The use of economic analysis for water quality improvement investments

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PART I

Introduction

Chapter 1.
Introduction

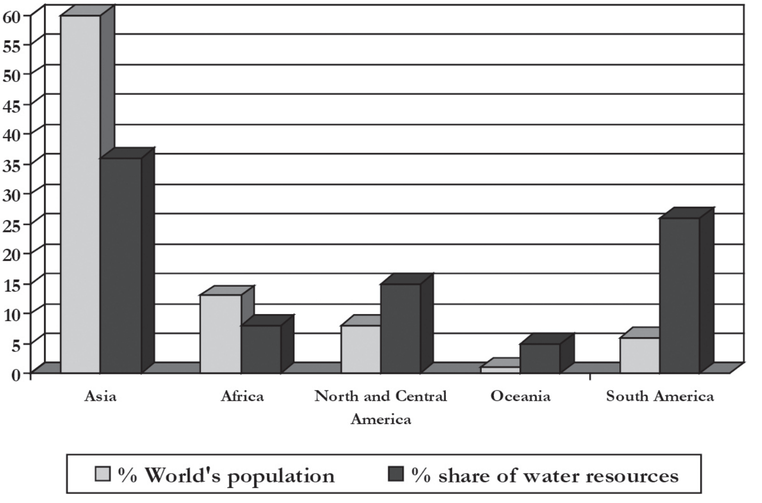
1.1 The Global Water Challenges

The importance of water cannot be overstressed: water is life, it a critical input to ensure food security, human health and dignity. Water is fundamental for our physical environment. Water provides stability and security and access to clean water is a necessary condition for growth and development. The effective management of this resource is one of the most significant challenges of our times.

Water seems to be abundant: 70% of the world is land; 30% is water. However, only approximately 2.5% is freshwater (United Nations 2006). Two thirds of the available freshwater is locked up in glaciers and permanent snow cover. In addition to the freshwater available from rivers, lakes, and aquifers, man-made storage in reservoirs adds a further 8,000 cubic kilometers of water (United Nations 2006). Still, less than 1% of freshwater is available for consumption. Approximately 70% of all water extracted for consumption is used for irrigation of agricultural land, 20% is used by industry, and the municipal sector uses around 10% (Parliamentary Office of Science and Technology 2002).

Water is distributed unevenly among and within continents. The global overview of water availability versus population stresses the continental differences. Asia supports 60% of the world's population but possesses 36% of the world's water resources; Africa has 13% of the world's population and 8% of the world's water resources; North and Central America has 8% of the population and 15% of the water; Oceania has less than 1% of the world's population but 5% of the world's water resources; and South America has 6% of the world's population but 26% of the world's water resources (United Nations 2003). Only 15% of the population of the world lives in areas with abundance of water (Revenga et al. 2000).

Figure 1.1. Global Distribution of Water and Population (in % share)



The uneven distribution and availability presents huge differences in different parts of the world with wide variations in seasonal and annual precipitation in many places. The most important drivers facing water resources are population growth and rapid urbanization, increase in consumption from improved living conditions and higher per capita incomes, and climate change. These pressures will be faced mostly by developing countries. Approximately 90% of the 3 billion people expected to be added to our planet by 2050 will be in developing countries (United Nations 2009). Current estimates for 2030 put 81% of the urban population living in the developing world; in Africa and Asia, the urban population will double in size between 2000 and 2030 (United Nations 2009). Economic growth and development is demanding more of the resource with competing uses. In many regions and countries of the world, the increased demand is causing not only shortages and scarcity but also water pollution.

According to the Comprehensive Assessment of Water Management in Agriculture (2007) one in three people are already facing water shortages. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity[1], while another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage (where

1 Physical scarcity is where water consumption exceeds 60% of the usable supply. There is limited spare capacity, so even with the highest efficiency and productivity rates, water supply is not sufficient to meet the demand for agriculture, domestic, and industrial sectors while satisfying environmental needs (Parlamientary Office of Science and Technology 2002).

countries has sufficient water resources but lacks the necessary infrastructure to extract and store water from rivers and aquifers or from aging and deteriorating existing infrastructure); nearly all of which are in the developing countries. Twenty percent of the water scarcity increase will be due to climate change (United Nations 2005).

1.2. Neglecting the Water Quality Challenge

The water scarcity problems of the present and the future should not be underestimated. However, most of the analysis of the current trends in developed and developing countries indicate that the main water crisis in the coming years most likely will stem primarily from deteriorating water quality particularly caused by the lack of sustained infrastructure investments and funding, rather from physical scarcity per se (Biswas et al. 2006).

Approximately one billion people do not have access to safe and affordable drinking water, and 2.4 billion people live in conditions lacking adequate sanitation. Each year around 4 million people die of waterborne diseases (particularly cholera, hepatitis, dengue fever, malaria and other parasitic diseases), including 2 million children, who die of diarrhea. Waterborne diseases inflict high economic costs to society in terms of loss productivity days of workforce and health-related expenses. Recent studies have found other harmful constituents resistant to water treatment such as pathogens including enteric viruses and parasitic protozoa as well as disinfection byproducts, endocrine disrupters, hormones, pharmaceutically active compounds and personal care products (IWA 2006). The long-term health effect of many of these constituents is not well understood. Most of the affected are in developing countries and are among the poorest of the poor (DFID 2001). These people are more likely to be exposed to the dangers created by the latter (no sewers) because they have to use the available ambient water—for drinking, cooking, laundry, and recreation. And they may even find it difficult to be able to boil the water before ingesting it. This might be called the neighborhood water quality problem and is most likely the source of the greatest public health threat. Access to clean water is essential in the fight against HIV/AIDS because it is needed for the consumption of antiretroviral medication and hygiene prevents exposure to additional infections.

Poor ambient water quality (AWQ) is a serious problem in developed and in most developing countries. Today approximately 85-90% of the wastewater produced in the developing countries is discharged to water bodies without receiving any kind of treatment with serious impacts on public health and ambient environmental quality (Khatri and Vairavamoosrthy 2007; Botkin and Keller 2007). Improvement of ambient water quality, the focus of this thesis, has become a critical issue. Economic and demographic growth has stressed water resources and rendered water and the ecosystems it supports increasingly scarce and valuable. The costs of reversing the trend of ever-deteriorating water quality in rivers and estuaries near large metropolitan areas are simply enormous. In 2008, in a report to the United States Congress, the U.S. Environmental Protection Agency (EPA), reported that the total needs of America's publicly owned treatment works for the next 20 years (as of January 1, 2004) were $202.5 billion (USEPA 2008). The World Business Council for Sustainable Development estimates that the total costs of replacing ageing water supply and sanitation infrastructure in industrial countries may be as high as $200 billion a year (WBCSD 2006).

Improvement in ambient water quality stems primarily from the treatment of wastewater. In industrialized systems the conventional approach is mostly centralized in nature, using extensive sewer networks and very large sewage treatment plants. This approach has been widely promoted and adopted in many developing countries. It is based on the premise that the wastewater should be collected, transferred, and treated before released back into the water bodies (Ujang and Henze 2006). Large water infrastructure is required to implement such approach requiring: (a) very high capital costs to provide the necessary sewerage network and wastewater treatment facilities. The World estimated sewerage investment costs in eight developing countries and this range from $600 to $4,000 per household (Mara 1996); (b) strong institutions, legal and regulatory frameworks to ensure proper connection from generation point to sewer networks; (c) very high operation and maintenance costs; (d) in-house water and sewer connections in all premises in that particular catchment (Ujang and Henze 2006).

Poor water quality impacts other sectors of the economy such as agriculture, industry, and energy. The use of water of poor quality for irrigation has public health impacts. Water quality standards preclude the use of wastewater for certain crops so a decrease in the quality of the water can have economic impact with the loss of revenue from agricultural production. Industry uses water as an input in production processes. Poor water quality can affect many industrial systems and equipment. As we will see in this study, water of poor quality can also affect the generation of hydropower. When dissolved oxygen in reservoirs is depleted (anoxic conditions) hydrogen sulfide is produced. Hydrogen sulfide corrodes the cooling system of the hydropower generators, substantially decreasing the useful life of the equipment. Anoxic conditions also promote the growth of green algae and hyacinth, also known as kulavasha; one of the most invasive and gregarious aquatic weeds. Algae and hyacinth impede the proper functioning of the turbines causing the halting of hydropower generation.

The severity of the problem of poor water quality and increased pollution of water bodies is highly perceived and noticed in industrialized countries as evidenced by a time series of the top environmental concerns of the American people as determined by long term polling (1997-2008) by Gallup organization. Gallup has evaluated the perceptions, beliefs, and policy priorities of different public audiences on a variety of environmental problems[2]. Consistently, the most serious expressed concerns were about water-related problems, including pollution of drinking water, pollution of rivers, lakes and reservoirs, and maintenance of the nation's supply of freshwater for household needs. Approximately half of all respondents worries "a great deal" about each of these three problems (Gleick 2009). Between 26 and 31 of January 2009, a survey was conduced in Europe, commissioned by the European Commission (EU), to examine the EU citizens' awareness about an array of water-related problems, their perceptions about the impact of several factors on their country's water environment, and their willingness to take individual actions to reduce or solve some of these problems (European Commission 2009). Over 25,500 randomly-selected individuals were interviewed in the 27 EU Member States. A majority of EU citizens thought that water quality is a serious problem; 3 out of 10 interviewees that it was a very serious problem and 38% said it was a fairly serious problem. Three quarter of EU citizens stated that chemical pollution was by far the most mentioned threat to a country's water environment (European Commission 2009).

1.3. Study Background, Problem Statement, and Research Questions

Despite the abovementioned problems, a consensus on the need for increased urban wastewater treatment has been slow to develop. Local populations have demonstrated a willingness to pay (WTP) for wastewater collection and removal, but not for treatment and safe disposal (Briscoe 1992). Western environmentalists

2 The list of problems included the following: (i) pollution of drinking water, (ii) pollution of rivers, lakes, and reservoirs, (iii) contamination of soil and water by toxic waste, (iv) maintenance of nation's supply of fresh water for household needs, (v) loss of natural habitat for wildlife, (vi) air pollution, (vii) damage to Earth's ozone layer, (viii) loss of tropical rain forests, (ix) extinction of plant and animal species, (x) urban sprawul and loss of open space, (xi) greenhouse effect or global warming, and (xii) acid rain.

have largely ignored the problem altogether[3]. The priorities of the populace and of the international environmental community, not surprisingly, have been reflected in the ambivalence of foreign aid agencies and local governments toward wastewater treatment[4]. These priorities, taken together, have led to a shortage of new treatment facilities and acute operational deficiencies at existing facilities.

The low priority for wastewater treatment can in turn be attributed to four different factors. First, and most obvious, the expense and complexity of treatment facilities puts them beyond the reach of many communities in the developing world[5]. Second, foreign aid agencies and local governments have traditionally preferred water supply projects over sanitation projects (Biswas 2006; Porter 1996). This preference is due, to a large extent, to the fact that it is easier to charge for water than for sanitation. The third factor is the position of wastewater treatment in the sanitation triage that dominates city planning in many communities:

> *Households and communities typically go through three stages in their efforts to obtain (1) safe, hygienic conditions in their houses, (2) clean, sanitary neighborhoods, and (3) improved quality of surface waters. Stage 1 involves the removal of excreta and wastewater from the household's living space. In the course of solving their own individual sanitation problems, households often impose costs on their neighbors by discharging untreated human wastes and wastewater from their property onto streets and other public property. This creates the setting for Stage 2: neighborhood collection of household wastewater. Collecting and removing wastewater from neighborhoods improves neighborhood public health conditions, but the quality of the surface water receiving the wastes will*

3 Easterbrook (1994) asserts that Western environmentalists have been preoccupied with the preservation of tropical forest and endangered species and consequently have been content to blame the wretched living conditions that prevail in many developing countries on these countries' high birth rates. Easterbrook's essential point is that this distinction is fallacious because high birth rates are largely a function of poor living conditions. This argument is similar to Massignon's about the distinction between urban and rural development: "It is now accepted that urban and rural development, far from conflicting, are mutually reinforcing and ought to be pursued simultaneously. The idea that the various problems of urbanization can be solved through strategies designed to improve life in rural areas has to be abandoned. If the rural labor force does not turn to urban activities, it will, to be able to grow crops, have no choice but to destroy forests or move onto land that is environmentally sensitive or ill-suited to farming. That process is already well under way in a large and steadily increasing number of countries." (Massignon 1993, p. 20)

4 It appears that attitudes may be changing. For example, cleaning up Mexico's rivers—some of the most contaminated on the continent—has recently become a national priority in Mexico as depicted in the country's national development plan. President Calderon has expressed the mandate that 70% of the wastewater must be treated by the end of his mandate (2013), up from approximately 30% in 2007.

5 European countries have consistently invested, on average, up to 1 percent of gross domestic product in wastewater management systems, but untreated discharges from municipal, industruial, and agricultural activities continue to contaminate waterways and coastal areas on all continents (Mariño and Boland 1999).

> *likely deteriorate. Stage 3 is the improvement of the quality of surface waters. In most industrialized countries, cities built their sewer lines first and then later, when they could afford it, they built wastewater treatment plants. This staged approach improved public health conditions in cities because it removed the human waste from town. However, the rivers and lakes were often badly polluted by the discharge of untreated wastewater.* (Choe et al. pp. 520–521, 1996)

The pattern outlined in the quotation introduces the notion that cleaning up the immediate neighborhood sanitation problems of a rapidly growing city can lead to the creation of a different environmental problem—the pollution of rivers (or of coastal waters) because rivers are in effect transformed into extensions of the sewer system by the discharge of collected but untreated sewage.

The future looks even more demanding than the past. Just holding the line at the current 70 percent sanitation coverage level over the next 20 years will require that new sanitary facilities be provided for over 6 million persons per year, the statistical equivalent of a new megacity annually. The major urban areas also have become centers of industrial concentration, and severe industrial pollution problems have appeared in most large cities.

1.3.1. Problem Statement and Research Questions

Let's begin by recognizing that decision-makers in most developing country governments face tight budget constraints and difficult resource allocation choices in addressing a host of environmental and social concerns. One or two expensive, poorly chosen projects can preclude other, more socially desirable interventions, so a hard line is almost a necessity if one takes the rhetoric of sustainability seriously.

The complexity is exacerbated by the complexity of projects aiming to improve ambient water quality. Water quality improvement initiatives can be characterized by their level of geographic scope and their ability to allow benefits to be monetized. Poor water quality or lack of proper treatment of wastewater leads to clear damages, in the technical, economic sense of monetized losses to society, via downstream (or along shore) public health problems, increased downstream treatment cost for potable water intake, restrictions on the use of water for irrigating crops, loss of commercial fisheries, and in certain settings the discouragement of tourism. Less obvious in the developing country setting because of immediate concerns with poverty and health are the aesthetic problems (smell) created by low dissolved oxygen and the accumulating ecosystem damage, especially where coastal wetlands or coral reefs may be affected. The monetization of an array of nonmarket benefits for these projects is imperative, but challenging. **Problem statement:** the main purpose of this thesis is to conduct the economic analysis of a large water infrastructure project to improve ambient environmental quality providing recommendations whether the investment should be undertaken or not, draw lessons from this application, and demonstrate the usefulness of such an exercise in other large infrastructure investments.

Research objective 1: *to illustrate the application of Cost-Benefit analysis in water quality improvement investments.*

In the case of investments designed to improve water quality, analysts emphasize that the analysis of prospective investments should, to the extend possible, be done in a basin context and should be integrated with other water resources management investment decisions, such as those involving water withdrawals for urban, industrial or agricultural use, the creation of impoundments, and the management of watershed land (hence, of soil, and pesticide or herbicide discharges).

Translating the above into terms that are specific to the public wastewater treatment investment problem by combining the general objective of net benefit maximization with an integrated basin approach to management of water resources produces an ambitious problem statement. Ideally, the location, scale, removal efficiency, and timing of wastewater plan investments should be chosen so that in conjunction with mandated (or voluntary) private industrial pollution control efforts, they will maximize the present value (PV) of the net benefits from improvements in ambient water quality. But the limitation to achieving a basinwide optimum in water quality arises mainly from the economics. The main research questions that we address here are:

1.1. What are the critical limitations on achieving a basin-wide optimum water quality?
1.2. Is Cost-Benefit Analysis a suitable method to apply to analyze water quality improvement investments?

The ideal of a cost-benefit analysis that designs individual projects using basinwide maximization of net benefits is not a part of current reality, but it is possible to do an approximate search for economic efficiency at the basin level.

Research objective 2: *to present the different existing valuation techniques to measure economic benefits in water quality improvement investments.*

A limitation in the economics of water quality lies in the difficulties in benefit measurement when attempting to translate outcomes predicted by water quality models into realistic descriptive end-point characterizations that individuals can readily understand, such as ‘swimmable’ or ‘fishable’ water (Cropper 2000).

2.1. What are the existing nonmarket benefit estimation techniques that could be utilized to measure the economic value of water quality improvements?
2.2. What are the major problems that plague the estimation of benefits from ambient water quality improvement by the traditional approaches?
2.3. What is the recommended alternative approach?

Research objective 3: *to demonstrate how uncertainty about the timing and magnitude of investment costs and benefits can be successfully handled through Monte Carlo risk analysis.*

The point estimates of willingness to pay for better environmental quality are inherently uncertain, whether they are obtained from contingent valuation or via another route. No single economic valuation method provides a unique benefit number that is independent of the analyst’s judgment, and variation across methods is common as well. Although the extent of statistical uncertainty (the variance of the mean benefit estimate) can be objectively quantified, methodological uncertainty is more elusive, so of necessity analysts must make subjective judgments to arrive at a reasonable or preferred estimate of benefits. Moreover, investment costs, operating costs, and the timing of project impacts are also uncertain.

3.1. How does the incorporation of alternative benefit measures results affects the outcome of the project?
3.2. How to incorporate uncertainty, especially about benefits, in an economic cost-benefit analysis by using Monte Carlo simulation?
3.3. Will the outcome of the project differ if uncertainty is ignored from the analysis?

These research questions will be addressed in the various chapters of this thesis utilizing data gathered to appraise a large water quality improvement investment undertaken in Brazil, in the Rio Tietê located in the State of São Paulo. The next section outlines the structure of the chapters in this study.

1.4. Plan of the Book

The study is divided into three parts. The first part consists of this Chapter and Chapter 2. This Chapter provides an introductory overview of the global water quality challenges, the problem statement, and the main research questions that will be addressed by this dissertation. Chapter 2 presents the water quality challenges in Brazil and introduces the case study in question: a water quality improvement program in the state of São Paulo.

The second part of the book, consisting of Chapters 3-5, presents the methodological framework to be applied in the thesis. Chapter 3 is devoted to a more complete discussion of what a full cost-benefit model would look like where multiple sources exist in a regional setting with multiple routes by which benefits can accrue to society. This chapter discusses the difficulties in making judgments about the relative values of the advantages and disadvantages of an isolated project analysis, or a subset analysis as opposed to basinwide optimization. In Chapter 4 the searchlight is turned more narrowly on the benefit side of cost-benefit analysis. Here the methods of benefit estimation are examined more closely, with special emphasis on the contrast between methods based on observed behavior and those based on the posing of hypothetical questions to random samples of persons potentially affected by a project or policy. The current dominance of the latter method for practical project work is noted and the apparent reasons set out. Variations on the standard contingent valuation method (CVM) are described as well, and their potential contributions and pitfalls are cataloged. Chapter 5 reveals the two most widely used and accepted routes to analyzing referendum data: parametric and nonparametric approaches. The theoretical underpinnings are introduced, along with the advantages and disadvantages of each approach. A score of alternative ways to measure the mean or the median of willingness to pay for environmental improvements with referendum CV survey data are presented.

The third part of the book consists of Chapters 6 and 7. In these two Chapters, the methodological framework from Part II is applied to the valuation of a large water infrastructure program. In Chapter 6, the results of the cost-benefit analysis are presented by comparing the project costs, including shadow price adjustments, and the main benefits stemming from the project and resulting from the application of a battery of parametric and nonparametric approaches to referendum CV survey data. The results are then presented in standard form and a sensitivity analysis is depicted. Chapter 7 sheds light on what uncertainty means and how to approximate it empirically. More important, it emphasizes that uncertainty is inherent in project analyses that are based on CV benefit estimates. It explains how to take uncertainty fully into account in economic cost-benefit analyses by using Monte Carlo simulation rather than conventional sensitivity analysis, which provides a great deal less information about project risk. The chapter argues that when benefits and costs are uncertain, decision makers would be well served by a full economic evaluation of the risks associated with prospective investments.

Chapter 8, the concluding chapter, provides answers to the research questions abovementioned, contains a summary of the main findings, provides major recommendations on the importance of the application of cost-benefit analysis, on the need to estimate an array of benefit measures utilizing both parametric and nonparametric approaches, and a strong suggestion to incorporate quantitative risk analysis in the cost benefit analysis, particularly for large water infrastructure public projects. The chapter concludes with some areas and topics for further research[6].

6 Some sections in the present work contain (parts of) revised versions of previously published articles and reports. At the same time, this thesis has benefited from the incorporation of new material, including more than three years of recent research work. These publications have been updated and/or sections rewritten. In particular:

Rodriguez, Diego. May 1998. "Estimating Willingness To Pay from Referendum Models: Some Empirical Issues." Environment Division Background Paper. Washington, D.C.: Inter American Development Bank.

Rodriguez, Diego. August 1998. "Assessing the Benefits of Groundwater: A Cost-Benefit Analysis Approach." Unpublished.

Rodriguez, Diego. 2000. "Cost-Benefit Analysis of Environmental Quality Improvement Projects: Uncertain Benefits of Willingness to Pay from Referendum Contingent Valuation." Masters of Arts Thesis. Virginia Polytechnic Institute and State University. Blacksburg: Virginia.

Russell, Clifford S., William J. Vaughan, Christopher D. Clark, Diego J. Rodriguez, and Arthur H. Darling. 2001. "Investing in Water Quality: Measuring Benefits, Costs and Risks." Washington, D.C.: Inter-American Development Bank.

Russell, Clifford S., Christopher D. Clark, William J. Vaughan, Arthur Darling, and Diego J. Rodriguez. 1999. "The Economic Analysis of Water Quality Improvement Investments: A Good Practice Paper". Technical Paper, Environment Division, Sustainable Development Department. Washington D.C.: Inter American Development Bank.

Vaughan, William J., and Diego J. Rodriguez. 2001. "Obtaining Welfare Bounds in Referendum Contingent Valuation Studies: Comment." Land Economics 77(3), pp. 457-465.

Vaughan, William J., Clifford S. Russell, Diego J. Rodriguez, and Arthur H. Darling. 1999. "Willingness to Pay: Referendum Contingent Valuation and Uncertain Project Benefits". Environment Division Technical Paper ENV-130. Washington, D.C.: Inter-American Development Bank.