24.33	0.00	0.00	0.00
511.00	24.33	24.33	24.33	0.00	0.00	0.00
525.60	24.33	24.33	24.33	0.00	0.00	0.00
540.20	24.33	24.33	24.33	0.00	0.00	0.00
554.80	24.33	24.33	24.33	0.00	0.00	0.00
569.40	24.33	24.33	24.33	0.00	0.00	0.00
584.00	24.33	24.33	24.33	0.00	0.00	0.00

Source: Author's calculations

Table 5.8b: Estimated RAUC using the 10 per cent SDR for the West Zone, in Php per cu.m.

Discharge capacity (MCM/year)	Maynilad					
	Optimal Prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet
639.48	32.06	32.06	32.06	0.00	0.00	0.00
661.38	32.06	32.06	32.06	0.00	0.00	0.00
683.28	32.06	32.06	32.06	0.00	0.00	0.00
705.18	32.06	32.06	32.06	0.00	0.00	0.00
727.08	32.06	32.06	32.06	0.00	0.00	0.00
748.98	32.06	32.06	32.06	0.00	0.00	0.00
770.88	32.06	32.06	32.06	0.00	0.00	0.00
792.78	32.06	32.06	32.06	0.00	0.00	0.00
814.68	32.06	32.06	32.06	0.00	0.00	0.00
836.58	32.06	32.06	32.06	0.00	0.00	0.00
858.48	32.06	32.06	32.06	0.00	0.00	0.00

Source: Author's calculations.

Table 5.9a: Estimated RAUC using the 5.20 per cent SDR for the East Zone, in Php per cu.m.

Discharge capacity (MCM/ year)	Manila Water					
	Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet
438.00	24.33	24.33	24.33	0.00	0.00	0.00
526.60	24.33	24.33	24.33	0.00	0.00	0.00
467.20	24.33	24.33	24.33	0.00	0.00	0.00
481.80	24.33	24.33	24.33	0.00	0.00	0.00
496.40	24.33	24.33	24.33	0.00	0.00	0.00
511.00	24.33	24.33	24.33	0.00	0.00	0.00
525.60	24.33	24.33	24.33	0.00	0.00	0.00
540.20	24.33	24.33	24.33	0.00	0.00	0.00
554.80	24.33	24.33	24.33	0.00	0.00	0.00
569.40	24.33	24.33	24.33	0.00	0.00	0.00

Source: Author's calculations.

Table 5.9b: Estimated RAUC using the 5.20 per cent SDR for the West Zone, in Php per cu.m.

Discharge capacity (MCM/ year)	Maynilad					
	Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet
639.48	32.06	32.06	32.06	0.00	0.00	0.00
661.38	32.06	32.06	32.06	0.00	0.00	0.00
683.28	32.06	32.06	32.06	0.00	0.00	0.00
705.18	32.06	32.06	32.06	0.00	0.00	0.00
727.08	32.06	32.06	32.06	0.00	0.00	0.00
748.98	32.06	32.06	32.06	0.00	0.00	0.00
770.88	32.06	32.06	32.06	0.00	0.00	0.00
792.78	32.06	32.06	32.06	0.00	0.00	0.00
814.68	32.06	32.06	32.06	0.00	0.00	0.00
836.58	32.06	32.06	32.06	0.00	0.00	0.00

Source: Author's calculations.

The results suggest that the RAUC is still zero, which is the same as the base case scenario, regardless of the discount rate. Although the discount rate influences the RAUC, it is offset by the estimated high net inflows that recharge the Angat Dam. Similar with the base case

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[21] Chu and Grafton (2021) set the discount rate based on the 10-year Australian government bond from 2010 to 2019.

[22] Although the elasticities are slightly different, the table only shows the optimal prices and the RAUC to summarise the results, since the RAUC is zero.

scenario, households, regardless of the discount rate, are not willing to pay an additional scarcity premium and maintain their water consumption when water levels are declining.

Sensitivity analysis on reduced inflows

As pointed out in the previous analysis, the RAUC is zero because the net inflows are significantly larger than the consumptive domestic flows. The scenario here is that the Kaliwa Dam will not be fully operational in 2025 and that the inflows are substantially reduced to simulate the time when the inflows are at its lowest. Historically, the El Niño has affected the water levels in Angat Dam. For instance, the 1991–1992 El Niño event caused the water level in the dam to drop to as low as 150 metres (Hilario et al. 2009), which means that the dam was operating at only 70 per cent of its total capacity. Additionally, Yumul et al. (2010) attribute the decline in the water supply in Angat Dam as being due to the declining water inflows from the Umiray River and into the dam (see Figure 5.2).

In a situation described above, this thesis sets the reduction in net inflows in the year 2023, which is two years before the supposed time that the Kaliwa Dam is operational if construction started in 2021.[23] This is also in anticipation that the water demand will exceed the water supply by that year. Alternative values of net inflows for the dry, normal, and wet seasons were introduced until they produce a non-zero value for RAUC. The simulation results indicate that when the net flows decline to 950 MCM/year for the dry, 1,500 MCM/year for the normal, and 1,700 MCM/year for the wet season, households will have to pay a RAUC so as not to experience interruption in their water consumption. The specific results for the base year 2023 for each district are shown in Tables 5.10 and 5.11, and in Figures 5.9 and 5.10. The discount rate used is 10 per cent to abide by the new rate that the NEDA-ICC has set on September 30, 2016.

The results of the sensitivity analyses suggest that the RAUC that households in Metro Manila must pay ranges from Php0.0416 to Php0.5216, or US$0.00083 to US$0.010 per cu.m. of additional discretionary water they consume. As a per cent of the water prices, the RAUC ranges from 0.09 per cent to 1.36 per cent of the water prices. What this means is that the regulator can impose only a small scarcity premium to avoid disruption in the water consumption of households and ensure availability of water supply for future use. It can also

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[23] However, it should be noted that due to the legal problems surrounding the project, the Kaliwa Dam's construction has constantly been delayed. This thesis assumes that the construction will start by 2021 before President Duterte will end his term in June 2022.

be observed that the households in the East Zone have higher willingness-to-pay as compared to their counterparts in the West Zone. This is mainly because the water users in the East Zone have lower water-demand elasticities, which means that they are more dependent on the water services of Manila Water. The higher water-demand elasticities of households in the West Zone mean that they are less dependent on the water services of Maynilad. Consequently, they have a lower willingness-to-pay to avoid water restrictions.

Table 5.10: Estimated RAUC for base year 2023 for households in the East Zone (Manila Water), in Php per cu.m.

Discharge capacity (MCM/ year)	District 2: Elasticity = –0.717						Discharge capacity (MCM/ year)	District 2: Elasticity = –0.721					
	Optimal prices			RAUC				Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet		Dry	Normal	Wet	Dry	Normal	Wet
438.00	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	438.00	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
526.60	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	526.60	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
467.20	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	467.20	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
481.80	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	481.80	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
496.40	38.8616	38.8616	38.8616	0.5216	0.5216	0.5216	496.40	38.8587	38.8587	38.8587	0.5187	0.5187	0.5187
511.00	38.6738	38.6738	38.6738	0.3338	0.3338	0.3338	511.00	38.6720	38.6720	38.6720	0.3320	0.3320	0.3320
525.60	38.6319	38.6319	38.6319	0.2919	0.2919	0.2919	525.60	38.6303	38.6303	38.6303	0.2903	0.2903	0.2903
540.20	38.6289	38.6289	38.6289	0.2889	0.2889	0.2889	540.20	38.6273	38.6273	38.6273	0.2873	0.2873	0.2873
554.80	38.5449	38.5449	38.5449	0.2049	0.2049	0.2049	554.80	38.5438	38.5438	38.5438	0.2038	0.2038	0.2038
569.40	38.5027	38.5027	38.5027	0.1627	0.1627	0.1627	569.40	38.5018	38.5018	38.5018	0.1618	0.1618	0.1618
584.00	38.5015	38.5015	38.5015	0.1615	0.1615	0.1615	584.00	38.5006	38.5006	38.5006	0.1606	0.1606	0.1606

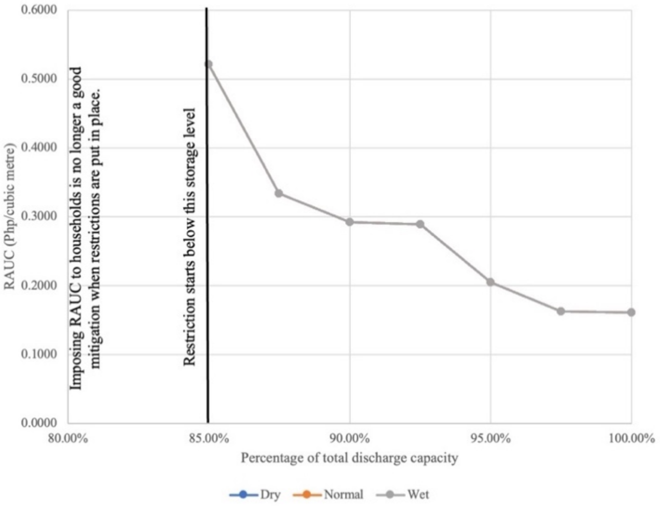
Source: Author's calculations.

Table 5.11: Estimated RAUC for base year 2023 for households in the West Zone (Maynilad), in Php per cu.m.

Dis-charge capacity (MCM/ year)	District 3: Elasticity = –0.993						Dis-charge capacity (MCM/year)	District 2: Elasticity = –0.721					
	Optimal prices			RAUC				Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet		Dry	Normal	Wet	Dry	Normal	Wet
657.00	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	657.00	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000
678.90	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	678.90	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000
700.80	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	700.80	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000
722.70	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	722.70	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000
744.60	48.1403	48.1403	48.1403	0.2003	0.2003	0.2003	744.60	48.1401	48.1401	48.1401	0.2001	0.2001	0.2001
766.50	48.0736	48.0736	48.0736	0.1336	0.1336	0.1336	766.50	48.0734	48.0734	48.0734	0.1334	0.1334	0.1334
788.40	48.0353	48.0353	48.0353	0.0953	0.0953	0.0953	788.40	48.0352	48.0352	48.0352	0.0952	0.0952	0.0952
810.30	48.0133	48.0133	48.0133	0.0733	0.0733	0.0733	810.30	48.0133	48.0133	48.0133	0.0733	0.0733	0.0733
832.20	48.0062	48.0062	48.0062	0.0662	0.0662	0.0662	832.20	48.0062	48.0062	48.0062	0.0662	0.0662	0.0662
854.10	47.9950	47.9950	47.9950	0.0550	0.0550	0.0550	854.10	47.9949	47.9949	47.9949	0.0549	0.0549	0.0549
876.00	47.9817	47.9817	47.9817	0.0417	0.0417	0.0417	876.00	47.9816	47.9816	47.9816	0.0416	0.0416	0.0416

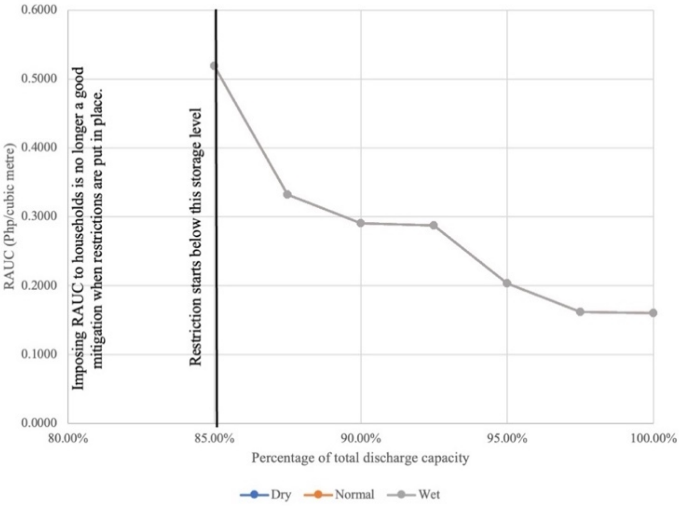
Source: Author's calculations.

Figure 5.9a: Estimated RAUC for base year 2023 for households in district 2 in the East Zone, in Php per cu.m.



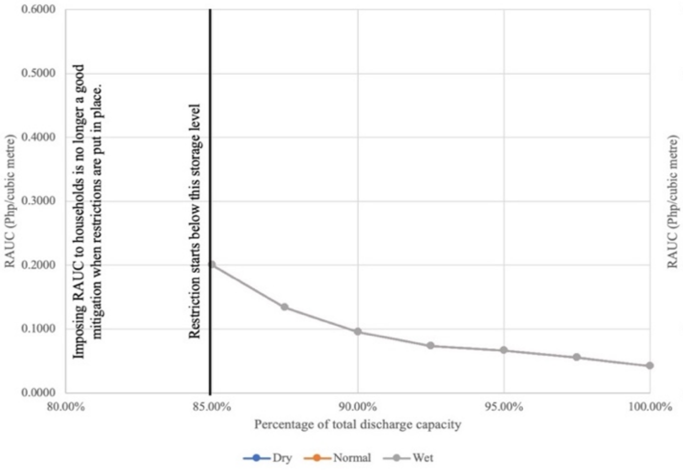
Source: Author's calculations.

Figure 5.9b: Estimated RAUC for base year 2023 for households in district 4 in the East Zone, in Php per cu.m.



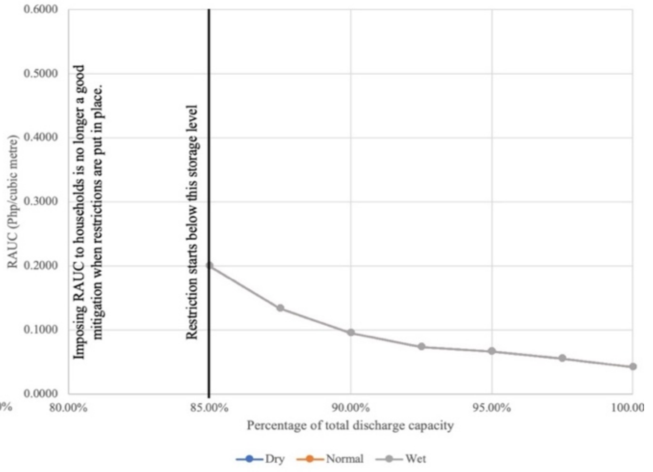
Source: Author's calculations.

Figure 5.10a: Estimated RAUC for base year 2023 for households in district 3 in the West Zone, in Php per cu.m.



Source: Author's calculations.

Figure 5.10b: Estimated RAUC for base year 2023 for households in district 1& 4 in the West Zone, in Php per cu.m.



Source: Author's calculations.

Our estimates in Table 5.11 indicate that the households in the East Zone will have to pay an additional amount ranging from Php0.1606 to Php0.5216, or US$0.0032 to US$0.010, per cu.m. of additional discretionary water use. This constitutes to 0.42 to 1.36 per cent of the water tariff that water users pay to Manila Water. On the other hand, those in the West Zone will have to pay an additional amount ranging from Php0.0416 to Php0.2003, or US$0.00082 to US$0.0039, per cu.m. of additional discretionary water use. This is equivalent to 0.09 to 0.42

per cent of the water tariff that households pay to Maynilad. The increase in RAUC as water levels decline is also consistent with that of Chu and Grafton (2021).

An interesting finding is that the RAUC is the same regardless of the season. This is in contrast with Chu and Grafton (2021), showing that the RAUC is high during the season when water consumption is at its peak. Looking closely at the behaviour of households in Metro Manila, the water consumption during the wet, normal, and dry seasons are almost the same. This means that water users in Metro Manila do not significantly adjust their water consumption regardless of the season. Thus, the RAUC is the same for all seasons

Third sensitivity analysis: 100 per cent household connected to centralised supply

The thesis also investigates whether lower demand price elasticities in the future, coupled with reduced inflows to account for extreme dry weather events, may result in the imposition of a RAUC on households. Both concessionaires aim to have a 99 per cent to 100 per cent service coverage in their respective areas by 2023 (Manila Water and Maynilad 2017). The sensitivity analysis uses the estimated water-demand elasticity of David and Inocencio (1998) for Metro Manila, which is –0.5.

Two climate scenarios are examined for the sensitivity analysis. The first case is that the thesis accounts for the RCP 8.5 weather variation, specifically the lower bound scenario, wherein the driest probability will cause a decline in precipitation by 12.1 per cent. Thus, the RCP 8.5 is chosen in the sensitivity analysis.[24] The second case considers the reduced net inflows for dry, normal, and wet seasons under extreme dry weather event, the same as the second sensitivity analysis above. Tables 5.12 and 5.13 summarise the results of the sensitivity analysis.

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[24] RCP 4.5 is considered to have medium emissions while RCP 8.5 is considered to have high emissions.

Table 5.12: Estimated RAUC for base year 2023 for households serviced by Manila Water, in Php per cu.m.

Discharge capacity (mcu.m./year)	Reduced flows based on RCP 8.5 Elasticity = –0.5						Reduced inflows under extreme dry weather events Elasticity = –0.5					
	Optimal prices			RAUC			Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
438.00	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
526.60	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
467.20	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
481.80	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000
496.40	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.8587	38.8587	38.8587	0.5187	0.5187	0.5187
511.00	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.6720	38.6720	38.6720	0.3320	0.3320	0.3320
525.60	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.6303	38.6303	38.6303	0.2903	0.2903	0.2903
540.20	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.6273	38.6273	38.6273	0.2873	0.2873	0.2873
554.80	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.5438	38.5438	38.5438	0.2038	0.2038	0.2038
569.40	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.5018	38.5018	38.5018	0.1618	0.1618	0.1618
584.00	38.3400	38.3400	38.3400	0.0000	0.0000	0.0000	38.5006	38.5006	38.5006	0.1606	0.1606	0.1606

Source: Author’s calculations.

Table 5.13: Estimated RAUC for base year 2023 for households serviced by Maynilad, in Php per cu.m.

Discharge capacity (mcu.m./ year)	Reduced flows based on RCP 8.5 Elasticity = –0.5						Reduced inflows under extreme dry weather events Elasticity = –0.5					
	Optimal prices			RAUC			Optimal prices			RAUC		
	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet	Dry	Normal	Wet
657.00	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	47.9400	47.9400	47.9400	0.0400	0.0400	0.0400
678.90	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	47.9400	47.9400	47.9400	0.0400	0.0400	0.0400
700.80	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	47.9400	47.9400	47.9400	0.0400	0.0400	0.0400
722.70	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	47.9400	47.9400	47.9400	0.0400	0.0400	0.0400
744.60	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	48.1401	48.1401	48.1401	0.2401	0.2401	0.2401
766.50	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	48.0734	48.0734	48.0734	0.1734	0.1734	0.1734
788.40	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	48.0352	48.0352	48.0352	0.1352	0.1352	0.1352
810.30	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	48.0133	48.0133	48.0133	0.1133	0.1133	0.1133
832.20	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	48.0062	48.0062	48.0062	0.1062	0.1062	0.1062
854.10	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	47.9949	47.9949	47.9949	0.0949	0.0949	0.0949
876.00	47.9400	47.9400	47.9400	0.0000	0.0000	0.0000	47.9816	47.9816	47.9816	0.0816	0.0816	0.0816

Source: Author’s calculations.

The first case shows that even with lower water-demand elasticity, the RAUC for households in both concessions is zero. This is because the net inflows are still significantly higher than the household water consumption despite the decline in the net inflows due to the higher emissions case. The results of the second case are consistent with those of Chu and Grafton (2019) where the lower water-demand elasticity, together with the lower net inflows equivalent to 950, 1,500, and 1,700 MCM for the dry, normal, and wet seasons, respectively, cause the

RAUC to be marginally higher as compared with the estimates in the second sensitivity analysis. The RAUC per cu.m. in the East Zone ranges from Php0.1606 to Php0.5187, or US$0.0032 to US$0.01, which is 0.42 per cent to 1.35 per cent of the water tariff. On the other hand, the RAUC per cu.m. in the West Zone ranges from Php0.0816 to Php0.2401, or US$0.0016 to US$0.0047, which is 0.17 per cent to 0.50 per cent of the water tariff. Interestingly, even if households have the same –0.5 water-demand elasticity, households in the East Zone still have a higher RAUC than those in the West Zone. This is because households in the West Zone serviced by Maynilad already face higher water tariffs than households in the East Zone serviced by Manila Water.

The sensitivity analyses yield two important insights. The first insight is that the critical net inflows when RAUC is going to be imposed appear to be at 950 MCM for dry season, 1,500 MCM for normal season, and 1,700 MCM for wet season. The other insight is that results are consistent with the findings of Chu and Grafton (2019) that the RAUC increases as water storage declines. As more water is extracted from Angat Dam, less water will be available for future use. This increases the risk of future water restrictions, resulting in welfare losses to future water users, especially when the current storage approaches its lowest threshold. One striking difference from the results in Chu and Grafton (2019) is that in this thesis, the risk is higher during the normal and wet weather—due to higher household water consumption during these periods. Although the RAUC should be lower when dams are full or above the threshold, the households' tendency to consume more water during the normal and wet seasons influence the increase in RAUC. This means that the RAUC is not only dependent on the weather condition, but also on the water consumption patterns of the households in each weather type. It is to be noted that the estimated increases in the water prices with the RAUC are minimal.

V. Conclusion

This chapter explores the use of a scarcity price, the RAUC, as an alternative demand management instrument given the pending construction and uncertainty of the Kaliwa Dam. The RAUC allows the concessionaires and the regulators to not impose water restrictions, which can significantly decrease the social welfare. Moreover, water restrictions decrease their consumer surplus from using the water services. In the case of the water pricing in Metro Manila, water users are still required to pay the flat charge, or the charge of the first block, despite not having water supply for a certain length of time. Although households in the capital region have alternative sources of water, such as water refilling stations and own deep well, the costs of such alternatives are much higher.

The results of the dynamic optimisation show that the RAUC of households in Metro Manila is zero. This suggests that the current water tariffs imposed on households do not require a scarcity price despite the increasing water scarcity problem from the Angat Dam. There are three factors that explain these results. The first factor is that the net inflows are more than enough to recharge the water storage in Angat Dam. Even at the driest scenario, the water consumption is only 36 per cent of the total annual net inflows into the dam. This is because the inflows to Angat Dam do not come only from rainfall but also from the Umiray River. A caveat that this thesis points out is that the country is prone to extreme weather events, which can affect the sustainability of the water storage in the decades to come. The second factor is that households have relatively high price elasticities, which means that they generally have a relatively low willingness-to-pay to avoid any water restrictions. This is mainly due to the households' access to alternative water supply sources, such as water refilling stations and groundwater. Lastly, the NWRB can freely reallocate irrigation water for consumptive domestic use for Metro Manila. When outflows from Angat Dam are too low, the NWRB can redirect the water volume, with a maximum of 15 cu.m., to MWSS when the consumptive domestic water use flow is below 46 cu.m. Under the Water Code of the Philippines, the NWRB is mandated to give the highest water allocation to domestic and municipal use in times of water scarcity.

Three sensitivity analyses were evaluated when estimating the RAUC. The first sensitivity analysis explores the use of 10 per cent and 5.20 per cent social discount rates. The results indicate that the RAUC is still zero, which is the same as the base case scenario. The second and the third sensitivity analyses present possible scenarios when the Kaliwa Dam is not operational by 2025, the concessionaires achieve 100 per cent service connections for all households in Metro Manila, and extreme dry weather events happen that could substantially reduce the net inflows. If these scenarios materialise, the RAUC could be justified for households in Metro Manila. This happens when the net inflows decline to 950 MCM for the dry season, 1,500 MCM for the normal season, and 1,700 MCM for the wet season. Households in the East Zone serviced by Manila Water have a higher RAUC because they have lower water-demand elasticities. Households in the West Zone serviced by Maynilad will have a lower RAUC because of their relatively higher water-demand elasticities.

Sensitivity results show that households in the East Zone are willing to pay between Php0.1606 and Php0.5216, or US$0.0032 to US$0.010, per cu.m. for increased reliability of water supply, whereas households in the West Zone are willing to pay between Php0.0416 and Php0.2003, or US$0.00082 to US$0.0039, per cu.m. for their water use to remain undisrupted. This translates to an increase in the water prices ranging from 0.42 to 1.36 per cent in the East Zone and from 0.09 to 0.42 per cent in the West Zone. These increases seem to be insignificant, but not necessarily so if compared with actual increases previously effected by both concessionaires. More specifically, from 2018 to 2021, the recorded price increases in the East Zone range from Php0.24 (US$0.00048) to Php0.99 (US$0.020) per cu.m.. In the West Zone, the recorded price increases ranges from Php0.06 (US$0.0012) to Php1.48 (US$0.030) per cu.m..[25] The calculated RAUC for both zones are similar to that of the recent water price increases imposed by both concessionaires. These results are consistent with the findings of Chu and Grafton (2021) that indicate that water users with lower price elasticities have a higher willingness-to-pay to avoid any water restriction that can disrupt their daily water consumption.

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[25] These are based on the press releases from both Manila Water (East Zone) and Maynilad (West Zone) for various years.

Chapter 6

Estimating the optimal policy timing for operationalising the Kaliwa Dam

This chapter estimates the optimal time to construct the Kaliwa Dam. The analysis considers two financing scenarios: (i) the public-private partnership (PPP) financing scheme, and (ii) the official development assistance (ODA).

This chapter is organised as follows: The first section discusses the cost-of-service of regulated water services and the economics of the water supply augmentation and optimal timing, which draws on Grafton et al. (2015). The second section applies and calibrates the supply augmentation model to the Kaliwa Dam. It explains the dynamic stochastic model for estimating the optimal timing for the construction of the Kaliwa Dam. The third section presents the results using the PPP and ODA financing schemes under three weather scenarios and the results of the sensitivity analyses on: (i) using different social discount rates; (ii) the varying household growth rates; and (iii) the hot dry weather scenario. The fourth section summarises the key findings while the last section provides the conclusion.

I. Cost-of-service of regulated water services, economics of supply augmentation and optimal timing

Cost-of-service for regulated water services

Water prices are designed to reflect the full cost of the provision of water to consumers, which comprises the operations and maintenance (O&M) and investment payback (Barraquè 2020). When water utilities are regulated, the full cost of water provision is called the 'cost-of-service'. The cost-of-service includes the (i) user costs, (ii) opportunity costs, and (iii) environmental costs that are incorporated in the water tariffs imposed on users (Rogers et al. 1998, Grafton et al. 2014). The user cost and opportunity costs account for potential water scarcity problems, while the environmental costs consider water quality problems (Barraquè 2020). The cost-of-service also considers the cost of water infrastructure capital (Grafton et al. 2014). Barraquè (2020) argues, however, that in developing countries, typically, only the O&M costs are imposed on users to maintain the affordability of water prices.

The funding to cover the cost of capital investment for water infrastructures, typically, comes from (i) tariffs from water users, (ii) taxes from local taxpayers, and (iii) transfers from international donors or from national governments (Libey et al. 2020, Barraquè 2020). These are commonly referred to as the '3Ts' pertaining to water infrastructure investments. Tariffs imposed on users are also used to cover the costs of the repayable financing as well as the full life cycle costs of water service provision (Libey et al. 2020). Nevertheless, there are instances when keeping tariffs low has led to water service providers struggling to recover the O&M costs and to generate a surplus to fund new capital expenditure (Libey et al. 2020, Pories et al. 2019). Consequently, water utilities have grown dependent on the private sector through PPP and ODA to finance the investments for long-term asset management and future capital (Libey et al. 2020).

Although the Philippines is a developing country, the current situation contrasts with Barraquè (2020) in terms of how the water prices are designed. As discussed in Chapter 2, the water services in Metro Manila underwent privatisation due to the government's inability to meet water connectivity and improvement in infrastructure targets. The privatisation of the water services led to concession contracts, which means that the public sector has ownership and rights while the private sector is responsible for providing financial resources and technical expertise (Neville 2011).

Water tariffs allow the concessionaires to have a constant stream of revenues and, at the same time, gather resources for future capital investments. In this case, the concessionaires' expectation is that the capital cost of existing and future infrastructure must be paid for by the households (Grafton et al. 2015). The rate rebasing exercise gives the concessionaires the opportunity to submit their respective business plans that includes proposed expansion plans of water infrastructure to justify tariff adjustments.[1] According to the National Water Resources Board (NWRB 2005), concessionaires are allowed to adjust water prices to cater for new capital investments if the existing assets—including replacement and rehabilitation—cannot meet the required demand. Further, if the capital investments are funded by a secured loan, related accounts should be included in the price projections (NWRB 2005).

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[1] See Chapter 2 for explanation of the rate rebasing.

Economics of supply augmentation and optimal timing

Water supply augmentation is one of the options that many governments around the world adopt to meet increasing future water demand in urban areas. This may include constructing an entirely new water infrastructure or improving an existing one to boost the current water supply. Supply augmentation faces challenges. One is financing—as augmenting water supply entails costs that are, typically, significantly higher than the historical costs of the current assets of water utilities (Whittington et al. 2009). Another challenge is ensuring that the fixed costs of increasing the water supply capacity are partially or fully paid for by imposing a fixed and/or variable component in the corresponding water tariff that water utilities charge (Grafton et al. 2015).

The theoretical frameworks of Scarato (1969), Riordan (1971), and Dandy et al. (1984) examine how the optimal timing of building a water infrastructure is determined by considering the costs and benefits of construction. None, however, consider weather variability. The theoretical framework developed by Grafton et al. (2015) is deemed most suitable for this thesis because its structure allows important factors—such as water inflows influenced by weather conditions—in modelling the dynamic optimisation. Bagtasa (2019) observes that from 1901 to 2018, the average temperatures in Metro Manila rose by 0.12°C per decade while the annual mean rainfall increased annually at a rate of 77.99 millimetre (mm) per decade, resulting in more wet days.[2]

Augmenting the water supply may potentially reduce the limitation on the water supply capacity that consumers experience in times of water scarcity. However, supply augmentation also imposes financing constraints on the consumers. This is because in the perspective of the water concessionaires, the marginal cost of water provision and the fixed cost of existing structure will be paid for by the consumers (Grafton et al. 2015). Moreover, supply augmentation also entails an additional financing constraint on the consumers if they are made to pay for the increased fixed costs. These financing constraints push the water price to be higher and may result in a reduction in the consumer surplus.

A more complete analysis requires the use of water supply augmentation dynamic models that consider both the changes in the supply and demand variables (Grafton et al. 2015). Water

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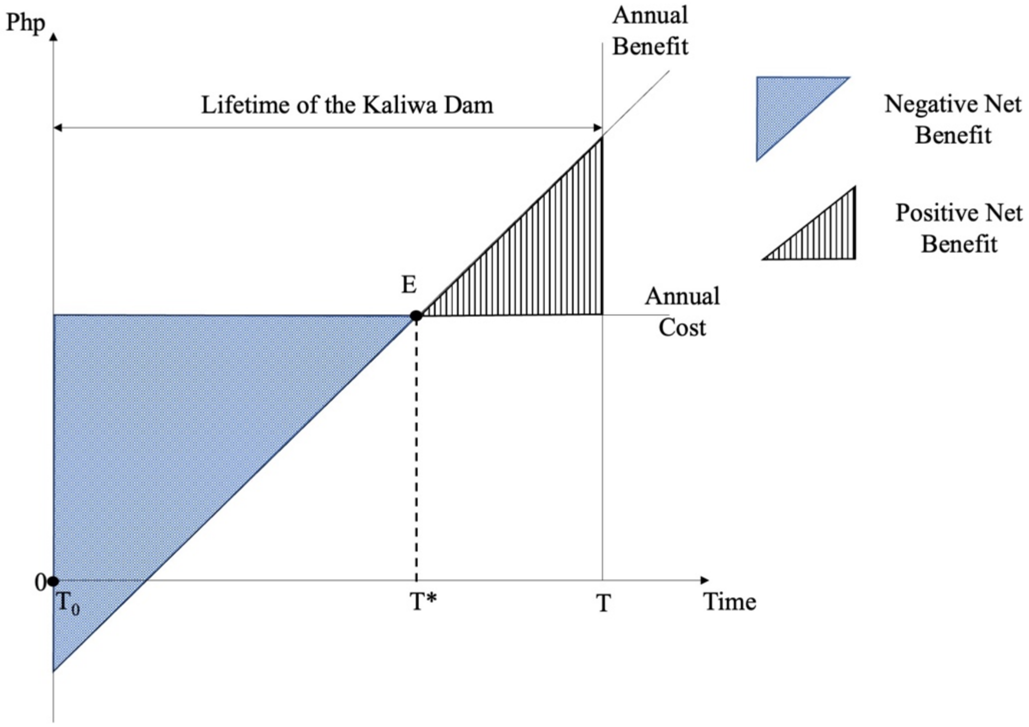
[2] This is given a 99 per cent significance interval in Bagtasa (2019).

inflows are a supply variable because they influence the available water supply in the dam, especially if it is weather-dependent. An increase in the inflows expands the capacity of the dam that, *ceteris paribus*, raises the social surplus. However, the available water supply in the dam is also dependent on the number of households connected to the water system. The increase in the number of connected households results in an increase in water demand, which potentially decreases the capacity in the dam. If the inflows are not able to recharge the water levels in the dam, then it will cause water scarcity problems and can lead to further depletion in water supply levels.

Figure 6.1 illustrates the dynamics of augmenting the water supply. The analysis shows the annual benefit and the cost of augmenting the water supply, where the services associated with the expansion of the capacity starts at time period T_0. Initially, the annual benefit of enlarging water capacity has a negative value since it is assumed that because of the financing constraint, the households pay a significantly higher volumetric price for their water consumption. The higher volumetric price imposed on the consumers covers the expected higher fixed cost. Due to the higher volumetric price, consumers' water consumption is assumed to decrease from their usual water uses before the supply augmentation.

Figure 6.1: Determining the optimal timing for augmenting the water supply of a water infrastructure



Source: Adopted from Grafton et al. (2015).

The urban household population in Metro Manila is growing at an average of 4.1 per cent annually. Given that the household population is increasing, the excess capacity that is associated when the volumetric price is equal to the average cost of supply is expected to decrease over time as more households share the burden of the cost. Moreover, this will generate a consumer surplus where the annual benefits are greater than the annual costs—as compared to the initial case before augmenting the water supply. In Figure 6.1, the annual cost is assumed to be constant and is equal to the annualised capital cost of augmenting water supply—in this case, the Kaliwa Dam. The annual cost of supply augmentation depends on the operational life and the rate of return on the regulated asset base, particularly the discount rate (Grafton et al. 2015).

In Figure 6.1, T* and point E represent the time at which the annual benefit equals the annual cost of supply augmentation. Thus, the time is identified as the optimal timing to augment the water supply and the start of the water supply augmentation. Any succeeding time period after T* will yield positive net benefit in supply augmentation because the annual benefit exceeds the annual cost. In contrast, any period before T* means that the supply augmentation is premature. Grafton et al. (2015) point out that the overall net benefit is the sum of the net economic benefits before T* and the net economic benefits after T* when there is a net benefit from augmenting water supply.

II. Optimal timing for the construction and calibration of the Kaliwa Dam

This thesis applies the discussion in Section 1 and builds a model for the optimal timing when water supply should be augmented through the Kaliwa Dam. It is important to evaluate how the annual benefit of building an additional dam for the water supply in Metro Manila will change through time. To determine the optimal timing for the supply augmentation, this thesis considers two alternative financing schemes—the PPP and the ODA. It also examines the sensitivity of the results to different social discount rates. Evaluating the annual benefit through time requires a model that can capture the demand and supply uncertainties. In this thesis, these uncertainties are (i) the household population growth, (ii) the weather variations, and (iii) the marginal cost of both PPP and ODA financing schemes.

The dynamic model specification

The model formulation begins by introducing the golden rule in estimating the optimal time to operationalise a water supply augmentation. Grafton et al. (2015) introduce the golden rule dynamic model that estimates the optimal time, T*, to start the supply augmentation, which is shown in *Equation 6.1*. The left-hand side of this equation is the annual benefit of supply augmentation, which is the difference in the annual social surplus between the scenario cases of 'with' and 'without' the Kaliwa Dam. The right-hand side is the annualised expenditure of Kaliwa Dam. If the left-hand-side is less than the right-hand side, this means that the Kaliwa Dam was built prematurely. Otherwise, the Kaliwa Dam generates a positive net benefit to the society. Table 6.1 describes each of the variables and parameters in *Equation 6.1*.

$$U^{aug}(H_t) - U^{bau}(H_t)|_{t=T^*} = \frac{\rho}{1-\left(\frac{1}{1+\rho}\right)^T} CK_j^{aug} \qquad Eq. 6.1$$

Table 6.1: Parameters of the golden rule dynamic model

Variable/parameter	Name	Description
H_t	Household population	Household population, since one connection is for one household.
$g(H_t)$	Household population growth rate	Growth rate of the population.
$U^{aug}(.)$	Annual net social surplus with augmentation	The annual net social surplus (social surplus net of variable costs of water supply), at time t, with supply augmentation.
$U^{bau}(.)$	Annual net social surplus for business-as-usual case	The annual net social surplus (social surplus net of variable costs of water supply), at time t, at the business-as-usual case, where the Kaliwa Dam has not yet been built.
ρ	Social discount rate	The social discount rate, which is set by the National Economic Development Authority (NEDA) for all infrastructure projects.
CK_j^{aug}	Capital cost	Capital cost of Kaliwa Dam for ODA or PPP.
T	Planning horizon (in years)	Planning horizon of Kaliwa Dam, which is 100 years.

ODA = official development assistance, PPP = public private partnership.
Sources: Author and based on Grafton et al. (2014).

The dynamic optimisation problem defines the state variable, $E(s_t)$, as the average disposable water supply in Angat Dam at time t, which is given by *Equation 6.2*. The average disposable water supply is the water supply that can be allocated to the households, net of the non-domestic water allocation, which comprises the irrigation and environmental flows.[3] *Equation 6.2* is

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[3] The Angat Dam has an allocation for irrigation water for the nearby provinces. Thus, irrigation water had to be subtracted in the state variable to compute for the disposable water available for Metro Manila.

based on the Angat Reservoir mass balance equation that Libisch-Lehner et al. (2019) introduced specifically for the said water storage.[4]

$$E(s_t) = \max\left(\min\{s_{t-1} + I(W_t) - envi_t - irr_t(W_t), \overline{D}\}, 0\right) \qquad Eq. 6.2$$

The $E(s_t)$ is taken as the minimum between the water storage at the previous time period, s_{t-1}, plus the inflows that are dependent on weather factors, $I(W_t)$, net of the irrigation flows that are dependent on weather factors, $irr_t(W_t)$, the environmental flows, $envi_t$, and the dam capacity, $\overline{D}$.[5] The irrigation flows are weather-dependent because the demand for irrigation water varies depending on the season, which usually peaks during the dry season (Libisch-Lehner et al. 2019). Instead of the loss from evaporation of Libisch-Lehner et al. (2019) and Grafton et al. (2015), this thesis uses the environmental flows from the World Bank (2012).[6] Environmental flows are considered in the allocation from the Angat-Umiray River system. The NWRB preserves the environmental flows in the current water storage to maintain the quasi-natural flow condition, thus, maintaining the dependable flows in existing and proposed storage dams (World Bank 2012). The configuration in *Equation 6.2* specifies that water supply can be depleted, but $E(s_t)$ cannot have a negative value.[7]

The next step is to define the per household water-demand function. This thesis only considers the water demand by households because they comprise a significant number of customers connected to the water services of the concessionaires. More specifically, households comprise 91.4 per cent of the customers in the East Zone and 92.6 per cent in the West Zone.[8] Two water-demand functions are included because there are two available water sources that households in Metro Manila can access. The first water-demand function is the household water demand for the water services, or piped water, from the concessionaires. This demand function does not classify water use into indoor and outdoor water use. Instead, the water-demand equation considers only one component as shown in *Equation 6.3*. The per household water demand for the piped water, $q(p)$, is estimated using the parameter for water demand for water services,

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[4] The Angat Reservoir is governed by the rule curve, wherein the water released to the MWSS concession areas and to the irrigation districts is based on the current water level (NWRB 2009).

[5] Dams can only hold a certain amount of water. If water levels are above the capacity of dams, water is released to avoid dam failure.

[6] According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the agency does not have any data on the evaporation rates in Angat Dam. Using the evaporation rate in other areas will yield less precise estimates.

[7] Although the critical level in Angat Dam is 160 metres, the NWRB and the MWSS do not completely cut off the allocation for Metro Manila. Instead, as mentioned in Chapter 5, the flows are reduced. This is to abide with the concession agreement that households should have water services 24/7.

[8] See Appendix 7, section A7.2 for further explanation on the household and non-household consumers.

W_1, the price of water, p_w, and the water-demand elasticity, ε_w. The values for the ε_w are taken from the estimated long-run elasticities that this author estimated in Chapter 4. Separate analyses are done for each concession area because they have different water prices and demand elasticities.

$$q(p) = W_1 p_w^{-\varepsilon_W} \qquad Eq. 6.3$$

The other water-demand equation is the backstop technology when piped water is insufficient. In the case of Metro Manila, the water refilling stations act as the backstop technology. In times of restricted water supply from the concessionaires (and with the Kaliwa Dam not yet built), the water refilling stations provide some of the needed water supply for households. ADB (2016) points out that residential households tend to buy bottled water from the water refilling stations if there are water interruptions. Appendix 6 explains how the household water-demand elasticities for water from refilling stations were calculated using the FIES datasets.

Equation 6.4 differs from *Equation 6.3* because the per household water demand for water from refilling stations, q^*, is dependent on (i) the parameter for water refilling station demand, W_2; (ii) the prices imposed by the water refilling stations, p_R; and (iii) the water-demand elasticity for water refilling stations, ε_R, which was also estimated by the author.

$$q^*(p) = W_2 p_R^{-\varepsilon_R} \qquad Eq. 6.4$$

Two scenarios are considered in estimating the optimal time for operationalising the Kaliwa Dam. The first scenario is the business-as-usual (BAU) case, which assumes that the only water supply available to the households comes from the Angat Dam and the alternative option is to use the water refilling stations. The second scenario considers the addition of the Kaliwa Dam in the urban water supply for Metro Manila.

To solve the dynamic optimisation problem, the sum of the total social surplus is maximised, in present value terms, over the planning horizon of 100 years (see *Equation 6.5*). The planning horizon of 100 years is set by the Philippine national government specifically for the Kaliwa Dam (EMB 2014) and the solution gives (i) the optimal household water consumption from the Angat Dam, (ii) the optimal consumption of backstop water for each year, and (iii) the efficient volumetric price. *Equation 6.6a* shows the dynamic optimisation problem—to compute for the $U^{bau}(H_t)$ in *Equation 6.1*. Appendix 7, section A7.3 includes the mathematical proof of how the social surplus, SS_t^{HH}, is estimated algebraically.

The BAU case (no water supply augmentation) is represented in the following equations:

$$SS_t^{HH} = \int_{p_w}^{p_R} q(p)dp - [(A_t c_d + R_t c_R) - q^* c_R] \qquad Eq. 6.5$$

$$U^{bau}(H_t) = max_{<A_t, R_t>} H_t SS_t^{HH} \quad subject\ to \qquad Eq. 6.6a$$

$$Q_t = H_t A_t + H_t R_t \qquad Eq. 6.6b$$

$$0 \leq H_t A_t \leq E(s_t) \qquad Eq. 6.6c$$

$$H_t[(p_w A_t + p_R R_t) - (A_t c_d + c_R R_t)] \geq FC_t^{non-aug} \qquad Eq. 6.6d$$

The first term in the right-hand side of *Equation 6.5* is the consumer surplus and the second term is the marginal cost of supplied water. In the second term, c_d is the cost of supplying water by the water concessionaires and is assumed to be equal to the average basic charge imposed on the households. The backstop technology cost, c_R, is the cost of supplying water from the water refilling stations. The parameter A_t is the water supply allocated to households from the Angat Dam, while R_T is the water supply from water refilling stations. The q^* represents the quantity of water supplied from water refilling stations if there is insufficient water supply from the Angat Dam. The c_R is the marginal cost in MCM of water supplied by water refilling stations.

Equation 6.6a describes the maximised overall household benefit that is based on (i) each point in time, (ii) the water prices of each concessionaire at time *t*, and (iii) the water storage from the Angat Dam and water refilling stations. *Equations 6.6b–6.6d* are the constraints in maximising the social surplus without supply augmentation. *Equation 6.6b* is the total water supply that the households can use from the possible water sources present. It is the sum of the total water demand for the water services, $H_t A_T$, and the total water demand for water refilling stations, $H_t R_T$. *Equation 6.6c* states that $H_t A_t$ cannot exceed the amount of water available in Angat Dam vis-à-vis what is available for domestic consumption, $E(s_t)$. This constraint examines the outcome if the net inflows are sufficient to replenish the storage in Angat Dam.[9] *Equation 6.6d* is the financing constraint that specifies that (i) the revenues from tariff collections of the concessionaires, $(p_w A_t)$; (ii) the water refilling stations, $(p_R R_t)$; and (iii) the net of the variable costs of the water suppliers, $(A_t c_d + c_R R_t)$, are able to cover the fixed cost of supplying water to the households, $FC_t^{non-aug}$. This ensures that the water concessionaires and the water refilling stations can make a profit from supplying water to the households. In

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[9] Net inflows are computed as $I(W_t) - irr_t - envi_t$ component in *Equation 6.2.*

addition, it is assumed that water refilling stations pay the fixed cost of producing their water services.[10]

The dynamic optimisation is extended by including the Kaliwa Dam as an additional source of water supply. The framework is similar to the BAU scenario, but with the inclusion of an additional constraint and the annualised cost of constructing the Kaliwa Dam. *Equation 6.7* shows the social surplus that includes the Kaliwa Dam, while *Equations 6.8a–6.8e* are the constraints.

The water supply augmentation case (with Kaliwa Dam) is represented in the following equations:

$$SS_t^{HH} = \int_{p_w}^{p_R} q(p)dp - [((A_t + K_t)c_d + R_t c_R) - q^* c_R] \qquad Eq. 6.7$$

$$U^{aug}(H_t) = max_{<A_t,R_t,K_t>} H_t SS_t^{HH} \quad subject\ to \qquad Eq. 6.8a$$

$$Q_t = H_t A_t + H_t K_t + H_t R_t \qquad Eq. 6.8b$$

$$0 \leq H_t A_t \leq E(s_t) \qquad Eq. 6.8c$$

$$\begin{aligned} H_t[(p_w(A_t + K_t) + p_R R_t) - ((c_d(A_t + K_t)) + c_R R_t)] \\ \geq FC_t^{non-aug} + CK \end{aligned} \qquad Eq. 6.8d$$

$$H_t[A_t + K_t] \leq Cap^{aug} \qquad Eq. 6.8e$$

To estimate the social surplus in *Equation 6.7*, c_d represents the cost of supplying water from Angat and Kaliwa dams. The cost of supplying water from both the Kaliwa and Angat dams is assumed to be the price of water imposed on households, hence, $c_d = p_w$. *Equation 6.8a* is similar to the value function of the BAU case, but the water supply from Kaliwa Dam, alongside with the water supply from the Angat Dam and the water refilling stations, is also maximised. In *Equation 6.8b*, the total water supply for Metro Manila includes the water supplied to the households from the Kaliwa Dam. *Equation 6.8c* is the same as *Equation 6.6c* in that the allocated water for domestic consumption should not exceed the water that is available at Angat Dam.

The financing constraint in *Equation 6.8d* includes the cost of supplying water from both dams. Thus, the fixed cost with supply augmentation is the sum of the fixed cost without

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[10] According to the Department of Trade and Industry (DTI), the direct cost of providing water services is Php58,356.15 (US$1,222.34) per month. Indirect costs, or overhead costs, are Php18,570.61 (US$389.00) per month.

augmentation and the annualised cost of constructing the Kaliwa Dam (CK). In the analysis, the CK is different for the PPP and the ODA financing schemes. The government's purpose to switch from PPP to ODA financing is to reduce the cost of capital for building the Kaliwa Dam. Although the specifications of the dam are the same, the Department of Finance (DOF 2019) claims that after the negotiations with the government of the People's Republic of China (PRC), the total cost went down from Php18.50 billion (US$413.20 million) for the PPP financing scheme to Php12.19 billion (US$233.55 million) for the ODA financing scheme.[11]

The financing constraint has two assumptions on the distribution of the total cost of capital. The first assumption is that in the PPP financing scheme, the total cost of Php18.50 billion will be paid through household financing. According to EMB (2014), the project's revenues only come from the amortisation payments of the MWSS, which cover the cost of construction, financing the project, and the return on investment. The National Economic and Development Authority (NEDA) Board approved a water security charge (WSC) as a payment mechanism. Originally, the WSC would be charged to the water users in Metro Manila and collected by Manila Water and Maynilad. However, the WSC is not included in this thesis as the analysis computes the efficient price that follows Grafton et al.'s (2015) framework. The analysis assumes that households in the east cover 40 per cent of the total cost and 60 per cent for the West Zone.[12] Thus, the East Zone pays Php7.40 billion (US$0.15 billion) while the West Zone pays Php11.10 billion (US$0.23 billion).

The second assumption is that in the ODA financing scheme, the total cost of the Kaliwa Dam amounts to Php12.20 billion (US$0.25 billion) (DOF 2019). The China Eximbank provides the Philippine Government with a soft loan that is equivalent to 85 per cent (Php10.40 billion or US$0.21 billion) of the total cost while the Philippine Government finances the remaining 15 per cent (Php1.80 billion or US$ 0.04 billion).[13] However, the total cost of the project is passed on to the consumers through the government's public financing. Similar to the PPP financing scheme, it is assumed that households in the East and West Zones pay 40 per cent and 60 per cent of the total cost, respectively, based on their respective water allocation. Unfortunately,

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[11] See <https://www.dof.gov.ph/oda-financing-on-kaliwa-dam-project-to-benefit-consumers-with-cheaper-project-financing-costs/>

[12] No information is publicly available on how the costs will be split up. Thus, to be consistent with the allocation of the water supply to Metro Manila, the analysis assumes such case.

[13] See <https://mwss.gov.ph/why-the-ncws-kaliwa-dam-instead-of-the-japanese-proposed-kaliwa-weir-project/ and https://www.dof.gov.ph/oda-financing-on-kaliwa-dam-project-to-benefit-consumers-with-cheaper-project-financing-costs/>.

there is no specific monetary amount or a tax equivalent, similar to the WSC, that is included in the analysis due to the Philippine Government's aggregate approach in budgeting and in the decision making on paying for the loans from foreign-funded projects.[14] Thus, the East Zone pays Php4.87 billion (US$0.10 billion) while the West Zone pays Php7.31 billion (US$0.15 billion) of the total cost.

The additional constraint in the supply augmentation case is shown in *Equation 6.8e*, which states that the water supplied to households, $H_t(A_t + K_t)$, should not exceed the total water supply capacity of both Angat and Kaliwa dams. This thesis further assumes that the discharge capacity of the Kaliwa Dam, which is 600 MLD, or 219 MCM/year, is the total allowable consumptive flows allocated for domestic use. Furthermore, the analysis assumes that the inflows into the Kaliwa Dam from the Kaliwa River can maintain the storage's capacity. This assumption is made because the recorded flows from the Kaliwa River are not publicly available and there are data constraints.

The numerical parameters in estimating the optimal timing of operationalising the Kaliwa Dam—using the specific values for the ODA and PPP financing schemes—are shown in Table 6.2. Just to simplify, the marginal cost of supplying dam water is the reported average basic price that each concessionaire publicly reports annually. Most of the parameters in the PPP financing scheme, except for the social discount rate and the capital cost, are utilised in the ODA financing scheme analysis.[15] This is because the Metropolitan Waterworks and Sewerage System (MWSS) has not made publicly available most of the important parameters for the ODA financing scheme. According to the Environmental Management Bureau (EMB 2014), it would take 5 years to complete the construction of the Kaliwa Dam.

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[14] National Budget Circular No. 581 <https://www.dbm.gov.ph/index.php/258-national-budget-circular-2020/1788-national-budget-circular-no-581>.

[15] This was done due to the lack of public data available on the parameters that were set using the ODA financing scheme.

Table 6.2: Numerical parameters

Parameter symbol	Parameter name	Parameter values
ρ	Social discount rate (both were determined using the SOC method) [a]	PPP: 15% ODA: 10%
CK_j^{aug}	Capital cost of Kaliwa Dam	PPP: Php18.50 billion (US$413.20 million) [b] ODA: Php12.19 billion (US$233.55 million)
$\bar{D}$	Angat Dam discharge capacity	4,000 MLD or 1,460 MCM/year Manila Water: 1,600 MLD or 584 MCM/year Maynilad: 2,400 MLD or 876 MCM/year
Cap^{aug}	Additional total capacity	PPP and ODA: 4,600 MLD or 1,679 MCM/year (additional 600 MLD or 219 MCM/year capacity from Kaliwa Dam)
T	Planning horizon	100 years
I_t	Inflows	Weather scenario 1 (low inflows): 1,950.49 MCM Weather scenario 2 (normal inflows): 2,462.67 MCM Weather scenario 3 (high inflows): 2,561.60 MCM (Based on the 10-year recorded inflows from 2010 to 2019 from PAGASA)[d]
irr_t	Irrigation flows	Estimated by the author (different values for each year)
$envi_t$	Environmental flows	Approximately 59.95 MCM
c_d	Marginal cost of supplying dam water or average basic charge [c]	Manila Water: Php28.52 (US$0.59/cu.m.) (2019 prices) Maynilad: Php36.24 (US$0.75/cu.m.) (2019 prices)
c_R	Marginal cost of supplying water from water refilling stations	Php129.93 (US$2.54/cu.m.) (2019 prices)
W_1	Demand coefficient for water services	Manila Water: 0.00326 Maynilad: 0.01022
W_2	Demand coefficient for water refilling stations	Manila Water: 0.08182 Maynilad: 0.01604
ε_w	Household water-demand elasticity for water concessionaires	Manila Water: –0.721 Maynilad: –0.994
ε_R	Household water-demand elasticity for water refilling stations	Manila Water: –0.691 Maynilad: –0.664
H_t	Number of households	Manila Water: 1,311,066 (2019) and growing at 1.66% annually Maynilad: 1,346,741 (2019) and growing at 3.62% annually

MCM = million cubic metres; MLD = million litres per day; ODA = official development assistance; PAGASA = Philippine Atmospheric, Geophysical and Astronomical Services Administration; Php = Philippine peso; PPP = public-private partnership; SOC = social opportunity cost; US = United States.

[a] In the Philippines, the NEDA-ICC estimates the social discount rate using the marginal social opportunity cost of capital method.

[b] Using the 31 December 2014 exchange rate.

[c] The marginal cost is based on the average basic charge that both concessionaires impose on their respective concession zones and is publicly reported.

[d] Categories are based on the recorded rainfall.

Sources: Author's calculation, MWSS, EMB (2014), and the World Bank (2012).

III. Results and discussions

This section discusses the results using the dynamic model and calibration discussed in the previous section. The analyses include the optimal timing under weather scenario 1 (low inflows), weather scenario 2 (normal inflows), and weather scenario 3 (high inflows), assuming that the variations are based on the calculated rainfall variation values of the representative concentration pathways (RCP) 8.5 high emissions scenario.[16] The optimal timing analysis is

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[16] Sumabat et al. (2016) point out that the country's economic growth has led to an increase in emissions. Thus, the RCP 8.5 is chosen in the sensitivity analysis.

done separately for the East and West Zones because they charge different water tariffs on the households in their respective concession areas and they also have different estimated household water-demand elasticities.[17]

The first part discusses the optimal timing of operationalising the Kaliwa Dam using the PPP financing scheme and the second part using the ODA financing scheme. The third part discusses the weather realisations, the efficient price, and the inclusion of the Kaliwa Dam. The fourth part presents the sensitivity analyses, which are the 10.0 per cent social discount rate for the PPP, the 5.2 per cent social discount rate for both financing schemes, the slower and faster household growth rates, and the hot dry weather scenario.

Analysing and comparing the optimal timing between the PPP and ODA

To determine the optimal time for operationalising the Kaliwa Dam under the PPP scheme, the annual benefits and costs are estimated under the following assumptions—the 100-year weather scenario 1 (low inflows), weather scenario 2 (normal inflows), and weather scenario 3 (high inflows). Based on the Philippine Government's proposal, the Kaliwa Dam has a 100-year life span with a discount rate of 15 per cent under the PPP scheme (EMB 2014). On the other hand, the social discount rate under the ODA scheme is 10 per cent as mandated by the NEDA-Investment Coordination Committee (ICC) for all projects after September 2016.[18] The analyses are done separately for each concession zone as well as for each financing scheme. Table 6.3 shows the estimates of the optimal timing for both schemes and concession zones. Appendix 8 shows the graphical estimates.

The results show that the optimal timing for each concession zone and financing schemes are different. However, in all cases, the optimal time to operationalise the Kaliwa Dam is based on the estimates of the West Zone. The optimal time is estimated to be at 2042 under the ODA scheme and at 2043 for the PPP scheme. The lower cost and social discount rate of the ODA results in an earlier optimal time by one year.

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[17] The estimated price demand elasticities were estimated in Chapter 4.

[18] The social discount rates are set by the Philippine Government. Appendix 5, section A5.1 has a thorough explanation as to why the social discount rates are high for developing countries like the Philippines.

Table 6.3: Optimal timing to operationalise the Kaliwa Dam under the PPP and ODA schemes

Kaliwa Dam's optimal timing	PPP financing scheme	ODA financing scheme
	ρ=15%	ρ=10%
Weather scenario 1 (low inflows)		
East zone (Manila Water)		
Year	2047	2045
Change in social surplus (in Php billion)	1.28	0.1
Number of households at optimal time (in million)	2.08	2.01
Time when Angat Dam will be insufficient	2045	2045
Time when Angat + Kaliwa Dam will be insufficient	2054	2054
West zone (Maynilad)		
Year	2043	2042
Change in social surplus (in Php billion)	1.72	0.15
Number of households at optimal time (in million)	3.16	3.05
Time when Angat Dam will be insufficient	2042	2042
Time when Angat + Kaliwa Dam will be insufficient	2046	2046
Weather scenario 2 (normal inflows)		
East zone (Manila Water)		
Year	2047	2045
Change in social surplus (in Php billion)	1.28	0.1
Number of households at optimal time (in million)	2.08	2.01
Time when Angat Dam will be insufficient	2045	2045
Time when Angat + Kaliwa Dam will be insufficient	2054	2054
West zone (Maynilad)		
Year	2043	2042
Change in social surplus (in Php billion)	1.72	0.15
Number of households at optimal time (in million)	3.16	3.05
Time when Angat Dam will be insufficient	2042	2042
Time when Angat + Kaliwa Dam will be insufficient	2046	2046
Weather scenario 3 (high inflows)		
East zone (Manila Water)		
Year	2047	2045
Change in social surplus (in Php billion)	1.28	0.1
Number of households at optimal time (in million)	2.08	2.01
Time when Angat Dam will be insufficient	2045	2045
Time when Angat + Kaliwa Dam will be insufficient	2054	2054
West zone (Maynilad)		
Year	2043	2042
Change in social surplus (in Php billion)	1.72	0.15
Number of households at optimal time (in million)	3.16	3.05
Time when Angat Dam will be insufficient	2042	2042
Time when Angat + Kaliwa Dam will be insufficient	2046	2046

Source: Author’s calculations.

The results show that water-demand elasticities influence the net benefit that households obtain from the additional water source, which is the Kaliwa Dam. The water-demand price elasticity in the West Zone is higher than that in the East Zone. Although the water-demand elasticity of the East Zone is lower than that of the West Zone, the number of households and the increase in households is much greater in the West Zone. Thus, the increase in water demand for the allocation in the West Zone is much greater than the increase in the East Zone.

Although the optimal timing for each concession area varies, the concession agreement does not allow water allocation transfers between the concessionaires, which is a regulatory constraint. In *Equations 6.6b, 6.6c, 6.8b, and 6.8c*, the water supplied from the dams is based on the water allocation for each of the concession area. If the water supply becomes insufficient in one of the concession areas, the water allocation between Maynilad and Manila Water cannot be adjusted.

The results highlight two important observations. The first observation is that by 2042, Angat Dam's water supply will not be able to meet the water demand without supply augmentation and the estimated optimal time to operationalise the Kaliwa Dam is also 2042. This means that positive net benefits will be realised by the households when the additional storage will be operational. The second observation is that the total water supply coming from both the Kaliwa and Angat dams will be insufficient to meet the water demand by 2046. Although, the Kaliwa Dam can be expanded from 600 MLD (219 MCM/year) to 2,400 MLD (875 MCM/year) if the need arises, it must be noted that the analysis in this thesis only focuses on the optimal time to operationalise the Kaliwa Dam and not its optimal capacity.[19] Should additional water supply from the Kaliwa Dam no longer meet future demand for water, and that no other water augmentation is put in place, the concessionaires and the MWSS may consider applying a demand management tool such as the RAUC discussed in Chapter 5. Specific plans regarding the phases of the expansion are also not yet determined by the government since the Kaliwa Dam is supposed to address the immediate water supply concern in Metro Manila, given an assumed price. This thesis is also not concerned with determining the optimal capacity for the additional water supply as this will entail estimating additional costs that cannot be determined due to lack of data. Figure 6.2 shows the estimated water demand and water supply from 2040 to 2060.

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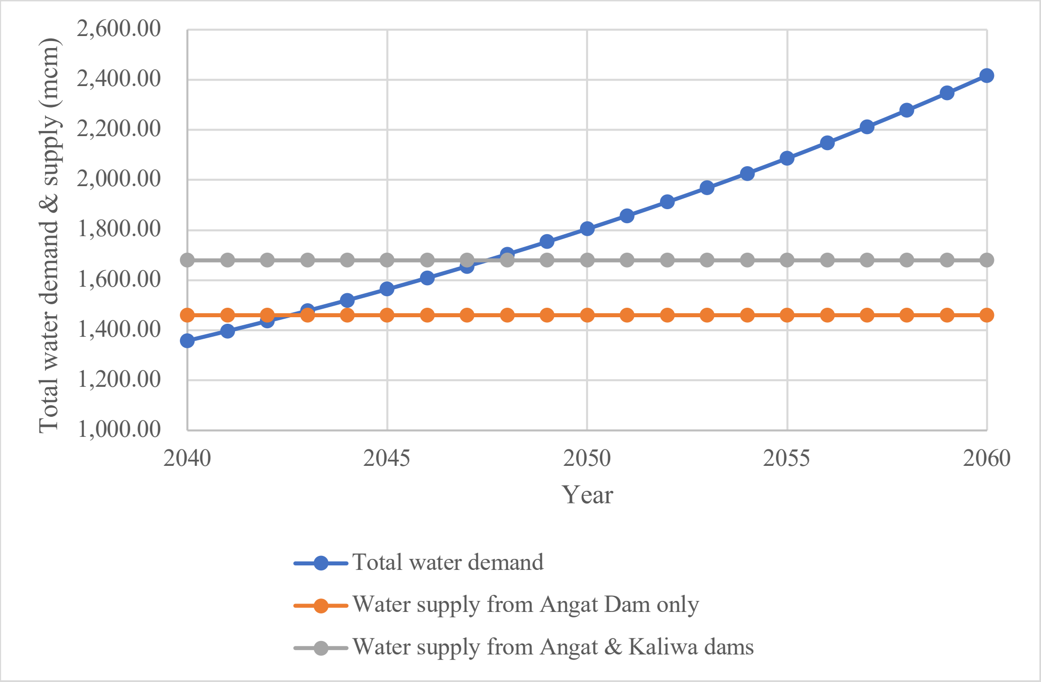
[19] See: <https://mwss.gov.ph/why-the-ncws-kaliwa-dam-instead-of-the-japanese-proposed-kaliwa-weir-project/>.

Figure 6.2: Estimated water demand and water supply, 2040–2060



MCM = million cubic metres.
Source: Author's calculations.

Although the expectation is that the optimal timing would be sensitive to the weather scenarios, the results suggest otherwise. The results across each scenario are marginally different, if not the same. Table 6.4 shows that the capacity of the Angat Dam from 2010 to 2019 remained above 80 per cent of the maximum capacity of the current water storage, noting that the dam is operating at a critical level if the water elevation reaches 160 metres, or approximately 75.5 per cent of the total capacity. During the years 2010, 2014, 2015, 2016, 2017, and 2019—which were identified as the dry years—the average annual water level remained above the critical level.[20] With the exception of 2010 and 2019, the average water level during the dry years was at least 90 per cent of the total storage capacity. This supports the results of the simulation, as well as the claims of NWRB (2021), that there is sufficient water supply coming from Angat Dam during the dry season. However, it is also noted that there were one or two days within the year that the water levels almost reached the critical water level. The water level rises to its normal operating levels in the second half of the year due to the monsoon and typhoon season.

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[20] Aside from the monsoon rains, PAGASA reported that Metro Manila was affected significantly by one tropical depression, one severe tropical storm, Typhoon Doksuri, and Tropical Storm Haikui, which brough significant amounts of rainfall in the region and in the province where Angat Dam is located <http://bagong.pagasa.dost.gov.ph/>.

Table 6.4: Annual inflows, average annual water level, volume of water, and percentage capacity in Angat Dam, 2010–2019

Year	Annual inflows (MCM/year)	Average annual water level (masl)	Estimated annual volume of water in Angat Dam (MCM)	Per cent of the maximum capacity of Angat Dam[21]
2010*	1,389.87	181.77	728.8	85.7
2011	2,874.14	203.10	814.3	95.8
2012	2,462.67	204.75	820.9	96.6
2013	2,591.40	202.46	811.8	95.5
2014*	1,888.57	190.87	765.3	90.0
2015*	1,952.62	194.13	778.4	91.6
2016*	2,063.89	196.85	789.3	92.9
2017*	2,620.92	200.03	802.0	94.4
2018	2,219.25	202.35	811.3	95.4
2019*	1,787.07	186.45	747.6	88.0

masl = metres above sea level, MCM = million cubic metres.
Note: * = identified as the dry years are El Niño years.
Sources: National Power Corporation (NAPOCOR); Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA); and author's calculations.

Analysis on the estimated efficient price

The dynamic optimisation estimates the efficient price under two case scenarios—the 'with' and 'without' supply augmentation for both the east and the West Zones. The estimated efficient user price is computed from the interaction between the water demand and the available water supply at time *t*. As expected, when the total household water demand exceeds the total water supply, the price of water increases. It is also noteworthy that the behaviour of the efficient price is the same across the different weather scenarios. This is because the results of the optimal time are insensitive to the various weather scenarios in both concession zones.

In the East Zone, when the water demand will exceed the water supply allocation in 2045— in the absence of the Kaliwa Dam scenario—households will have to pay an average basic charge of Php28.63 (US$0.59) per cu.m., which is slightly higher than the 2019 basic charge of Php28.52 (US$ 0.59) per cu.m.. However, as water demand increases while water supply remains the same, the efficient price increases over time and the difference in the efficient price between the 'with' and 'without' Kaliwa Dam widens (see Figure 6.3). The price increase will

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[21] The volume was estimated by the author as NAPOCOR only reports the water levels in the Angat Dam.

only be delayed when the addition of the Kaliwa Dam into the urban water system can meet the increasing water demand in Metro Manila until 2054.

Figure 6.3: Efficient water price for the East Zone (PPP)

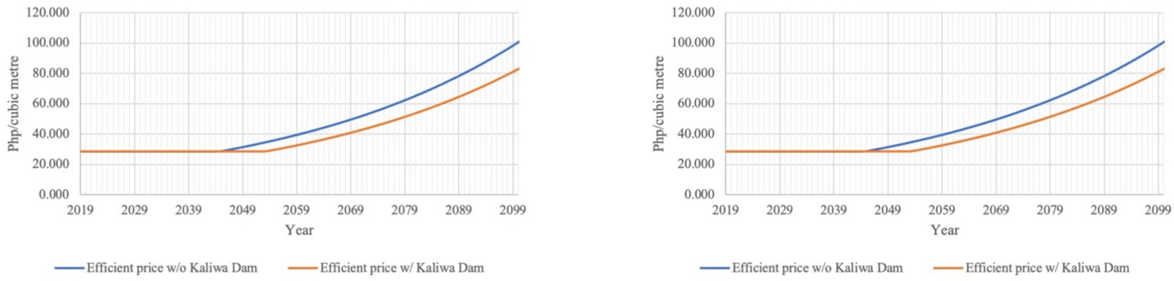


Figure 6.3a Efficient price under weather scenario 1 (low inflows) for the East Zone

Figure 6.3b Efficient price under weather scenario 2 (normal inflows) for the East Zone

Figure 6.3c Efficient price under weather scenario 2 (high inflows) for the East Zone

Source: Author's calculations.

Figure 6.4: Efficient water price for the West Zone (PPP)

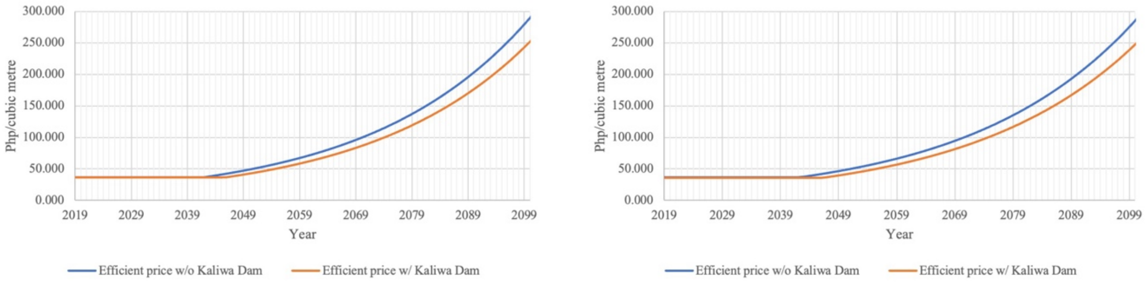


Figure 6.4a Efficient price under weather scenario 1 (low inflows) for the West Zone

Figure 6.4b Efficient price under weather scenario 2 (normal inflows) for the West Zone

Figure 6.4c Efficient price under weather scenario 3 (high inflows) for the West Zone

Source: Author's calculations.

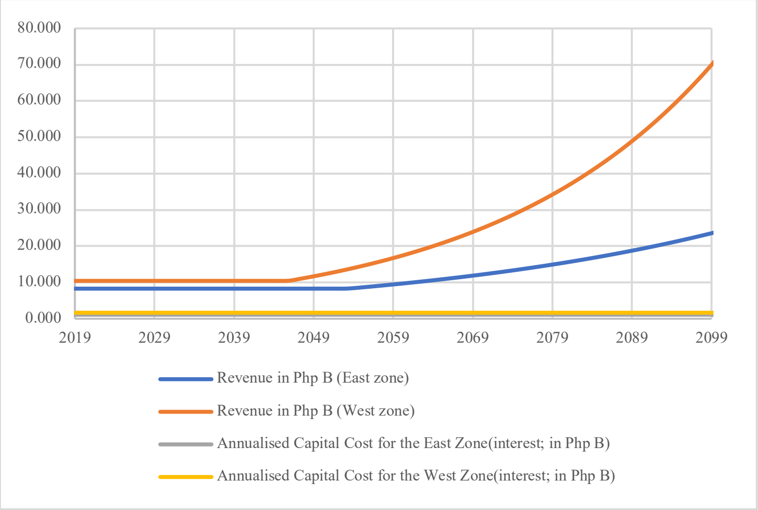
In the West Zone, the average basic charge increases depending on the weather scenario—without the supply augmentation (see Figure 6.4). Under weather scenario 1 (low inflows), the average basic charge slightly increases from Php36.24 to Php36.37 (US$0.75) per cu.m. in 2042. After 2042, the price increases over time when the water demand exceeds the water supply. In both the normal and wet weather scenarios, the average basic charge, which both the concessionaires publicly report, increases from Php36.24 to Php37.09 (US$0.77) per cu.m. in 2042. Similarly, the price increases over time after 2042 when the water supply becomes insufficient to meet the growing water demand.

Figures 6.3 and 6.4 present an important result—that the efficient price increases even if the Kaliwa Dam has been built. This is consistent with the finding mentioned earlier that the designed capacity of the Kaliwa Dam will be insufficient in a few years after its optimal time to be operational. In the East Zone, the efficient price will increase from Php28.52 to Php28.97 (US$0.60) per cu.m. in 2054 for all three weather scenarios. In the West Zone, the efficient price for weather scenario 1 (low inflows) will increase from Php36.24 to Php36.46 (US$0.75) per cu.m. in 2046. In both normal and wet weather scenarios, the average basic price will increase from Php36.24 to Php37.18 (US$0.77) per cu.m. in 2047. Likewise, the average basic price will increase in the succeeding years if no expansion is done in the Kaliwa Dam.

Analysis on the total revenue of the concessionaires and the total cost of the Kaliwa Dam

The estimated annual revenues of both concessionaires are compared with their respective annual capital cost for the 100-year planning period for both PPP and ODA schemes. Under the PPP scheme, the cost of capital for the Kaliwa Dam is lower as compared to the estimated revenue of both concessionaires using the estimated efficient price (see Figure 6.5). In the East Zone, the estimated total revenue of Manila Water is Php8.30 billion, or US$0.16 billion, considering the estimated efficient price until 2053. The total revenue increases as the efficient price increases after 2054 when the Kaliwa Dam will need to be expanded. Similarly, in the West Zone, the estimated total revenue of Maynilad is Php10.44 billion, or US$0.21 billion, considering the estimated efficient price until 2045. Consequently, the total revenue of Maynilad increases as the efficient price increases after 2046 when the Kaliwa Dam will need to be expanded.

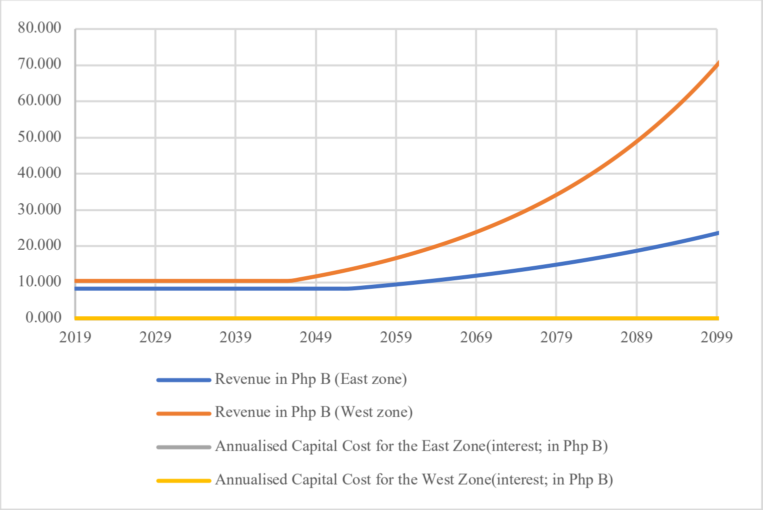
Figure 6.5: Comparing the total revenue and the annualised capital cost under the PPP scheme



PPP = public-private partnership.
Source: Author's calculations.

The results are also similar under the ODA financing scheme, as shown in Figure 6.6. The revenues of both concessionaires do not change because the revenue is dependent on the estimated efficient price. The behaviour of the efficient price and the total revenues of each concession zone is the same as with that of the PPP financing scheme. The only difference is the annualised cost of capital, which is lower in the ODA financing scheme than in the PPP financing scheme. The results suggest that the total revenues of the concessionaires are higher than the annualised capital cost to build the Kaliwa Dam.

Figure 6.6: Comparing the total revenue and the annualised capital cost under the ODA scheme



Source: Author's calculations.

Sensitivity analyses

This section discusses the results of the sensitivity analyses. Four sensitivity analyses were performed, as follows: (i) setting the PPP financing scheme's social discount rate at 10.0 per cent and 5.2 per cent for both the PPP and ODA financing schemes, (ii) setting slower and faster household growth rates, (iii) considering the hot dry weather scenario and the lowest recorded water level, and (iv) operationalising the Kaliwa Dam in 2025.

Change in discount rates

The sensitivity analyses conducted aim to investigate if optimal timing would change if the social discount rates were lowered. Grafton et al. (2014) explain that given a long operational life, a lower discount rate increases the desirability of water supply augmentation. The first sensitivity analysis sets the social discount rate of the PPP scheme to 10 per cent. The second analysis sets the social discount rate of both the PPP and ODA at 5.2 per cent, which is based on the 10-year Philippine Government bond.[22]

The 5.2 per cent social discount rate is below the prescribed rates for the Philippines as discussed in Chapter 5. Medalla (2014) points out that lower discount rates, specifically in the Philippine setting, would mean that there will be a higher number of projects that would qualify, which increases the probability of choosing inefficient projects.[23] Most of these public projects, such as dams, have environmental concerns. Markandya and Pearce (1991) stress that lower discount rates are not advisable if environmental concern is one of the issues involved in public projects. They further explain that "the higher the discount rate, the less attractive are projects such as dams, in which a large amount of capital has to be expended at the beginning, in return for water or power over a prolonged period of time" (p.141). Thus, this thesis only does the sensitivity analysis to: (i) better compare the PPP and ODA schemes; and (ii) see if there is indeed a change in the optimal time if social discount rates are changed. Table 6.5 shows the results of the sensitivity analyses on the different social discount rates.

The estimates suggest that lowering the social discount rate only has a marginal effect on the optimal time for operationalising the Kaliwa Dam. Changing the social discount rate from 15 per cent to 10 per cent for the PPP does not change the estimated optimal time to operationalise

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[22] Chu and Grafton (2019) used a social discount rate based on the 10-year Australian government bond from 2010 to 2019.

[23] See also Appendix 5, section A5.1.

the Kaliwa Dam. The optimal time remains in 2047, which is the same as the original estimates. The change in social surplus also remains the same since the optimal time is the same. Lowering the social discount rate to 5.2 per cent produced mixed results. Under the PPP scheme, the optimal time was estimated to be a year earlier in the East Zone, which is 2046, for all weather scenarios. However, that is the only change that can be observed when the social discount rate is lowered. The optimal time remains the same for the West Zone. The same can also be observed under the ODA scheme in that the optimal time remains in 2042.

Table 6.5: Sensitivity analyses on different social discount rates

Kaliwa Dam's optimal timing	**PPP financing scheme**			**ODA financing scheme**	
	ρ=5.2%	**ρ=10%**	**ρ=15%**	**ρ=5.2%**	**ρ=10%**
Weather scenario 1 (low inflows)					
East zone (Manila Water)					
Year	**2046**	**2047**	**2047**	**2045**	**2045**
Change in social surplus (in Php B)	0.68	1.28	1.28	0.10	0.10
West zone (Maynilad)					
Year	**2043**	**2043**	**2043**	**2042**	**2042**
Change in social surplus (in Php B)	1.72	1.72	1.72	0.15	0.15
Weather scenario 2 (normal inflows)					
East zone (Manila Water)					
Year	**2046**	**2047**	**2047**	**2045**	**2045**
Change in social surplus (in Php B)	0.68	1.28	1.28	0.10	0.10
West zone (Maynilad)					
Year	**2043**	**2043**	**2043**	**2042**	**2042**
Change in social surplus (in Php B)	1.72	1.72	1.72	0.15	0.15
Weather scenario 3 (high inflows)					
East zone (Manila Water)					
Year	**2046**	**2047**	**2047**	**2045**	**2045**
Change in social surplus (in Php B)	0.68	1.28	1.28	0.1	0.1
West zone (Maynilad)					
Year	**2043**	**2043**	**2043**	**2042**	**2042**
Change in social surplus (in Php B)	1.72	1.72	1.72	0.15	0.1

ODA = official development assistance, PPP = public-private partnership.
Source: Author's calculations.

Analysis on varying household growth rates

A sensitivity analysis was also performed for different household population growth rates. The analysis considers two scenarios—slower and faster household growth rates—which are shown in Table 6.6. The growth rates are set such that the lower and the upper bounds are symmetric in terms of the difference in percentage points from the estimated growth rates used in the previous sections.[24] The results of each household growth scenario for each concession area under the PPP and ODA financing schemes are shown in Table 6.7 and Table 6.8, respectively. Appendix 8 shows the graphical results of the estimation of the optimal timing.

Table 6.6: Sensitivity analysis of two household growth rates, per concession area

Concession area	Slower growth rate (%)	Base growth rate (%)	Faster growth rate (%)
East zone (Manila Water)	1.32	1.66	2.00
West zone (Maynilad)	3.24	3.62	4.00

Source: Author's calculations and assumptions.

Table 6.7: Summary of the results for two household growth rates for each weather scenario, per concession area, under PPP financing scheme

Kaliwa Dam's optimal timing	PPP Financing Scheme					
	East zone (Manila Water)			West zone (Maynilad)		
	Slower growth (1.32%)	Base growth (1.66%)	Faster growth (2.00%)	Slower growth (3.24%)	Base growth (3.62%)	Faster growth (4.00%)
Weather scenario 1 (low inflows)						
Year	**2054**	**2047**	**2043**	**2046**	**2043**	**2041**
Number of households (in million)	2.075	2.079	2.109	3.186	3.162	3.192
Change in social surplus (in Php billion)	1.210	1.285	1.824	2.060	1.718	2.149
Year when Angat Dam water supply is insufficient	2052	2045	2041	2044	2042	2040
Year when Angat + Kaliwa Dam water supply is insufficient	**2063**	**2054**	**2048**	**2049**	**2046**	**2044**
Weather scenario 2 (normal inflows)						
Year	**2054**	**2047**	**2043**	**2046**	**2043**	**2041**
Number of households (in million)	2.075	2.079	2.109	3.186	3.162	3.192
Change in social surplus (in Php billion)	1.210	1.285	1.824	2.060	1.718	2.149
Year when Angat Dam water supply is insufficient	2052	2045	2041	2044	2042	2040
Year when Angat + Kaliwa Dam water supply is insufficient	**2063**	**2054**	**2048**	**2049**	**2046**	**2044**
Weather scenario 3 (high inflows)						
Year	**2054**	**2047**	**2043**	**2046**	**2043**	**2041**
Number of households (in million)	2.075	2.079	2.109	3.186	3.162	3.192
Change in social surplus (in Php billion)	1.210	1.285	1.824	2.060	1.718	2.145
Year when Angat Dam water supply is insufficient	2052	2045	2041	2044	2042	2040
Year when Angat + Kaliwa Dam water supply is insufficient	**2063**	**2054**	**2048**	**2049**	**2046**	**2044**

Source: Author's calculations.

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[24] For the East Zone, the difference from the base growth rate is ±0.34 percentage points. For the West Zone, the difference from the actual growth rate is ±0.38 percentage points.

Table 6.8: Summary of the results for two household growth rates, for each weather scenario, per concession area, under the ODA financing scheme

Kaliwa Dam's optimal timing	**ODA Financing Scheme**					
	East zone (Manila Water)			**West zone (Maynilad)**		
	Slower growth (1.32%)	**Base growth (1.66%)**	**Faster growth (2.00%)**	**Slower growth (3.24%)**	**Base growth (3.62%)**	**Faster growth (4.00%)**
Weather scenario 1 (low inflows)						
Year	**2052**	**2045**	**2041**	**2045**	**2042**	**2040**
Number of households (in million)	2.021	2.012	2.027	3.086	3.051	3.069
Change in social surplus (in Php billion)	0.263	0.099	0.365	0.632	0.151	0.398
Year when Angat Dam water supply is insufficient	2052	2045	2041	2045	2042	2040
Year when Angat + Kaliwa Dam water supply is insufficient	**2063**	**2054**	**2048**	**2049**	**2046**	**2044**
Weather scenario 2 (normal inflows)						
Year	**2052**	**2045**	**2041**	**2045**	**2042**	**2040**
Number of households (in million)	2.021	2.012	2.027	3.086	3.051	3.069
Change in social surplus (in Php billion)	0.263	0.099	0.365	0.632	0.151	0.398
Year when Angat Dam water supply is insufficient	2052	2045	2041	2045	2042	2040
Year when Angat + Kaliwa Dam water supply is insufficient	**2063**	**2054**	**2048**	**2049**	**2046**	**2044**
Weather scenario 3 (high inflows)						
Year	**2052**	**2045**	**2041**	**2045**	**2042**	**2040**
Number of households (in million)	2.021	2.012	2.027	3.086	3.051	3.069
Change in social surplus (in Php billion)	0.263	0.099	0.365	0.632	0.151	0.398
Year when Angat Dam water supply is insufficient	2052	2045	2041	2045	2042	2040
Year when Angat + Kaliwa Dam water supply is insufficient	**2063**	**2054**	**2048**	**2049**	**2046**	**2044**

Source: Author's calculations.

For the slower household population growth rates, the estimated optimal timing is delayed for both financing schemes. Under the PPP financing scheme, the estimated optimal time to operationalise the Kaliwa Dam is 2054 in the East Zone and 2046 in the West Zone. The expected change in social surplus is equivalent to Php1.21 billion (US$24 million) for the East Zone and Php2.06 billion (US$41 million) for the West Zone. Under the ODA financing scheme, the estimated optimal time is delayed to 2052 for the East Zone and 2045 for the West Zone. The estimated change in social surplus is equivalent to Php263 million (US$5.2 million) for the East Zone and Php632 million (US$13 million) for the West Zone. The estimated time when the water storages will be insufficient is also delayed.

The estimated optimal time to operationalise the Kaliwa Dam is earlier under the faster household growth rate scenarios for both financing schemes. Under the PPP financing scheme, the estimated optimal time is 2043 for the East Zone and 2041 for the West Zone. The change in social surplus is estimated to be Php1.82 billion (US$36 million) for the east and Php2.15 billion (US$43 million) for the West Zone. Under the ODA financing scheme, the estimated optimal time for the East Zone is 2041, and for the West Zone, it is 2040. Consequently, the estimated social surplus for the East Zone is Php365 million (US$7.26 million) and Php398 million (US$7.92 million) for the West Zone. The surpluses are expected to be higher since the increase in water demand is also driven by the household growth. In addition, the time when the water storages will be insufficient the meet the demand for water, considering the ‘with’ and ‘without’ supply augmentation scenarios, is earlier.

Result of sensitivity analysis on hot dry weather scenario

Another sensitivity analysis performed considers the lowest recorded inflows during the hot dry season.[25] From 2010 to 2019, the lowest recorded monthly inflow occurred during May 2010 when it reached a total monthly inflow of 256.7 cubic metre per second (cu.m./s), or approximately 22.18 MCM/month. If such inflows continue for the rest of the year, the estimated annual inflow is equivalent to 266.15 MCM/year.[26] During this month, the average water level is 172.46 metres above sea level (masl) and the water capacity in Angat Dam is approximately 81.35 per cent. It is assumed that, in this case, no water is allocated for irrigation. As noted in Chapter 5, water for irrigation can be reallocated to Metro Manila in times of low inflows and the water level of the dam reaches the critical point. An important assumption in this sensitivity analysis is that, at the start of the analysis, the Angat Dam’s capacity begins at 81.35 per cent of its total capacity. Table 6.9 shows the results that account for the hot dry weather scenario.

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[25] PAGASA identifies the two sub-categories of the dry weather season in the Philippines: (i) cool dry season from December to February, and (ii) hot dry season from March to May. <http://bagong.pagasa.dost.gov.ph/information/climate-philippines>.

[26] See Appendix 7, section A7.4 for the total flows for each month from 2010 to 2019.

Table 6.9: Results of a sensitivity analysis of hot dry weather scenario, under two financing schemes, by concession area

Kaliwa Dam's optimal timing	PPP financing scheme		ODA financing scheme	
	East Zone	West Zone	East Zone	West Zone
Hot dry weather scenario (very low inflows)				
Year	2035	2037	2033	2037
Number of households (in million)	1.706	2.554	1.651	2.554
Change in social surplus (in Php billion)	1.414	1.206	0.358	1.206
Year when Angat Dam water supply is insufficient	2033	2037	2033	2037
Year when Angat + Kaliwa Dam water supply is insufficient	2043	2041	2043	2041

Source: Author's calculations.

The results suggest that in the hot dry weather scenario, the optimal time to build the Kaliwa Dam occurs earlier. It is noteworthy that, in both schemes, the East Zone's estimates give the earliest optimal time. This contrasts with the previous findings, which show that the West Zone's estimate dictated the earliest optimal time to operationalise the Kaliwa Dam. A possible explanation is that the East Zone's allocation is lower than that of the West Zone. The optimal time for the PPP financing scheme is 2035, and for the ODA financing scheme, it is 2033. Under the ODA financing scheme, the optimal time to operationalise the Kaliwa Dam is the same time as when the Angat Dam's water supply will be insufficient.

Prematurely operationalising the Kaliwa Dam

Following the Philippine Government's plan, this section quantifies the social loss of prematurely operationalising the Kaliwa Dam, assuming that the additional dam is operational in 2025. In the previous analyses, the estimated efficient price at the operational time is determined by the interaction between the supply and demand for water. In this scenario, the price is calculated by adding an additional charge to the estimated efficient price. This considers the expected effect of households' paying for the investment of the Kaliwa Dam. Under the PPP financing scheme, an additional Php1.07 (US$0.021) per cu.m. is imposed on the households for both concession zones. This additional charge is based on the water security charge (WSC) that was originally proposed when the PPP financing scheme was approved by the government. Under the ODA financing scheme, an additional Php0.70 (US$0.014) per cu.m. is imposed on the households.[27] Table 6.10 shows the results of prematurely

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[27] See Appendix 7, section A7.5 for the technical notes on how the additional charge under the ODA financing scheme is estimated and further explanation on the efficient price.

operationalising the Kaliwa Dam under the PPP and ODA financing schemes for both the east and West Zones.

Table 6.10: Results of prematurely operationalising the Kaliwa Dam in 2025[a]

	PPP financing scheme		**ODA financing scheme**	
	East zone (Manila Water)	**West zone (Maynilad)**	**East zone (Manila Water)**	**West zone (Maynilad)**
Operational parameters				
Year	2025	2025	2025	2025
Number of households (in million)	1.45	1.67	1.45	1.67
Excess water (in MCM)	250.25	527.11	250.25	527.11
Total social loss at operational time (in Php billion)	0.73	0.78	0.48	0.52
Total social loss from 2025 to estimated optimal time (in Php B)	17.08	17.27	11.10	11.36
Water price at operational time (Php/cu.m.)	29.55	37.27	29.20	36.92
Year when benefits exceed costs	2047	2043	2046	2043
Year when expansion of Kaliwa Dam is needed	2054	2046	2054	2046

[a]The estimates are consistent for all weather scenarios.
Source: Author’s calculations.

If the Kaliwa Dam becomes operational in 2025, the estimated excess water is 250.25 MCM for the East Zone and 527.11 MCM for the West Zone. Under the PPP financing scheme, the social losses in 2025 are estimated to be Php0.73 billion (US$15 million) for the East Zone and Php0.78 billion (US$16 million) for the West Zone. The total social losses from 2025 up to the estimated optimal time will be Php17.77 billion (US$350 million) for the East Zone and Php17.94 billion (US$360 million) for the West Zone.

Under the ODA financing scheme, the social losses in 2025 are estimated to be Php 0.48 billion (US$9.6 million) for the East Zone and Php0.52 billion (US$10 million) for the West Zone. The total social losses from 2025 up to the estimated optimal time will be Php11.54 billion (US$230 million) for the East Zone and Php11.81 billion (US$230 million) for the West Zone. Note that the sum of the estimated total losses for both zones are almost twice the investment costs for the PPP and ODA financing schemes.

Another important observation is that the years when the benefits exceed the annualised cost of capital are similar to those of the optimal time to operationalise, as shown in the previous estimates. The results suggest that the original estimates are, indeed, the optimal time to operationalise the Kaliwa Dam—to avoid social losses arising from its premature operationalisation. Further, the results are also consistent with the claims of Maynilad (2017) and Manila Water (2017). In its rate-rebasing plan, Maynilad (2017) points out that the water supply from the current water storage can still meet water demand in the West Zone up until

2033 even without a buffer. Manila Water (2017) also shows in its rate-rebasing plan that if the Kaliwa Dam is built by 2025, there will be excess water from 2026 up until 2037.

The last important observation is that the storage capacity of the Kaliwa Dam still has to be expanded to meet future water demand. Under the PPP financing scheme, the expansion of the Kaliwa Dam is needed by 2046 to meet the increasing water demand in the West Zone. Under the ODA financing scheme, the expansion is needed by 2046 considering the allocation of the West Zone. These estimates are consistent with those of the previous estimates obtained under the optimal time of operationalising the Kaliwa Dam.

IV. Summary of findings

This thesis uses the dynamic optimisation framework developed by Grafton et al. (2015) to identify the optimal time to operationalise a major public infrastructure, such as the Kaliwa Dam in the Philippines. The structure of the dynamic optimisation considers the inflows, which are weather dependent, into the current water storage. This is an important exogenous factor to consider when determining the optimal time to operationalise a dam, especially in Metro Manila where there is much weather variability. Such an exogenous factor greatly affects the water supply system in an urban area. Thus, the analyses conducted in this thesis incorporates the weather-dependent inflows to determine if such parameter would influence the optimal timing of building a water infrastructure.

Using the specifications of both the PPP and ODA financing schemes, the optimal time to build and operationalise the Kaliwa Dam is estimated. The analyses are done to examine the supply augmentation option in place of the price-measure water-demand management policy presented. Sensitivity analyses are performed to examine the effect of different discount rates, household growth rates, and hot dry weather scenario with the lowest inflows on the optimal timing for water supply augmentation. Table 6.11 summarises the optimal time for each financing scheme.

Table 6.11 Optimal timing for operationalising the Kaliwa Dam, by financing scheme

Financing scheme	Year to operationalise	Year to construct	Year when expansion is needed
PPP (15% discount rate)	2043	2038	2046
ODA (10% discount rate)	2042	2037	2046

ODA = official development assistance, PPP = public-private partnership.
Source: Author’s calculations.

Following the current policy of the Philippine Government, which is to use the ODA financing scheme, the optimal time to operationalise and construct the Kaliwa Dam is 2042 for the East Zone and 2037 for the West Zone.[28]

The following observations are made based on these results. *First,* the results are not sensitive to changes in weather scenarios. Even at the low inflows (weather scenario 1) and hot dry weather scenario, the water levels remained above the critical level at Angat Dam. This is consistent with the NWRB (2021), which states that the water supply from Angat Dam is still sufficient to supply the allocation to Metro Manila. It is noted, however, that in the sensitivity analysis that considers the hot dry weather scenario with the lowest recorded inflows, the results show that the optimal time will be earlier. In this case, it is assumed that the water supply in Angat Dam is maintained at 81.35 per cent of its total capacity. *Second,* the proposed 600 MLD or 219 MCM/year capacity of the Kaliwa Dam will be insufficient to meet the projected water demand. Without an inter-concession transfer of water allocation, it is necessary to add water storage for Metro Manila's needs, and this is by a three-fold expansion of the Kaliwa Dam's capacity—from 600 MLD to 2,400 MLD—or 876 MCM/year by 2046. *Third and last*, if the Philippine Government continues with its plan to construct the Kaliwa Dam in 2019 and operationalise it by 2025, social losses are going to occur due to the excess water supply from the Kaliwa Dam. Notwithstanding this excess water, an additional cost will be imposed on the households starting in 2025 to finance the cost of capital of the Kaliwa Dam.

V. Conclusion

To address an expected water supply problem in Metro Manila, the Philippine Government has decided to pursue supply augmentation. The supply augmentation is to build the Kaliwa Dam, initially planned under the Aquino administration to be built in 2016, under a PPP financing scheme, and should have been operational by 2018. The current Duterte administration decided to shift the financing of all major infrastructure projects from PPP to ODA financing schemes. This effectively delayed the construction of the Kaliwa Dam. After successfully arranging an ODA financing scheme with the government of the PRC, the Philippines' Commission on

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[28] Land acquisition and resettlement costs of those affected by the construction of the Kaliwa Dam are already included in the total project cost. A delay in concluding the community negotiations may have implications on the optimal timing. One is that if the investment cost increases and approaches that of the PPP, then the optimal timing will be moved by one year later. The other is that it may delay the implementation of the project which may go beyond the optimal time. If this happens, then realisation of the net benefit consumers can derive from the operationalisation of the Dam can likewise be delayed.

Audit (COA) raised legal issues that needed to be addressed first before proceeding with the construction. These include, among others, the (i) questionable bidding process for choosing the contractor, (ii) displacement of many indigenous peoples, and (iii) destruction of flora and fauna in the project site.

The results provided here—using a dynamic optimisation—estimated the optimal timing to operationalise the Kaliwa Dam. This thesis is the first to analyse a key public water infrastructure in the Philippines and dynamically inspect whether weather dependent-inflows influence the decision when to build. This may prove important in a country such as the Philippines—which is prone to climate change and extreme weather events, such as the El Niño and La Niña phenomena. These events are important factors that influence and/or determine the water levels and storage necessary to efficiently provide a consistent water supply to Metro Manila.

The dynamic optimisation analysis of this thesis considers weather factors, population growth, and the backstop technology, and offers an analysis on the optimal timing of providing such infrastructure that is governed by exogenous factors.[29] As shown in earlier studies and analyses, these factors affect the operations of the water supply system in urban areas, as well as the water consumption behaviour of households. This is especially true when the household's water consumption is disrupted due to problems in water storage levels. As this thesis shows, exogeneous factors such as the existence of a backstop technology also influence the optimal timing of building major water infrastructures such as dams. In the case of Metro Manila, a backstop technology in the form of water refilling stations serves as an additional water source that households can access in times of water scarcity.

The estimated optimal timing of operationalising the Kaliwa Dam suggests that it is not beneficial to build the dam before 2042. This will result in prematurely operationalising the dam and lowering the social surplus. The estimates further show that there will be social losses as the water supply in Angat Dam is still projected to be adequate to meet the water demand in Metro Manila before 2042. The Kaliwa Dam's designed capacity of 600 MLD is only 15 per cent of the total capacity of the Angat Dam. The capacity of the Kaliwa Dam will only be sufficient for 4 years. Thus, an expansion of the Kaliwa Dam will also be required to meet

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[29] The lack of national land use policy can lead to unwarranted conversion of forest land to agricultural lands. This can indeed also explain the health of the watershed that will also affect the surface water supply. However, this was not explicitly considered in the modelling because there is no publicly available information about the extent of conversion of forest land to agricultural lands in both the Angat Dam and Kaliwa Dam areas.

potential future household demand. These findings, however, contradict the Philippine Government’s decision to proceed with the construction of the Kaliwa Dam in 2019 and to operationalise it by 2025.

Chapter 7

Summary, conclusion, policy insights, and potential areas for further research

The Asian Development Bank (2008) described the water service in Metro Manila, the country's national capital region, as one of the worst in the Southeast Asian region in the 1990s. Thus, to improve the efficiency in the provision of water services in Metro Manila, the Philippine Government privatised the water services in 1997, dividing the service areas between two water concessionaires—with Manila Water servicing the East Zone and Maynilad covering the West Zone. The Metropolitan Waterworks and Sewerage Systems (MWSS), which used to be the sole government-owned provider of water services in the region, regulates both concessionaires. This oversight includes regulating tariffs and its components to ensure that they are kept at affordable rates for water users while ensuring the two water concessionaires earn a reasonable profit.

After the water services were privatised in Metro Manila, the service quality has considerably improved. The number of households that were connected with the two water concessionaires greatly increased while the non-revenue water (NRW) substantially declined, albeit at different speeds in each service area. Despite improvement in supply, Metro Manila still experiences intermittent water supply interruptions. This, typically, occurs during the summer months when the water level at the Angat Dam, the main source of water for the region and nearby agricultural areas, falls below critical levels. To preserve the structural integrity of the dam and the flora and fauna in the dam's watershed, the NWRB reduces the volumetric flows for domestic water use. As this approach results in lower water pressures flowing to the households, the two concessionaires have chosen to impose timed water disruptions in their respective service areas. Under the current IBTs pricing mechanism, households pay the full price of the connection whether they consume 10 cubic metres (cu.m.) or less per month. As found by David and Inocencio (1998), the poor households, on average, consume only 6 cu.m. per month.

MWSS (2012) has stated that, beginning in 2025, the water demand in Metro Manila at the existing water tariff will exceed the available storage in Angat Dam. In 2014, it secured approval from the national government to augment the water storage for Metro Manila by constructing the Kaliwa Dam, which would be operational in 2020. Aside from meeting future domestic water demand, the Kaliwa Dam will be able to ease the dependence of Metro Manila on the Angat Dam for its water supply. Thus, there can be potential relief in the allocation of water supply from the Angat Dam between consumptive use (i.e., domestic use) and non-consumptive use (i.e., irrigation purposes). The cost of this investment will be passed on to the water consumers. Initially, the government considered using the public-private partnership (PPP) scheme to finance this investment, but the Duterte administration, which assumed office in mid-2016, preferred to use the official development assistance (ODA) financing scheme. Although the government succeeded in lowering the investment cost by using this financing scheme, this also caused a delay in the construction of the Kaliwa Dam. Questions raised by the Commission on Audit (COA) regarding the awarding of the contract by the MWSS to a certain contractor and the non-compliance with certain government regulations further delayed the dam's construction. Even prior to these issues, both water concessionaires had already expressed concerns over the uncertainty in the timing of operationalising the Kaliwa Dam should water demand exceed available supply as per MWSS' projection.

Examining the implications and summary of key findings

This thesis aims to answer the following research questions:

1. To what extent are the households in the two concessionaires sensitive to changes in water tariffs?
2. If price is used as water-demand management tool, instead of using water interruptions and reduced water pressure, how much would households be willing to pay to have their water consumption undisrupted with the current climate and existing water storage in the Angat Dam?
3. If the national government proceeds with water supply augmentation by building the Kaliwa Dam, when is the optimal time for such augmentation?

This thesis highlights the importance of examining the implications of water-demand management and supply augmentation in the government's efforts to address the water supply problems in the national capital region. The decision regarding what instrument can be imposed on the public requires a guided framework as there are stakeholders in both supply- and demand-side. The framework should have a dynamic cost-benefit analysis that considers the households long-run water demand elasticities. The dynamic cost-benefit analysis can be two-fold: (1) introduce a dynamic price that households must pay to avoid water restrictions when supply augmentation is not being considered; and (2) estimate the optimal time to operationalise an additional water storage. Introducing a dynamic price lessens the risks, such as rainfall variability, temperature, and other weather-related factors, in both demand for and supply of water in situations where there is increasing water scarcity. This water demand management strategy can potentially be less costly compared to augmenting water supply. On the other hand, water supply augmentation can be more sustainable in the long run when addressing water scarcity problems. A dynamic analysis on the optimal time also considers weather variability because this can also affect the available water supply in a water storage. Factors such as water inflows, which are also weather dependent, influence both the water levels and the available water supply for consumptive and non-consumptive purposes. Other factors, such as a backstop technology, environmental flows, and irrigation flows influence the available water supply available, specifically in the case of the water supply system in Metro Manila. Thus, the problem this thesis aims to address is how water security in urban centres can be achieved. To help achieve water security, there are two possible economic instruments that can be imposed in the capital region: (1) price-based water demand management; and (2) public sector investments for water supply augmentation.

To answer the three research questions raised above, a key objective of this thesis is to provide economic analyses on the implications of a price-measure water-demand management and the proposed water supply augmentation on social welfare. The specific objectives of this thesis are to:

1. Estimate the household water-demand elasticities in Metro Manila;
2. Explore the use of an alternative water-demand management; and
3. Determine dynamically the optimal timing for operationalising the Kaliwa Dam to avoid social welfare losses from building the infrastructure prematurely.

Objective 1: Household water-demand elasticities in Metro Manila

To answer the first research question, this thesis estimates the long-run household water-demand elasticities for each of the concession areas using the Almost Ideal Demand System (AIDS) model. The data used for the analysis come from the Family Income and Expenditure Survey (FIES) for 2009, 2012, and 2015. The estimated household water-demand elasticities range from –0.717 to –0.721 for the East Zone and –0.993 to –0.994 for the West Zone. Manila Water has a better performance in supplying reliable water services and its NRW is lower than

Maynilad and this situation makes households more dependent to their services. By contrast, Maynilad's higher pass-through costs and high NRW are the main reasons why households are less dependent on their water services. Initially, Maynilad decided to centrally operate the water supply, which is similar to the setup of the MWSS prior to the privatisation, but it yielded inferior outcomes than those of Manila Water's decentralised operation. It was only in 2016 that Maynilad adopted a decentralised operational framework that eventually saw improvements in its water services.

This thesis examined the differential impacts of household characteristics on the water-demand elasticities to assess the vertical equity of the water services. The results suggest that other household characteristics, such as household head gender, household head marital status, household head age, and the household type are endogenous variables that have statistically significant influence on water demand, aside from the family size and income that existing literatures have considered. The magnitude of their effects is, however, minimal.

Objective 2: Use of an alternative water-demand management

To answer the second research question, this thesis provides an analysis of an alternative demand management instrument—the risk-adjusted-user-cost (RAUC)—introduced by Chu and Grafton (2019). The RAUC, which is a scarcity price, is a demand management instrument that allows water utilities not to impose water restrictions and, instead, to introduce a scarcity water price used. This pricing instrument estimates the households' willingness-to-pay to avoid water restrictions and allows households to consume water undisrupted despite the declining water levels in Angat Dam. The estimated water-demand elasticities are one of the key parameters in the RAUC analysis.

The results of the RAUC analysis suggest that households in Metro Manila do not require a scarcity price due to the following three factors. *First,* the net inflows are sufficient to keep the water levels in Angat Dam at its current operating level even during the low inflows weather scenario throughout the year. *Second,* the estimated household water price elasticities mean that the households have low willingness-to-pay to avoid the water restrictions. This is due to households having access to other water supply sources, such as water refilling stations and groundwater for their water consumption. *Third,* the National Water Resources Board (NWRB) freely adjusts the allocation from irrigation water to consumptive domestic use for Metro Manila. Its decision is guided by the Philippine Water Code, which states that the highest water allocation during water supply crises is for domestic and municipal water use. Thus, imposing the RAUC on the households will not be an effective water-demand management strategy in the water services market in Metro Manila.

This thesis conducted three sensitivity analyses in estimating the RAUC. The first sensitivity analysis explores the use of lower social discount rates, which yielded the same result as with the original social discount rates. Hence, an additional scarcity component to the volumetric price is not needed. The second and third sensitivity analyses present possible scenarios when the Kaliwa Dam is not operational by 2025, such as when (i) the concessionaires achieve 100 per cent service connections for all households in Metro Manila, and (ii) extreme dry weather events happen that could substantially reduce the net inflows. If these scenarios materialise, the RAUC can be applied to the households in Metro Manila. This happens when the net inflows go down to 950 million cubic metres (MCM) for the dry season, 1,500 MCM for the normal season, and 1,700 MCM for the wet season. Households in the East Zone have a higher RAUC because they have lower water-demand elasticities. By comparison, households in the West Zone have a lower RAUC because of their relatively higher water-demand elasticities. Specifically, the results show that households in the East Zone are willing to pay between Php0.1606 and Php0.5216 (US$0.0032 to US$0.010) per cu.m., or about 0.42 to 1.36 per cent of the water price, for increased reliability of water supply. On the other hand, households in the West Zone are willing to pay between Php0.0416 and Php0.2003 (US$0.00082 to US$0.0039) per cu.m., or about 0.09 to 0.42 per cent of the water price, for their water use to remain undisrupted. Although the calculated RAUCs appear to be small, however, they are within the range of the water price hikes between 2018 to 2021 imposed by both concessionaires. More specifically, the price increases range from Php 0.25 (US$0.0048) to Php 0.99 (US$0.020) per cu.m. in the East Zone and from Php 0.06 (US$ 0.0012) to Php 1.45 (US$0.030) per cu.m. in the West Zone. Further, these results are consistent with the findings of Chu and Grafton (2021) that water users with lower demand elasticities have a higher willingness-to-pay to avoid any water restriction that can disrupt their daily water consumption.

Objective 3: Optimal timing for operationalising the Kaliwa Dam

To answer the third research question, this thesis estimates the optimal timing of operationalising the Kaliwa Dam using the dynamic optimisation. Both the PPP and ODA financing schemes are considered in the analysis. The framework of the dynamic optimisation includes important external factors such as the inflows, which are weather dependent, and the presence of a backstop technology. The model is calibrated to the specifications of the Kaliwa Dam to fit to the current situation of the region as well as for each concession zone. The calibration also includes the estimated water-demand elasticities for the water services and that of the water refilling stations. Three weather scenarios are considered in the analyses, namely, (i) weather scenario 1 (low inflows), (ii) weather scenario 2 (normal inflows), and (iii) weather scenario 3 (high inflows).

The estimated optimal timing for the east and West Zones appears to be different under each financing scheme. Under the PPP financing scheme, the optimal timing to operationalise the dam is the year 2043 for the West Zone and considering all three weather scenarios. For the East Zone, the optimal time is much later—in the year 2047. Upon further inspection, the water demand in the West Zone will exceed the water supply by 2042. Thus, operationalising the Kaliwa Dam by 2043 will yield a positive net benefit immediately for the households in the West Zone.

Under the ODA financing scheme, the optimal time to operationalise the additional storage is 2042 for the West Zone under all three weather scenarios. This is one year ahead of the year indicated under the PPP financing scheme and when the water supply in Angat Dam will be insufficient to meet the household water demand. Should the Philippine Government pursue its current plan to use the ODA financing scheme, then the optimal timing to operationalise the Kaliwa Dam is the year 2042. Considering that it takes five years to complete the project, the construction of the dam should start in 2037.

Some important observations are highlighted in the estimation of the optimal time to operationalise the Kaliwa Dam. Operationalising the additional storage before 2042 will be premature and water users will have zero net benefit from using it. This is because the inflows, even considering weather scenario 1 (low inflows), are still sufficient to recharge the water storage in Angat Dam up until 2042 and satisfy projected water demand. Thus, the disposable dam water can still meet the household water demand in Metro Manila up until 2042, considering all three weather scenarios. The total water supply, which includes both the Angat and Kaliwa dams, will also be insufficient four years after the Kaliwa Dam is operationalised to meet the increasing water demand in the West Zone. According to the MWSS, however, the Kaliwa Dam can be expanded from 600 million litres per day (MLD) to 2,400 MLD if the need for additional water supply arises. It is also noticeable that the difference in optimal timing between the PPP and ODA is minimal noting there is a small difference in the capital cost under each scheme.

This thesis conducted four sensitivity analyses to determine the effects of various scenarios on the optimal timing for operationalising the Kaliwa Dam. The scenarios are as follows: (i) lowering the social discount rate from 15 per cent to 10 per cent under the PPP financing scheme, (ii) lowering the social discount rate from 10 per cent to and 5.2 per cent under both the PPP and ODA financing schemes, (iii) using different household growth rates, and (iv) using the lowest recorded inflows during the hot dry weather season.

Lowering the social discount rates does not induce any significant change in the optimal timing to operationalise the Kaliwa Dam. The reduction in the social discount rate from 15 per cent to 10 per cent under the PPP financing scheme does not change the optimal time to operationalise the Kaliwa Dam. Lowering the social discount rate further to 5.2 per cent causes only marginal changes, which is true only for the East Zone under the PPP financing scheme. Instead of the year 2047, the optimal time to operationalise the Kaliwa Dam in the East Zone advances by just one year—to 2046. The estimated optimal time under the ODA financing scheme, considering both east and West Zones and all three weather scenarios, remains the same.

Significant changes in the optimal time to operationalise Kaliwa Dam occur when the household population growth rates are altered. Specifically, a slower household population growth rate results in delaying the optimal time to operationalise the Kaliwa Dam while a faster household growth rate causes the optimal time to be brought forward under both financing schemes and in both concession zones. This means that the important factor that changes the optimal time is the household population growth rate.

This thesis further conducted a sensitivity analysis for the very hot dry weather scenario. In this case, the lowest monthly recorded total inflows for the months of March to May, from 2010 to 2019, were taken as the inflows. The results indicate that the optimal time to operationalise the Kaliwa Dam occurs earlier in this scenario. For the PPP financing scheme, the estimated optimal time is 2035 while for the ODA financing scheme, it is 2033. Should the latter option be pursued, the construction of the dam could start in 2028.

The last sensitivity analysis follows the Philippine Government's plan to operationalise the Kaliwa Dam in 2025. The results suggest that the current plan would result in social losses. The social losses would be due to the excess water supply coming from the Kaliwa Dam but which households would have to pay for through the increase in water tariffs to cover the expected capital cost? Should the government pursue the use of the ODA financing scheme, the expected social losses from 2025 up to the estimated optimal time would range from Php0.48 billion (US$9.6 million) to Php0.52 billion (US$10 million).

What the thesis offers

This thesis offers a framework and methodology to aid policymakers in making informed decision on the best time to build the additional water storage. In particular, the dynamic optimisation analysis—which takes into account several critical factors together, such as, water inflows, weather, population growth, social discount rate, water-demand elasticities, investment cost, and backstop technology—yields information on the optimal timing for building such infrastructure. The evidence from this analysis is important to help the government avoid making a decision that will generate negative social welfare consequences arising from prematurely building or delaying the operationalisation of the infrastructure.

Potential areas for further research

This thesis demonstrates the importance of exploring alternative demand management and estimating the optimal time for augmenting water storages to avoid social losses. In the last two decades, the Philippines has experienced rapid urbanisation that saw the emergence of metropolitan areas other than Metro Manila. Currently, there are two metropolitan areas in the Visayas and three in Mindanao, which are centres of commerce, industry, and education. The high population growth rates in these areas, which are partly caused by migration of people from neighbouring provinces, place increasing pressure on the provision of water services. Metropolitan areas in other developing countries are also considering challenges in providing adequate water services. The methods in this thesis would help governments better formulate policies, plans, and programs for their respective water services.

A possible area for further research would be estimating the effect of a non-price measure, such as the reduction in water flows from Angat Dam, on social welfare. This would help to identify if a price or a non-price measure to curb the decline in water level in the water storage will have less adverse effects on the households in Metro Manila. The challenge here, however, is the availability of data, such as specific information on the (i) water disruptions by the concessionaires, (ii) actual recorded flows during the water disruptions and decrease in allocative water flows from Angat Dam, (iii) actual recorded flows for the irrigation and environmental flows, and (iv) actual recorded household water consumption, particularly from Maynilad.

An important result of this thesis suggests that the capacity of the Kaliwa Dam would become insufficient four years after the optimal time of its operationalisation. Thus, an analysis of increasing the storage capacity of the Kaliwa Dam, taking into account the future demand for water in Metro Manila, would be another possible extension of this thesis.

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Appendix 1: Water prices and computing the volume of the Angat Dam

Section A1.1: Water prices for households/residential

Table A1.1: Residential water price schedule for Maynilad and Manila Water, 2009
In Php/cu.m.

Maynilad			**Manila Water**		
More than 10 cu.m.			More than 10 cu.m.		
First 10	106.77	/conn	First 10	77.6	/conn
Next 10	13.04	/cu.m.	Next 10	9.47	/cu.m.
Next 20	24.79	/cu.m.	Next 20	17.95	/cu.m.
Next 20	32.56	/cu.m.	Next 20	23.64	/cu.m.
Next 20	38.03	/cu.m.	Next 20	27.62	/cu.m.
Next 20	39.76	/cu.m.	Next 20	28.93	/cu.m.
Next 50	41.59	/cu.m.	Next 50	30.22	/cu.m.
Next 50	43.44	/cu.m.	Next 50	31.52	/cu.m.
Over 200	45.28	/cu.m.	Over 200	32.82	/cu.m.

Table A1.2: Residential water price schedule for Maynilad and Manila Water, 2012
In Php/cu.m.

Maynilad			**Manila Water**		
More than 10 cu.m.			More than 10 cu.m.		
First 10	129.07	/conn	First 10	97.88	/conn
Next 10	15.77	/cu.m.	Next 10	11.94	/cu.m.
Next 20	29.97	/cu.m.	Next 20	22.65	/cu.m.
Next 20	39.36	/cu.m.	Next 20	29.82	/cu.m.
Next 20	45.97	/cu.m.	Next 20	34.83	/cu.m.
Next 20	48.07	/cu.m.	Next 20	36.49	/cu.m.
Next 50	50.27	/cu.m.	Next 50	38.12	/cu.m.
Next 50	52.52	/cu.m.	Next 50	39.75	/cu.m.
Over 200	54.53	/cu.m.	Over 200	41.40	/cu.m.

Table A1.3: Residential water price schedule for Maynilad and Manila Water, 2015
In Php/cu.m.

Maynilad			**Manila Water**		
More than 10 cu.m.			More than 10 cu.m.		
First 10	133.2	/conn	First 10	101.01	/conn
Next 10	16.27	/cu.m.	Next 10	12.32	/cu.m.
Next 20	30.93	/cu.m.	Next 20	23.37	/cu.m.
Next 20	40.62	/cu.m.	Next 20	30.77	/cu.m.
Next 20	47.44	/cu.m.	Next 20	35.94	/cu.m.
Next 20	49.61	/cu.m.	Next 20	37.66	/cu.m.
Next 50	51.88	/cu.m.	Next 50	39.34	/cu.m.
Next 50	54.19	/cu.m.	Next 50	41.02	/cu.m.
Over 200	56.48	/cu.m.	Over 200	42.72	/cu.m.

Table A1.4: Residential water price schedule for Maynilad and Manila Water, 2019
In Php/cu.m.

Maynilad			**Manila Water**		
10 cu.m. or less	63.16	/conn	10 cu.m. or less	63.16	/conn
More than 10 cu.m.			More than 10 cu.m.		
First 10	164.16	/conn	First 10	111.27	/conn
Next 10	20.03	/cu.m.	Next 10	13.56	/cu.m.
Next 20	38.09	/cu.m.	Next 20	25.71	/cu.m.
Next 20	50.03	/cu.m.	Next 20	33.89	/cu.m.
Next 20	58.45	/cu.m.	Next 20	39.58	/cu.m.
Next 20	61.13	/cu.m.	Next 20	41.49	/cu.m.
Next 50	63.93	/cu.m.	Next 50	43.34	/cu.m.
Next 50	66.78	/cu.m.	Next 50	45.20	/cu.m.
Over 200	65.85	/cu.m.	Over 200	47.06	/cu.m.

Section A1.2: Discussion on the IBTs of both concessionaires

Both concessionaires follow the increasing block tariffs (IBTs) pricing mechanism prescribed by the regulator, the Metropolitan Waterworks and Sewerage System (MWSS). This is the same pricing scheme the MWSS applied before the privatisation. The IBTs should attain the goals of (1) financial stability, (2) good governance, (3) economic efficiency, (4) distributive justice, and (5) fair pricing. Many developing countries have been using IBTs to attain these same goals.

The design of the IBTs for the Metro Manila water services is almost the same as those used by other countries, but with slight deviations. The size of the first two blocks is 10 cu.m.; the 3rd to the 6th blocks, 20 cu.m.; the 7th and the 8th blocks, 50 cu.m.; and the last block, any consumption beyond 200 cu.m.. The first block is larger than the international standard of the average consumption per household set by the Asian Development Bank (ADB), which is 4–5 cu.m. per day. However, the difference of the initial block in the IBT of the concessionaires from those of other countries is that it has a fixed tariff. Whether households consume 10 cu.m. or not in a month, households are still required to pay the basic tariff of the initial block. The tariff changes starting from the second block. The tariff then increases first by about 1.9 per cent. As the block increases, the per cent increase in the tariff declines.

Section A1.3: Water prices for semi-business and business groups

Aside from residential customers, the concessionaires also provide their water services to non-households, namely, (i) semi-business, (ii) business group 1, and (iii) business group 2. The semi-business covers those who are engaged in small businesses, where their business activities do not use water as a fundamental input (MWSS 2008). Commercial businesses are categorised under business group 1, while the industrial firms belong to business group 2. The water tariffs imposed on the non-households are much higher than those on the residential customers (Table A1.5 and Table A1.6). These businesses only comprise less than 10 per cent of the total number of customers connected to both Manila Water and Maynilad pipes in Metro Manila.

Table A1.5: Non-household water tariff schedule for Manila Water, 2018, in Php/cu.m.,

Semi-business		
More than 10 cu.m.		
First 10	105.27	/conn
Next 10	21.49	/cu.m.
Next 20	26.50	/cu.m.
Next 20	33.68	/cu.m.
Next 20	39.25	/cu.m.
Next 20	41.00	/cu.m.
Next 50	42.76	/cu.m.
Next 50	44.52	/cu.m.
Over 200	46.39	/cu.m.

Business group 1			Business group 2		
First 10 cu.m.	478.39	/conn	First 10 cu.m.	517.63	/conn
Next 90	47.89	/cu.m.	Next 90	52.08	/cu.m.
Next 100	48.16	/cu.m.	Next 100	52.36	/cu.m.
Next 100	48.30	/cu.m.	Next 100	52.77	/cu.m.
Next 100	48.43	/cu.m.	Next 100	53.18	/cu.m.
Next 100	48.69	/cu.m.	Next 100	53.43	/cu.m.
Next 100	48.83	/cu.m.	Next 100	53.85	/cu.m.
Next 100	48.99	/cu.m.	Next 100	54.25	/cu.m.
Next 100	49.28	/cu.m.	Next 100	54.50	/cu.m.
Next 100	49.38	/cu.m.	Next 100	54.90	/cu.m.
Next 100	49.53	/cu.m.	Next 100	55.36	/cu.m.
Next 200	49.77	/cu.m.	Next 200	55.63	/cu.m.
Next 200	49.92	/cu.m.	Next 200	56.01	/cu.m.
Next 200	50.06	/cu.m.	Next 200	56.27	/cu.m.
Next 200	50.34	/cu.m.	Next 200	56.70	/cu.m.
Next 200	50.47	/cu.m.	Next 200	57.09	/cu.m.
Next 500	50.61	/cu.m.	Next 500	57.36	/cu.m.
Next 500	50.86	/cu.m.	Next 500	57.78	/cu.m.
Next 500	51.00	/cu.m.	Next 500	58.17	/cu.m.

Business group 1 (continuation)			Business group 2 (continuation)		
Next 500	51.13	/cu.m.	Next 500	58.44	/cu.m.
Next 500	51.40	/cu.m.	Next 500	58.84	/cu.m.
Next 500	51.55	/cu.m.	Next 500	59.27	/cu.m.
Next 500	51.69	/cu.m.	Next 500	59.52	/cu.m.
Next 500	51.96	/cu.m.	Next 500	59.93	/cu.m.
Next 500	52.08	/cu.m.	Next 500	60.37	/cu.m.
Next 500	52.23	/cu.m.	Next 500	60.60	/cu.m.
Next 500	52.36	/cu.m.	Next 500	61.01	/cu.m.
Next 500	52.65	/cu.m.	Next 500	61.27	/cu.m.
Next 500	52.77	/cu.m.	Next 500	61.72	/cu.m.
Next 500	52.90	/cu.m.	Next 500	62.10	/cu.m.
Next 500	53.18	/cu.m.	Next 500	62.37	/cu.m.
Next 500	53.29	/cu.m.	Next 500	62.79	/cu.m.
Over 10,000	53.43	/cu.m.	Over 10,000	63.18	/cu.m.

Table A1.6: Non-household water price schedule for Maynilad, 2018, in Php/cu.m.

Semi-business		
More than 10 cu.m.		
First 10	164.16	/conn
Next 10	33.62	/cu.m.
Next 20	41.45	/cu.m.
Next 20	52.57	/cu.m.
Next 20	61.13	/cu.m.
Next 20	63.96	/cu.m.
Next 50	66.78	/cu.m.
Next 50	69.60	/cu.m.
Over 200	72.34	/cu.m.

Business group 1			Business group 2		
First 10 cu.m.	746.05	/conn	First 10 cu.m.	807.27	/conn
Next 90	74.95	/cu.m.	Next 90	81.25	/cu.m.
Next 100	75.15	/cu.m.	Next 100	81.74	/cu.m.
Next 100	75.38	/cu.m.	Next 100	82.40	/cu.m.
Next 100	75.63	/cu.m.	Next 100	82.92	/cu.m.
Next 100	75.88	/cu.m.	Next 100	83.46	/cu.m.
Next 100	76.23	/cu.m.	Next 100	84.07	/cu.m.
Next 100	76.56	/cu.m.	Next 100	84.60	/cu.m.
Next 100	76.82	/cu.m.	Next 100	85.10	/cu.m.
Next 100	77.07	/cu.m.	Next 100	85.74	/cu.m.
Next 100	77.31	/cu.m.	Next 100	86.23	/cu.m.

Next 200	77.66	/cu.m.	Next 200	86.82	/cu.m.
Next 200	77.89	/cu.m.	Next 200	87.33	/cu.m.
Next 200	78.30	/cu.m.	Next 200	87.98	/cu.m.
Business group 1 (continuation)			Business group 2 (continuation)		
Next 200	78.51	/cu.m.	Next 200	88.43	/cu.m.
Next 200	78.70	/cu.m.	Next 200	89.05	/cu.m.
Next 500	78.93	/cu.m.	Next 500	89.61	/cu.m.
Next 500	79.35	/cu.m.	Next 500	90.11	/cu.m.
Next 500	49.62	/cu.m.	Next 500	90.63	/cu.m.
Next 500	79.90	/cu.m.	Next 500	91.30	/cu.m.
Next 500	80.05	/cu.m.	Next 500	91.76	/cu.m.
Next 500	80.39	/cu.m.	Next 500	92.43	/cu.m.
Next 500	80.73	/cu.m.	Next 500	92.92	/cu.m.
Next 500	80.92	/cu.m.	Next 500	93.41	/cu.m.
Next 500	81.25	/cu.m.	Next 500	94.06	/cu.m.
Next 500	81.53	/cu.m.	Next 500	94.62	/cu.m.
Next 500	81.74	/cu.m.	Next 500	95.15	/cu.m.
Next 500	82.06	/cu.m.	Next 500	95.80	/cu.m.
Next 500	82.40	/cu.m.	Next 500	96.21	/cu.m.
Next 500	82.63	/cu.m.	Next 500	96.89	/cu.m.
Next 500	82.92	/cu.m.	Next 500	97.38	/cu.m.
Next 500	83.21	/cu.m.	Next 500	97.99	/cu.m.
Over 10,000	83.46	/cu.m.	Over 10,000	98.50	/cu.m.

Section A1.4: Computing for the volume of the Angat Dam

The volume at the maximum and at the critical points of Angat Dam were computed since the exact values are not given by MWSS. The Angat watershed area is usually given but the thesis investigates using the storage area of the dam itself. In estimating the volume at the critical levels, the following steps are shown below.

Step 1: Computing for the area of Angat Dam at full capacity

Volume at full capacity: 850 mcm

Water surface level: 212 m

Area = $\frac{850\ x\ 10^{6}\ m^{3}}{212\ m} = 4{,}009{,}433.96\ m^{2} \approx 4.009\ km^{2}$

Step 2: Computing for the volume at each critical level

a.) When water level is at 180 m

Volume = $180m\ (4{,}009{,}433.96\ m^2) = 721.70\ mcm$

Capacity at 721.70 = ${}^{721.70}/_{850} = 85\%$

b.) When water level is at 170 m

Volume = $170m\ (4{,}009{,}433.96\ m^2) = 681.6\ mcm$

Capacity at 681.6 = ${}^{681.6}/_{850} = 80\%$

c.) When water level is at 168.95 m

Volume = $168.95m\ (4{,}009{,}433.96\ m^2) = 677.43\ mcm$

Capacity at 677.43 = ${}^{677.43}/_{850} = 79.7\%$

d.) When water level is at 160.71 m

Volume = $160.71m\ (4{,}009{,}433.96\ m^2) = 644.36\ mcm$

Capacity at 644.36 = ${}^{644.36}/_{850} = 75.8\%$

e.) When water level is at 160 m

Volume = $160m\ (4{,}009{,}433.96\ m^2) = 641.51\ mcm$

Capacity at 641.51 = ${}^{641.51}/_{850} = 75.5\%$

Appendix 2: Technical notes in organising and estimating the dataset

Section A2.1: Details on dataset

Family Income and Expenditure Survey, or FIES (2009, 2012, and 2015)

- The National Capital Region (NCR), which is divided into four districts, is serviced by two water concessionaires. District 1 (Manila), District 3 (Caloocan, Malabon, Navotas, and Valenzuela), and parts of District 4 (Las Piñas, Muntinlupa, Parañaque, and Pasay) are under the Maynilad concession area. District 2 (Mandaluyong, Marikina, Pasig, Quezon City, and San Juan) and parts of District 4 (Makati, Pateros, and Taguig) are under the Manila Water jurisdiction.
- District 4 includes households that are either customers of Manila Water or Maynilad. The FIES provides information on which district each household is located but not the specific city/municipality. There is therefore a need to find a way to identify households of District 4 who belong to a specific city. Since the Philippine Statistical Authority (PSA) reports cities in District 4 always in alphabetical order, the percentage shares of the households of the cities in this district were used to distribute the FIES sample households to each city, starting from the first household to the last (See Table A2.1).

Table A2.1: Household distribution per city in District 4

2015 Household Distribution

City/Municipality	No. of households	% Share
City of Las Piñas	141,925	16%
City of Makati	154,095	17%
City of Muntinlupa	122,286	14%
City of Parañaque	163,074	18%
Pasay City	107,619	12%
Pateros	14,188	2%
Taguig City	198,256	22%

2010 Household Distribution

City/Municipality	No. of households	% Share
City of Las Piñas	127,723	17%
City of Makati	126,457	17%
City of Muntinlupa	103,949	14%
City of Parañaque	137,405	18%
Pasay City	97,966	13%
Pateros	14,629	2%
Taguig City	150,190	20%

2007 Household Distribution

City/Municipality	No. of households	% Share
City of Las Piñas	119,911	17%
City of Makati	120,858	17%
City of Muntinlupa	106,642	15%
City of Parañaque	125,912	17%
Pasay City	98,274	14%
Pateros	12,923	2%
Taguig City	136,942	19%

The PSA conducts the population census every 5 years. Since data for 2009 and 2012 were not readily available, the population censuses of 2007 and 2010, respectively, were taken as basis for the distribution households per city.

Schedule of tariffs of both Manila Water and Maynilad, and MERALCO, an electric company that owns the franchise for Metro Manila, for the years: 2009, 2012, and 2015.

- Schedule of electricity tariffs of MERALCO for the years: December 2010, December 2012, and December 2015. Note that the December 2010 schedule of tariffs was used since the December 2009 schedule was not available from MERALCO. All the cities mentioned above are under the MERALCO franchise.
- Manila Water and Maynilad have different tariff schedules that are regulated by the MWSS. Maynilad introduced lower tariff rates for households and communities that are below the poverty line since 2009. Manila Water followed this practice and introduced lower tariff rates for households and communities that are below the poverty line in 2012.

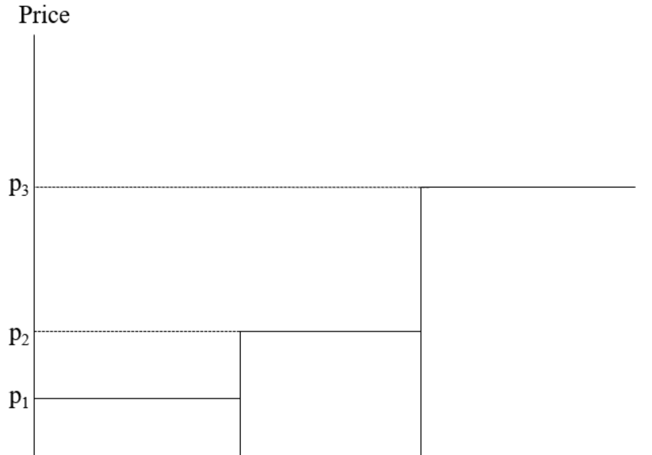
Section A2.2: Estimation on the effective price of water

The thesis uses the effective prices of water. ‘Effective price’ is defined as the price for each cubic metre (cu.m.) based on actual household consumption. The pricing mechanism of the water services in the National Capital Region follows a step-wise cost function, in which the cost increases as consumption increases. The estimated effective price reflects the step-wise cost function. In computing for the effective prices, the following steps were done:

The first step is to estimate the volume of water consumed. The FIES reports household expenditures for water supply. The 2012 and 2015 FIES classify water expenditure into: (1) rentals, (2) actual rentals, (3) imputed rentals, (4) imputed rentals-imputed, (5) imputed rentals-other, (6) maintenance and repair, (6) maintenance and repair-materials, (7) maintenance and repair-services, (8) water supply and miscellaneous services, and (9) water supply and miscellaneous services-water supply, water supply and miscellaneous services-other services). The 2009 FIES classification is not as comprehensive as that of 2012 and 2015. For this thesis, only the expenditure for water supply for 2012 and 2015 and water expenditure for 2009 were considered because this is the service provided by the concessionaires. This was done for two reasons. First, according to the FIES questionnaire, the responses of the households are only based on their estimated water consumption.[1] Second, the questionnaire does not specify any "tap water" option as the main source of water supply. Additionally, the definition of "own use, faucet, community water system" option means that households obtain their water supply through a water pipeline from the community water system, which includes Maynilad, Manila Water, or other local water districts.[2]

Given that the pricing mechanism of each concession follows an increasing price block tariff, we compute for the successive maximum cost for each block. The total cost per block is added to the cost of the previous block to reflect the increasing price block tariff (see example below). Dahan and Nisan (2007) introduce how the budget constraint of a utility-maximising household is computed using a three-block IBT. Figure A2.1 below shows the three-block IBT.

Figure A2.1 Three-block IBT



We consider a household that has a water supply expenditure *E*. Water consumption is denoted as *w*. The household then faces three increasing blocks, with each block having a price, p_i, in

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[1] Please see the PSA's report, with the sample questionnaire: https://psa.gov.ph/sites/default/files/FIES%202015%20Final%20Report.pdf

[2] Please see PSA's data archive: http://psada.psa.gov.ph/index.php/catalog/199/datafile/F2/V229

the *i*th block. The first block has a range of w_1, and w_2 is the range of the second block. In computing for the water supply expenditure, the household is then faced with three segments as shown in the following equations:

$$E = p_1 w \qquad if\ w < w_1 \qquad Eq.A2.1$$

$$E + (p_2 - p_1)w_1 = p_2 w \qquad if\ w_1 < w < w_1 + w_2 \qquad Eq.A2.2$$

$$E + (p_3 - p_2)w_2 + (p_3 - p_1)w_1 = p_3 w \quad if\ w > w_1 + w_2 \quad Eq.A2.3$$

Using *Equation A2.3*, we can derive that the water consumption is:

$$w = \frac{E - (p_2 w_2 + p_1 w_1)}{p_3} + (w_2 + w_1) \qquad Eq.A2.4$$

Converting equation d in its general form for any IBT with n number of blocks:

$$w = \frac{E - \sum_1^n p_i w_i}{p_n} + (\sum_1^n w_i) \qquad Eq.A2.5$$

Or

$$w = (\sum_1^n w_i) - \frac{\sum_1^n p_i w_i + E}{p_n} \qquad Eq.A2.6$$

Where price p_n is the maximum price of the highest block.

Following the discussion above, the thesis adopts *Equation A2.5*. The consumption of water is then computed as:

$$WConsumption_h = MaxCblock_j - \frac{\left(CostBlock_j - WatExp_{hj}\right)}{MaxPriceBlock_j} \quad Eq.A2.7$$

Where, *h* is the household and j is the concession (Manila Water or Maynilad).

- $WatExp_{hj}$ is the water supply expenditure and is equivalent to *E* in equation e.
- $CostBlock_j$ is the total cost of the price block based on $WatExp_{ij}$. $CostBlock_j$ is equal to $\sum_1^n p_i w_i$ in equation e. But using the IBT of the concessionaires, it is then modified as $CostBlock_j = p_1 + \sum_2^n p_i w_i$, since the initial block will have a constant price even if the household consumes less than 10 cu.m.
- $MaxPriceBlock_j$ is the price of the highest block, and it is p_n in equation e.
- $MaxCblock_j$ is the maximum cu.m. consumption for the specific price block, and is equal to $(\sum_1^n w_i)$ in equation *e.*

Following the equation above, the $MaxCblock_j$ and the corresponding $CostBlock_j$ are computed using the schedule of tariffs of both concessionaires for the years 2009, 2012, and 2015 (see tables A2.2 to A2.4 below).

Table A2.2: $MaxCblock_j$ and $CostBlock_j$ for 2009

Maynilad	$MaxPriceBlock_j$	$MaxCblock_j$	$CostBlock_j(Php)$
First 10	106.77	10	106.77
Next 10	13.04	20	237.17
Next 20	24.79	40	732.97
Next 20	32.56	60	1,384.17
Next 20	38.03	80	2,144.77
Next 20	39.76	100	2,939.97
Next 50	41.59	150	5,019.47
Next 50	43.44	200	7,191.47
Over 200	45.28		9,455.47
Manila Water	$MaxPriceBlock_j$	$MaxCblock_j$	$CostBlock_j(Php)$
First 10	77.6	10	77.6
Next 10	9.47	20	172.3
Next 20	17.95	40	531.3
Next 20	23.64	60	1,004.1
Next 20	27.62	80	1,556.5
Next 20	28.93	100	2,135.1
Next 50	30.22	150	3,646.1
Next 50	31.52	200	5,222.1
Over 200	32.82		6,863.1

Source: Maynilad, Manila Water and author’s calculations.

Table A2.3: $MaxCblock_j$ and $CostBlock_j$ for 2012

Maynilad	$MaxPriceBlock_j$	$MaxCblock_j$	$CostBlock_j(Php)$
First 10	129.07	10	129.07
Next 10	15.77	20	286.77
Next 20	29.97	40	886.17
Next 20	39.36	60	1,673.37
Next 20	45.97	80	2,592.77
Next 20	48.07	100	3,554.17
Next 50	50.27	150	6,067.67
Next 50	52.52	200	8,693.67
Over 200	54.53		11,420.17
Manila Water	$MaxPriceBlock_j$	$MaxCblock_j$	$CostBlock_j(Php)$
First 10	97.88	10	97.88
Next 10	11.94	20	217.28
Next 20	22.65	40	670.28
Next 20	29.82	60	1,266.68
Next 20	34.83	80	1,963.28
Next 20	36.49	100	2,693.08
Next 50	38.12	150	4,599.08
Next 50	39.75	200	6,586.58
Over 200	41.4		8,656.58

Source: Maynilad, Manila Water and author’s calculations

Table A2.4: $MaxCblock_j$ and $CostBlock_j$ for 2015

Maynilad	$MaxPriceBlock_j$	$MaxCblock_j$	$CostBlock_j(Php)$
First 10	133.2	10	133.2
Next 10	16.27	20	295.9
Next 20	30.93	40	914.5
Next 20	40.62	60	1,726.9
Next 20	47.44	80	2,675.7
Next 20	49.61	100	3,667.9
Next 50	51.88	150	6,261.9
Next 50	54.19	200	8,971.4
Over 200	56.48		11,795.4

Manila Water	$MaxPriceBlock_j$	$MaxCblock_j$	$CostBlock_j(Php)$
First 10	101.01	10	101.01
Next 10	12.32	20	224.21
Next 20	23.37	40	691.61
Next 20	30.77	60	1,307.01
Next 20	35.94	80	2,025.81
Next 20	37.66	100	2,779.01
Next 50	39.34	150	4,746.01
Next 50	41.02	200	6,797.01
Over 200	42.72		8,933.01

Source: Maynilad, Manila Water and author's calculations.

After estimating the monthly consumption using the base price, the effective price is computed using the formula below.

$$Effective\ price\ of\ water = \frac{WatExp_{hj}}{Consumption_h} \qquad Eq. A2.8$$

Examples of computing the household consumption and effective price:

For a household under Maynilad that has a water supply expenditure of Php800 in the year 2009:

$MaxCblock_j$is at Php 32.56 per cu.m., with a maximum consumption of 60 cu.m.

$$CostBlock_j = (106.77) + (13.04 * 10) + (24.79 * 20) + (32.56 * 20) = 1384.17$$

$$MaxPriceBlock_j = Php\ 32.56\ per\ cu.m.$$

$$WConsumption_i = 60 - \frac{(1384.17 - 800)}{32.56} = 42.06\ cu.m.$$

For a household under Manila Water that has a water supply expenditure of Php974.33 in 2012:

$MaxCblock_j$is at Php 29.82 per cu.m., with a maximum consumption of 60 cu.m.

$$CostBlock_j = (97.88) + (11.94 * 10) + (22.65 * 20) + (29.82 * 20) = 1266.68$$

$$MaxPriceBlock_j = Php\ 29.82/cu.m.$$

$$WConsumption_i = 60 + \frac{1266.68 - 974.33}{29.82} = 50.20\ cu.m.$$

NOTE: Since the Almost Ideal Demand System (AIDS) method uses translog, all households with zero expenditure for water were removed from the dataset.

Section A2.2: Estimation of effective price for electricity

The procedure in estimating for the effective price of electricity is similar than that of the estimation of the effective price of water. The effective price of electricity is defined as the price for each kilowatt hour (kWh) based on household consumption. The difference of the electricity tariff with the water tariff is that it does not follow the increasing price block, but it is identified as a volumetric block. The following steps were done to compute for the effective price of electricity:

MERALCO sets the increase in distribution charge only when the household starts to consume more than 200 kWh and an energy tax is charged when households consume more than 600 kWh. The total price is computed first by assuming that there is 1 kWh.

$$\begin{aligned} &Total\ Price_{ht} = \\ &Generation\ charge + Adjustment\ on\ generation + Transmittion\ charge \\ &\qquad + distribution\ charge + Supply\ charge + Metering\ charge \\ &\qquad + system\ loss\ charge + universal\ charge \qquad Eq.A2.9 \end{aligned}$$

We then compute for the maximum cost per block by:

$$MaxCost = Total\ price\ x\ MaxElec_c \qquad Eq.A2.10$$

Where $MaxElec_a$ is the maximum kWh for *e* block.

In computing for the electricity consumption:

$$EConsumption_h = \frac{Elecexp_h - MaxCost}{Total\ Price_{ht}} + MaxEBlock_e \quad Eq.A2.11$$

Where $Elecexp_h$ is the electricity expenditure of each household, and $MaxEBlock_e$ is the maximum kWh consumption for the specific price block.

After computing for the electricity consumption, we estimate the total effective electricity price that each household pays for the electricity consumption:

$$Effective\ price\ of\ electricity = \frac{Elecexp_h}{EConsumption_h} \quad Eq.A2.12$$

Examples in computing for the consumption and effective price of electricity:

For a household that has an expenditure of Php 2,554.91 in the year 2012:

$$Total\ Price_{ht} = 5.4817 + 0.859 + 1.15518 + 0.595 + 0.4003 + 0.872277 + 0.1188 + 0.1332 + 0.6228 + 0.0406 = Php\ 10.67548/kWh$$

$$MaxCost = 10.67548 * (300) = Php3202.643$$

$$EConsumption_h = \frac{2554.91 - 3202.643}{10.67548} + 300 = 239.33kWh$$

For a household that has an expenditure of Php 9,534.52 in the year 2015:

$$Total\ Price_{ht} = 4.1299 + 0.8128 + 2.1387 + 0.5085 + 0.3377 + 0.785041 + 0.1 + 0.3524 + 0.0818 + 0.4322 + 0.0406 = Php\ 9.719641/kWh$$

$$MaxCost = 9.719641 * (1000) = Php9719.641$$

$$EConsumption_h = \frac{9534.52 - 9719.641}{9.719641} + 1000 = 980.95\ kWh$$

Since the Almost Ideal Demand System (AIDS) method uses translog, all households with zero expenditure for electricity were removed from the dataset.

Section A2.3: Estimating the CPI of other goods

This thesis uses the AIDS method to estimate own-price elasticities and cross-product elasticities among water, electricity, and other goods. In order to carry out this estimation, a price index needs to be constructed that will represent the price of other goods consumed by households (excluding water and electricity). In this thesis, the price index is represented by the consumer price index (CPI) of the other goods and is computed as follows:
From the FIES, we get the expenditures for Food & Non-alcoholic beverages, Alcoholic & Tobacco, Clothing & Footwear, Furnishing & Household fixtures, Health, Transport, Communication, Recreation, and Restaurant & Miscellaneous services.

We compute for the expenditure share of each item mentioned above using the formula below.

$$Expenditure\ share = \frac{Expenditure_a}{Total\ expenditure} \quad Eq.A2.13$$

Where *a* is the item expenditure.

The PSA reports the specific CPI of each item for each year. In this case, the CPI was based on constant 2006 prices. To estimate the CPI of each item, we use the equation below:

$$CPI_a = expenditure\ share_a \times CPI_b \qquad Eq.A2.14$$

Where CPI_a is the CPI of the specific item and CPI_{bt} is the reported CPI of that item by the PSA at a specific year t.

This is consistent with the PSA's methodology in estimating the total CPI (All items), where the weights of each item were multiplied by their corresponding item CPI.

After estimating the CPI_a for each item, we take the sum to arrive at the CPI of the non-water and electricity goods. Thus,

$$CPI_{Nonwater\&electricity} = \sum CPI_a \qquad Eq. A2.15$$

The estimated CPI in *Equation A2.15* is the price index of each household for non-water and electricity goods.

Appendix 3: Descriptive statistics

Table A3.1: Summary statistics of households in the East Zone (Manila Water), 2009–2015

Summary statistics

		2009				2012				2015			
Variable Name	**Variable**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
Income decile	incdecile	7.93	1.95	1.00	10.00	7.82	2.03	1.00	10.00	7.53	2.16	1.00	10.00
Family size	famsize	4.56	2.10	1.00	17.00	4.66	2.22	1.00	15.50	4.56	2.21	1.00	18.00
Total income	toinc	385,773.50	442,866.80	36,615.00	7,068,000.00	370,709.20	331,105.50	32,083.43	2,964,313.00	360,903.90	328,888.00	32,517.57	5,492,790.00
Per-capita income	toincpc	103,522.20	167,079.90	7,185.26	3,396,391.00	93,818.55	97,223.97	7,828.75	1,325,836.00	93,610.09	103,121.00	7,807.46	1,909,475.00
Total expenditure	toexp	328,245.50	291,825.30	37,803.00	3,347,326.00	312,262.40	266,470.10	33,395.73	2,410,984.00	298,195.60	234,750.50	30,808.18	2,889,891.00
Per-capita expenditure	toexppc	87,187.54	111,690.80	5,787.58	2,303,375.00	78,890.21	78,911.97	6,644.51	1,229,752.00	77,131.70	74,729.78	10,950.89	1,110,645.00
Total water supply expenditure	watexp	5,228.25	5,035.21	300.00	84,000.00	5,277.39	4,584.95	223.45	67,553.57	5,349.29	4,578.58	135.22	98,812.35
Per month water supply expenditure	watexpmonth	435.69	419.60	25.00	7,000.00	439.78	382.08	18.62	5,629.46	445.77	381.55	11.27	8,234.36
Water supply consumption in cu.m.	watvol	32.69	17.11	9.32	204.17	28.44	14.33	9.19	175.92	25.67	13.08	9.11	186.40
Per-capita water supply expenditure	watexppc	1,373.56	2,419.52	89.60	84,000.00	1,270.85	1,122.89	49.65	14,550.00	1,326.78	1,179.47	30.59	19,242.40
Total electricity expenditure	elecexp	16,789.41	19,033.81	300.00	228,000.00	17,896.99	19,123.40	519.64	285,803.60	16,037.64	16,717.55	171.62	197,624.70
Per month electricity expenditure	elecepmonth	1,399.12	1,586.15	25.00	19,000.00	1,491.42	1,493.62	43.30	23,816.96	1,336.47	1,393.13	14.30	16,468.72
Electricity consumption in kilowatt-hour	elecvol	166.99	170.39	3.20	1,996.62	139.80	136.63	4.28	1,999.59	153.17	144.88	1.73	1,651.89
Per-capita electricity expenditure	elecexppc	4,526.15	7,483.28	35,337.00	162,000.00	4,479.16	5,368.32	129.91	77,946.43	4,145.14	4,977.31	50.97	83,210.40
Total expenditure on other goods	othdexp	306,227.90	273,173.40	4,934.95	2,135,375.00	288,128.50	247,247.00	29,066.47	2,243,366.00	282,232.90	223,017.20	30,153.37	2,815,271.00
Per-capita expenditure on other goods	othdexppc	81,287.83	103,464.30	4,934.95	2,135,375.00	72,902.13	73,474.95	6,319.82	1,033,426.00	73,062.83	71,368.44	10,091.61	1,070,520.00
Effective price of water	WatP	12.90	8.77	7.02	77.60	17.30	16.55	9.82	97.88	23.20	27.29	8.98	133.20
Effective price of electricity	ElecP	8.05	0.36	7.82	9.52	10.35	0.37	10.13	12.06	8.45	0.34	4.31	9.97
Effective price of other goods	othdP	74.09	14.19	15.68	108.56	109.97	19.58	11.07	178.33	120.93	22.65	16.96	191.67
Share of water supply expenditure	watshr	0.0180	0.0112	0.0016	0.1647	0.0194	0.0119	0.0011	0.1439	0.0204	0.0131	0.0010	0.2109
Share of electricity expenditure	elecshr	0.0500	0.0250	0.0024	0.2315	0.0562	0.0278	0.0051	0.2126	0.0527	0.0265	0.0020	0.2259
Share of other goods expenditure	othdshr	0.9319	0.0303	0.6693	0.9870	0.9213	0.0338	0.7524	0.9885	0.9451	0.0325	0.6067	1.0067

Note: Data on income, expenditure and prices are in nominal terms in Philippine peso.

Table A3.2: Summary statistics of households in the West Zone (Maynilad), 2009–2015

Summary statistics

		2009				2012				2015			
Variable Name	**Variable**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**
Income decile	incdecile	7.70	2.02	1.00	10.00	7.39	2.18	1.00	10.00	7.39	2.21	1.00	10.00
Family size	famsize	4.62	2.20	1.00	17.50	4.55	2.17	1.00	19.50	4.54	2.16	1.00	17.50
Total income	toinc	340,620.20	319,513.40	16,609.00	6,668,738.00	322,032.40	291,795.30	17,233.16	3,657,524.00	338,299.60	296,172.80	32,517.57	3,525,617.00
Per-capita income	toincpc	87,440.44	88,880.20	9,992.00	1,312,136.00	83,447.06	85,752.61	9,049.00	1,436,132.00	86,575.10	91,997.45	9,144.86	1,909,475.00
Total expenditure	toexp	300,033.30	248,649.10	14,360.00	2,995,293.00	278,399.50	226,318.60	26,377.82	2,337,161.00	287,420.50	225,123.20	30,808.18	2,889,891.00
Per-capita expenditure	toexppc	77,376.27	74,061.28	9,681.69	866,534.00	71,948.74	68,360.71	8,584.95	992,901.40	72,971.60	65,252.77	10,950.89	1,110,645.00
Total water supply expenditure	watexp	4,491.83	3,693.58	48.00	52,800.00	4,678.57	3,988.54	259.82	45,208.93	5,224.42	4,471.98	249.63	98,812.35
Per month water supply expenditure	watexpmonth	374.32	307.80	4.00	4,400.00	389.88	332.38	21.65	3,767.41	435.37	372.67	20.80	8,234.36
Water supply consumption in cu.m.	watvol	24.26	11.66	9.04	135.11	21.94	10.92	9.17	104.24	23.20	11.33	9.16	186.40
Per-capita water supply expenditure	watexppc	1,123.65	996.29	18.00	14,880.00	1,163.62	1,015.38	47.24	166,628.57	1,288.37	1,054.91	30.59	14,116.05
Total electricity expenditure	elecexp	15,177.89	15,098.29	300.00	162,000.00	15,292.10	14,613.33	155.89	155,892.90	15,264.71	15,467.27	254.83	187,223.40
Per month electricity expenditure	elecectmonth	1,264.82	1,258.19	25.00	13,500.00	1,274.34	1,217.78	12.99	12,991.07	1,272.06	1,288.94	21.24	15,601.95
Electricity consumption in kilowatt-hour	elecvol	152.16	138.25	3.20	1,441.37	120.64	107.10	1.28	1,090.69	146.38	134.55	2.57	1,564.95
Per-capita electricity expenditure	elecexppc	3,884.22	4,604.84	75.00	81,000.00	3,938.14	4,382.43	41.57	67,553.57	3,874.59	4,194.30	50.97	54,606.82
Total expenditure on other goods	othdexp	280,363.70	234,932.60	12,980.00	2,900,973.00	257,602.00	212,135.80	23,661.21	2,249,387.00	272,159.60	214,575.10	30,153.37	2,815,271.00
Per-capita expenditure on other goods	othdexppc	72,368.39	69,949.43	9,049.14	816,734.00	66,635.76	64,112.68	8,043.79	905,233.90	69,136.01	62,581.91	10,091.61	1,070,520.00
Effective price of water	WatP	21.43	24.81	10.69	106.77	26.98	32.82	4.64	129.07	27.61	32.87	8.98	133.20
Effective price of electricity	ElecP	8.03	0.35	7.82	9.56	10.30	0.32	10.13	11.91	8.43	0.31	8.25	9.97
Effective price of other goods	othdP	75.29	14.18	16.23	125.74	116.61	20.38	22.19	197.56	123.76	2,219,372.00	19.86	189.65
Share of water supply expenditure	watshr	0.0177	0.0115	0.0006	0.1328	0.0190	0.0115	0.0011	0.1134	0.0207	0.0131	0.0010	0.1804
Share of electricity expenditure	elecshr	0.0496	0.0258	0.0029	0.2271	0.0541	0.0290	0.0017	0.2386	0.0525	0.0269	0.0024	0.2187
Share of other goods expenditure	othdshr	0.9327	0.0301	0.6735	0.9932	0.9327	0.0301	0.6735	0.9937	0.9950	0.0328	0.7825	1.0055

Appendix 4: Sampling design of the FIES and robustness check results for estimating the water-demand elasticities

Section A4.1: Sampling design of the FIES

The Family Income and Expenditure Survey (FIES) is a nationwide household survey conducted every three years by the Philippine Statistics Authority (PSA). It is a sample survey designed to provide data on the household income and expenditure that are representative of the Philippines and its 17 regions. Its sampling method uses the 2003 Master Sample (MS) that was created for household surveys on the basis of the 2000 Census of Population and housing. MS is a sample from which subsamples or list of sample households are drawn. Starting in the 2012 FIES, the survey adopted the 2009 Philippine Classification of Individual Consumption According to Purpose (PCOICOP), which is the first standard classification of individual consumption expenditure in the country. The discussions below draw on the technical notes on the FIES sampling methodology posted by the PSA on its website.[1]

The FIES enumeration is conducted twice during the survey year. This scheme is intended to minimise the respondent's memory bias and to capture the seasonality of income and expenditure pattern. The first visit is done in July as reference for the first semester, January to June, and the second visit is made in January for the second semester, July to December. In both visits, the respondent, defined as the household head or any household member who manages the finance of the family that can give reliable information or answers to the survey questionnaire, answers the same set of questions.

The FIES utilises a stratified, three-stage random sampling design. Survey weights are used to produce valid estimates of the population parameter. The sample selection involves three stages. In the first stage, the number of households/families for the FIES is estimated using the 2000 Census of Population and Household (CPH)-based population projections and information from the 2000 CPH on the average household size by province. The PSA designs the master sample that consists of randomly assigned and selected set of geographic areas with non-overlapping and discernible boundaries and these are called the primary sampling units (PSUs). The PSU can be: (i) the whole barangay; or (ii) a portion of a large barangay; or (iii) combinations of small barangays. Due to the wide variation in the PSU sizes, the PSUs with

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[1] <https://psada.psa.gov.ph/index.php/2003-ms-design>

selection probabilities greater than one are identified and are included in the sample as certainty selections (Ericta and Fabian 2009). In the second stage, the enumeration areas are selected within the sampled PSUs. In the third stage, housing units are selected within the sampled enumeration areas. Given the FIES sampling methodology, it is very rare that the same household is selected twice in two consecutive surveys. Also, each FIES is a cross-section or a snapshot.

The FIES data are the results of the sample survey and are subject to sampling variations because observations are not taken from the entire population. The survey estimates may also face non-sampling errors such as the deliberate under or over reporting of household income and expenditures, or from the reluctance of the respondents to reveal the true levels of their actual income and expenditures. The sampling error that the FIES follows falls within a range of plus or minus two times the standard error of that statistic in 95 per cent of all possible samples of the same size and design. Table A4.1 shows the total number of households in the Philippines and NCR as well as their respective FIES sample sizes for 2009, 2012, and 2015.

Table A4.1: Number of household samples in the FIES, 2009, 2012, 2015

	2009		2012		2015	
	Total	**FIES sample**	**Total**	**FIES sample**	**Total**	**FIES sample**
No. of households in the Philippines	18,452,000.00	38,400.00	21,426,000.00	40,171.00	22,730,000.00	41,544.00
No. of households in NCR	2,461,000.00 (13.3%)	4,285.00 (11.2%)	2,917,000.00 (13.6%)	4,232.00 (10.5%)	3,019,000.00 (13.3%)	4,130.00 (9.9%)

Source: Philippine Statistics Authority.
Note: The percentage shown is the share of the households in NCR to the total number and sample households in the Philippines.

Section A4.2: Quadratic AIDS

The Quadratic AIDS (QUAIDS) model is used for robustness tests and for comparing the estimated elasticities with the AIDS. Banks et al. (1997) introduced QUAIDS as an extension of the AIDS model. Their purpose is to allow the corresponding impact of demographic and other household characteristics to enter in all the terms in the AIDS model. The authors point out that the AIDS model only allows for straight Engel curves and notice the polynomial relationship between extra income and some goods. Thus, they suggest that there should be an additional term which is quadratic in supernumerary income which further fleshes out the income expansion paths of any system in consumer demand. The QUAIDS model is given as:

$$w_i = \alpha_i + \sum_{j}^{J} \gamma_{ij} lnp_j + \beta_i \ln\left[\frac{x}{a(p)}\right] + \frac{\lambda_i}{b(p)}\left\{\ln\left[\frac{x}{a(p)}\right]\right\}^2 \qquad Eq. A4.1$$

To calculate the elasticities of the QUAIDS model, differentiate *Equation A4.1* with respect to both *x* and p. This yields:

$$\mu_i \equiv \beta_i + \frac{2\lambda_i}{b(p)}\left\{\ln\left[\frac{x}{a(p)}\right]\right\} \qquad Eq. A4.2$$

$$\mu_{ij} \equiv \gamma_{ij} - \mu_i(\alpha_j + \sum_{k}^{K} \gamma_{ij} lnP_k) - \frac{\lambda_i \beta_j}{b(p)}\left\{\ln\left[\frac{x}{a(p)}\right]\right\}^2 \qquad Eq. A4.3$$

The Marshallian (uncompensated), Hicksian (compensated), and income elasticities for QUAIDS are given, respectively, as follows:

$$e_{ij}^{u} = \frac{\mu_{ij}}{w_i} - \delta_{ij} \qquad Eq. A4.4$$

$$e_{ij}^{c} = e_{ij}^{u} + e_i w_j \qquad Eq. A4.5$$

$$e_i = \frac{\mu_i}{w_i} + 1 \qquad Eq. A4.6$$

Where δ is the Kronecker delta.

Section A4.3: Two-stage Least Squares (2SLS)

Some empirical studies use the 2SLS model to circumvent the simultaneity and endogeneity problems arising from using Ordinary Least squares (OLS). Simultaneity and endogeneity will produce biased and inconsistent estimates when using OLS. These problems arise when the main pricing policy is the increasing block tariffs. The price variable is endogenous as it is determined by the household consumption. The structure, price, and the block size are determined by the concessionaires and the regulator. Hence, consumers will consume water being purchased, taking into account some measure of price. The price paid also depends on how much is consumed (David and Inocencio 1998). In the first stage, the water price is estimated. In the second stage, the predicted water price is specified together with the other independent variables in the demand equations with the share of water as the dependent variable. The share of water expenditure is in the left-hand side in the second stage to follow the structural equation of the AIDS model in estimating elasticities. Control variables, such as the water source, family size, district, and year dummy are included to control for the endogeneity problems associated with increasing block tariffs.

In estimating the elasticities using the 2SLS, the structural equations are considered:

First stage:

$$lnwatP = \propto_0 + \sum \propto_i \, lnp_i + fsize + watersrce + District + YearDum + \varepsilon_u \qquad Eq. A4.7$$

Second stage:

$$watshr = \propto_0 + \propto_1 \, lnwatP + \sum \propto_i \, lnp_i + fsize + watersrce + District + YearDum + \varepsilon_u \qquad Eq. A4.8$$

The variables in equations A4.7 and A4.8 are defined in Table A4.2. The results of the three models are presented in A4.3 for Manila Water and A4.4 for Maynilad.

Table A4.2: Parameters for 2SLS regression

Variable	Name	Description
watshr	Expenditure share of water	Expenditure share of water
famsize	Family size	Household or family size of each household
District	District	The district which the household belongs to (District 1–4); each district is being served by either of the concessionaires.
watsrce	Type of Water source	Households' main water supply source (1–Private, 2–shared)
YearDum	Year Dummy	Year dummies (0–2009, 1–2012, 2–2015)
lnp	Natural logarithm of prices of good *i*	Vector of prices of the different goods considered, except for water price.
lnwatP	Natural logarithm of water price	Vector of water prices.

Source: Author.

Table A4.3: AIDS, QUAIDS, and 2SLS elasticity estimates for Manila Water by District

		District 2			District 4	
	AIDS	**QUAIDS**	**2SLS**	**AIDS**	**QUAIDS**	**2SLS**
ε_{wat}	–0.763***	–0.768***	–0.3539***	–0.765***	–0.777***	1.621
	(0.018)	*(0.038)*	*(0.107)*	*(0.019)*	*(0.035)*	*(4.623)*
$\varepsilon_{wat/elec}$	0.034***	–0.071***	0.059***	0.032***	–0.059***	–0.1190
	(0.008)	*(0.014)*	*(0.016)*	*(0.007)*	*(0.011)*	*(0.376)*
$\varepsilon_{wat/food}$	–0.006	–0.042***	–0.0460**	–0.006	–0.045***	0.3509
	(0.004)	*(0.004)*	*(0.016)*	*(0.004)*	*(0.004)*	*(1.012)*
$\varepsilon_{wat/othgds}$	–0.013**	0.034***	0.0600**	–0.013**	0.033***	–0.3270
	(0.005)	*(0.004)*	*(0.020)*	*(0.004)*	*(0.004)*	*(0.922)*
ε_{income}	0.666***	0.636***	–0.002	0.670***	0.652***	0.0226
	(0.016)	*(0.055)*	*(0.005)*	*(0.017)*	*(0.048)*	*(0.090)*

* p<0.05, ** p<0.01, *** p<0.001

Table A4.4: AIDS, QUAIDS, and 2SLS elasticity estimates for Maynilad by District

	District 1			District 3			District 4		
	AIDS	**QUAIDS**	**2SLS**	**AIDS**	**QUAIDS**	**2SLS**	**AIDS**	**QUAIDS**	**2SLS**
ε_{wat}	–1.011***	–1.037***	–2.2682	–1.012***	–1.037***	–0.0457***	–1.012***	–1.039***	–0.0973***
	(0.011)	*(0.009)*	*(7.017)*	*(0.011)*	*(0.009)*	*(0.003)*	*(0.011)*	*(0.010)*	*(0.011)*
$\varepsilon_{wat/elec}$	0.036***	–0.031***	–0.0054	0.038***	–0.036	0.001	0.035***	–0.031	0.003
	(0.004)	*(0.022)*	*(0.068)*	*(0.005)*	*(0.027)*	*(0.001)*	*(0.004)*	*(0.020)*	*(0.002)*
$\varepsilon_{wat/food}$	–0.003	–0.034***	–0.4017	–0.003	–0.033***	–0.005	–0.003	–0.036***	–0.009*
	(0.002)	*(0.004)*	*(1.243)*	*(0.002)*	*(0.004)*	*(0.003)*	*(0.002)*	*(0.005)*	*(0.004)*
$\varepsilon_{wat/othgds}$	–0.006	0.119***	0.2668	–0.005	0.133***	0.003	–0.006	0.109***	0.0004
	(0.003)	*(0.023)*	*(0.841)*	*(0.003)*	*(0.030)*	*(0.001)*	*(0.003)*	*(0.018)*	*(0.003)*
ε_{income}	0.601***	0.882***	–0.1636	0.585***	0.875***	–0.0134***	0.571***	0.876***	–0.0010***
	(0.014)	*(0.037)*	*(0.498)*	*(0.014)*	*(0.035)*	*(0.001)*	*(0.015)*	*(0.040)*	*(0.002)*

* p<0.05, ** p<0.01, *** p<0.001

Comparing the results from all three methods, the AIDS and the QUAIDS models produce more consistent results. Although the estimates of AIDS and QUAIDS have slight differences, the signs of the water own- and cross-price elasticities conform to expectation. Since water is considered a necessary good, both models produce negative own-price elasticities as expected. The cross-price elasticities of water and food, and non-alcoholic beverages, with respect to water, are as what empirical studies suggest. Goods that are used as inputs in household production, such as water, electricity, and food, and non-alcoholic beverages, are complementary goods. Income elasticities have a positive sign for both models, which is consistent with *a priori* expectation and the results of existing empirical studies.

In the case of the 2SLS, there are some cases wherein the results show both inelastic and elastic values and have a positive value for the own-price elasticities. Additionally, income elasticities have negative signs. Since water is a necessary good, the own-price elasticities are expected to have a negative sign while the income elasticities have a positive sign. Clearly, the estimates of 2SLS are inconsistent and unreliable, and therefore they are not used in this thesis. In contrast, the AIDS and the QUAIDS estimated elasticities appear to be consistent with *a priori* expectations and the results of earlier empirical studies.

Although the estimates of the QUAIDS model are almost the same as those of the AIDS model, the regression runs do not converge to zero whereas those of the AIDS model converge to zero after only a few iterations. In the AIDS and QUAIDS models, it is important that the regression runs converge to zero to obtain more precise results. The syntax that Lecocq and Robin (2015) introduce can set the number of iterations to zero. By doing this, the estimates are based on the linearised version of the model, and that *a(p)* is replaced by the Stone price index and *b(p)* =

1. However, by setting the iterations to zero, the QUAIDS model will be like how the AIDS is estimated. Thus, the estimates generated by using the AIDS model are more precise given that the model converges to zero and that imposing the homogeneity restriction correctly estimates the elasticities. The example below shows a sample regression result using the pooled dataset of all households in Maynilad. It can be observed that in each iteration, the criterion for each iteration to reach $1x10^{-5}$ is not achieved using the QUAIDS model after 50 iterations.

Example of the QUAIDS regression run:

```
INSTRUMENTAL REGRESSION(S)

      Source |       SS           df       MS      Number of obs   =     7,603
-------------+----------------------------------   F(9, 7593)      =   7801.27
       Model |  2722.36501         9  302.485002   Prob > F        =    0.0000
    Residual |  294.409742     7,593  .038773837   R-squared       =    0.9024
-------------+----------------------------------   Adj R-squared   =    0.9023
       Total |  3016.77476     7,602  .396839615   Root MSE        =    .19691

------------------------------------------------------------------------------
     lntotex |      Coef. Std.Err.     z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnWATP |  -.0154107   .0040039    -3.85   0.000    -.0232583   -.0075631
 lnELECFUELP |  -.0281002   .0046461    -6.05   0.000    -.0372064   -.0189939
   lnFODNACLP |  -.2653208   .0097944   -27.09   0.000    -.2845175   -.2461241
    lnOTHGDP |   .0767289   .0062213    12.33   0.000     .0645353    .0889225
     lntoinc |   .7489313   .0049901   150.08   0.000     .7391508    .7587118
       fsize |   .0330626   .0012723    25.99   0.000      .030569    .0355562
    District |  -.0155015   .0019956    -7.77   0.000    -.0194128   -.0115903
   watersrce |  -.0053765   .0010192    -5.28   0.000     -.007374    -.003379
     YearDum |   -.001714   .0040129    -0.43   0.669    -.0095792    .0061512
       _cons |   3.853699    .091645    42.05   0.000     3.674078     4.03332
------------------------------------------------------------------------------

Iteration = 1       Criterion = .2612782
Iteration = 2       Criterion = .12681288
Iteration = 3       Criterion = .23998672
Iteration = 4       Criterion = .30029848
Iteration = 5       Criterion = .56295793
Iteration = 6       Criterion = .37885825
Iteration = 7       Criterion = .65419527
Iteration = 8       Criterion = .42336901
Iteration = 9       Criterion = .67173464
Iteration = 10      Criterion = .42623832
Iteration = 11      Criterion = .66879372
Iteration = 12      Criterion = .42931196
Iteration = 13      Criterion = .67100195
Iteration = 14      Criterion = .42794808
Iteration = 15      Criterion = .66970949
Iteration = 16      Criterion = .42882774
Iteration = 17      Criterion = .67049329
Iteration = 18      Criterion = .42830505
Iteration = 19      Criterion = .67002202
Iteration = 20      Criterion = .42862082
Iteration = 21      Criterion = .67030601
Iteration = 22      Criterion = .42843078
Iteration = 23      Criterion = .67013499
Iteration = 24      Criterion = .42854528
Iteration = 25      Criterion = .67023801
Iteration = 26      Criterion = .42847633
Iteration = 27      Criterion = .67017596
Iteration = 28      Criterion = .42851786
Iteration = 29      Criterion = .67021333
```

```
Iteration = 30      Criterion = .42849285
Iteration = 31      Criterion = .67019082
Iteration = 32      Criterion = .42850791
Iteration = 33      Criterion = .67020438
Iteration = 34      Criterion = .42849884
Iteration = 35      Criterion = .67019622
Iteration = 36      Criterion = .42850431
Iteration = 37      Criterion = .67020113
Iteration = 38      Criterion = .42850101
Iteration = 39      Criterion = .67019817
Iteration = 40      Criterion = .428503
Iteration = 41      Criterion = .67019996
Iteration = 42      Criterion = .4285018
Iteration = 43      Criterion = .67019888
Iteration = 44      Criterion = .42850252
Iteration = 45      Criterion = .67019953
Iteration = 46      Criterion = .42850209
Iteration = 47      Criterion = .67019914
Iteration = 48      Criterion = .42850235
Iteration = 49      Criterion = .67019937
Iteration = 50      Criterion = .42850219
Iteration = 51      Criterion = .67019923

QUAIDS - PROPER ESTIMATION WITH FIXED ALPHA_0 = 0
HOMOGENEITY CONSTRAINED ESTIMATES

------------------------------------------------------------------------------
Equation           Obs  Parms        RMSE    "R-sq"    F( 11,  7591)   Prob > F
------------------------------------------------------------------------------
WATSHR            7603     11    .0108358    0.2543          258.90     0.0000
ELECFUELSHR       7603     11    .0233787    0.8519         4368.64     0.0000
FODNALCSHR        7603     11    .0493737    0.8486         4256.79     0.0000
TOTHGDSHR         7603     11    .0537335    0.8786         5493.21     0.0000
------------------------------------------------------------------------------
```

The results shown in Tables A4.5 and A4.6 are based on the model that includes additional household characteristics. The estimated own-price elasticity of water demand of the 2SLS model is positive for the households under the Manila Water concession area. The positive own-price elasticity is due to the endogeneity of water prices on water consumption since prices are determined based on household consumption. Thus, using the results of the 2SLS model cannot reflect the household water demand in Metro Manila.

The QUAIDS results are almost similar to those of AIDS, with the exception of the households serviced by Maynilad. The estimates suggest that water demand is elastic with the correct sign and is closer to the estimates without the additional household characteristics. It is to be noted, however, that the QUAIDS model does not converge. This is similar to the problem with the results generated previously, in which convergence is not attained even up to the 50th iteration. Thus, estimates are less precise and can also be biased due to the non-convergence of the supposed quadratic Engel Curve.

Table A4.5: AIDS, OLS and 2SLS elasticity estimates for Manila Water by District (with additional household characteristics)

	District 2			District 4		
	AIDS	**QUAIDS**	**2SLS**	**AIDS**	**QUAIDS**	**2SLS**
ε_{wat}	-0.717***	–0.697***	0.063**	-0.721***	–0.704***	0.128**
	(0.019)	*(0.039)*	*(0.012)*	*(0.02)*	*(0.038)*	*(0.048)*
$\varepsilon_{wat/elec}$	0.065***	0.078***	0.016	0.060***	0.071***	–0.113*
	(0.008)	*(0.009)*	*(0.016)*	*(0.007)*	*(0.008)*	*(0.044)*
$\varepsilon_{wat/food}$	–0.011**	–0.021***	–0.006	–0.012**	–0.022***	–0.039
	(0.004)	*(0.003)*	*(0.026)*	*(0.004)*	*(0.004)*	*(0.065)*
$\varepsilon_{wat/othgds}$	–0.018***	–0.006	0.032	-0.017***	–0.007	0.088*
	(0.005)	*(0.005)*	*(0.018)*	*(0.005)*	*(0.005)*	*(0.043)*
ε_{income}	0.617***	0.628***	–0.146***	0.622***	0.633***	–0.133**
	(0.019)	*(0.053)*	*(0.021)*	*(0.02)*	*(0.049)*	*(0.049)*

* p<0.05, ** p<0.01, *** p<0.001

Table A4.6: AIDS, QUAIDS and 2SLS elasticity estimates for Maynilad by District (with additional household characteristics)

	District 1			District 3			District 4		
	AIDS	**QUAIDS**	**2SLS**	**AIDS**	**QUAIDS**	**2SLS**	**AIDS**	**QUAIDS**	**2SLS**
ε_{wat}	–0.993***	–1.015***	–0.033	–0.994***	-1.035***	–0.631***	–0.993***	–1.037***	–0.320***
	(0.011)	*(0.010)*	*(0.037)*	*(0.011)*	*(0.010)*	*(0.035)*	*(0.012)*	*(0.011)*	*(0.030)*
$\varepsilon_{wat/elec}$	0.058***	0.101***	0.003	0.063***	–0.134***	0.007	0.056***	0.091***	0.036
	(0.004)	*(0.016)*	*(0.028)*	*(0.005)*	*(0.025)*	*(0.027)*	*(0.004)*	*(0.013)*	*(0.025)*
$\varepsilon_{wat/food}$	–0.003	–0.005	0.001	–0.004	–0.005	0.154*	–0.004	–0.005	0.027
	(0.002)	*(0.003)*	*(0.055)*	*(0.002)*	*(0.003)*	*(0.064)*	*(0.002)*	*(0.003)*	*(0.045)*
$\varepsilon_{wat/othgds}$	–0.013***	–0.006	0.050	–0.012***	–0.006	–0.004	-0.012***	–0.006	–0.009
	(0.003)	*(0.033)*	*(0.0355)*	*(0.003)*	*(0.003)*	*(0.037)*	*(0.003)*	*(0.003)*	*(0.028)*
ε_{income}	0.630***	–0730***	–0.358***	0.615***	0.727***	–0.318***	0.603***	0.711***	–0.131***
	(0.016)	*(0.029)*	*(0.049)*	*(0.017)*	*(0.029)*	*(0.050)*	*(0.017)*	*(0.031)*	*(0.320)*

* p<0.05, ** p<0.01, *** p<0.001

Appendix 5: Technical notes on estimating the RAUC

Section A5.1: Technical notes on social discount rate

The social discount rate (SDR) plays a crucial role in determining which proposed public projects should be approved or disapproved by the government. Setting SDR too high will unnecessarily screen out socially desirable projects, while setting it too low will pave the way for the inclusion of economically inefficient, less socially desirable projects. In a competitive capital market without distortions, the market rate of interest should be the appropriate SDR. However, capital markets in many countries, especially developing countries like the Philippines, are far from perfect. Thus, governments conduct studies to determine the appropriate SDR that must be hurdled by public projects.

Zhuang et al. (2007) provide a comprehensive review of the theoretical foundations for the choice of SDR and actual SDRs used by countries around the world. They find that among the countries surveyed, developing countries apply higher SDRs, ranging from 8 to 15 per cent, than developed countries, ranging from 5 to 7 per cent. Gurluk (2016) also finds that SDRs in developing countries range from 7.3 to 15 per cent. Aside from scarcity of capital, other factors such as (i) poorer financial intermediation, (ii) greater market distortions, and (iii) more difficult ways in accessing international capital markets contribute to higher SDRs in developing countries. These findings are also consistent with Markandaya and Pearce (1991) and that because of the shortage of capital, the SDRs are high on the justification of optimal allocation of scarce capital. Campos et al. (2015) add that the reason for the higher SDRs is that there is a higher opportunity cost of capital in developing countries. Medalla (2015) stresses that, especially in the Philippines, lower discount rates will increase the probability of choosing inefficient projects.

In the Philippines, all major capital projects (MCPs) undergo a prescribed evaluation process.[1] A cabinet-level Investment Coordination Committee (ICC) chaired by the Secretary of Finance reviews or evaluates specific MCPs with respect to technical, financial, economic, social, and institutional development, feasibility/viability as well as from the context of sectoral plans and geographical strategies. Projects that pass the evaluation are then submitted to the National

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[1] An MCP is a program costing at least PhP500 million and involves investments in physical and human capital through expenditures or transfers by the National Government. As a rule, MCPs can be evaluated, specifically in terms of financial and economic viability.

Economic Development Authority (NEDA) Board which is chaired by the President for confirmation of ICC action. The ICC also determines the SDR and submits it to the NEDA Board for confirmation. It uses the social opportunity cost of capital (SOC) method in determining the SDR.

The ICC had been prescribing an SDR of 15 per cent since the late 1980s up until 2016 when it revised the SDR downward to 10 per cent (ICC 2016). It points out that the new SDR is consistent with the 10 to 12 per cent rates that are being used by multilateral banks. The current SDR appears to be lower than those being used by some developing countries in Asia (Table A5.1).

Table A5.1: Social discount rates of selected developing countries

Country	SDR
India	12%
Pakistan	12%
Indonesia	15%
Vietnam	12%

Source: Zhuang et al. (2007); JICA (2012); Campos et al. (2015).

Section A5.2: Additional information on water refilling station groundwater usage in Metro Manila

As discussed in Chapter 5, the households in Metro Manila have elasticities ranging from –0.717 to –0.994. Although inelastic, the estimated elasticities are higher than what had been expected. This is because households in Metro Manila have alternative sources of water supply that augment the insufficient amount of water the concessionaires provide. More specifically, households have access to groundwater as well as water refilling stations. In fact, the MWSS and the concessionaires use 90 million litres per day (MLD), or roughly 1 cu.m. per second, as an additional supply of water for Metro Manila. Before the privatisation of the water services, many households in Metro Manila drew water from aquifers due to the MWSS' inability to provide reliable water services and that many households were not connected to the water system. Magtibay (2004) also reports that households in Metro Manila have a strong preference for water refilling stations as a source of drinking water due to the poor water quality that MWSS provided pre-privatisation.

Inocencio et al. (2002) report that 82 per cent, 15 per cent, and 6 per cent of the high-, middle-, and low-income households, respectively, use a combination of the service connections of

MWSS and alternative sources of water supply. One of the alternative sources is the groundwater source. JICA (2013) points out that groundwater can provide an additional 2.78 cu.m. per second of additional water to Metro Manila, which is equivalent to 2.1 per cent of the total water supply source in the region. Many households use it either as a substitute or a supplement to their water needs. Many of those who installed private deep wells before the water services privatisation still maintain them after the privatisation even without water permits from the National Water Resources Board (NWRB) to ensure that they have water supply during times when normal water services of the concessionaires are interrupted. Moreover, David et al. (2014) point out that the water tariffs from drawing surface water sources are more expensive than tapping ground water. This is because the operational costs of drawing water from surface water sources entail high costs for water treatment as compared to treating groundwater. However, JICA (2013) warns that the persistent use of groundwater by water users has caused the water level in the National Capital Region to drop by as much as 80 metres below sea level. This has allowed saltwater to enter the aquifers, causing the quality of water in aquifers to deteriorate.

Section A5.3: Planting season in the Philippines

Gutierrez et al. (2019) point out that farming in the Philippines is divided into two semesters. They map the duration of rice planting months in the country to identify which months need much water allocation for irrigation purposes. The province of Bulacan, where Angat Dam is located and is part of the Central Luzon region, starts the planting of rice, the country's staple food, in the first semester in November. The peak planting season starts in December and ends in January. The planting of rice in the second semester starts in May, peaks in July, and ends in August. In total, the region spends 92 days in the first semester and 62 days in the second semester in planting rice. It is expected that during peak planting days, AMRIS requires NWRB irrigation flows coming from Angat Dam but not on off-planting days.

Another reason why the NWRB reduces the flows for irrigation purposes is because it found out that the AMRIS area has been experiencing a significant reduction in the irrigable land during the wet and dry cropping seasons (Tabios and De Leon 2020). More specifically, the irrigable land has declined from 31,400 hectares to 17,500 hectares and 24,000 hectares during the wet and dry cropping seasons, respectively. This is partly due to the conversion of some farmlands into commercial, industrial, and housing purposes as urbanisation proceeds in the area and partly due to increased flooding in some areas.

Appendix 6: Vended water as the backstop technology of households in Metro Manila

This appendix discusses an alternative water source of households in Metro Manila, that is, vended water or water bought by households from vendors such as water refilling stations. Vended water is considered as a ‘backstop technology’ of households in Metro Manila when water disruptions occur or when water supply provided by the two concessionaires, Manila Water and Maynilad, is inadequate. The first section of this chapter deals with the importance of water vending in developing countries. The second section deals with vended water as the backstop technology of households in Metro Manila. The third section discusses the data on household consumption of vended water. The fourth section compares the prices and volumetric consumption of households that are dependent on vended water and those with metered connections to the concessionaires. The fifth section estimates the water-demand elasticities for vended water using the Almost Ideal Demand System (AIDS) model. The last section concludes.

Section A6.1: Water vending in developing countries

Water vending exists in many developing countries due to lack of access to piped water or poor services provided by water suppliers. Vended water is treated using water purifying instruments and then sold to the consumers. Collignon and Vezina (2000) and McGranahan et al. (2006) enumerate three categories of water vendors: (1) wholesale vendors; (2) distributing vendors; and (3) direct vendors. Wholesale vendors source the water from private boreholes or directly from utility companies. Distributing vendors go directly to the customers and usually conduct door-to-door transactions, while direct vendors require their customers to come to them directly to their water kiosks or stations. They are not necessarily mutually exclusive. A wholesale vendor may distribute water directly to customers and entertain customers who go to its kiosk or station to buy water.

Kjellén and Mcgranahan (2006) argue that water vending is a symptom of failed piped systems, which is common in many developing countries, hindering the households’ access to water supply. Gulyani et al. (2005) find that, despite a water utility present in Urban Kenya, many poor and non-poor households depend on water vendors due to the inadequate supply from the public utility. In Southeast Asia, McIntosh (2003) reports that small water vendors provide vended water to approximately 20–45 per cent of households. According to Conan (2003) and

Karuiki & Schwartz (2005), vended water in South Asia is delivered through tanker services but only when water services are intermittent. Thus, many developing countries, especially in low income or informal settlements, around the world rely on private water vendors.

In the Philippines, there are many modes of accessing vended water. Households may either buy water from the vendors' shops, neighbourhood kiosks, retail delivery vans, tanker trucks for bulk water, or ambulant water vendors (World Bank 2019). The convenience of accessing water, albeit at an added cost, influences households in urban areas to use vended water to meet their daily water needs. Water vendors, typically, use aquifers as the main source of their water supply. An increase in the number of deep wells in Metro Manila is causing a rise in the costs of accessing groundwater (David et al. 2014). Concerns about overextraction of groundwater led the National Water Resources Board (NWRB) to impose stricter enforcement in using groundwater from July 22, 2015, including raising the fees and charges for the use of groundwater.

Section A6.2: Vended water as the backstop technology of households in Metro Manila

Despite the importance of vended water to the urban poor, Opryszko et al. (2009) note that there are only a few studies. In the Philippines, the studies of Magtibay (2004) and Israel (2009) are the only ones that examine water refilling stations as an alternative water supply for many households in Metro Manila and in other Metro cities in the Philippines. While Magtibay (2004) discusses the cost, features, and the institutions and policies of water vendors, specifically water refilling stations, in Metro Manila, Israel (2009) analyses the local service delivery of potable water in the Philippines.

Water refilling stations in Metro Manila secure their water either from the piped connections of the concessionaires or from private deep wells, with the latter being the more popular source because it is cheaper. Water supply from both sources is required by regulatory agencies to undergo purification by treating the water using various equipment, such as sedimentation and carbon filters, water softeners, reverse osmosis membranes, ultra-violet lamps, and ozone generators (Magtibay 2004). These water refilling stations can produce 3,000 to 12,000 litres, or 3 to 12 cu.m., of purified water per day. However, there are some water refilling stations that can deliver 25,000 litres, or 25 cu.m., of water per day.

Magtibay (2004) describes the basic features of water refilling stations in the Philippines. The area of the water refilling station is, typically, at least 20–25 square metres and have a refilling and selling room, an enclosed water purification room, container washing and sanitising room, a storage room for empty and refilled containers, source water storage facility, toilet and office (see Figure A6.1). Table A6.1 shows the personnel complement of a typical water refilling station.

Figure A6.1a: Enclosed water purification room

Figure A6.1b: Refilling and selling room and storage room

Sources: <https://businessdiary.com.ph/835/water-refilling-station-study/> and <https://ofwnewsbeat.com/business-opportunity-starting-water-refilling-station/>

Table A6.1: Required human resource in a water refilling station

Employee	Function
Manager	Reports to work at least 4 hours a day and oversees the operations
Accountant or Bookkeeper	Organises the financial statements of the store
Administrative assistant	Records and handles all sales and purchases of their products
Front liner	Receives and refills the water containers of customers
Technical Assistant	Oversees the maintenance and operations of the equipment in the water refilling station
Driver or delivery man	Transports the refilled and empty containers to and from the customers.

Source: Magtibay (2004).

All businesses involved in water and sanitation are subjected to the relevant provisions of the Presidential Decree No. 856, or the Sanitation Code of the Philippines. Water refilling stations must comply with regulations set by different regulatory government agencies. Table A6.2 shows the various agencies that regulate the establishment and operation of water refilling stations in the Philippines. Table A6.3 shows the distribution of water refilling station establishments per city within Metro Manila from 2010 to 2019 reported by the Philippine Statistical Authority (PSA).

Table A6.2: Agencies that regulate the establishment and operations of water refilling stations in the Philippines.

Agency	Function
Department of Health (DOH)	Implements the rules and regulations prescribing the sanitary standards for all water supply systems, including water refilling stations, in the Philippines.
Local Government Units (LGUs)	Conducts sanitary inspection of the water refilling stations and issues: (1) sanitary permit; (2) sanitary clearance; (3) health certificates; (4) certificate of potability; and (5) drinking water site clearance and closure order. These permits along with other permits such as Bureau of Fire Permit, building permit, among others, are necessary for securing a business permit from a local government.
Water Quality Association of the Philippines, Inc. (WQAP)	Organisation of private firms that conducts activities, such as lectures, regarding water treatment processes, DOG policies, and other related topics; also monitors and implements the code of ethics and truth-in-advertising rules.
Association of Water Refilling Entrepreneurs	In-charge of resolving business management issues among its members.

Source: Magtibay (2004).

Israel (2009) discusses the reasons why households in the Philippines buy water from water refilling stations. He points out that while water supplied by concessionaires and provincial water utilities may be accessible, the potable water supplied is still limited and, in his view, a large share of it is contaminated. He also finds that water prices have an impact on water demand and he underscores that the increasing block tariffs that water utilities in the Philippines follow is regressive, as the poor end up paying more per cu.m. of water as compared to richer households.

People began buying water from water refilling stations when water quality became a problem. This happened when the MWSS assumed the management and distribution of water in the capital region in 1971 (Magtibay 2004). Thousands of water refilling stations exist in the Philippine landscape, and many of them are scattered over Metro Manila. As shown in Table A6.3, the number of refilling stations increased by 44 per cent between 2010 and 2019, from 3,028 to 4,348. Thus, the water refilling density ratio, that is, the number of people served per water refilling station, declined from 911.44 in 2010 to 787.72 in 2019, although there were years when the ratio rose as a result of closures of several firms due to a variety of reasons, such as non-compliance of government regulations, non-renewal of office land and/or building leases, and losses from operation.

Table A6.3: Number of water refilling station establishments in the National Capital Region, 2010–2019

City	**Year**									
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
City of Manila	525	522	801	799	799	784	786	785	754	753
Mandaluyong City	107	106	139	142	141	112	112	112	143	147
Marikina City	99	129	165	164	164	112	112	112	142	142
Pasig City	179	210	268	270	271	203	198	197	185	185
Quezon City	654	678	1069	1067	1066	868	741	201	956	956
San Juan City	38	43	69	69	68	66	69	69	67	67
Caloocan City	246	277	393	393	393	395	424	424	412	412
Malabon City	62	99	129	129	129	116	120	120	121	121
Navotas City	39	64	70	68	68	63	67	67	75	75
Valenzuela City	120	188	236	236	236	294	258	258	265	265
Las Piñas City	194	201	243	242	242	217	219	218	223	223
Makati City	233	241	261	261	262	245	223	223	219	218
Muntinlupa City	108	118	138	138	142	117	120	120	165	165
Parañaque City	168	219	275	275	277	264	276	275	283	282
Pasay City	87	96	175	176	177	168	168	168	172	172
Pateros	17	17	23	23	23	23	22	22	21	21
Taguig City	152	159	168	167	175	171	175	175	145	144
Total number of refilling stations	3028	3367	4622	4619	4633	4218	4090	3546	4348	4348
Ratio of households per station	911.44	839.63	626.66	642.58	656.63	733.94	776.03	917.89	767.82	787.72

Source: Philippine Statistical Authority, Author's calculations.

Water purifiers can cost between Php18,375 (US\$360) and Php38,790 (US\$760) per unit for households while the price of bottled water sold in groceries ranges from Php10.70 (US\$0.21) to Php21.40 (US\$0.42) per litre. By comparison, the price of water per 5-gallon of purified water, which water refilling stations sell, is between Php1.17 (US\$0.023) and Php1.38 (US\$0.027) per litre inclusive of delivery charge.[1] In terms of benefits, Israel (2009) points out that refilling stations have brought easier access of potable water to many households and that they are less expensive than having individual deep wells. Magtibay (2004) makes the same observation that people have a strong preference for the water refilling stations as an alternative source of water supply because it is cheaper than operating their own private deep wells for domestic use. The provision of water also has health, gender, and social impacts. Moreover, it is affected by institutional factors which have a significant role in water provisions (Israel 2009).

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[1] Water in a 5-gallon (using Imperial UK gallons) container is equivalent to 22.7 litres or 0.0227 cubic metres.

Section A6.3: Data on household consumption of vended water

There are two possible of sources of data on household consumption of vended water. The first source of data is the Family and Expenditure Survey (FIES) which was discussed in Chapter 4 and Appendix 4. The second is the Annual Poverty Indicator Survey (APIS), which is conducted by the Philippine Statistics Authority (PSA) since 2004 every year except for the years when the FIES is administered.[2] Like the FIES, the APIS uses the 2003 Master Sample created for household surveys on the basis of the 2000 Census of Population and Housing (CPH) results before 2013, and on the basis of the 2013 Master Sample beginning in 2013. It also uses a three-stage sampling design. Unlike the FIES, however, the APIS uses a smaller sample size and is conducted once a year covering January to June only. Up until 2011, the APIS covered a national sample of households deemed sufficient to provide estimates about the population at the national and regional levels only. The region includes the NCR. After 2011, however, the APIS covered a national sample of households deemed sufficient to provide estimates about the population at the national levels only. Hence, the PSA does not report the tabulated and cross-tabulated the variables at lower geographic levels since these may not be statistically reliable.

Table A6.4 shows a comparison of the FIES and APIS sample households. For APIS, the nearest years, namely, 2010, 2013, and 2016, are used to compare with the FIES 2009, 2012, and 2015. Both datasets report statistics on the main source of water supply.[3] This thesis uses the FIES datasets for the estimation of price elasticities of the demand for vended water because its sample size is larger than the APIS and its Public Use File that contains sample households at the city/municipal level is available for analysis.

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[2] The pilot APIS was conducted in April 1998 in five selected provinces.

[3] Note that if the household uses more than one source, the one being used mostly for the family is reported as the main source. This implies that there is a possibility that a household uses other sources of water supply.

Table A6.4: Comparison of the FIES and APIS sample households, 2009–2016

	2009		2010		2012		2013		2015		2016	
	Total	**FIES Sample**	**Total**	**APIS Sample[a]**	**Total**	**FIES Sample**	**Total**	**APIS Sample**	**Total**	**FIES Sample**	**Total**	**APIS Sample**
No. of households in the Philippines	18,452,000.00	38,400.00	18,803,000.00	20,103.00	21,426,000.00	40,171.00	21,892,000.00	10,864.00	22,730,000.00	41,544.00	23,771,000.00	10,332.00
No. of households in NCR	2,461,000.00	4,285.00	2,498,000.00	2,402.00	2,917,000.00	4,232.00	-	-	3,019,000.00	4,130.00	-	-
No. of households using water vendors as main source, Philippines	-	1,021.00	-	663.00	-	831.00	-	424.00	-	851.00	-	331.00
No. of households using water vendors as main source, NCR	-	313.00	-	113.00	-	206.00	-	-	-	222.00	-	-
% of households using water vendors as main source, Philippines	-	2.66%	-	3.30%	-	2.07%	-	3.90%	-	2.05%	-	3.20%
% of households using water vendors as main source, NCR	-	7.30%	-	4.70%	-	4.87%	-	-	-	5.38%	-	-

[a] Only the 2010 and 2011 APIS have a regional sample. All the other APIS after 2011 have national sample of households deemed sufficient to provide estimates about the population at the national levels only.

Source: PSA and author's calculations.

Section A6.4: Data description and comparison of prices of vended water and water tariffs of the concessionaires

To compare the prices of vended water and tariffs of the concessionaires as well as the average consumption of water, this thesis uses the FIES, which the PSA conducts, for the years 2009, 2012, and 2015.[4] It is to be noted that data on the annual cost per cu.m. of vended water is not publicly available. The price that Magtibay (2004) provides for the year 2004 is used to calculate the annual prices of vended water from 2004 to 2015 employing the inflation rates of the housing, water, electricity, gas, and other fuels, at constant 2012 prices reported by the PSA. The volumetric price of vended water ranges from Php80 to Php95 per cu.m.. This thesis uses the lower bound of the range, which is Php80 per cu.m.. Equation A6.1 below shows how the adjusted price of vended water is calculated for each year from 2005 to 2020. Sample calculations are also shown. Table A6.5 below shows the yearly inflation rates and the adjusted price of vended water from 2004 to 2020.

$$Adjusted\ price_t = Adjusted\ Price_{t-1} \times (1 + inflation_t) \qquad Eq.A6.1$$

Sample calculations:

Computing for the adjusted price for 2005:

$$Adjusted\ price_{2005} = 80 \times \left(1 + (0.075)\right) = Php\ 86\ per\ cubic\ metre$$

Computing for the adjusted price for 2015:

$$Adjusted\ price_{2015} = 119.8 \times \left(1 + (-0.012)\right) = Php\ 118.3\ per\ cubic\ metre$$

Computing for the adjusted price for 2020:

$$Adjusted\ price_{2020} = 129.9 \times \left(1 + (0.009)\right) = Php\ 131.1\ per\ cubic\ metre$$

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[4] The FIES sampling design is discussed in Appendix 4.

Table A6.5: Inflation rates and adjusted prices of vended water, 2004–2015

Year	Inflation (%)	Adjusted price of vended water (Php per cubic metre)
2004	3.8	80.0
2005	7.5	86.0
2006	6.0	91.2
2007	2.3	93.2
2008	4.7	97.6
2009	1.7	**99.2**
2010	5.1	104.3
2011	5.1	109.6
2012	4.6	**114.7**
2013	1.8	116.7
2014	2.6	119.8
2015	–1.2	**118.3**
2016	0.5	118.9
2017	2.7	122.1
2018	3.9	126.9
2019	2.4	129.9
2020	0.9	131.1

Source: BSP and author's calculations.

The volumetric prices for 2009, 2012 and 2015 are used to compute the volumetric water consumption for households using vended water. The total water expenditure is first computed on a monthly basis. This is because households that use metered connection are billed on a monthly basis. To be consistent with this monthly billing, this thesis computes the monthly expenditure for each household. A sample computation for a household in 2015 is shown below:

Total annual water expenditure = Php7,680

$$Monthly\ water\ expenditure = \frac{7{,}680}{12} = Php640/month$$

$$Water\ consumption = \frac{Monthly\ water\ expenditure}{Volumetric\ Price_t} = \frac{640}{118.32} = 5.41\ cu.m.$$

Table A6.6 presents a summary of descriptive statistics of the sample households. The households in the sample are those whose main water supply comes from vended water only. Although it is possible that households have multiple sources of water supply, the FIES, however, does not have a category of households that have access especially to both vended water and the water connections from the concessionaires. It is to be noted that the sample size for the East Zone is substantially smaller than the West Zone. This is expected because a larger proportion of the total household population of the East Zone is already connected to water services compared with the West Zone.[5] An important observation is that the average income of households that use vended water is substantially lower than those that have a metered connection with the concessionaires.[6] More specifically, the average annual income of the former ranges from Php168,387.00 (US$3,506.90) to Php251,764.70 (US$5,243.36) while that of the latter, from Php358,650.7 (US$7469.42) to Php420,855.0 (US$8764.92).[7] This is consistent with Solo's (1999) finding that water vendors, typically, provide water supply to lower income households.

The mean expenditure of the households that are dependent on vended water are almost half of those with metered connections. However, the mean total water supply expenditure of those dependent on vended water is almost the same as those connected to the water services of the concessionaires. Another important observation is that the households that use vended water spend between 2.5 and 3.32 per cent of their income for water consumption. This compares to the 1.7 to 2.0 per cent share of water expenditure to total income of those households that are connected to Manila Water and Maynilad.

Table A6.7 shows the average water expenditure per month, the average cost per cu.m., the average water consumption, and the number of households that use vended water and the water connection from concessionaires as their primary source. The water expenditure per month of households that use vended water is lower than those that are dependent on the water connections of Manila Water and Maynilad, except for the households in the East Zone in 2015. In 2009, 2012, and 2015, 8.08 per cent, 5.11 per cent, and 5.85 per cent of the total FIES household samples, respectively, are dependent on the water sold by water vendors.

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[5] Chapter 2 discusses in detail the performances of the two concessionaires and the factors that contributed to the early successes of Manila Water, which services the East Zone, in rapidly increasing the number of households connected to its water services and bringing down the non-water revenue during the early stages of privatisation. As of 2017, Manila Water' service coverage already reached 94 per cent of the total household population of the East Zone. In contrast with Manila Water's performance, Maynilad achieved a service coverage ratio of only 75.8 per cent of the total household population in the West Zone.

[6] See Table 4.4, Chapter 4.

[7] The conversion rate on Feb. 9, 2021, is US$ 1.00 = Php 47.98. The same conversion rate is used in all chapters of this thesis.

Table A6.7 also shows that the price per cu.m. of vended water is significantly higher than that of the water tariffs of the concessionaires. It ranges from Php 99.21 (US$1.98) to Php (US$2.36) per cu.m.. This is consistent with the ADB's (2016) report indicating that the cost of alternative water supply is more expensive than the economic supply price of water from Angat Dam, which is US$0.23 (Php 11.75) per cu.m.. This is also consistent with the findings of Kjellén and Mcgranahan (2006) showing that the cost of per volumetric water is more expensive if sourced from water vendors as compared to house connections.

There is also a striking difference between the households that have metered connection and those who are dependent on water vendors in terms of the average water consumption. This is consistent with the findings of Crane (1994) and Inocencio et al. (2002) that show that households which are dependent on water vendors, typically, have substantially less volumetric water consumption than metered households. However, since they pay more for vended water than for water supply from concessionaires, they spend more per cu.m.. Thus, their expenditure on vended water can be the same as those who are dependent on a water connection.

The large increase in the water consumption in 2015 is noteworthy. A possible explanation for this increase is that, from September 2015 to February 2016, Metro Manila experienced major water supply disruptions due to the El Niño phenomenon. This affected around 355,500 households in Metro Manila—18 per cent in the West Zone and 9 per cent in the East Zone of their respective total households (Ranada 2015).

Table A6.6: Summary of descriptive statistics (annual mean values)

Variable	2009		2012		2015	
	East Zone	**West Zone**	**East Zone**	**West Zone**	**East Zone**	**West Zone**
Number of households	32	281	27	179	33	189
Income Decile	6.03	6.36	4.89	5.61	5.94	5.7
Family size	4.66	4.84	5.17	4.77	5.33	4.63
Total income[a]	168,387.00	211,953.90	184,045.50	186,008.10	251,764.70	220,950.30
Total expenditure[a]	160,794.90	187,192.30	170,664.00	171,002.00	218,447.40	192,909.00
Total water supply expenditure[a]	4,730.25	4,335.91	5,161.78	4,833.08	6,865.64	5,899.18
Monthly Water supply consumption[b]	3.97	3.64	3.75	3.51	4.84	4.15
Annual Water supply consumption[b]	47.64	43.68	45.00	42.12	58.08	49.80
Total electricity expenditure[a]	19,607.06	23,481.86	18,645.11	20,001.65	14,949.82	12,945.97
Total expenditure on Food & non-alcoholic beverages[a]	86,582.47	90,333.13	82,904.15	91,067.51	95,946.55	103,502.60
Total expenditure on other goods[a]	31,828.13	41,597.35	69,275.25	67,153.08	83,315.03	76,605.35
Share of water supply expenditure	0.028	0.025	0.030	0.030	0.035	0.030
Share of electricity expenditure	0.119	0.128	0.110	0.114	0.070	0.067
Share of food & non-alcoholic beverages expenditure	0.554	0.518	0.524	0.550	0.488	0.543
Share of other goods expenditure	0.192	0.208	0.346	0.369	0.413	0.418

[a] In current Philippine peso.

[b] In cubic metres (cu.m.).

Source: FIES (PSA).

Table A6.7: Average expenditure, cost, and volume of water consumed by households in Metro Manila: 2009, 2012, 2015

	2009				**2012**				**2015**			
	Vended water		**Connection**		**Vended water**		**Connection**		**Vended water**		**Connection**	
	West Zone	**East Zone**	**West Zone**	**East Zone**	**West Zone**	**East Zone**	**West Zone**	**East Zone**	**West Zone**	**East Zone**	**West Zone**	**East Zone**
Water expenditure per month (in Php)	361.33	394.19	374.51	451.59	402.76	430.15	461.98	511.7	491.6	572.14	504.3567	537.6443
	(321.8047)	*(313.4779)*	*(296.1764)*	*(441.8028)*	*(296.3259)*	*(388.0822)*	*(385.3011)*	*(454.0508)*	*(354.6046)*	*(370.2098)*	*(432.6248)*	*(461.1257)*
Average cost per cu.m. (in Php)	99.21	99.21	13.93	11.92	114.66	114.66	17.03	17.61	118.32	118.32	17.80	15.09
	(0)	*(0)*	*(3.2388)*	*(3.0825)*	*(0)*	*(0)*	*(4.4729)*	*(4.8713)*	*(0)*	*(0)*	*(4.2307)*	*(3.7510)*
Volume in cu.m.	3.64	3.97	24.33	33.38	3.51	3.75	24.24	25.73	4.15	4.84	25.49	31.75
	(3.2577)	*(3.1598)*	*(11.3094)*	*(18.0903)*	*(2.5843)*	*(3.3844)*	*(11.4764)*	*(12.8091)*	*(2.9970)*	*(3.1286)*	*(12.4447)*	*(16.0725)*
Number of observations	281	32	2208	1668	179	27	2398	1636	189	33	2216	1580

NOTE: (1) Italicised values are standard deviations; (2) the standard deviation for the average cost per cu.m. of the vended water is zero because this was calculated using the annual inflation rates and the price indicated by Magtibay (2004).
Sources: Author’s calculation; FIES 2009, 2012, and 2015; Magtibay (2004).

Section A6.5: Long-run water-demand elasticity of households that use vended water

This section examines the sensitivity of households that are dependent on vended water to price changes. The Almost Ideal Demand System (AIDS) model is used to estimate the water-demand elasticities. The specification of the AIDS model follows *Equation 4.20* of Chapter 4, which includes other household characteristics. Table A6.8 below shows the own-price, cross-price, and income elasticities.

Table A6.8: Long-run water-demand elasticities for vended water (average), 2009–2015

	Coefficients	
	East Zone	**West Zone**
ε_{wat}	–0.691***	–0.664**
	(0.179)	*(0.196)*
$\varepsilon_{wat/elec}$	–0.527***	–0.494***
	(0.079)	*(0.073)*
$\varepsilon_{wat/food}$	–0.862***	–0.841***
	(0.012)	*(0.011)*
$\varepsilon_{wat/othgds}$	1.417***	1.488***
	(0.036)	*(0.036)*
ε_{income}	0.699***	0.669***
	(0.065)	*(0.070)*
N	92	649

*p<0.05, ** p<0.01, *** p<0.001; Note: Italicised values are standard deviations.
Source: Author's calculations.

The estimated own-price elasticities of the demand for vended water are –0.691 and –0.664 for the East and West Zone, respectively. It suggests that households that use vended water as their primary source for water supply are *less* sensitive to price changes as compared to the households that have metered connections to the concessionaires as reported in Chapter 4. Although the per volumetric price of water from water vendors is significantly higher than that of the concessionaires, households depend to a large extent on vended water as their alternative source of water supply. Moreover, households are more aware of the additional per volumetric cost of vended water because they purchase it in 5-gallon containers at prices quoted by the water vendors. In contrast, those that have metered connection face an increasing block tariff, in which case they may have difficulty knowing the marginal cost of the water they consume from piped water (Boland and Whittington 2000, Sibly and Tooth 2019).

The estimated cross-price elasticities of water with respect to electricity and food and non-alcoholic beverages have similar signs for both households in the east and West Zone. They indicate that households treat electricity and food and non-alcoholic beverages as complementary goods with vended water. The cross-price elasticities, however, are significantly higher compared to the households that have a metered connection (see Table 4.6, Chapter 4). The income elasticities for the east and West Zone also indicate that households that use vended water are income inelastic. That is, a one-per cent increase in income leads to a less than one-per cent increase in vended water consumed.

Section A6.6: Concluding remarks

Water provided by vendors is an important water source for households in urban areas in developing countries. This is also the case in Metro Manila. Water refilling stations proliferate in Metro Manila, are increasing in number over time, and are able to deliver up to 25,000 litres, or 25 cu.m, of water per day to various households. Given that these businesses are subject to regulations and inspections by various agencies, households are assured that vended water is safe and a viable alternative source of water supply. Although average per volumetric prices of vended water are 7.1 to 8.3 times higher than that of the water concessionaires, households still consider vended water as an important alternative source of water supply available to them. The estimated long-run demand elasticities for vended water in both the east and West Zones suggest that households are price-inelastic with respect to this water source.

Appendix 7: Technical notes on estimating the optimal timing

This appendix supplements the discussions on estimating the optimal timing to operationalise the Kaliwa Dam in Chapter 7.

Section A7.1: On environmental flows and ecological/environmental consequence of the Kaliwa Dam

According to the World Bank (2011, 2012), the environmental river flows are part of the water allocation in the Angat-Umiray river system. The World Bank (2011, 2012) estimates that the environmental flows are maintained at 1.9 cubic meters (cu.m.) per second, which is equivalent to 10 per cent of the dependable flows for a quasi-natural condition. Environmental flows preserve the ecological status of rivers and protect aquatic habitats (Tharme 2003, Jowett 1997). Dams can alter the natural flow patterns of streams and rivers, thus, establishing environmental flows greatly reduces the hydrological alteration and mitigates the degradation of ecosystems (Mezger et al. 2021).

The National Water Resources Board (NWRB) employs the quasi-natural flow condition to maintain the dependable flows in existing and proposed storage dams (World Bank 2011). This quasi-natural flow is maintained so that there is enough storage capacity to fully regulate the flow condition for a given storage dam. *Equation 6.2*, therefore, includes the environmental flows because the NWRB incorporates it in the water allocation and it affects the disposable flows allocated to Metro Manila. However, the analysis on its non-price effects will not be part of this thesis because the main concern is on the disposable flows—which are allocated for water use in Metro Manila. This thesis is also not concerned with the effects of the hydrological alteration if the Kaliwa Dam is built due to data constraints.

As highlighted in Chapter 2, the construction of the Kaliwa Dam will have impacts on the environment, as well as on the people living in the proposed area. Although not explicitly shown, the land acquisition and resettlement costs are estimated at Php1.97 billion or US$38.09 million (EMB 2014). The cost includes resettlements and payments to affected households, particularly indigenous peoples; pay for the right-of-way; and finance pavements to be built for access roads.

The Environmental Impact Statement (EIS) of the Metropolitan Waterworks and Sewerage System (MWSS 2019) presents key findings on the consequences of building the Kaliwa Dam. The project site was found to have considerable flora and fauna biodiversity, with several key important species recorded. The Kaliwa watershed is home to various wildlife, particularly, resident/native and endemic species, and the area has diversity of bird species. Portions of the project are located within ancestral domains of the Dumagat-Remontado indigenous group. The location also houses sacred sites that are the source of their drinking water, hygiene, and medical purposes, as well as cultural rites and rituals. The majority of the families have monthly incomes of Php5,000 (US$100.07) and below. The dam is also located near fault lines, namely, the Philippine Trench, the Philippine Fault Zone, the West Marikina Valley Fault, and the Manila trench. EMB (2014) lists other major social impacts that include: (i) loss of public infrastructure, facilities, and services; (ii) disruption of the existing government systems; (iii) altering social networks and community integrity; and (iv) potential loss of natural landmarks that are considered ecotourism sites.

Section A7.2: On why only household demand was considered in the analysis

The thesis considered only the water consumption of households because this already comprised a significant number of the customers connected to the water services of the concessionaires. Households comprise 91.40 per cent of the customers of the East Zone and 92.59 per cent of the West Zone. Non-households constitute less than 10 per cent of the customers of both concessionaires. Consequently, households shoulder the majority of the cost of capital for the Kaliwa Dam. Additionally, PSA (2020) reports that on the average, more than half of the distributed water were used by households (55%). Table A7.1 shows the number of connections per customer class for the East Zone and Table A7.2 for the West Zone. Table A7.3 shows the amount of water distributed in the Philippines.

Table A7.1: Number of connections per customer class, East Zone (Manila Water)

Customer class	Number of connections (as of 2016)	% of total connections
Domestic (households)	849,929	91.40
Semi-business	38,044	4.09
Commercial	39,005	4.19
Industrial	2,895	0.31

Source: Manila Water (2017).

Table A7.2 Number of connections per customer class, West Zone (Maynilad)

Customer class	Number of connections (as of 2016)	% of total connections
Domestic (households)	1,153,884	92.59
Semi-business	42,028	3.37
Commercial	41,953	3.37
Industrial	8,338	0.67

Source: Maynilad (2017).

Table A7.3 Amount of water distributed to the different sectors in the national level, 2010–2019

Sector	% of water distributed
Households	55.0
Service sector	31.5
Mining and quarrying, manufacturing, and construction	12.5
Agriculture and power	1.0

Source: PSA (2020).

Another reason for not including the non-households in the analysis is the complexity of the water tariff structures imposed. For semi-business connections, the concessionaires impose 9 increasing blocks for the water tariffs. Semi-businesses are households that have micro and small businesses. For both business groups 1 and 2, the concessionaires impose 30 increasing blocks for water tariffs. Commercial businesses are categorised under Business Group 1 while industries are under Business Group 2. The concessionaires do not report the average basic tariff imposed on non-households, which will lead to complexities in the estimation of the optimal time when considering such groups. Also, the water consumption data on the non-household groups are not publicly available due to data confidentiality constraints. Appendix 1 presents the water tariff schedules for all customer types for both concessionaires.

Section A7.3: Mathematical proof of the social surplus equation

This section shows the mathematical proof of the social surplus equation, which was used to estimate the welfare effects of supply augmentation. The social surplus is given as:

$$SS_t^{hh} = \int_{p}^{c_R} q_t(p)dp - [C(q_t) - c_r q^*] \qquad Eq. A7.1$$

Using *Equation A7.1*, as the per household water-demand equation (for all the population), the equation above becomes:

$$SS_t^{hh} = \int_{p}^{p_R} W_1 p_w^{-\varepsilon_W} dp - [C(q_t) - c_r q^*] \qquad Eq.A7.2$$

We evaluate the first term of *Equation A8.2*:

$$= H_t W_1 \int_{p}^{p_R} p_t^{-\varepsilon_w} dp = H_t \frac{W_1}{1 - \varepsilon_w} \left[p_t^{1-\varepsilon_w}\right]_p^{p_R} = H_t \frac{W_1}{1 - \varepsilon_w} \left[p_R^{1-\varepsilon_W} - p_t^{1-\varepsilon_W}\right] \quad Eq.A7.3$$

The term, $p_t^{1-\varepsilon_W}$, is the inverse demand function, where $p_t(q_t)$ because the current pricing policy that the concessionaires follow is the increasing block tariff (IBT). This means that the price that households must pay is determined by the household's water consumption. Additionally, q_t is the sum of the capacity of Angat Dam, A_t, the water refilling stations, R_t in the business-as-usual case, and in the augmentation case, the capacity of Kaliwa Dam, K_t, is added. By plugging-in *Equation A7.3*, and applying the assumption for the inverse demand function $p_t(q_t)$, we re-write the original social surplus equation for the business-as-usual (BAU) case as:

$$\begin{aligned} SS_t^{hh} = & \frac{W_1}{1 - \varepsilon_w} \left[p_R^{1-\varepsilon_W} - p_t(A_t(W_t))^{1-\varepsilon_W}\right] \\ & - \left[\left(c_d \times A_t(W_t)\right) + (p_R \times R_t) - (p_R \times q^*)\right] \qquad Eq.A7.4 \end{aligned}$$

It is to be noted that $(p_R \times q^*)$, which is the revenue of the water refilling stations when households use them as backstop when there are water supply problems, is subtracted from the producer surplus. This is because the producer surplus represents the surplus of the concessionaires. Consequently, the social surplus equation for the augmentation is given as:

$$\begin{aligned} SS_t^{hh} = & \frac{W_1}{1 - \varepsilon_w} \left[p_R^{1-\varepsilon_W} - p_t(A_t(W_t))^{1-\varepsilon_W}\right] \\ & - [(c_d \times (A_t(W_t) + K_t) + (p_R \times R_t) \\ & - (p_R \times q^*)] \qquad Eq.A7.5 \end{aligned}$$

In *Equation A7.5*, the cost of supplying water from the dam, c_d, comprises the cost of supplying water from both the Angat and Kaliwa dams. This is done because the cost of investment of the Kaliwa Dam is passed on to the consumers and is incorporated in the imposed water tariffs. Note that no data on the cost of supplying water from the Kaliwa Dam is publicly available since the dam has not been built yet.

Section A7.4: On the estimated monthly inflows

This section shows the estimated monthly inflows from 2010 to 2019. In Chapter 7, one of the sensitivity analyses considers the month with the lowest inflows during the hot dry season. Table A7.4 shows that the month of May in 2010 during the hot dry season had the lowest recorded total monthly inflows. Therefore, it was considered in the sensitivity analysis.

Table A7.4: Total monthly inflows in MCM per day, 2010–2019

Month	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan	133.88	160.84	161.29	216.54	106.73	135.75	162.20	336.97	229.25	277.59
Feb	30.49	83.13	152.43	201.83	96.21	102.78	113.32	173.89	127.35	100.97
Mar	36.43	143.07	144.18	86.09	117.27	52.50	81.41	91.33	101.56	59.98
Apr	34.38	75.80	78.13	61.55	55.33	36.54	39.36	67.15	75.41	32.64
May	22.18	70.14	78.59	90.50	57.71	29.39	32.17	73.63	43.28	49.60
June	39.80	285.02	89.67	127.23	40.63	21.03	66.42	78.02	103.27	47.72
July	57.12	125.91	295.57	246.64	112.09	203.05	63.67	209.29	267.36	129.13
Aug	141.09	267.53	611.87	464.25	225.69	160.72	381.21	202.42	435.76	256.06
Sept	127.08	390.29	224.07	202.88	363.20	199.32	118.58	190.25	297.66	228.04
Oct	228.99	252.50	275.28	245.60	162.19	332.72	258.15	230.14	108.22	140.31
Nov	352.87	488.38	171.12	469.80	158.88	208.96	348.44	553.61	127.06	159.30
Dec	185.55	531.48	180.47	178.48	392.66	469.86	398.96	414.22	320.35	305.73

Sources: National Power Corporation (NAPOCOR) and author's calculations.

Section A7.5: Technical notes on the price estimation for operationalising the Kaliwa Dam, 2025

Additional cost imposed on households

In conducting the sensitivity analysis for the operationalisation of the Kaliwa Dam in 2025, additional charges on top of the efficient price were included to cover the capital cost. Under the public-private partnership (PPP) scheme, a water security charge (WSC) is be imposed on the water users in Metro Manila and collected by both Manila Water and Maynilad. The NEDA Board approved a WSC equivalent to Php1.07 (US$0.021) per cu.m. and is the additional fixed cost that households must pay to cover the capital cost of the Kaliwa Dam. However, under the ODA scheme, there is no information showing the equivalent amount of the cost that households will pay. To arrive at an estimate on the additional charge under the ODA scheme, the ratio of the total capital cost of the ODA to PPP is calculated as follows:

$$\frac{Total\ capital\ cost\ of\ ODA}{Total\ capita\ cost\ of\ PPP} = \frac{Php12.189\ B}{Php18.504\ B} = 0.6587$$

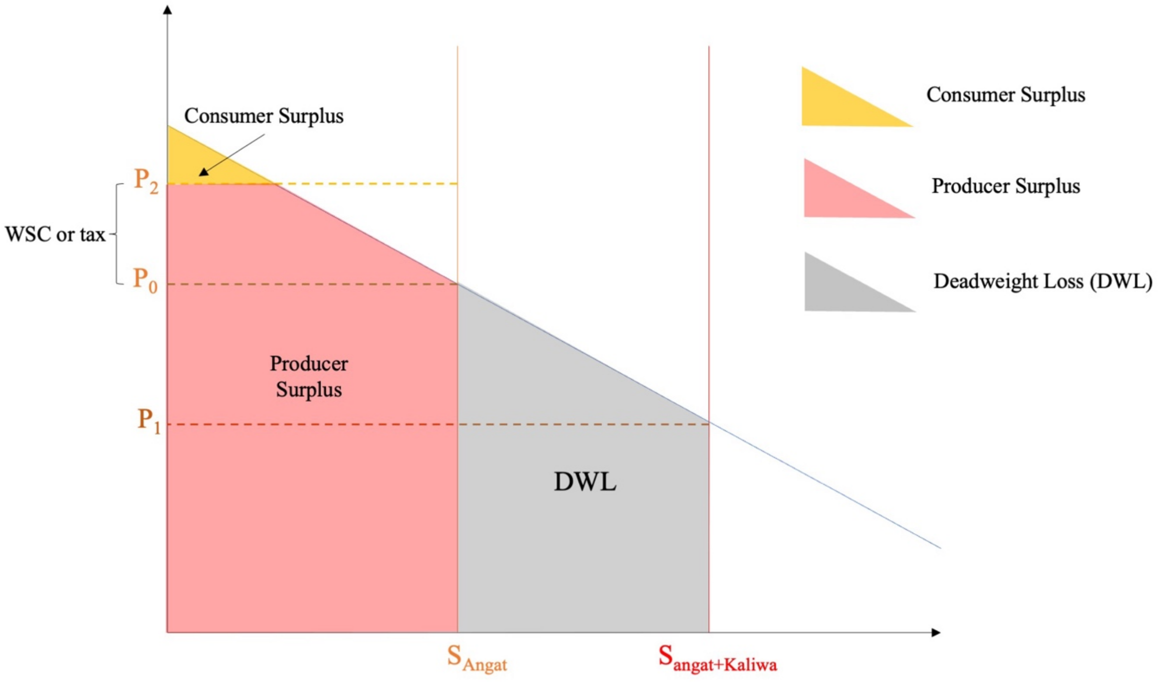
The additional volumetric price imposed on households under the ODA scheme is arrived at by the following equation:

$$(WSC_{ODA}) = 0.6587(1.07) = Php\ 0.7048\ per\ cubic\ metre$$

Notes on the efficient price

The efficient price follows Grafton et al.'s (2015) framework, which is based on the user-cost pay principle. The estimated efficient price is the outcome of the interaction between the water demand and water supply in a service area. However, the addition of the water from the Kaliwa Dam will decrease the efficient price because of the interaction between the water demand and supply (see Figure A7.1). To avoid this result, the water price is taken as the maximum between the estimated efficient price from the demand and supply interaction and the average basic price plus the additional charge from the PPP or ODA scheme. This method is utilised because there is a regulatory constraint that the water price is set by the concessionaires and is regulated by the MWSS. The price obtained is, however, an inefficient one, yielding a deadweight loss that is equivalent to the social loss due to excess water coming from Kaliwa Dam, as well as a reduction in consumer surplus.

Figure A7.1: Demand and supply interaction



Source: Author's illustration.

Appendix 8: Graphical results of the optimal timing analyses

The following figures present the results of the analyses under the two schemes: public-private partnership (PPP) at 15 per cent social discount rate, and the official development assistance (ODA) at 10 per cent social discount rate.

Figure A8.1: Supply augmentation with Kaliwa Dam, under three weather scenarios for the East Zone (PPP)

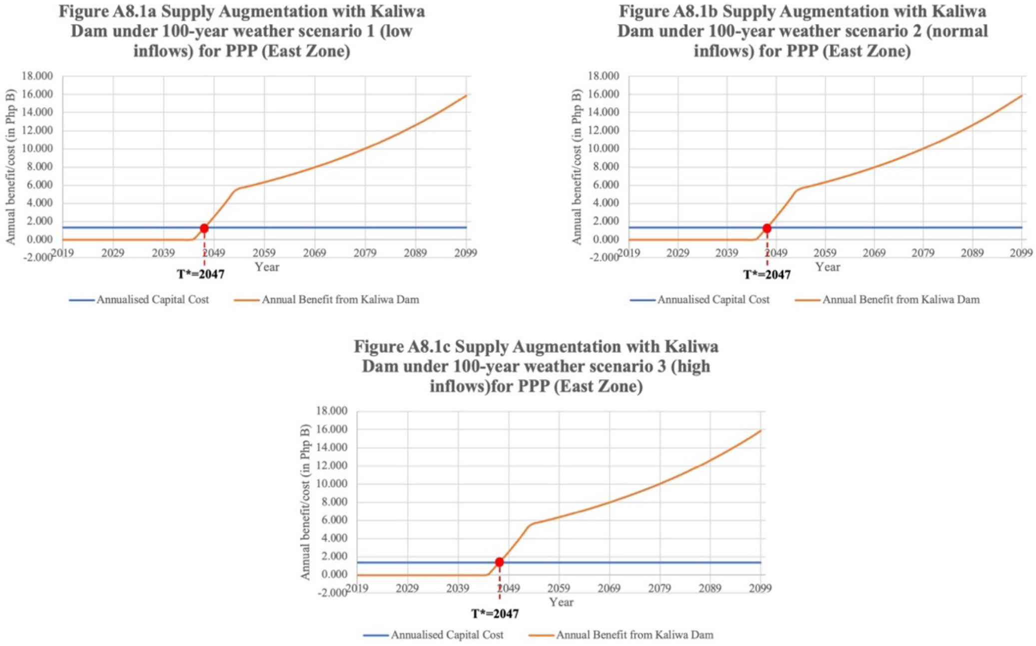


Figure A8.2: Supply augmentation with Kaliwa Dam, under three weather scenarios for the West Zone (PPP)

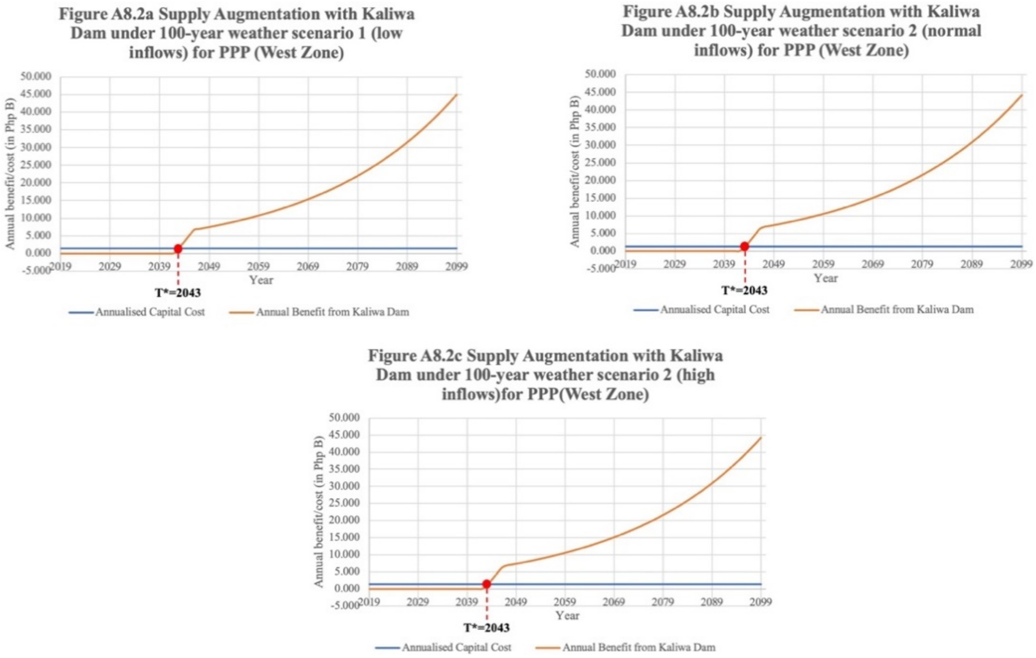


Figure A8.3: Supply augmentation with Kaliwa Dam, under three weather scenarios for the East Zone (ODA)

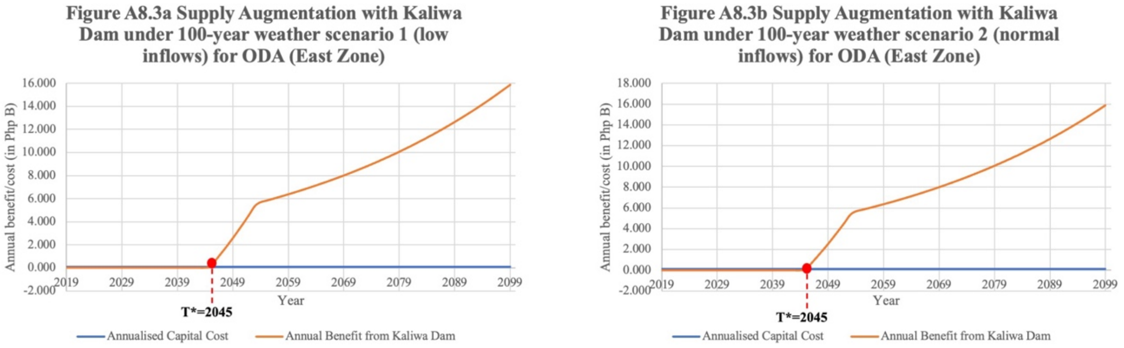


Figure A8.3a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA (East Zone)

Figure A8.3b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA (East Zone)

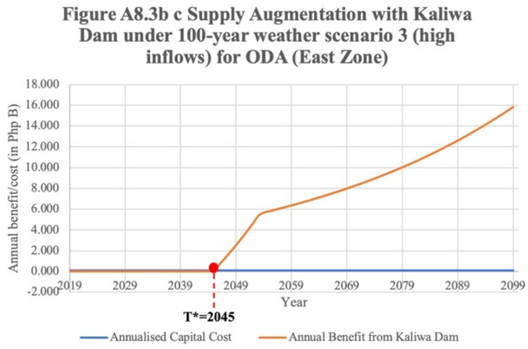


Figure A8.3b c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA (East Zone)

Figure A8.4: Supply augmentation with Kaliwa Dam, under three weather scenarios for the West Zone (ODA)

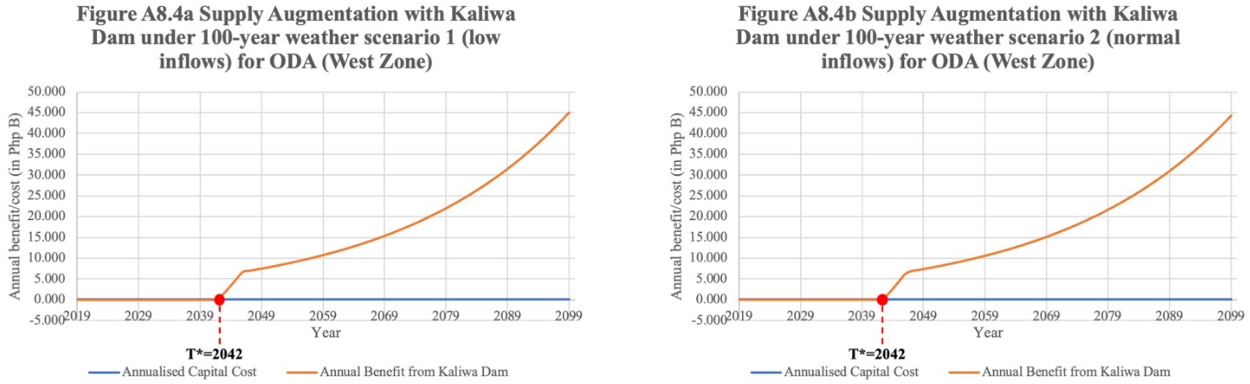


Figure A8.4a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA (West Zone)

Figure A8.4b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA (West Zone)

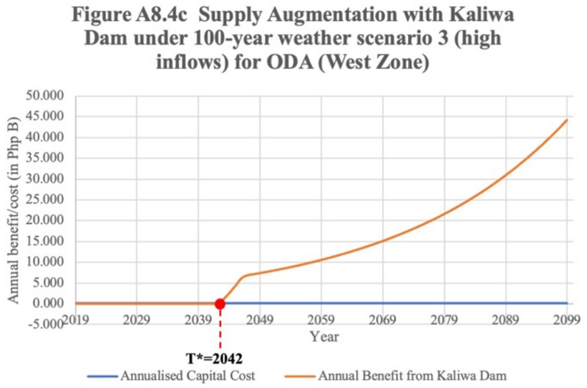


Figure A8.4c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA (West Zone)

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The following figures present the results of the sensitivity analyses using 10.0 per cent and 5.2 per cent discount rates.

Figure A8.5: Supply augmentation with Kaliwa Dam under each weather scenario using the 10% social discount rate for the East Zone (PPP)

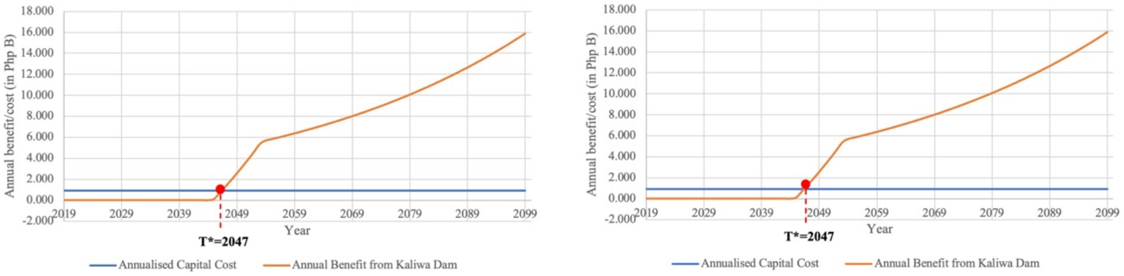

Figure A8.5a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) with 10% social discount rate (East Zone)

Figure A8.5b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) with 10% social discount rate (East Zone)

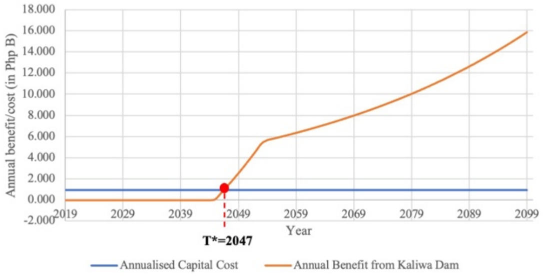

Figure A8.5c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) with 10% social discount rate (East Zone)

Figure A8.6: Supply augmentation with Kaliwa Dam under each weather scenario using the 10% social discount rate for the West Zone (PPP)

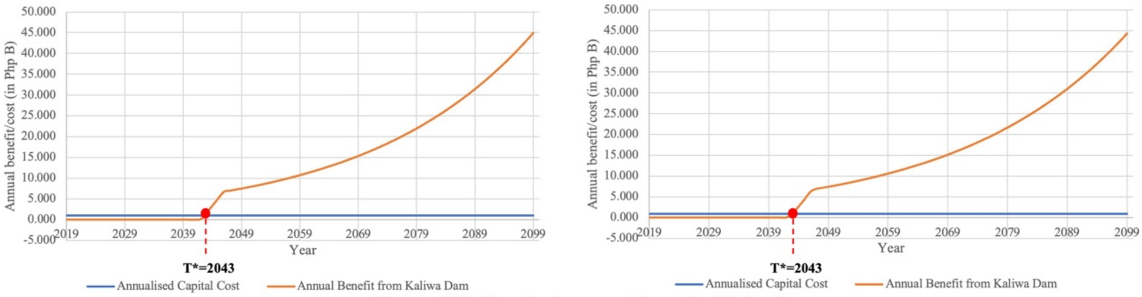

Figure A8.6a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) with 10% social discount rate (West Zone)

Figure A8.6b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for 10% social discount rate (West Zone)

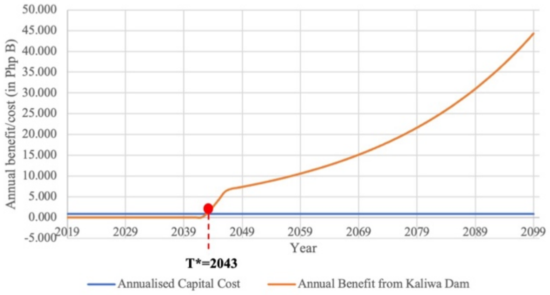

Figure A8.6c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for 10% social discount rate (West Zone)

Figure A8.7: Supply augmentation with Kaliwa Dam under each weather scenario using the 5.2% social discount rate for the East Zone (PPP)

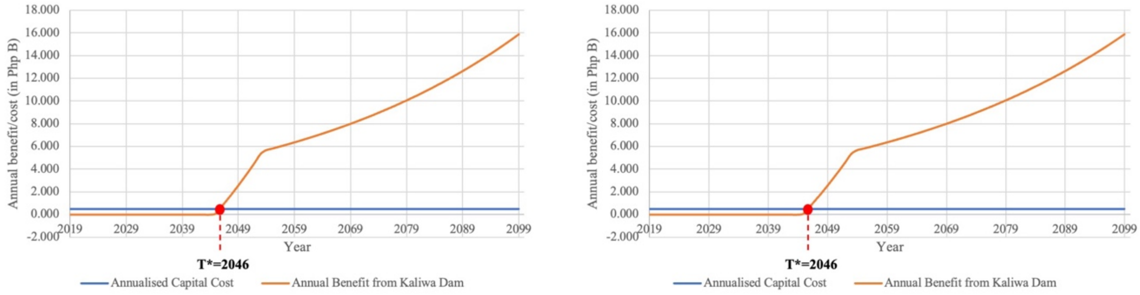

Figure A8.7a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for PPP with 5.2% discount rate (East Zone)

Figure A8.7b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for PPP with 5.2% discount rate (East Zone)

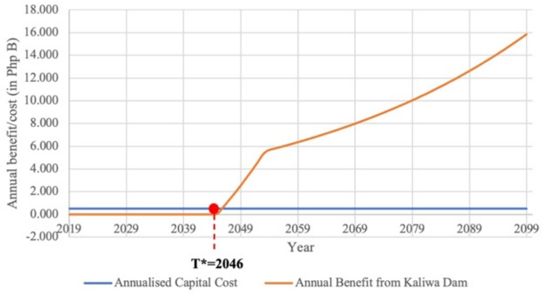

Figure A8.7c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for PPP with 5.2% discount rate (East Zone)

Figure A8.8: Supply augmentation with Kaliwa Dam under each weather scenario using the 5.2% social discount rate for the West Zone (PPP)

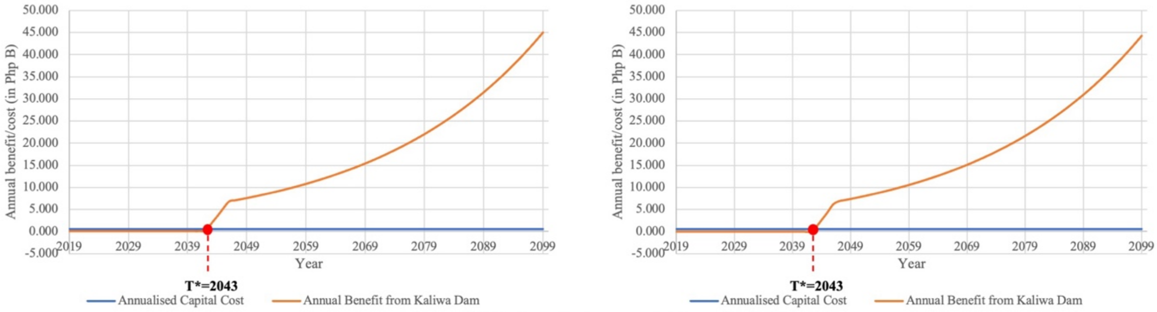

Figure A8.8a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for PPP with 5.2% discount rate (West Zone)

Figure A8.8b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflow) for PPP with 5.2% discount rate (West Zone)

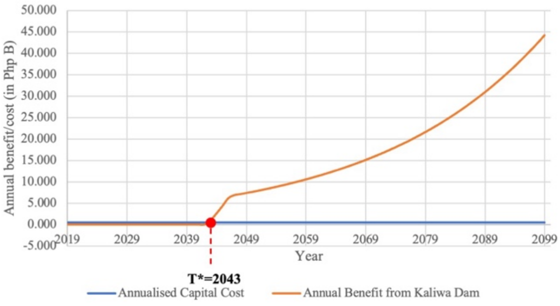

Figure A8.8c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for PPP with 5.2% discount rate (West Zone)

Figure A8.9: Supply augmentation with Kaliwa Dam under each weather scenario using the 5.2% social discount rate for the East Zone (ODA)

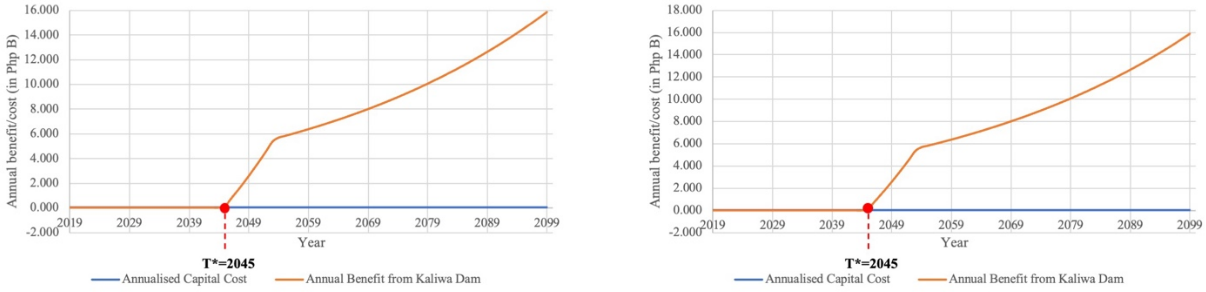

Figure A8.9a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA with 5.2% discount rate (East Zone)

Figure A8.9b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA with 5.20% discount rate (East Zone)

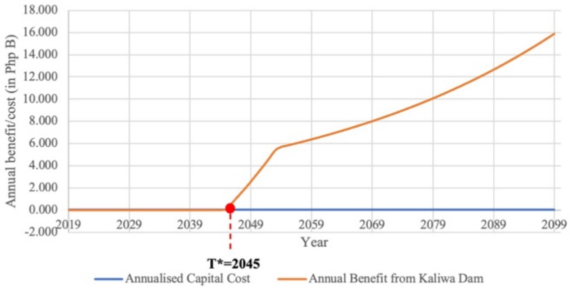

Figure A8.9c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA with 5.20% discount rate (East Zone)

Figure A8.10: Supply augmentation with Kaliwa Dam under each weather scenario using the 5.2% social discount rate for the West Zone (ODA)

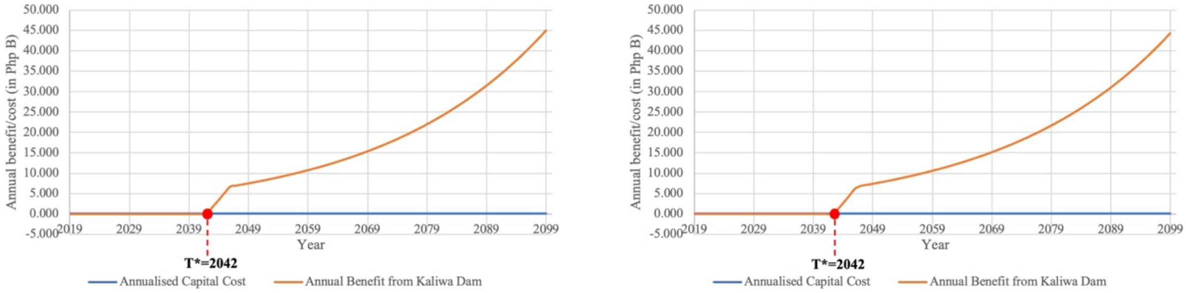

Figure A8.10a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA with 5.2% discount rate (West Zone)

Figure A8.10b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA with 5.2% discount rate (West Zone)

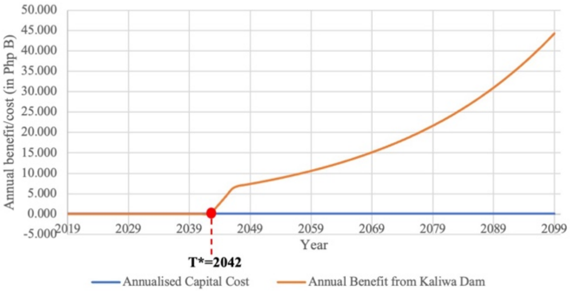

Figure A8.10c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA with 5.2% discount rate (West Zone)

The following figures present the results of the analyses of variations in household growth rates.

Figure A8.11: Supply augmentation with Kaliwa Dam with 1.32% household growth rate for the East Zone (PPP)

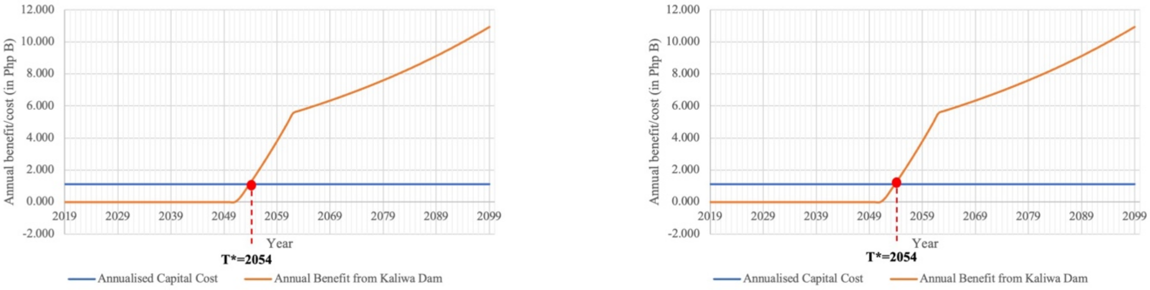
Figure A8.11a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for PPP with 1.32% household growth rate (East Zone)

Figure A8.11b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2(normal inflows) for PPP with 1.32% household growth rate (East Zone)

Figure A8.11c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (high inflows) for PPP with 1.32% household growth rate (East Zone)

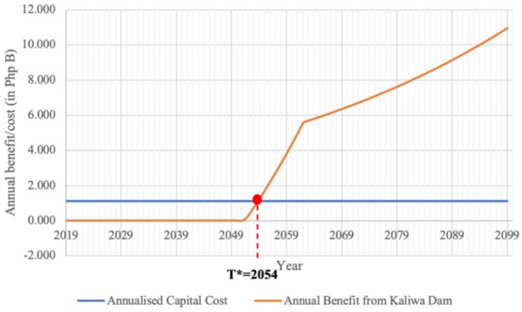

Figure A8.12: Supply augmentation with Kaliwa Dam with 3.24% household growth rate for the West Zone (PPP)

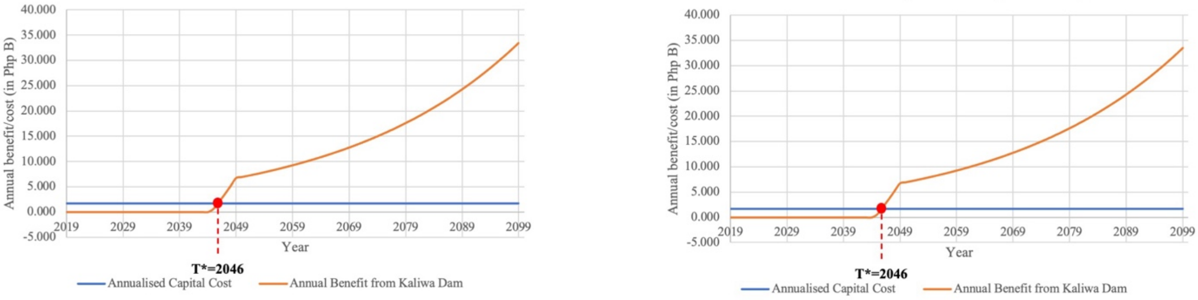
Figure A8.12a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for PPP with 3.24% household growth rate (West Zone)

Figure A8.12b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for PPP with 3.24% household growth rate (West Zone)

Figure A8.12c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for PPP with 3.24% household growth rate (West Zone)

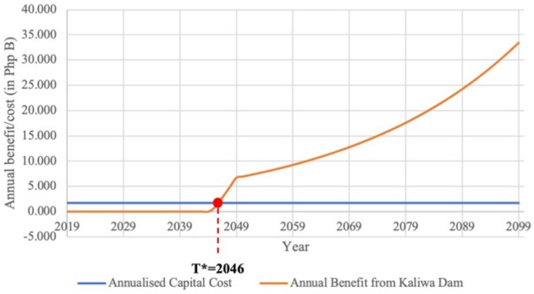

Figure A8.13: Supply augmentation with Kaliwa Dam with 2% household growth rate for the East Zone (PPP)

Figure A8.13a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for PPP with 2% household growth rate (East Zone)

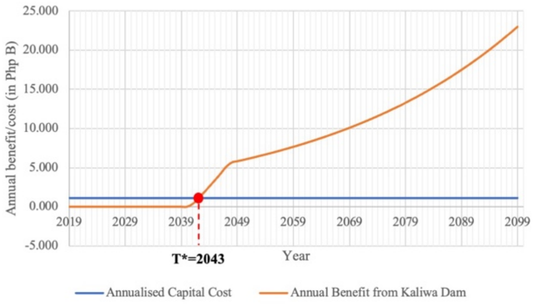

Figure A8.13b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for PPP with 2% household growth rate (East Zone)

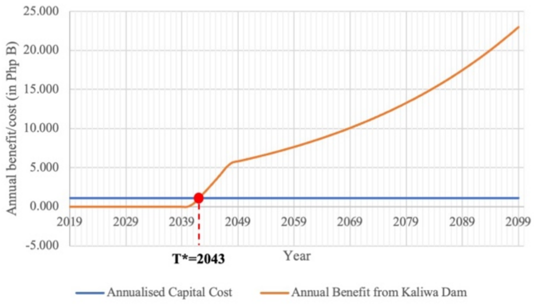

Figure A8.13c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (high inflows) for PPP with 2% household growth rate (East Zone)

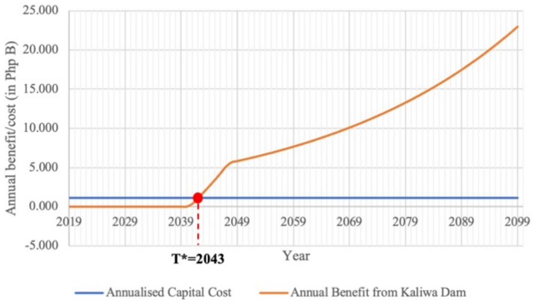

Figure A8.14: Supply augmentation with Kaliwa Dam with 4% household growth rate for the West Zone (PPP)

Figure A8.14a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1(low inflows) for PPP with 4% household growth rate (West Zone)

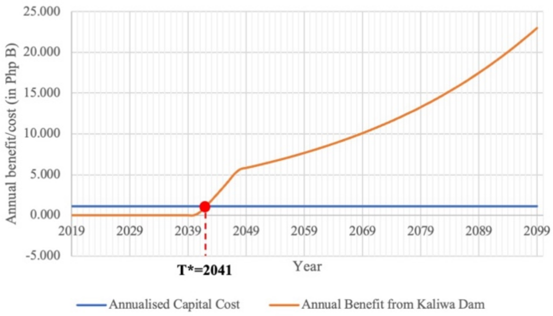

Figure A8.14b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2(normal inflows) for PPP with 4% household growth rate (West Zone)

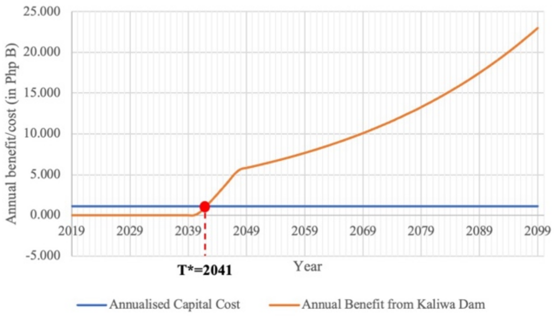

Figure A8.14c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for PPP with 4% household growth rate (West Zone)

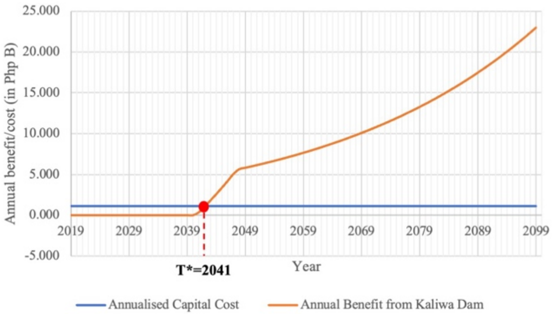

Figure A8.15: Supply augmentation with Kaliwa Dam with 1.32% household growth rate for the East Zone (ODA)

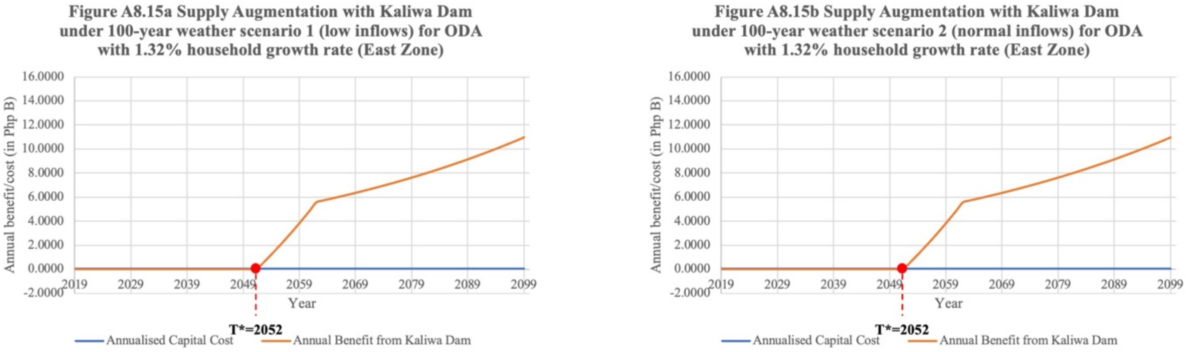
Figure A8.15a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA with 1.32% household growth rate (East Zone)

Figure A8.15b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA with 1.32% household growth rate (East Zone)

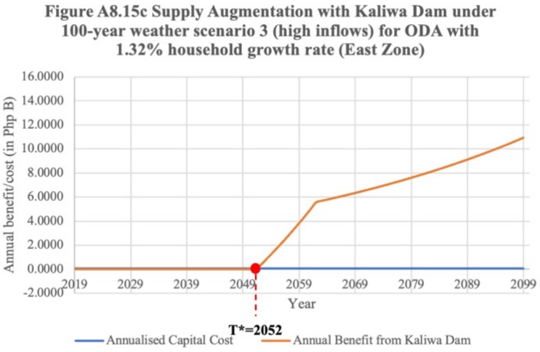
Figure A8.15c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA with 1.32% household growth rate (East Zone)

Figure A8.16: Supply augmentation with Kaliwa Dam with 3.24% household growth rate for the West Zone (ODA)

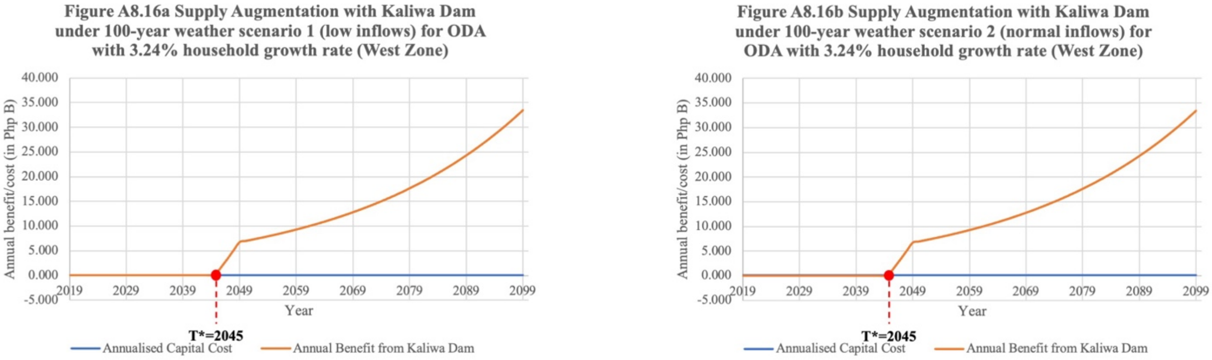
Figure A8.16a Supply Augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA with 3.24% household growth rate (West Zone)

Figure A8.16b Supply Augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA with 3.24% household growth rate (West Zone)

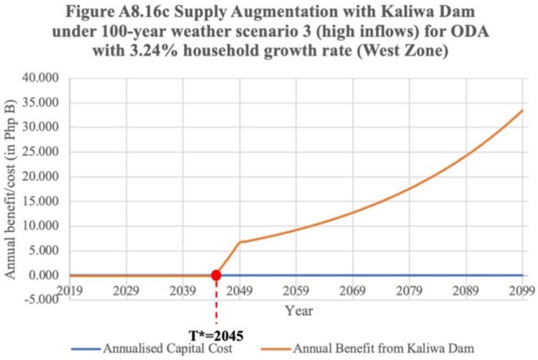
Figure A8.16c Supply Augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA with 3.24% household growth rate (West Zone)

Figure A8.17: Supply augmentation with Kaliwa Dam with 2% household growth rate for the East Zone (ODA)

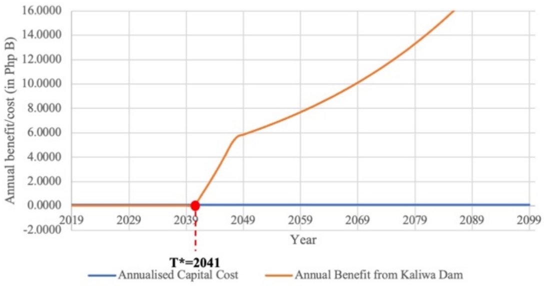

Figure A8.17a Supply augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA with 2% household growth rate (East Zone)

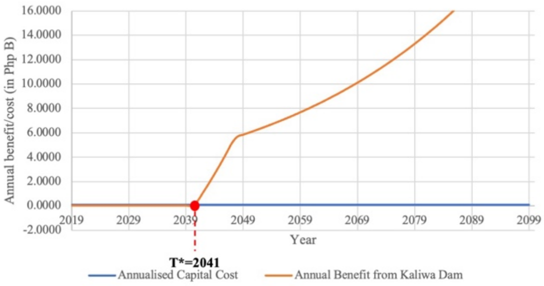

Figure A8.17b Supply augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA with 2% household growth rate (East Zone)

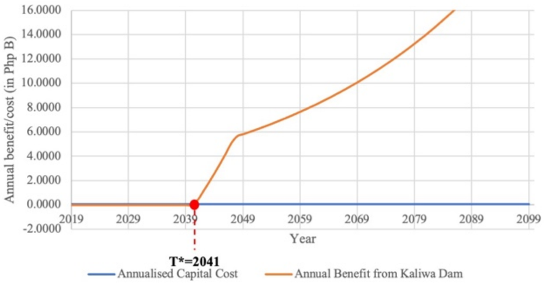

Figure A8.17c Supply augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA with 2% household growth rate (East Zone)

Figure A8.18: Supply augmentation with Kaliwa Dam with 4% household growth rate for the West Zone (ODA)

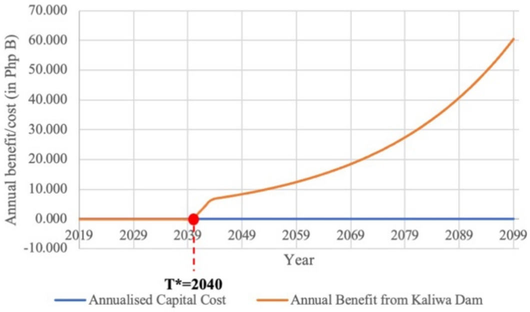

Figure A8.18a Supply augmentation with Kaliwa Dam under 100-year weather scenario 1 (low inflows) for ODA with 4% household growth rate (West Zone)

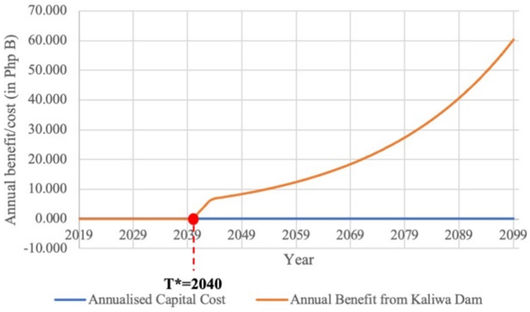

Figure A8.18b Supply augmentation with Kaliwa Dam under 100-year weather scenario 2 (normal inflows) for ODA with 4% household growth rate (West Zone)

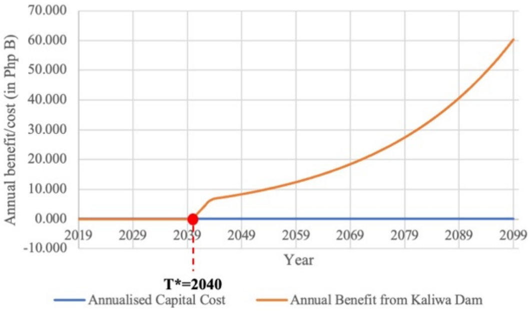

Figure A8.18c Supply augmentation with Kaliwa Dam under 100-year weather scenario 3 (high inflows) for ODA with 4% household growth rate (West Zone)

The following figures present the results of the analyses on hot dry weather scenario.

Figure A8.19: Results of the hot dry weather scenario under the PPP scheme

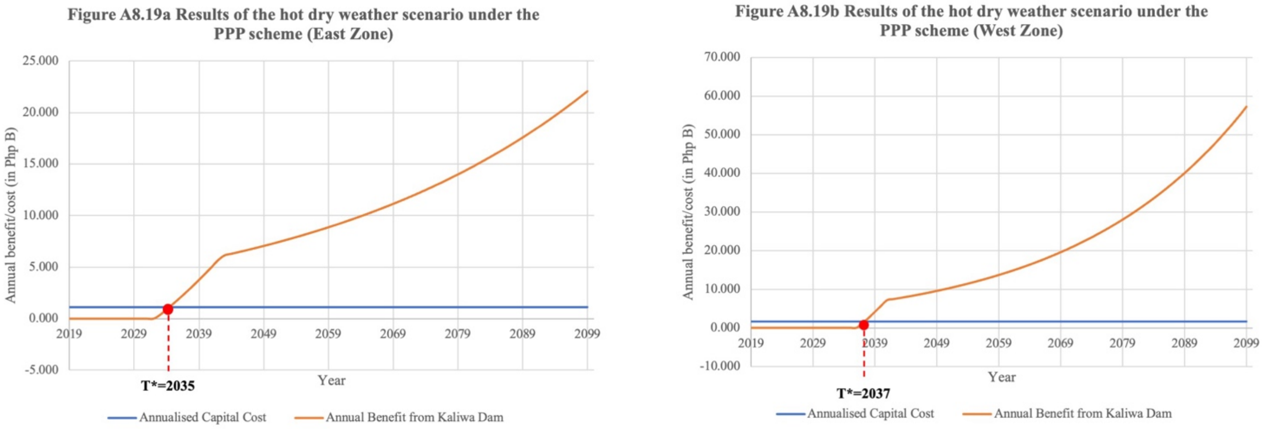

Figure A8.19a Results of the hot dry weather scenario under the PPP scheme (East Zone)

Figure A8.19b Results of the hot dry weather scenario under the PPP scheme (West Zone)

Figure A8.20: Results of the hot dry weather scenario under the ODA scheme

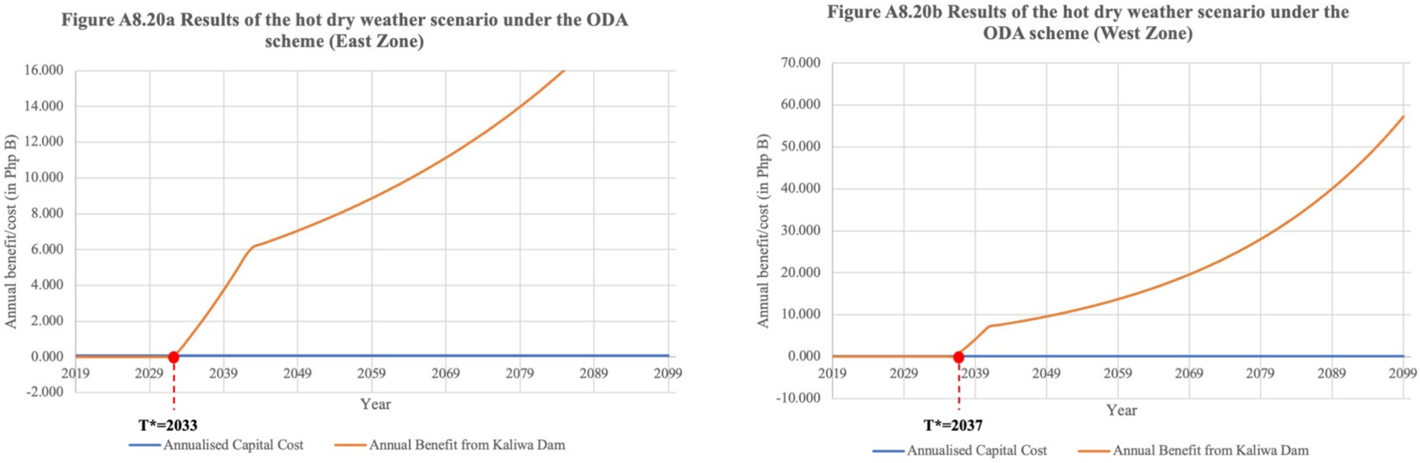

Figure A8.20a Results of the hot dry weather scenario under the ODA scheme (East Zone)

Figure A8.20b Results of the hot dry weather scenario under the ODA scheme (West Zone)

<u>The following figures present the results of the analyses on operationalising the Kaliwa Dam in 2025.</u>

Figure A8.21: Results of operationalising the Kaliwa Dam in 2025 under the PPP scheme

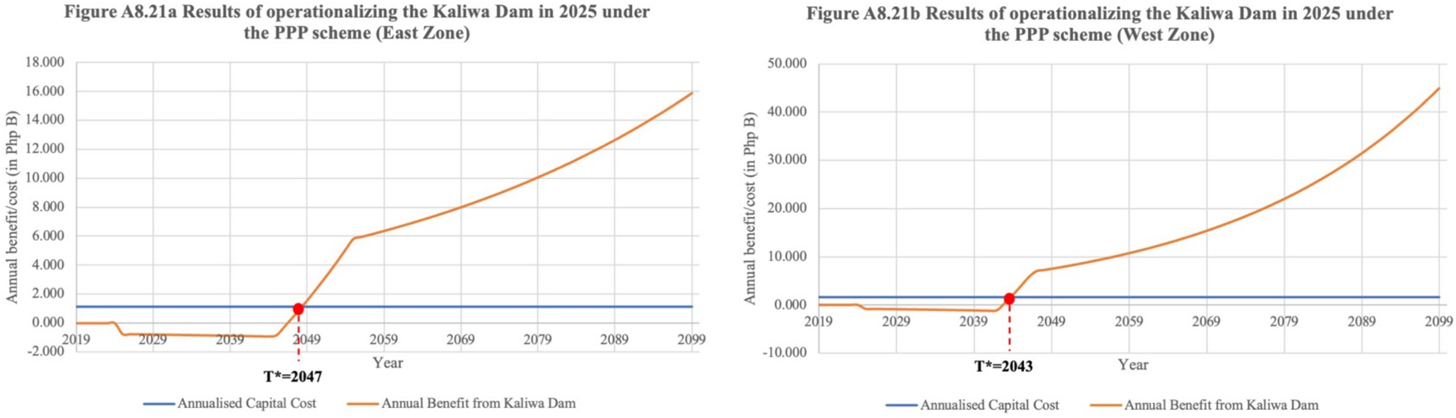

Figure A8.21a Results of operationalizing the Kaliwa Dam in 2025 under the PPP scheme (East Zone)

Figure A8.21b Results of operationalizing the Kaliwa Dam in 2025 under the PPP scheme (West Zone)

Figure A8.22: Results of operationalising the Kaliwa Dam in 2025 under the ODA scheme

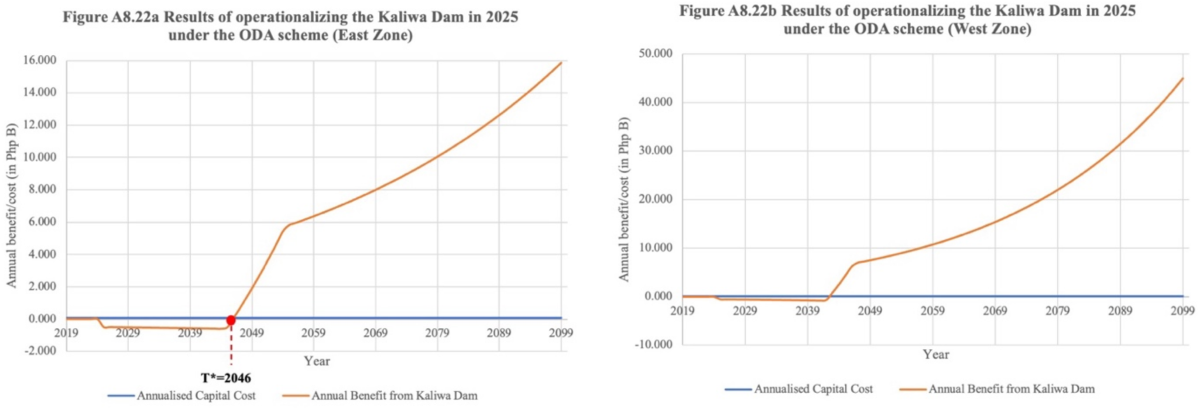

Figure A8.22a Results of operationalizing the Kaliwa Dam in 2025 under the ODA scheme (East Zone)

Figure A8.22b Results of operationalizing the Kaliwa Dam in 2025 under the ODA scheme (West Zone)