Challenge Paper

The Challenge of Water and Sanitation

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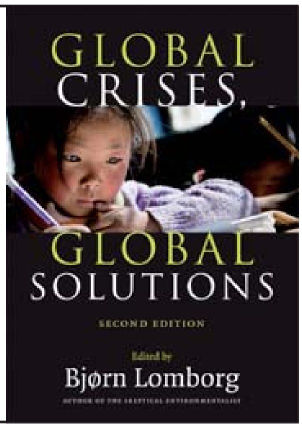

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Sanitation and Water

Water and Sanitation Challenge Paper

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Table of Contents

Table of Contents 2
List of Tables 4
List of Tables 4
List of Figures 5
Introduction 6
Part I – Assessing the Costs and Benefits of Investments in Water and Sanitation Infrastructure.. 9
Background 9
Costs of Municipal Water and Sanitation Network Infrastructure 14
Economic Benefits of Water and Sanitation Network Infrastructure Services 24
Market Data: Water Vending 25
Avertive Expenditures: Coping Costs 27
Avoided Costs of Illness 29
Stated Preferences: Household Willingness to Pay for Improved Water and Sanitation Services 32
Comparing Costs and Benefits of Network Infrastructure Services 35
Discussion 40
Part II – Analysis of Four Water and Sanitation Interventions 43
Introduction 43
Water and Sanitation Intervention 1 – A rural water supply program providing poor rural communities in Africa with deep boreholes and public hand pumps 52
Description of the Intervention 52
Discussion of Costs 57
Economic Benefits from the Installation of the Borehole and Public Hand Pump 59
Comparison of Costs and Benefits (Intervention 1) 64
Water and Sanitation Intervention 2 – Total Sanitation Campaigns to achieve open-defecation–free communities in South Asia 71
Description of the Intervention 71
Discussion of Costs Associated with Community-Led Total Sanitation Programs 74
Economic Benefits of Community-Led Total Sanitation Programs 77
Comparison of Costs and Benefits of Community-Led Total Sanitation Programs 79

Water and Sanitation Intervention 3 – Biosand Filters for Point-of-use Household Water Treatment 83
Description of the Intervention 83
Discussion of Costs Associated with Programs for the Distribution of Biosand Filters 87
Economic Benefits of Biosand Filter Dissemination Programs 89
Comparing the Costs and Benefits of Biosand Filter Dissemination Programs 89
Water and Sanitation Intervention 4 – Large Multipurpose dams in Africa 93
Description of the intervention 93
Discussion of Costs of A Large Multipurpose Dam in Africa........ 101
Discussion of Benefits of A Large Multipurpose Dam in Africa 102
Comparison of Costs and Benefits of a Large Multipurpose Dam in Africa........ 104
Discussion of the Costs and Benefits of the Four Water and Sanitation Interventions........ 111
Concluding Remarks 121
Acknowledgments 122
References 123

List of Tables

Table 1. Cost Estimates: Improved Water and Sanitation Services (Assuming 6% discount rate).[a] 16
Table 2. Cost Estimates: Improved Water and Sanitation Services for Low-Cost Option for Private Water and Sewer Connections (Assuming 6% discount rate).[a] 20
Table 3. Range of Estimates of Monthly Water Use (In-house, private connection). 21
Table 4. Range of Estimates of the Full Economic Cost of Providing Improved 21
Table 5. Comparison of Costs of Rebar, Cement, and Industrial 24
Table 6. Examples of Prices Charged by Water Vendors – Selected Countries. 26
Table 7. Median Monthly Household Expenditures on Water (1998 US$). 27
Table 8. Average Monthly Household Coping Costs of Acquiring 29
Table 9. Average per Capita *Ex-ante* COI for Typhoid Fever, New Delhi Slum 31
Table 10. Average Household Willingness to Pay (WTP) for Water Services: A Summary 34
Table 11. Comparing Monthly Household Costs and Benefits of Improved 36
Table 12. Equations for Cost-Benefit Analysis of Water Supply Project. 55
Table 13. Parameters Used in Cost-Benefit Analysis of Water Supply Project.[a] 56
Table 14. Base Case Results for Intervention 1: Borehole and Public Hand Pump.[a] 66
Table 15. Intervention 1: Typology of Water Project Sites Categorized by Benefit–Cost Ratio (BCR). 67
Table 16. Intervention 2: Equations for Cost-Benefit Analysis of Community-Led Total Sanitation (CLTS) Project 74
Table 17. Intervention 2: Parameters Used in Cost-Benefit Analysis of CLTS Project.[a] 76
Table 18. Base Case Results for Intervention 2: CLTS Project.[a] 79
Table 19. Intervention 2: Typology of CLTS Project Sites Categorized by Benefit–Cost Ratio (BCR).[a] 81
Table 20. Intervention 3: Equations for Cost-Benefit Analysis of Biosand Filter. 86
Table 21. Intervention 3: Parameters Used in Cost-Benefit Analysis of Biosand Filter.[a] 87
Table 22. Base Case Results for Intervention 3: Biosand Filters.[a] 90
Table 23. Intervention 3: Typology of Biosand Filter Project Sites Categorized by Benefit–Cost Ratio (BCR).[a] 92
Table 24. Benefits and Costs of Large Dam Projects.[a] 94
Table 25. Intervention 3: Equations for Cost-Benefit Analysis of Large Dam. 99
Table 26. Intervention 4: Parameters Used in Cost-Benefit Analysis of Large Dam Project.[a] ... 100
Table 27. Base Case Results for Intervention 4: A Large Dam in Africa.[a] 106
Table 28. Intervention 4: Typology of Dam Project Outcomes Categorized by Benefit–Cost Ratio (BCR).[a] 109
Table 29. Parameters with the Same Values in Each of the Three Community Water and Sanitation Interventions and Base Case Assumptions. 112
Table 30. Parameters with the Greatest Effects on the Benefit–Cost Ratios: Comparison of Assumed Values (with Ranges) Across the Three Community Water and Sanitation Interventions. 113
Table 31. Comparison of the Components of the Benefits and Costs of the Four Water and Sanitation Interventions (US$/hh-month).[a] 115

List of Figures

Figure 1. Infrastructure coverage as a function of household income, from Komives et al. (2003) 13
Figure 2. Demand curve for water as a function of collection time, showing different types of benefits from water project........ 59
Figure 3. Intervention 1: Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions........ 68
Figure 4. Intervention 1 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)........ 69
Figure 5. Intervention 2: Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions........ 80
Figure 6. Intervention 2 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)........ 83
Figure 7. Intervention 3 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)........ 91
Figure 8. Intervention 3: Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions........ 92
Figure 9. Water storage per person in different countries (from Grey and Sadoff, 2007) 95
Figure 10. Intervention 4: Distribution of costs and benefits in time (η function from Table 25) 104
Figure 11. Intervention 4 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)........ 107
Figure 12. Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions........ 108
Figure 13. Components of the Benefits of Three Water and Sanitation Interventions: Base Case Parameter Values........ 116
Figure 14. Components of the Costs of Three Water and Sanitation Interventions: Base Case Parameter Values........ 116
Figure 15. Frequency Distribution of the Benefit–Cost Ratios for the Three Water and Sanitation Interventions........ 118
Figure 16. Cumulative Frequency Distribution of the Benefit–Cost Ratios (BCRs) for Three Water and Sanitation Interventions 118

Introduction

The 1980s were designated the International Water and Sanitation Decade, and the international community committed itself to ensuring that everyone in the world have access to at least basic water and sanitation services by 1990. This target was not met. While hundreds of millions did receive new access, at the end of the decade well over 1.1 billion people still lacked improved water supplies, and more than 2.7 billion lacked sanitation services. By the year 2000, although another billion people had obtained access to improved water and sanitation services, population growth had left the number of those still unserved at roughly the same absolute level. In 2002, at the Johannesburg World Summit on Sustainable Development, the global community made a new commitment to a set of Millennium Development Goals (MDGs), one of which was to cut by half the proportion of people in the world living without access to water and sanitation by 2015.

While we certainly hope that the global goals for water and sanitation will be met this time, there are grounds for concern. Some important physical and economic features of water supply and sanitation make it inherently difficult to achieve broad-scale goals such as those of the Water and Sanitation Decade and the MDGs – more difficult than for other MDGs such as electrification and technology access. These features have not been well recognized in the existing economics literature or in the policy literature.

Several factors are involved, but one key contributing factor in why improving access has been so difficult to achieve has been a fundamental misunderstanding of the economics of investment in the water and sanitation sector. The core problem is to ensure that the benefits of *improved* water and sanitation access will be large enough to cover or possibly exceed the costs for those who will bear them: yet surprisingly often, this need is overlooked. There are two aspects to this statement. One is distributional: those who pay the costs are not necessarily those who will receive the benefits. This problem has been recognized since the middle of the nineteenth century, when issues of inadequate sanitation first arose in the growing metropolitan areas of North America and Western Europe. In the United States, for example, while over 80% of the urban population had sewerage services by 1900, it took until about 1960 before 80% of the urban population had sewage *treatment*, and much of that was limited to primary treatment. Cities had been willing to spend money on treating their drinking water but not their sewage. An additional complication is that large-scale water supply infrastructure investments often have multiple goals, such as flood and drought protection, hydropower generation, navigation, fisheries, and recreation, which further exacerbates the challenge of aligning beneficiaries and bill payers.

The second issue is perhaps more surprising but, we believe, no less real. Even considering water supply alone (for which externalities are less significant than for sanitation, as most of the benefits accrue directly to those who consume the water), the incremental benefits of improved access to water and sanitation network infrastructure may simply not be large enough to cover the costs of improved access. This happens for two reasons. First, for the network infrastructure technologies presently available the cost of improved access to water is typically large, due to the capital intensity and the longevity of the capital associated with improved water supply. Second, the incremental benefit can be small. This statement too may seem surprising – after all, we know that water is essential for life. Herein lies the paradox: precisely because water is essential for life, everybody does manage to have some sort of access to water, however inadequate and cumbersome. It is for this reason that the *incremental* benefit from *improved* access to water may not be so large. Contrast, for example, water supply with electrification. Because electricity is *not* essential for life, by no means everybody has access to electricity in their home. Without access in the home, there is no affordable or convenient way to provide access to electricity because there is no way to carry electricity home. Therefore, when it becomes available, access to in-home electricity may thus be *perceived* as a greater boon than access to in-home piped water and sewerage. Consequently, users' willingness to pay for access to electricity may be greater than their willingness to pay for access to piped water and sewerage, even though water is essential for life and electricity is not. The key to successful water and sanitation investments is to discover forms of service and payment mechanisms that will render the improvements worthwhile for those who must pay for them.

This challenge paper is presented in two parts. Part I focuses on municipal water and sanitation network infrastructure. It opens with some general observations that are central to an understanding of the economics of municipal water and sanitation network infrastructure. We proceed from there to a focus on the costs of providing such infrastructure services, and then summarize some empirical evidence on the economic benefits of municipal investments in them. We then discuss the economic costs and the benefits involved and note the limitations of the analytical approach used in most such applications. Part I closes with observations regarding the implications of these results. Part II considers the costs and benefits of three specific low-cost, non-network water and sanitation interventions and one high-cost intervention—large multipurpose dams in Africa.

Part I – Assessing the Costs and Benefits of Investments in Water and Sanitation Infrastructure

Background

To introduce the economics of investments in municipal water and sanitation infrastructure in developing countries, we offer six observations about the sector.

First, broadly conceived, the provision of water supply and sanitation network infrastructure is a huge societal enterprise. In industrialized as well as in developing countries it often accounts for a substantial share of public sector investment. The cost of reservoirs, canals, water transmission lines, urban distribution networks, pumping stations, water treatment facilities, sewerage collection and conveyance, and wastewater treatment facilities – and the land required for all these facilities – makes this one of the largest "industries" in most industrialized economies. The payments an individual household makes for these assets, both in direct payments for services and in indirect taxes, are often a significant household budget expenditure, and a household's share of these capital assets can represent a substantial portion of its net worth, albeit typically publicly owned and typically not easily tradable.

Second, the provision of water and sanitation network infrastructure is very capital-intensive. In many cases there are significant economies of scale, and the physical capital tends to be long-lived. These factors have several important implications. It is critical to ensure that investment planning decisions are correct, because big mistakes can arise by overbuilding, by building too far in advance of demand, by building facilities that no one wants, or by failing to maintain and operate such capital-intensive facilities efficiently once they are in place. Also, because of this capital intensity, the financing of capital expenditures becomes a central issue in the provision of water and sanitation services. Because so much capital is at stake, the property rights to the revenue (and benefit) stream from water and sanitation facilities must be clearly established and well-secured for all parties involved – public and private investors and taxpayers alike – to feel confident in undertaking such large investments.[1]

Third, household demand for very small quantities of drinking water is extremely price-inelastic: people must have water to live. If there are no other sources of water, the amount of money someone will pay for 3 to 4 liters of water a day is limited only by income and the budget share required for food. When coupled with shortages of water supply, this extremely inelastic

[1] Because financing is so crucial to the provision of water supply and sanitation infrastructure, the availability of financing has historically been a major determinant of the timing and institutional structure through which these services were provided, including whether this was by the private sector or the public sector. In this context, the historical experience of water supply and sanitation in the US is quite instructive. Throughout the nineteenth century and for the first half of the twentieth century, the provision of urban water supply in the US was financed mainly by property taxes paid by water users. There were two key requirements for this to be a viable mechanism. First, there had to be a well-developed system of local government finance based on universal assessment and payment of property taxes. Secondly, there had to political acceptance of the use of property tax revenues for this purpose – property owners had to be willing to pay higher property taxes in return for access to piped water. That there was such a willingness to pay in the nineteenth century U.S. is due to two somewhat idiosyncratic factors: the fear of urban fires and the misplaced belief in the miasma theory of disease.

Wood was widely used for buildings in American cities, and fire was a constant threat throughout much of the nineteenth century. Having a piped water supply in a street made it possible to install fire hydrants, which greatly increased the protection against fire. This benefit was quickly reflected in improved property values and reduced fire insurance rates for properties served by a piped water supply. Moreover, the miasma theory of disease was widely believed for much of the nineteenth century. Under this theory, it was held that “bad air” caused illness, including diseases such as cholera. Miasma was considered to be a poisonous vapor or mist filled with particles from decomposed matter that could cause illnesses and was identifiable by its foul smell. An obvious public health solution was to remove foul smelling material from public access, and this could conveniently be accomplished by flushing the streets, washing away faeces and other foul smelling materials. This could only readily be done if the street was served by piped water supply. The reduced health risk was also immediately reflected in improved property values. Thus, two of the main perceived benefits of piped water were conveniently reflected in improved property values and, given the existence of an effective system of property taxation, this provided a viable financing mechanism not requiring any information on the specific quantity of water consumed by each individual homeowner. This convenient set of circumstances does not exist today in many of the large metropolitan areas in developing countries.

The history of sanitation in the U.S. offers some additional grounds for caution. By 1900, over 80% of the urban population in the U.S. was covered by sewerage services, but less than 4% of this population was served by sewage *treatment*. It took until about 1960 before 80% of the urban population in the U.S. was served by sewage treatment. This was not due to lack of technology, because the necessary technology had been known since the 1890s. It was mainly due to a lack of willingness to pay for the treatment services. It was considered more appropriate to treat drinking water than to treat sewage because it benefited users, whereas sewage treatment benefited other people downstream. As with water supply, finance was a crucial constraint on the effective provision of sanitation – even in a country as rich as the U.S.

demand for small quantities can create desperate situations in the developing world that are beyond the experience of people in richer countries. For example, in some places in rural Tanzania a 20-liter bucket of water can cost an unskilled laborer's daily wage. The only options are to walk all day for water, or to work all day in the fields and buy a bucket of water. In parts of Mozambique, one of the poorest countries on earth, the market price of a 20-liter jerrican of water can be four times the cost of desalinated water. During the civil war in Angola, a liter of water sometimes cost more than a liter of gasoline (although this was in large part due to the subsidized price of gasoline).

Because the price elasticity for small quantities of water is so low and the provision of network services is very capital-intensive, a lot of money can be made by operators gaining control of the capital assets and pursuing an objective of maximizing monopoly profits rather than public welfare. Thus it is not surprising to see water utilities engaged in complex rent-extracting arrangements in societies with poor governance and high levels of corruption (Lovei and Whittington, 1993; Davis, 2004). The capital intensity of these investments also provides enormous opportunities for bribery and kickbacks on construction contracts and equipment purchases. These problems greatly increase the transaction costs of doing business and thus influence the total cost of providing improved water and sanitation services in many developing countries.

Fourth, from a technological perspective, water is very different from electric power when it comes to storage and transport. The storage of water is relatively easy, but transporting water long distances to urban centers is expensive, because water is so heavy. With electricity, by contrast, storage is expensive and transportation is easy. Because it is typically costly to transport water over long distances, it can be prohibitively expensive to provide customers with very high levels of service reliability. Because it is impossible to import large supplies of water at short notice from distant locations during droughts or periods of limited production capacity, pricing and other demand-management tools become necessary for coping with water shortages. In industrialized countries good reservoir sites are often already utilized, and constructing new reservoirs is increasingly expensive and politically infeasible. Many developing countries, by contrast, have relatively little water storage and thus have little protection against drought. The capital and associated financing needs for additional storage and other components of the water and sanitation system are very large.

Fifth, there is a strong association between water and sanitation network infrastructure coverage and household income. As incomes increase in developing countries, more and more people are obtaining improved network infrastructure services. This is particularly so in China and India. Figure 1, based on interviews with more than 55,000 households in 15 developing countries (Komives et al., 2003), shows that at all income levels, more people have electricity than piped water or sewerage. Very few of the poorest households have piped water or sewerage, but almost a third of those households do have electrical service. As monthly household income increases from very low levels to US$300 per month, coverage of all of these infrastructure services increases rapidly; above US$300 coverage increases at a slower rate.

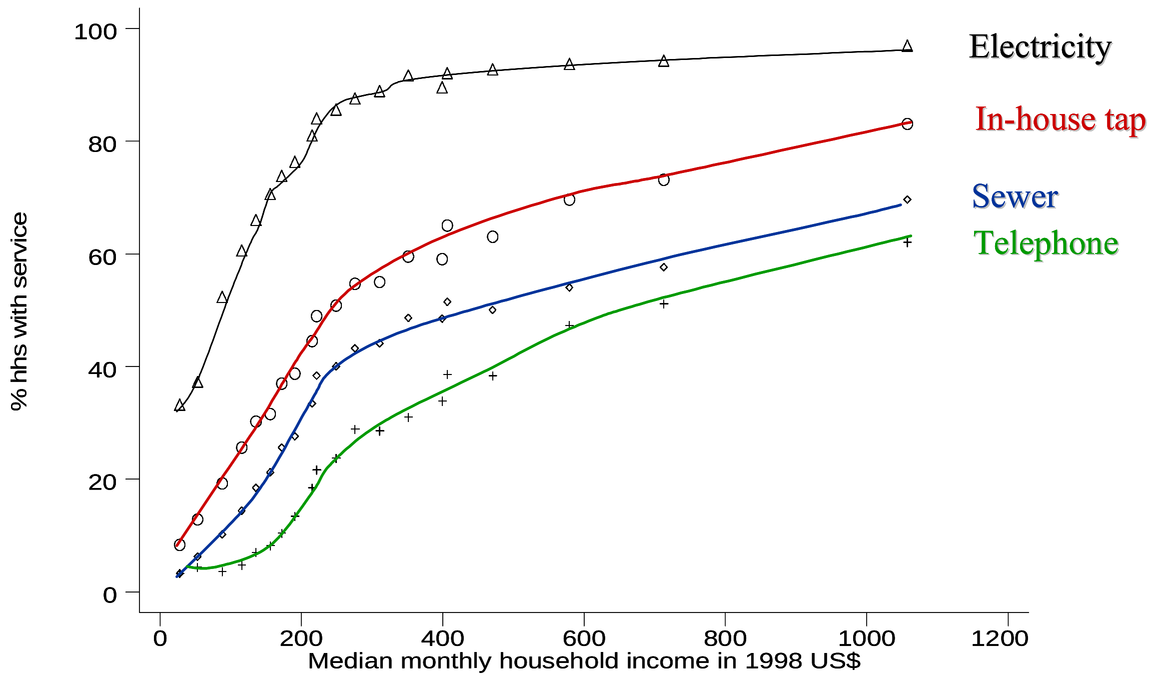

Figure 1. Infrastructure coverage as a function of household income, from Komives et al. (2003)

Although most households in developing countries would certainly like improved water and sanitation network services, this is generally *not* their most important priority. Water and sanitation planners often present the need for improved services as a moral imperative or a basic human right, arguing that these services are "merit goods." But given the choice, many households in developing countries appear to want electricity before an in-house piped water or sewer connection. In fact, it is unusual for a household in a developing country to have a piped water connection and *not* have electricity. That water itself is a necessity does not necessarily mean that people prefer piped water service over electrical service. Indeed, because it is a necessity, households must already have access to some source of water. The question thus becomes how much *improved access* to water (both quantity and quality) is worth to them.

Sixth, water is distinctive in terms of its strong social, environmental, and cultural values: many believe it should not be considered an economic good at all. A rights-based discourse has evolved on access to water as a human right, with potentially significant cost implications. The economics of water is also complicated by the challenge of attaching monetary values to today's ecosystem services and tomorrow's natural heritage. However hard to quantify, these non-market values need to be incorporated into the economic appraisal of water and sanitation investments.

Costs of Municipal Water and Sanitation Network Infrastructure

The preference for fresh, clean water supplies for drinking and washing lies deep in human consciousness and is reflected in all of the world's major religions (Priscoli, 2000). People may still long for a lost world in which wondering nomads could visit uncontaminated, refreshing springs, but in a world of more than 6 billion people such places are sadly few and remote. Even in areas with stringent water pollution control regulations, very few places remain where people can expect safely to drink untreated water from natural sources. The treatment and delivery of water to households, and the removal and treatment of their wastewater, cost serious money. Just as costs vary depending on individual circumstances, estimates of what it will cost to provide a certain level of service may vary widely in different locales. Also, most investments in this sector are incremental in nature. Only rarely would a community incur the costs of complete ("full service") piped water and sanitation systems at a single point in time.

Nevertheless, some rough calculations can be made that illustrate the true costs of such investments. The approach here is to estimate the average unit costs of providing an urban household with modern network water and sanitation services. We begin with representative unit costs per cubic meter for different components of water and sanitation services. Next we ascertain the typical quantities of water that households might use each month. Then we multiply representative unit costs by typical monthly household water use to obtain estimates of the monthly economic costs of providing a household with improved, piped water and sanitation services.

The economic costs of providing a household with modern water and sanitation infrastructure services are the sum of seven principal components:

1. Opportunity costs of diverting raw water from alternative uses to the household (resource rents)
2. Storage and transmission of untreated water to the urban area
3. Treatment of raw water to drinking water standards
4. Distribution of treated water within the urban area to the household
5. Collection of wastewater from the household (sewerage collection)
6. Treatment of wastewater (sewage treatment)
7. Any remaining costs or damages imposed on others by the discharge of treated wastewater (negative externalities).

Table 1 presents some illustrative average unit costs for each of these seven cost components. The unit costs of these different cost components could vary widely in different locations. For example, in a location with abundant fresh water supplies, item 1 (the opportunity cost of diverting water from existing or future users to our illustrative household) and item 7 (the damages imposed by the discharge of treated wastewater) may, in fact, be very low or even zero. In reality, however, in more and more places these opportunity costs are beginning to loom large.

Table 1. Cost Estimates: Improved Water and Sanitation Services (Assuming 6% discount rate).[a]

No.	Cost component	US$ per m^3 [b]	% of total
1	Opportunity cost of raw water supply	0.05	3%
2	Storage and transmission to treatment plant	0.10	5%
3	Treatment to drinking water standards	0.10	5%
4	Distribution of water to households (including house connections)	0.60	30%
5	Collection of wastewater from home and conveyance to wastewater treatment plant	0.80	40%
6	Wastewater treatment	0.30	15%
7	Damages associated with discharge of treated wastewater	0.05	3%
	Total	2.00	100%

[a] Using a 3% discount rate, the total cost is US$1.80/$m^3$.
[b] UNDP, 2006.

Some cost components are typically subject to significant economies of scale, particularly storage and transmission (item 2), treatment of raw water to drinking water standards (item 3), and treatment of sewage (item 6). This means that the larger the quantity of water or wastewater treated, the lower the per-unit cost. Other cost components are experiencing diseconomies of scale. As large cities go father and farther away in search of additional fresh water supplies, and good reservoir sites become harder to find, the unit cost of storing and transporting raw water (item 2) to a community can actually increase. There are also tradeoffs between different cost components: one can be reduced, but only at the expense of another. For example, wastewater can receive only primary treatment, which is much cheaper than secondary treatment; but then the negative externalities associated with wastewater discharge will increase.[2]

[2] Primary treatment of wastewater consists of physical operation only, such as screening and sedimentation. Secondary treatment includes biological and chemical processes that are used primarily to remove organic matter from water.

The cost estimates in

Table 1 include both capital expenses and operation and maintenance expenses. Annual capital costs are calculated using a capital recovery factor of 0.09, assuming a discount rate of 6% and an average life of capital equipment and facilities of 20 years.[3] The opportunity costs of raw water supplies (item 1) are still quite low in most places, on the order of a few cents per cubic meter. Even in places where urban water supplies are diverted from irrigated agriculture or valuable environmental assets, the unit costs will rarely be above US$0.25 per cubic meter. Desalinization and wastewater reclamation costs will set an upper limit on opportunity costs of

[3] Summary results also show total for a 3% discount rate. The capital recovery factor is defined as: $CR = r * (1 + r)^d / ((1 + r)^d - 1)$, where r is a real discount rate, and d is the duration of the capital. Our choice of a 3% to 6% range for a real discount rate was dictated by the organizers of the Copenhagen Consensus 2008 Project in order to ensure comparability across interventions in different sectors (e.g., water and sanitation services, health, global warming, etc.). The use of a single discount rate to account for both the social opportunity cost of capital and the social rate of time preference is appropriate when all of the funds for an investment or program displace alternative investments *and* the returns from displaced investments would have been reinvested in projects with the same rate of return. In this special case one can justify discounting by the social opportunity cost of capital, which is surely higher in developing countries than the 3%–6% range proposed by the Copenhagen Consensus organizers. This is the rationale for the use by the World Bank of a 10% real discount rate for project evaluation, i.e., that investment capital in developing countries is scarce and the opportunity costs of the project being evaluated are high.

The lower end of the 3%–6% range is a reasonable estimate for the social rate of time preference for use in discounting future benefits (and costs). Given that the relevant economic question becomes: what investment and consumption are displaced by expenditures on the investment being evaluated, and how should these opportunity costs be valued? The approach proposed by the Copenhagen Consensus 2008 Project organizers assumes a shadow value of capital equal to 1, which implies that governments in developing countries have ready access to the financing they need to undertake essentially all investments with real rates of return above 3%–6%. This seems to us improbable, especially in the context of capital-intensive interventions such as network water and sanitation infrastructure and large multipurpose dams. The use of a single, low real discount rate such as proposed by the Copenhagen Consensus organizers is in fact customary in the global health community, where a 3% real rate is used in the calculation of Disability-Adjusted Life Years (DALYs). But the implicit assumption is that funding will displace investment in rich countries, and the value of this displaced investment is low. If these donor funds could have been used by developing countries for alternative investments, the use of a 3% real discount rate without shadow pricing capital is theoretically incorrect.

The discount rate assumed has a significant effect on the monthly household costs of water and sanitation services. The use of a 3% real discount rate makes these costs appear significantly cheaper than they are likely to be in practice. This is one of the reasons that the costs of water and sanitation services in the global health literature appear so low.

raw water of about US$0.50–$1.00 per cubic meter for cities near the ocean, but the opportunity costs of raw water are nowhere near this level in most places.

Raw water storage and transmission and subsequent treatment (items 2 and 3) will typically cost about US$0.20 per cubic meter. Within a city the water distribution network and household connections to it (item 4) comprise a major cost component, in many cases on the order of US$0.60 per cubic meter. The collection and conveyance of sewage to a wastewater treatment plant (item 5) is even more expensive than the water distribution; this removal will cost about US$0.80 per cubic meter, 40% of the total cost. Secondary wastewater treatment (item 6) will cost about US$0.30 per cubic meter. Damages resulting from the discharge of treated wastewater are very site-specific, but environmentalists correctly remind us that that they can be significant, even for discharges of wastewater receiving secondary treatment. Let us assume for purposes of illustration that these costs are of the same order of magnitude as the opportunity costs of raw water supplies (US$0.05).

As shown, total economic costs are about US$2.00 per cubic meter in many locations. We emphasize that costs shown here are not intended to represent an upper bound. For example, in small communities in the arid areas of the western United States costs of water and sanitation services can easily be double or triple these amounts per cubic meter. Note too that these cost estimates assume that financing is available at competitive international market rates, and that countries do not pay a high default or risk premium. Using a real discount rate of 10% would result in monthly household costs about 25% higher.

Table 2 presents a reasonable lower-bound estimate of unit costs of piped water and sanitation services. Here the opportunity cost of raw water supplies and the damages from wastewater discharges are assumed to be zero. Only minimal storage is included, and the only intake treatment is simple chlorination. Costs for the water distribution network assume the use of PVC pipes and shallow excavation. Wastewater is collected with condominial sewers, and the only wastewater treatment is provided by simple lagoons. Given all these assumptions, unit costs of piped water and sanitation services can be reduced to about US$0.80 per cubic meter.

Table 2. Cost Estimates: Improved Water and Sanitation Services for Low-Cost Option for Private Water and Sewer Connections (Assuming 6% discount rate).[a]

No.	Cost Component	US\$ per m^3
1	Opportunity cost of raw water supply (steal it)	0.00
2	Storage and transmission to treatment plant (minimal storage)	0.07
3	Treatment of to drinking water standards (simple chlorination)	0.04
4	Distribution of water to households (PVC pipe)	0.24
5	Collection of wastewater from home and conveyance to wastewater treatment plant (condominial sewers)	0.30
6	Wastewater treatment (simple lagoon)	0.15
7	Damages associated with discharge of treated wastewater (someone else's problem)	0.00
	Total	0.80

[a] Using a 3% discount rate, the total cost is US\$0.70/m^3.

How much water does a typical household in a developing country "need"? The quantity of water used by a household will be a function of the price charged, household income, and other factors. Currently most households in developing countries are facing very low prices for piped water and sanitation network infrastructure services. One can look at typical water use figures from households around the world to see how much water a household might be expected to use for a comfortable modern lifestyle. For households with an in-house piped water connection, in many locations residential indoor water use falls in the range of 110 to 220 liters per capita per day. For a household of six, this would amount to about 20 to 40 cubic meters per month (Table 3). At the current low prices prevailing in many cities in developing countries, such levels of household water use are common. Other things equal, households living in hot, tropical climates use more water for drinking, bathing, and washing than households in temperate or cold climates.

Table 3. Range of Estimates of Monthly Water Use (In-house, private connection).

Per capita daily water use	Persons per household	Days per month	Monthly household water use
55 liters	6 persons	30 days	10 m^3

110 liters	6 persons	30 days	20 m^3
220 liters	6 persons	30 days	40 m^3

Assuming average unit costs of US$2.00 per cubic meter (

Table 1), the full economic costs of providing 20 to 40 cubic meters of water to a households (and then dealing with the wastewater) would be US$40 to US$80 per month (Table 4), more than most households in industrialized countries pay for the same services and far beyond the means of most households in developing countries.

Table 4. Range of Estimates of the Full Economic Cost of Providing Improved Water and Sanitation Services (In-house, private water connection; piped sewer).

Monthly household water use	Average cost US$0.80 per m^3	Average cost US$2.00 per m^3
10 m^3	US$8	US$20
20 m^3	US$16	US$40
40 m^3	US$32	US$80

One would expect poor households in developing countries with in-house water connections to respond negatively to high water and sanitation prices: they might curtail use to as little as 50 to 60 liters per capita per day. For a household with six members, at 55 liters per capita per day, total consumption would then amount to about 10 cubic meters per month. The full economic costs of this level of water and sanitation service at this reduced quantity of water use (assuming our unit costs of US$2.00 per cubic meter remained unchanged) would then be US$20.00 per month per household. At entirely plausible levels of water use (110 liters per capita per day), the total economic cost would be about US$40 per month for the same household. With the unit costs of the low-cost system depicted in

Table 2, the full economic cost of providing 10 cubic meters per month would be US$8 per household per month. This estimate should be regarded as a lower bound on the full economic costs of piped water and sanitation services in most locations.

In industrialized and developing countries alike, most people are unaware of the magnitude of the true economic costs of municipal water and sanitation network services. There are several reasons why these economic costs are so poorly understood.

First, the capital costs are heavily subsidized by higher levels of government, (and, in developing countries, by international donors), so that households with services do not see the true capital costs reflected in the volumetric prices they pay. Second, in many cities tariff structures are designed so that industrial water users subsidize residential users; households thus do not even see the full operation and maintenance costs in the prices they pay. Third, because many water utilities run financial deficits (in effect running down the value of their capital stock), water users in aggregate do not even see the full costs of supply. Fourth, most cities do not pay for their raw water supplies: typically the water is simply expropriated from any existing water sources (and their users) in outlying rural areas. Fifth, wastewater externalities are typically imposed on others (downstream) without compensation.

Sixth, the subsidies provided to consumers of water and sanitation services are not only huge, but also regressive. It is often not politically desirable for the majority of people to understand that middle- and upper-income households, who generally use more water, are thus actually receiving the most benefit from subsidies. Tariff designs may in fact be made overly complicated in order to offset this reality and appear to be helping poorer households (Komives et al., 2005). Most fundamentally, poor households are often not connected to the water and sanitation network at all and hence cannot receive the subsidized services. Even if they do have connections, the poor use less water than richer households, thus receiving lower absolute amounts of subsidy.

The estimates presented in Tables 1-4 are intended merely to suggest the likely magnitude of costs of water and sanitation services in many developing countries. A reasonable question to ask is whether costs differ much across countries in the developing world and between industrialized and developing countries. Labor costs are obviously lower in developing countries, but because water and sanitation projects are capital-intensive, this cost component has less of an impact on total costs than for other goods and services. To our knowledge there are no publicly available international indices of water and sanitation project construction costs. To illustrate the magnitude of international cost differentials for some related goods and construction costs,

Table 5 compares costs of rebar, cement, and industrial construction in 11 large cities in both industrialized and developing countries. Costs are indeed lower in cities such as New Delhi and Hanoi than in London and Boston, and lower costs for inputs such as cement and steel will translate into lower costs for water and sanitation projects.

Table 5. Comparison of Costs of Rebar, Cement, and Industrial Facility Construction in 11 Cities.

City	Rebar (US$/ton)	Cement (US$/ton)	Industrial Construction (US$ per m^2)
Boston	1100	85	915
Durban	1028	137	516
Los Angeles	992	135	699
London	981	96	850
Buenos Aires	765	82	n.a.
New Delhi	600	64	247
Jakarta	528	68	269
Bangkok	482	63	301
Shanghai	435	43	592
Hanoi	349	62	409
Nairobi	n.a.	n.a.	291

Source: Engineering News Record (2004).

It is, of course, less expensive to provide intermediate levels of water and sanitation services (such as public taps and communal sanitation facilities) than the costs in Table 4 would indicate. Monthly household costs for such services are, however, often quite considerable, roughly US$5 per month for much smaller quantities of water and lower levels of sanitation services. These costs are often reported to be as low as US$1 to US$2 per household per month, but such accounts often systematically underestimate key capital cost components and rarely reflect the real costs of financially sustainable systems.

Economic Benefits of Water and Sanitation Network Infrastructure Services

There are four main types of information sources where one can look for insight into the economic benefits that households receive from improved municipal water and sanitation services: (1) prices charged for vended water, (2) avertive expenditures (coping costs), (3) avoided costs of illness, and (4) stated preference studies.[4] Of course, other water users – industries, small firms, government – also receive economic benefits from improved water sources, and their benefits should count in any benefit–cost analysis of investments to improve water and sanitation infrastructure. However, the majority of economic benefits from municipal water and sanitation network infrastructure investments in most cities will accrue to households, and we restrict our focus in discussion below on household benefits in order to keep our task manageable.

Market Data: Water Vending

The first source of information about the benefits of improved water services is evidence on what households in developing countries are now paying to water vendors.

[4] Conceptually, a fifth source is hedonic property value studies. However, there are relatively few hedonic property value studies in the literature that provide convincing estimates of the capitalized value of water and sanitation network services, and we do not review them in this paper.

Table 6, which shows some of the prices that vendors have charged households in selected cities, illustrates that many of these prices are in fact higher than our estimated costs of both improved water and sanitation services. Millions of households in developing countries are purchasing relatively small quantities of drinking and cooking water from vendors, and for many of these households the benefits of improved water services would typically exceed the costs of network water services.

Table 6. Examples of Prices Charged by Water Vendors – Selected Countries.

Continent	Location	Type of Water Vendor	Price of Water (Dry season)
Africa	Ukunda, Kenya	Distributing vendor	US$9.40 per m^3
Central America	Tierra Nuevo, Guatemala	Tanker truck	US$2.00 per m^3
Asia	Delhi, India	Distributing vendor	US$6.00 per m^3
Asia	Jakarta, Indonesia	Tanker truck	US$1.80 per m^3

The data on water vending must, however, be interpreted with caution. The vast majority of households in developing countries do *not* buy water from vendors. This fact tells us that for most people the perceived private benefits of vended water services (as measured by the household's willingness to pay) are *less* than the price a vendor would charge. Water vending data from selected World Bank Living Standards Measurement Surveys for Ghana, Nicaragua, and Pakistan show that less than 1% of the sample households were purchasing water from vendors. In Côte d'Ivoire 15% of sample households were purchasing from vendors. The average household purchasing from water vendors was spending US$4.40 per month in Ghana, US$6.00 in Nicaragua, and US$7.50 in Pakistan (

Table 7) – substantial amounts no doubt, but still probably less than the full economic cost of piped services. Only in Côte d'Ivoire was the monthly expenditure of households purchasing from vendors (US$13.90) probably greater than the full economic cost of improved piped water services. Of course, there are numerous places like Côte d'Ivoire where water vending is widespread, but in communities where vendors do not sell water, this is usually a clear signal that there is no market for such high-priced water services.

Table 7. Median Monthly Household Expenditures on Water (1998 US$).

	Households with in-house piped water connection	Households purchasing from water vendors
Côte d'Ivoire	US$12.40	US$13.90
Ghana	US$4.90	US$4.40
Nicaragua	US$4.60	US$6.00
Pakistan	US$1.00	US$7.50

Source: World Bank Living Standard Measurement Surveys, authors' calculations.

Also, for some households improved piped water services are not an unambiguously better service than purchasing vended water. Water vendors offer an important advantage over piped network water services: households have better (tighter) control over their water expenditures. If a child leaves a tap running, the household must pay for this water. There is no such financial risk if one purchases from vendors. Also, purchasing from vendors gives a household greater control over cash flow. If money is tight one month, the household can stop purchasing from vendors and perhaps collect water from a public tap at much less cost.

Avertive Expenditures: Coping Costs

A second source of information on the benefits of improved water supplies is evidence about the amounts of money households in developing countries spend coping with unreliable, poor quality public supplies. In many developing countries households spend considerable amounts of both time and money trying to improve the poor services to which they currently have access. Many households incur expenses installing household storage capacity to ensure that they have water when the pipes run dry. Others undertake a wide variety of activities to treat contaminated water in their homes to make it safe to drink. These range from boiling, a common practice in many parts of Southeast Asia, to the installation of home filtration and disinfection systems. People expend time and effort walking to water sources outside their homes to collect water from public taps or unimproved, traditional water sources. Such coping costs should represent something close to a lower bound on the benefits households would receive from improved water and sanitation services; a household might well be willing to pay considerably more for improved water and sanitation services than it is spending now trying to deal with the deficiencies in the status quo.

A recent study by Pattanayak et al. (2005) attempts to quantify these coping costs for households in Kathmandu, Nepal. The existing public water system in Kathmandu is typical of the poor service in many Asian cities. About 70% of the population has a piped connection and receives low-quality water one or two hours per day. Households pay US$1–$2 per month for this poor water service. The other 30% of the population obtains its water from a combination of public taps, vendors, and private wells. Pattanayak and his colleagues estimated that the average monthly costs of coping with poor-quality, unreliable water supplies were about US$4 (

Table 8). These estimates do not include the costs of coping with poor sanitation facilities, and coping costs may well be somewhat higher in other locations. However, neither these estimates nor others in the literature provide evidence that the costs of coping with poor quality water and sanitation services are generally in excess of our estimates of the full economic costs of piped water services.

Table 8. Average Monthly Household Coping Costs of Acquiring Improved Water, Kathmandu, Nepal (US$ per month).

Type of Coping Cost	Households with piped connection	Households without piped connection
Collection (time spent)	US$1.57	US$1.60
Pumping	US$0.50	US$0.46
In-house treatment	US$0.78	US$0.83
In-house storage	US$1.22	US$1.29
Total	US$4.07	US$4.18

Source: Pattanayak et al., 2005. Averages are for 1500 households in 2001.

Avoided Costs of Illness

The third source of data on the benefits of improved water and sanitation services is calculations of the avoided costs of illness (COI) from waterborne diseases. Many people become ill as a consequence of poor water and sanitation services, and as a result both the public sector health system and households incur a variety of costs, including (but not limited to) money spent on medicines, physicians' time treating these illnesses, and lost earnings due to absence from work, both for patients and for household members who must care for them. If water and sanitation services were improved, the incidence of such waterborne diseases would be reduced, and this COI would be avoided. Thus, "avoided COI" is often cited as a component of the benefits of water and sanitation improvements.

In some respects calculations of avoided COI are the least useful source for insight into the benefits of improved water and sanitation improvements. It is widely understood by economists that these estimates of avoided COI are lower-bound estimates of the health benefits of water and sanitation improvements; they do not include the economic value of the pain and suffering associated with an episode of illness, or the value of reduced risk of mortality. Nor do these estimates of avoided COI place any value on non–health-related benefits that come with improved water supplies, such as time savings and/or reduced coping costs. Moreover, avoided COI cannot easily be added to non–health-related coping costs, because the latter (e.g., boiling water, other disinfection methods) may also result in avoided COI.

Calculating the avoided COI that would result from improved water and sanitation services involves two further complications. First, for a given population, improved services result in a reduction in the number of infections from a variety of major diseases, including typhoid, cholera, shigellosis, and rotavirus. Because each of these has unique characteristics – duration, severity, treatment regimen, etc. – it can be very difficult to arrive at a single COI measure that is acceptable for analysis. Second, improved water and sanitation services only reduce and do not eradicate the risk of infection from these various diseases.[5] Esrey (1996) found that probably the best one could hope for from improved water and sanitation services would be a reduction in overall diarrheal incidence by 30-40%. The effect of improved services even on specific diseases in a specific location is still largely a matter of professional judgment and conjecture.

As a lower-bound estimate of benefits, the *ex-ante* COI estimate (i.e., the expected value of COI, taking into consideration the incidence of the disease) would not tell us much unless it were higher than the full economic costs of providing water and sanitation services. In fact, most *ex-ante* estimates of avoided COI are rather low. An example of this drawback can be seen in a recent study (Bahl et al., 2004) reporting *ex-ante* estimates of COI for an outbreak of typhoid in

[5] This statement may be somewhat overoptimistic. Attempts to measure the health impacts of water and sanitation have had a long and checkered history, as Cairncross (1990) has noted. Cairncross argues for the importance of *behavioral change* as a key factor in health impacts from water and sanitation. He observes that in cases where a significant health impact was found, it was accompanied by improved hygienic behavior such as the washing of hands, food, and utensils. But the change in behavior did not always occur, and without it there was little health impact. Similar evidence that the provision of piped water is not a sufficient condition for improved child health is presented by Jalan and Ravallion (2003).

one of the poorest slums in New Delhi, where the incidence of the disease is probably as high as almost anywhere in the world. The study estimated *ex-ante* private and public COI for individuals in different age groups (Table 9). For a typical household of five in this New Delhi slum, the total monthly *ex-ante* COI was about US$0.65 per month.

Table 9. Average per Capita *Ex-ante* COI for Typhoid Fever, New Delhi Slum (US$ per month).

Age group	Private	Government (Public Sector)	Total
0–2 yr.	US$0.07	US$0.04	US$0.11
2–5 yr.	US$0.13	US$0.42	US$0.55
5–19 yr.	US$0.08	US$0.04	US$0.12
> 19 yr.	US$0.03	US$0.03	US$0.06
All ages	US$0.06	US$0.07	US$0.13

Source: Bahl et al., 2004.

Because these *ex-ante* COI estimates are for a single disease (typhoid), they will be an underestimate of the total *ex-ante* COI avoided from improved water and sanitation services. The World Health Organization estimates that roughly a quarter of the deaths due to poor water and sanitation in developing countries are due to typhoid fever. Assuming that COI estimates for other waterborne diseases would be similar in magnitude to those for typhoid, one crude estimate of total COI incurred from poor water and sanitation services might be made by increasing the *ex-ante* COI for typhoid by a factor of four (to US$2.60 monthly per household). But to obtain an estimate of the COI avoided due to improved water and sanitation, one would need to reduce this crude estimate to reflect the fact that improved services would only reduce the incidence by 35% (US$2.68 × 0.35 = US$0.91), or about US$1 per month per household.

This rough calculation is clearly inflated by the extremely high incidence of typhoid in the study area where data were gathered. In most locations in developing countries the incidence of typhoid would be one or two orders of magnitude less than in this particular slum, and the *ex ante* COI much lower than the estimates shown in Table 9.

However, our general point is that the empirical estimate of avoided COI is much less than the costs of improved water and sanitation services. Contrary to conventional wisdom in the sector, the estimate does not provide much economic justification for water and sanitation investments.

Stated Preferences: Household Willingness to Pay for Improved Water and Sanitation Services

A fourth source of evidence on the perceived household economic benefits of improved water and sanitation services in developing countries comes from a few dozen studies conducted over the past two decades in which households were asked directly whether improved water and sanitation services would be worth a specified amount per month – that is, whether the household would be willing to pay a specified monthly water bill if the residents could be assured of receiving higher quality services.[6]

Before such contingent valuation surveys were conducted in developing countries during the mid-1980s, water and sanitation professionals commonly believed that households in developing countries were too poor to pay much of anything for improved water and sanitation services. The CV surveys revealed that people were in fact often willing to pay considerably more

[6] Griffin et al. (1995) demonstrate that stated preference using the contingent valuation method can sometimes provide *ex-ante* predictions of household behavior that are quite similar to *ex-post* outcomes.

for improved water and sanitation services than anyone then had expected. In some instances the results of these CV surveys were used for financial analysis of water utility operations, not for benefit–cost analysis of new investments. Some water and sanitation sector professionals were delighted to incorporate this evidence from contingent valuation surveys and from water vending surveys into a new conventional wisdom that held that (1) people were willing and able to pay higher tariffs for improved water and sanitation services; (2) tariffs could be raised; and (3) private operators could recover the full costs of providing water and sanitation services.

Actually the contingent valuation surveys of household demand for improved water and sanitation services did not suggest that households' perceived economic benefits from improved water and sanitation services would commonly exceed the full economic costs of providing water and sanitation services. Indeed, as the results from selected contingent valuation studies for improved water services illustrate (

Table 10), households' stated willingness to pay (WTP) varied a great deal from place to place and in many cases was far below the costs of providing improved services.

Table 10. Average Household Willingness to Pay (WTP) for Water Services: A Summary of Eight Contingent Valuation Studies.

Author(s)	Study Location	Date of Study	Monthly WTP for Public Tap (unconnected HH)	Monthly WTP for new private connection	Monthly WTP for improved service
Whittington et al. (1990a)	Rural Haiti	1986	US$1.10	US$1.40	
Whittington et al. (1988)	Rural Tanzania	1987	US$0.32		
Briscoe et al. (1990)	Rural Brazil	1988		US$4.00	
Altaf et al. (1993)	Rural Pakistan	1989		US$1.50	
Whittington et al. (1993)	Kumasi, Ghana	1989		US$1.50	
Griffin et al. (1995)	Rural India	1989		US$1.38	
Whittington et al. (1998)	Lugazi, Uganda	1994	US$3.70	US$8.63	
Whittington et al. (2002)	Kathmandu, Nepal	2001	US$3.19	US$11.67	US$14.35

On the other hand, some CV studies revealed quite high household WTP for improved services.

Table 10 also shows that responses from a small market town in Uganda and from Kathmandu in Nepal revealed many households' expressed WTP for improved water services at rates close to US$10 per month, probably approaching the full economic costs of providing modest amounts of water using improved network services. CV studies for improved sanitation services conducted in Latin America (Russell et al., 2001) revealed much higher WTP (e.g., US$10 per household per month) than CV studies in Africa and Asia (Whittington et al., 1993; Choe et al., 1996) where WTP estimates often were extremely low (e.g., US$1–$2 per household per month).

The economic goal of an investment project is not, of course, to have the benefits approach or be equal to the costs, but rather to have the benefits *exceed* the costs. We know of no CV studies from anywhere in the developing world that show that a majority of a city's population would be willing to pay substantially *more* than the full economic costs of supplying water and sanitation services.

Comparing Costs and Benefits of Network Infrastructure Services

Table 11 offers examples of some of the types of benefit and cost estimates discussed in the previous sections, using the actual data presented from Kathmandu, Nepal. As can be seen from this example, there is little evidence to suggest that the current monthly benefits *exceed* the monthly costs of a conventional water and sanitation network system. The results of such cost–benefit calculations may be quite different for other locations, but for many places they are likely to look much worse. WTP for improved services in Kathmandu is much higher than in similar CV studies elsewhere. Such simple comparisons of monthly household costs and benefits have not, however, persuaded many people that development aid for improved water and sanitation network infrastructure is unwise or unnecessary. Proponents of increased investment in improved water and sanitation services in developing countries see five main problems or limitations with the kind of benefit–cost calculations presented in Table 11.

Table 11. Comparing Monthly Household Costs and Benefits of Improved Water and Sanitation Services: An Example from in Kathmandu, Nepal.

	Estimate
Costs (from Table 4)	US$20
Benefits	
Reduced water vending expenditures	Minimal
Coping costs avoided	US$ 4
COI avoided	< US$ 1
CV estimate of WTP	US$11–$14

Note: Benefit estimates are overlapping and cannot be summed to obtain total benefits.

First, they argue that lower service levels can result in much lower unit cost estimates. It is true, for example, that hand pumps and improved, ventilated pit latrines are considerably cheaper than network water and sewer services, and we explore lower cost, non-network interventions in Part II of this water and sanitation paper. But it is also clear from the results of the contingent valuation surveys that the perceived benefits of such "intermediate" service levels are also much lower. People are willing to pay much less for access to public taps and hand pumps than they are for an in-house water and sewer connection. Thus both the benefits and the costs of simpler technologies are lower. As we show in Part II, lower service levels therefore may, or may not, change the benefit–cost ratio.

Second, they argue that households' *perceived* economic benefits are not accurate reflections of the *actual* benefits people will receive from improved services. Many health professionals do not believe that people in areas that need such services (i.e. where health benefits would potentially be high) have an adequate understanding of the link between improved services and improved health, such that potential beneficiaries will tend to undervalue the water and sanitation services *ex-ante*.[7] From this perspective, *ex-ante* preferences, however they are measured, are not necessarily a sound guide to *ex-post* benefits. In effect, they contend that contingent valuation estimates of WTP for improved services are too low and are thus inclined to dismiss them in favor of other approaches to benefit estimation.

A related assumption is that poor people cannot clearly assess the value of future reductions in health risks. And because it has been observed that the poor typically have very high rates of time preference, indicating a focus on short-term concerns, it is also assumed that they will place little value on a stream of benefits provided by water and sanitation investments that may extend far into the future. The "misguided" priorities of beneficiaries are thus emphasized as a justification for decision makers' overriding beneficiaries' preferences, in the interest of protecting the welfare of both existing and future generations.

A third argument is that there are positive health externalities associated with water and sanitation investments that estimates of individual households' benefits simply do not capture. This argument would seem to be much stronger for sanitation than for improved water services, but empirical evidence on the magnitude of the economic value of the positive health externalities associated with sanitation improvements is quite limited. Moreover, even the private health benefits of improved water and sanitation investments are not as clear-cut or dramatic as is often assumed. There are numerous pathways for pathogens to infect people in a poor community besides contaminated drinking water, and in some situations bringing clean piped water but not improved sanitation to houses can even exacerbate the spread of infectious agents.

Along the same lines, proponents of full network services argue that there can also be positive environmental externalities associated with water and sanitation investments. A well-managed water system can provide people with clean, potable water, and then return clean water

[7] But see our caveat in note 4 about whether there is actually solid empirical evidence that improved water and sanitation is a sufficient condition for an *ex-post* improvement in health.

to the environment. Investments in sewerage and wastewater treatment protect aquatic ecosystems and dependent biodiversity, and return flows from municipal water systems can contribute to rivers' environmental flow requirements. Under some hydrological regimes municipal piped systems can curtail unregulated groundwater exploitation, which often leads to falling water tables and risks of ecosystem degradation and saltwater intrusion. Of course, these benefits would be specific to locations and circumstances, and their values difficult to ascertain.

Fourth, it is argued that the economic benefits of improved water and sanitation are not limited to households. Businesses and industries need piped water for many kinds of activities. Of particular importance to understanding the economic value of piped water and sanitation services is the macroeconomic risk that economies can face from outbreaks of diseases such as cholera. The emergence of SARS in 2003 and the recent cholera outbreak in Peru illustrate how epidemics can cause havoc with general macroeconomic conditions by curtailing travel, tourism, trade, and investment. Because improved water and sanitation services improve long-run health conditions, they represent a form of insurance against macroeconomic shocks. However, the evidence that improved water services greatly enhance business productivity and that business enterprises value improved water and sanitation services much more highly than households is largely a matter of conjecture. Davis et al. (2001) find that businesses in a small market town in Uganda actually place very little value on improved water services.

Fifth, it is argued that investments in improved water and sanitation investments benefit developing countries by serving as a kind of insurance against economic extremes. Water and sanitation investments are an important means of diversifying a development aid portfolio. A water supply reservoir and transmission line is likely to provide a city with raw water through both good economic times and bad. Unlike some forms of development assistance that only deliver benefits if economic growth is strong, water and sanitation supply projects tend to be less sensitive to cyclical changes in the business cycle. They thus provide households and businesses with a valuable service when they need it most.

All of these concerns may or may not apply in particular circumstances, and there is little in the literature on their empirical magnitude. Proponents argue that these, and other "intangible" benefits such as dignity and spirituality, easily tip the balance in favor of increased investment in improved water and sanitation services. But this presents hazards in both directions. On the one hand it invites policy makers to conjecture unsubstantiated benefits and forgo rigorous economic analysis, increasing the likelihood that valuable development dollars will be spent unwisely. On the other hand, dismissing these objections simply because it is not possible to attach robust economic values to them invites policy makers to discount potential social and environmental consequences of investing, or not investing, in water and sanitation.

Moreover, proponents of increased water and sanitation investment sometimes fail to address the risk that such projects may fail. In fact, in the past water and sanitation investments have been particularly prone to failure (Therkildsen, 1988). The benefit–cost comparison presented here is based on the assumption that water and sanitation investments will, in fact, deliver high-quality services and positive health outcomes. For example, the valuation estimates of households' WTP for improved water and sanitation services shown in Tables 10 and 11 were *contingent* on the proviso that a potable, 24-hour water supply of water would actually reach the household. If a water and sanitation project does not deliver this level of service, such contingent valuation estimates of household benefits will be much too high. Sadly, experience has shown that many water and sanitation investments in developing countries do in fact fail by almost any measure of success. This risk of project failure must also be factored into any systematic assessment of costs and benefits.

Discussion

From our perspective, the biggest limitation of the kind of benefit–cost calculation presented in Table 11 does not lie with the five concerns listed above. It is rather that the benefit stream associated with capital-intensive water and sanitation network infrastructure is assumed to be static. In fact, the benefits that flow from water and sanitation investments may grow over time, due largely to economic growth. There is limited evidence that investments in municipal water and sanitation services actually *cause* economic growth.[8] At the same time, however, the sequencing of significant water investments could in theory set in motion path-dependent patterns of development (for example, by diminishing disease risks and providing reliable water inputs for potential industrial uses) that will change the expected returns to, and hence incentives for, subsequent investments in all sectors. Moreover, as illustrated in Figure 1, there is a strong association between household income and the provision of both piped water and sewer services. Higher-income households definitely want improved water and sanitation services, and, as incomes grow, the demand for such services grows. Thus even in the absence of a causal relationship, the benefit stream of water and sanitation services becomes more valuable as economic growth proceeds.

Even though the benefits of improved water and sanitation services increase with economic growth, they must still be discounted back to the initial period to compare the present value of the benefit stream with the high initial capital costs and the present value of the operation and maintenance expenditures. For water and sanitation infrastructure, the magnitude of the present value of the benefit stream is very sensitive to the discount rate chosen because of the large up-front capital costs and the unusually long economic life of the assets. This is an old, well-known problem in the economic appraisal of water resources projects. How growth in the

[8] The available evidence for the United States is mixed but generally negative; for a summary, see Hanemann (2006).

demand for services affects the benefit–cost analysis of a water and sanitation investment project is largely determined by the relative magnitude of three parameters: (1) the rate of economic growth over the planning period, (2) the elasticity of WTP with respect to income, and (3) the discount rate (Whittington et al., 2004).

In practice it has proven almost impossible for national governments or donor agencies to conduct rigorous economic appraisals of water and sanitation projects that address this level of complexity. As Hirschman pointed out half a century ago,

> The trouble with investment in social overhead capital (*e.g., water and sanitation investments*). . . is that it is impervious to investment criteria. . . . As a result social overhead capital is largely a matter of faith in the development potential of a country or region. . . . Such a situation implies at least the possibility of wasteful mistakes. (1958, 84, emphasis added)

This is precisely what we have witnessed in recent decades in the water and sanitation sector in developing countries, where "white elephants" and poorly performing projects have been a standard feature of the sector landscape (Therkildsen, 1988). Too often when it appears that a particular project might not pass a cost-benefit test, water professionals appeal to intangible benefits to argue that the investment will in fact pass the test.[9]

In conclusion, it is not our intention to imply that all investments in municipal water and sanitation network infrastructure will fail a rigorous economic test. We do believe it is the case, however, that not all investments will pass. In cities in rapidly growing economies, we expect the benefits of many projects, properly estimated, to exceed the costs. In other cases, however, the economic reality will be more nuanced and the attractiveness of specific water and sanitation investments in network infrastructure less clear-cut. Especially in situations where long-term economic growth prospects are uncertain, large capital investments in water and sanitation network infrastructure will often be problematic from an economic perspective, and

[9] This is particularly the case in the evaluation of rural water and sanitation investments in developing countries, where neither donors nor national agencies attempt serious project appraisal of such projects.

preconceptions that seek to circumvent rigorous economic analysis should be viewed with considerable skepticism.

In Part II of this challenge paper we look at three non-network water and sanitation interventions that we believe will have higher economic returns than network services, for many developing country situations. We also consider multipurpose investments in major water resources infrastructure (large dams in Africa) that we show to be attractive economic development projects.

Part II – Analysis of Four Water and Sanitation Interventions

Introduction

In Part II of this water and sanitation Challenge paper we shift our focus from piped water and sewerage network infrastructure, which we have shown to be quite costly, to look at four specific water and sanitation interventions:

1. A rural water supply program for constructing deep boreholes with hand pumps in Africa
2. A sanitation program designed to halt open defecation in South Asia
3. Water disinfection technology installed at the household level (point-of-use)
4. Large multipurpose dams in Africa.

The first three interventions all seek to capture some of the potential benefits of improved water or sanitation systems without incurring the large capital costs of network infrastructure. Deep boreholes with hand pumps can be shared by many households, thus reducing the capital costs per household. The "total community sanitation" program is an intensive health-promotion campaign designed to stimulate demand for improved toilets without sewerage infrastructure (pour-flush toilets with drainage or improved sanitary pit latrines). Point-of-use (POU) disinfection technologies can be conceptualized either as add-on, inexpensive but partial solutions to the unreliable, contaminated piped water supplies in many cities in developing countries, or as a stand-alone intervention to disinfect a contaminated traditional water source. In either case, the advantage of POU interventions is that capital costs are low. POU interventions are only a partial solution to water and sanitation problems because one must still manage to get water to the home. The last intervention, large multipurpose dams in Africa, takes us back to the issue of large, capital-intensive investments but expands the focus from household water and sanitation services to questions of regional water resources management.

For all four interventions we present exploratory cost-benefit calculations for a range of conditions. There is inevitably some degree of uncertainty regarding the net benefits of a policy intervention in any arena, and water supply and sanitation investments are no exception. Both the benefits and the costs depend on circumstances that will vary with the specific locations and circumstances of implementation of the intervention. Estimates of net benefits for water and sanitation interventions such as those we present here are precisely that: estimates based on data from some specific instances that are being generalized for application to a broad range of circumstances. Our data still do not necessarily reflect the range of uncertainty associated with any specific implementation of the given water and sanitation intervention.

The question arises as to how to best conceptualize this uncertainty. One approach utilizes the concept of an additive error. The true benefits, B, may be thought of as the estimated benefits, $\overline{B}$, plus an additive error, ε_1; similarly, the true cost may be thought of as the estimated cost, $\overline{C}$, plus an additive error, ε_2. Consequently, the net benefit is

$$NB = \overline{B} - \overline{C} + \eta, \tag{1}$$

where $\eta \equiv \varepsilon_1 - \varepsilon_2$. In this context, it would be natural to assume that $E\{\eta\} = 0$ and $\text{var}\{\eta\} = \sigma_\eta^2$, a constant. In that case, the estimate ($\overline{B} - \overline{C}$) can be taken as the expected value of the net benefit, around which there is a distribution. A modification would be to make σ_η^2 heteroskedastic, allowing it to vary with certain factors perhaps associated with circumstances relating to the specific application of the water and sanitation intervention.

The key feature of this representation is that, whatever the uncertainty, it does not affect the estimate of expected net benefit. However, this may be too benign an assumption. Specifically, it overlooks some of the real complications associated with the implementation of water and sanitation interventions.

An alternative representation that captures the uncertainty of implementation has the following multiplicative error structure. One can think of the outcome of the intervention as dependent upon successfully surmounting a series of hurdles. There could, for example, be three hurdles. First, funds for the intervention project have to be allocated. Second, the project has to be implemented on the ground. Third, project beneficiaries have to modify their behavior: for example, when a household is connected to a piped water supply system, household members must begin washing their hands after defecation). Only then are the health (and perhaps other) benefits realized.

It may well be the case that once a water and sanitation project is implemented, some costs are definitely incurred (fixed costs if not variable costs). However the benefits – or, at least, the full benefits – accrue only if the participants change their behavior. Consequently there are four possible outcomes. If the funds are not allocated or if the project is not implemented on the ground, there are no expenditures and no benefits: the net benefit is zero. If the funds are allocated and the project is implemented on the ground but there is only a partial change in behavior, the benefits are $\theta \overline{B}$, where θ is a fixed constant between 0 and 1, while the costs are $\overline{C}$, where $\overline{B}$ and $\overline{C}$ are constants; hence the net benefit in this case is ($\theta\overline{B} - \overline{C}$). Finally, if the funds are allocated and the project is implemented on the ground and there is a complete change in behavior, the net benefit is ($\overline{B} - \overline{C}$).

Let γ denote the probability that the funds are allocated, and let λ denote the probability that intervention project is implemented on the ground, given that the funds are allocated. Finally, let π_1 denote the probability that there is only a partial behavior change given that the funds are allocated and the project is implemented on the ground, and let π_2 denote the probability that there is complete behavior change given that the funds are allocated and the project is implemented on the ground. Then the expected net benefits associated with the intervention are

$$\text{Expected Net Benefits} \;=\; \gamma\lambda[(\theta\pi_1 + \pi_2)\;\overline{B} \;-\; (\pi_1 + \pi_2)\;\overline{C}\,] \;<\; (\overline{B} - \overline{C}). \qquad (2)$$

Several observations should be noted. First, as already pointed out, (2) is a different type of representation of implementation uncertainty than (1), and it has different implications for how one might use information from literature on the estimated benefits and costs of the water and sanitation intervention, $\overline{B}$ and $\overline{C}$. In the case of (1), while there is uncertainty, it does not have a meaningful impact on the estimate of expected net benefits. In the case of (2), the uncertainty significantly reduces the estimate of expected net benefits.

Which model is the more appropriate depends, in part, on the data from which the estimates of $\overline{B}$ and $\overline{C}$ are derived. If the data pertain only (or largely) to successfully implemented projects, in which complete behavior change occurs, then (2) is more reliable than (1) as the basis for estimating the expected net benefits of an intervention chosen at random. Conversely, if the data on $\overline{B}$ and $\overline{C}$ are derived from *all* examples of the intervention in question, including unsuccessful ones in which the funds are not allocated, the project is not implemented on the ground, and/or there is only partial behavior change, then (1) would be reliable as the basis for estimating the net benefits of intervention and the formulation in (2) would be inappropriate. Finally, it should be noted that γ, λ, π_1, and π_2 depend in general on the specific circumstances of the intervention. It may be possible to alter them by planning or implementing the intervention differently. Accordingly, in designing the intervention, the goal would be to maximize γ, λ, and especially π_2.

These issues surrounding the uncertainty in the benefits and costs of water and sanitation investments are rarely addressed adequately in the existing literature. It is a common, understandable wish to know the costs and benefits of water and sanitation investments all over the world, even if this is impractical. Because it is not feasible to conduct cost-benefit analyses of the millions of possible water and sanitation projects, the question arises as to how best to derive approximate measures.

There are several possible approaches; all involve positing a model for the cost-benefit calculations and then settling on a way to apply it to different locations. Most of the cost-benefit models available in the literature for evaluating water and sanitation investments involve at most a few dozen input parameters (Powers, 1978; Powers and Valencia, 1980; Lovei and Whittington, 1993; Whittington and Swarna, 1994; Hutton and Haller, 2004). The Powers and Lovei models were developed to analyze the costs and benefits of specific development projects under consideration for donor funding. The Hutton and Haller model, on the other hand, was never intended for analysis of specific investment projects, but rather to generate a global picture of cost and benefits of all potential water and sanitation investments.

Conceivably, one could randomly sample potential water and sanitation projects in developing countries and apply the cost-benefit model to this sample of locations. To our knowledge, this has never been done, nor has it ever even been seriously considered by any multilateral donor organization, due to the expense and time required. A second approach to developing a global perspective on the array of possible water and sanitation investments would be to purposely select a number of representative locations and then collect site-specific, accurate information on the parameter values in the cost-benefit model. Given the time and resource constraints, this option was not available for us when preparing this challenge paper. Moreover, with data derived from only a limited number of non–randomly selected locations, this approach would still provide only a partial picture.

A third approach is to calculate the benefits and costs for each country or region in the world, using country or region-specific information from global data bases for those parameters for which such data are available. For parameters for which such secondary data are not available for each country or region, one would need to use evidence from a few site-specific studies or use professional judgment. One could then calculate the average benefits and costs of different types of water and sanitation interventions by county or region. This is the approach used by Hutton and Haller in their 2004 assessment of the global benefits of water and sanitation investments.

In this water and sanitation challenge paper, we use a fourth approach that constructs a probability distribution of a range of benefit–cost outcomes for four water and sanitation interventions. As in Part 1, for the first three interventions our unit of analysis is the individual household (not commercial enterprises): we compare the costs of providing an improved water source or sanitation environment to a typical household in the community with the benefits that it would receive. For each intervention discussed below, we specify a simple cost-benefit model in which the monthly net benefits to a household are a function of about twenty different parameters. Many (but not all) of the parameters are common to the models across the three household-based water and sanitation interventions. For large multipurpose dams in Africa, it is more sensible to consider costs and benefits on an aggregated basis. One way to compare all four interventions would be to consider the range of plausible cost-benefit outcomes as a ratio of benefits to costs, but we caution that this measure of comparison masks very important differences in scale, and the investment requirements that these imply.

For each parameter in the cost-benefit model for each of the three household-based water and sanitation interventions, we make three types of assumptions. First, we specify a range of plausible values based on professional judgment and our reading of the literature. Second, we assume a specific probability distribution that determines the likelihood that a specific value within the specified range will occur. Third, we specify whether there is likely to be a correlation (association) between this parameter and other parameters in the cost-benefit model. For example, the cost of drilling a borehole is likely to be higher in remote locations, which are also likely to be places where case fatality rates for diarrhea would be higher due to longer distances to health clinics. This approach thus follows the type of analysis described in equation (1) above rather than equation (2), as we are implicitly considering the likely parameter values that will occur in the field rather than a best-case scenario in which probabilities of success and failure must be explicitly included to yield realistic and expected outcomes. For the large dams intervention, our modeling approach is similar in practice, but there is a qualitative difference in the way it should be interpreted. Because the economic value of large dams is so dependent on context, we apply our cost-benefit model to only *one* illustrative situation and use the model and parameter ranges to represent our uncertainty about specific parameters, rather than the range these parameters can be thought to take in different locations.

We then conduct a Monte Carlo analysis that calculates the benefit–cost ratio for each of the thousands of different combinations of values for the parameters in the cost-benefit model for each intervention. This yields a distribution of benefit–cost ratios for each water and sanitation intervention. For the household-based interventions, the distribution of benefit–cost ratios for an intervention from the Monte Carlo calculations does not correspond to the distribution of actual situations in developing countries. Rather it is associated with the ranges of parameter values and other assumptions that we have made. Because we have used our best professional judgment to select the ranges for these parameters, in fact we expect to find rural water supply projects in developing countries with a similar range of benefit–cost ratios. We do not know, however, the frequency with which any specific combination of parameter values – or benefit-cost ratios – would arise in the real world. Here again, the distribution from the Monte Carlo simulation for the large dams intervention is qualitatively different; it represents plausible outcomes at only one *specific* dam location, informed by our uncertainty about model parameters.

There are three reasons why our approach is conceptually appealing. First, we specify ranges for all parameters in the cost-benefit model, not just a few selected parameters. We can thus easily identify which parameters have the largest effect on the benefit–cost ratio. Second, the Monte Carlo simulations allow us to incorporate into the model associations between selected parameters, and thus to reduce the occurrence of improbable combinations of parameter values. Third, we believe that probability distributions of benefit–cost ratios for the interventions are more useful than point estimates, because they allow us to focus on the question of where water and sanitation investments are likely to be most economically attractive.

With regard to the specific parameter values used in the cost–benefit models in Part II, there is an important distinction to make at the outset. In Part I of this water and sanitation challenge paper we assumed the value of *ex-ante* mortality risk reductions from water and sanitation network investments was captured in the estimates of economic benefits from available contingent valuation studies of households' willingness to pay for such improvements. In Part II stated preference studies were not generally available for the specific interventions we examined, so we use a different approach to estimate mortality risk reduction benefits from the first three interventions. Here we estimate the magnitude of the mortality risk reduction and multiply this by an assumed value of a statistical life (VSL). This latter approach might at first appear to be independent of stated preference methods, but in fact much of the literature on VSLs in developing countries uses stated preference methods.

If the estimates of economic benefits of network water and sanitation investments (based in part on stated preference methods) in Part I turn out to be overestimates, this will only enforce our conclusion: that in many circumstances in developing countries the incremental economic benefits of network water and sanitation infrastructure are likely to be less than the costs. In Part II our cost-benefit calculations use values of a statistical life (based in part on evidence from stated preference studies) that may seem to some observers to be too low. If so, then this adjustment would reinforce our conclusions about the economic attractiveness of the first three of our non-network water and sanitation interventions (since higher VSL would lead to higher estimates of the benefits of mortality reduction).

Water and Sanitation Intervention 1 – A rural water supply program providing poor rural communities in Africa with deep boreholes and public hand pumps

Description of the Intervention

A deep borehole with a public (non-motorized) hand pump is a commonly recommended improved water source for many poor rural communities in Africa and some other locations in the developing world. Many donors and national governments would consider this a low-cost, appropriate technology when households are too poor to afford individual household connections and when deep groundwater is the best available water source. When groundwater is shallow, a household can often afford its own private, hand-dug well and hand pump. When springs are available at higher elevations than the community, gravity-fed distribution systems with public taps and/or house connections will generally be preferred, because they enable households to avoid the effort associated with lifting water from the aquifer to the surface with a hand pump, and entail lower maintenance and repair costs.

Deep boreholes equipped with a public hand pump require the use of drilling rigs in potentially remote rural locations. It will often be necessary to transport drilling rigs on unpaved roads. Dry holes are not infrequent, so private contractors will either build into their pricing structure the cost of dry wells or simply charge by the depth of the well drilled without guaranteeing that the well will supply water. Public hand pumps need to be built to withstand heavy daily use.

Rural water supply programs in developing countries have had a checkered history. In the 1980s sector professionals recognized that many rural water supply programs were in disarray (Churchill et al., 1987; Briscoe and DeFerranti, 1988). Regardless of the type of technology utilized, rural water systems were not being repaired and many were simply abandoned. Sector professionals commenced a reexamination of the rural water sector to study why systems failed, and in the 1990s a new consensus emerged about how rural water supply programs should be planned and implemented. This new model for rural water supply programs, termed "demand-driven community management," sought to involve households in the choice both of technology and of institutional and governance arrangements, gave women a larger role in decision making, and aimed for households to pay all of the operation and maintenance costs of providing water services and at least some of the capital costs (Sara et al., 1996; Sara and Katz, 1997; Whittington et al., 1998).

New evidence suggests that this new planning model is working and that many of the problems associated with failed rural water projects can be overcome (Davis et al., 2007; Komives et al., 2007; Prokopy et al., 2007; Thorsten, 2007; Whittington et al., 2007). In three recent studies, a large majority of water projects that were part of demand-driven, community-managed rural water supply programs were found to be operational. Households were using the water from the improved sources and were satisfied with the improved water systems. Although numerous challenges remain, the rural water sector now has a set of planning and implementation procedures that promise much better results than were previously thought possible.

Clearly, rural water systems that are not being used and/or are broken will not pass a cost–benefit test. Now that there is a proven strategy for delivering more sustainable improved water systems in rural areas, the question as to whether such investments would pass such a test becomes relevant. We present here some preliminary cost–benefit calculations for investments in a demand-driven, community-managed rural water supply program that provides poor rural communities with deep boreholes and public hand pumps. Table 12 summarizes the equations used in the calculation of benefits and costs of this intervention. Table 13 presents the assumed parameter values and definitions. The assumptions behind the equations and parameter values are described below.

Table 12. Equations for Cost-Benefit Analysis of Water Supply Project.

Demand for water Q = f(T)	
Baseline demand	$Q_0 = 30 - (50/3) * T_0$
Additional demand	If $T_1 > T_0$, $dQ = 0$ $dQ = (50 / 3) * (T_0 - T_1)$ otherwise
Benefit type	
Time savings per trip (hours)	If $T_0 > T_1$, $T_s = (T_0 - T_1)$ $T_s = 0$ otherwise
Time savings per hh-month (hours)	$T_{s,m} = T_s * Q_0 * 30 * S / 20$
Value of time savings per hh-month ($)	$V_{ts} = \mathrm{T}_{\mathrm{s,m}} * (w / 8) * v_t$
Avoided morbidity per hh-month ($)	$m = (I / 12) * E * S * COI$
Avoided mortality per hh-month ($)	$M = (I / 12) * E * S * CFR * VSL$
Total health per hh-month ($)	$V_H = M + m$
Aesthetic (quantity) per hh-month ($)	If $(dQ * S * 30 / 20) * T_s * (w / 8) * v_t * a * (h) < V_H$, $V_A = (dQ * S * 30 / 20) * T_s * (w / 8) * v_t * a * (1 - h)$ $V_A = (dQ * S * 30 / 20) * T_s * (w / 8) * v_t * a - V_H$
Costs	
Capital recovery factor	$CR = r * (1 + r)^d / ((1 + r)^d - 1)$
Capital per hh-month ($)	$C_{c,m} = (C_c + C_p) * CR / (n * 12)$
Other - O&M + non-pecuniary mgmt per hh-month ($)	$C_{o,m} = (C_o + C_m) / (n * 12)$

Table 13. Parameters Used in Cost-Benefit Analysis of Water Supply Project.[a]

Symbol	Parameter	Base case	Lower limit	Upper limit	Correlated parameters
C_c	Capital cost ($) of borehole + hand pump	$6,500	$5,000	$8,000	O&M (0.5), Market wage (–0.5)
C_p	Program cost: capacity building and management ($/borehole)	$3,500	$2,000	$5,000	Market wage (–0.5)
C_o	O&M expenditures, repairs (annual)	$100	$50	$150	
C_m	Management costs (annual, non-pecuniary) - village + program	$500	$200	$800	
d	Water project duration (yrs)	15	10	20	Program costs (0.5)
r	Real (net of inflation) discount rate (%)	4.5%	3%	6%	
n	# Households served by borehole	60	30	90	New source collection time (0.5)
S	Household size	5	4	6	
T_0	Status quo collection time (hrs/20L): traditional source	1.0	0.1	1.9	
T_1	Collection time per liter (hrs/20L) - improved	0.3	0.1	0.5	
w	Market wage for unskilled labor ($/day)	$1.25	$0.50	$2.00	
v_t	Value of time savings / market wage for unskilled labor	30%	10%	50%	
a	Ratio of aesthetic and lifestyle benefits to time savings benefits	25%	0%	50%	
I	Diarrheal incidence (cases/person-yr) [b]	0.9	0.5	1.4	Capital cost (0.5), Program costs (0.5)
E	% Reduction in diarrhea incidence due to water project intervention	30%	10%	50%	
COI	Cost of illness ($/case)	$6	$2	$10	Market wage (0.5)
CFR	Diarrhea case fatality rate (%) [b]	0.08%	0.04%	0.12%	Capital cost (0.5), Program costs (0.5)
VSL	Value of a statistical life ($)	$30,000	$10,000	$50,000	Market wage (0.7)
h	Percentage of aesthetic benefits that are actually health-related	25%	0%	50%	

[a] Our uncertainty analysis does not purport to use the real probability distributions associated with these parameters but instead is aimed at assessing the range of possible situations in poor developing countries; therefore we use uniform distributions of parameters.

[b] Revised Global Burden of Disease (GBD) Estimates (WHO, 2002). Available at http://www.who.int/healthinfo/bodgbd2002revised/en/index.html. Diarrhea incidence in developing country subregions ranges 0.6–1.29 case per capita per yr (mean ~0.9) but may actually be higher or lower in some locations, CFR ranges 0.02–0.09, and is ~0.08% in Africa.

Discussion of Costs

Not only is the demand-driven, community management model for planning and implementing rural water supply programs now contributing to improved delivery of water services in rural Africa, but additional help has come from another, unexpected quarter. Over the past decade increasing numbers of Chinese contractors have become active in many countries in Africa. The majority of their work has been in road and other construction projects, but increasingly they also bid for drilling contracts from national rural water supply agencies. Chinese contractors typically bring Chinese-made drilling rigs and their own drilling teams.

As a result of the increased competition for drilling contracts, often from these Chinese firms, prices of borehole drilling and hand pump installation have fallen dramatically in Africa (Roche, 2007). Evidence shows that the price per borehole has dropped 50% in countries where small to medium-sized drilling contracts are regularly awarded – from about US$12,000 a decade ago to about US$6000 today. This large drop in the real prices of boreholes, coupled with the success of new planning and implementation procedures, has changed the economic landscape of rural water programs in Africa.

There are of course additional costs associated with managing and administrating a national rural water program (UNEP, 1998). Real resource costs should include donor manpower, national agency administration, and community organization and health promotion activities. We use a capital cost estimate for a borehole plus hand pump of US$6,500 (range US$5,000–$8,000). Program overhead that includes these capacity-building and "software" costs for a large national rural water supply program is estimated at US$3,500 (range US$2,000–$5,000), for a project total of US$10,000. The costs of stand-alone, "enclave" type donor-directed projects, common in the past, were substantially more (on the order of US$15,000–$20,000 per borehole plus hand pump).

To obtain costs on a household basis per month, we annualize the capital costs of the borehole and hand pump. Assuming a capital recovery factor (*CR*) of 0.093 (interest rate = 4.5%, life of the capital = 15 years; see Table 13), the annual capital costs of this intervention come to about US$930 (the formula for the capital recovery factor is shown in Table 12 and in footnote 3). To obtain total annual costs, we add an estimate of the operation and maintenance costs. Recurrent expenditures of spare parts and minor repairs are assumed to be on the order of about US$100 per year (range $50–$150), but this does not represent the full resource cost of running this water system. In the demand-driven, community management planning model, village water committees have assumed responsibility for management and oversight, and this entails the time and human capital of village leaders. A borehole attendant and/or caretaker is also typically assigned the tasks of keeping the borehole clean, making minor repairs, and collecting money from households who use the hand pump. Many times the borehole attendant and caretaker are unpaid, so assigning an opportunity cost to this labor is difficult. We assume for our calculations that these labor and management costs are about US$500 per year (range US$200–$800), for a total annual cost of US$1530, or about US$128 per month

To determine the cost per household, we need to make an assumption about how many households will share the improved water source. Water sources such as this are typically designed for 250–500 people. In our experience, 500 people per borehole will lead to considerable crowding and longer queue times. We thus assume that 60 households (range 30–90) will share the borehole, given an average household size of 5 people (range 4–6). In the base case, 300 people share one borehole, and the monthly cost per household comes to about US$2.13. In the Monte Carlo simulations, we treat all of these costs and design parameters as unknowns and allow them to vary over the specified parameter ranges, shown in Table 13. Note that this is for water supply only and does not include new facilities for improved sanitation.

Economic Benefits from the Installation of the Borehole and Public Hand Pump

The economic benefits of this improved water supply intervention have three main components (Figure 2):

1. The value of any time savings that result from the installation of the new water source
2. The value of lifestyle and aesthetic benefits from increased use of higher-quality and increased quantity of water obtained from the new source
3. The monetary value of the health benefits.

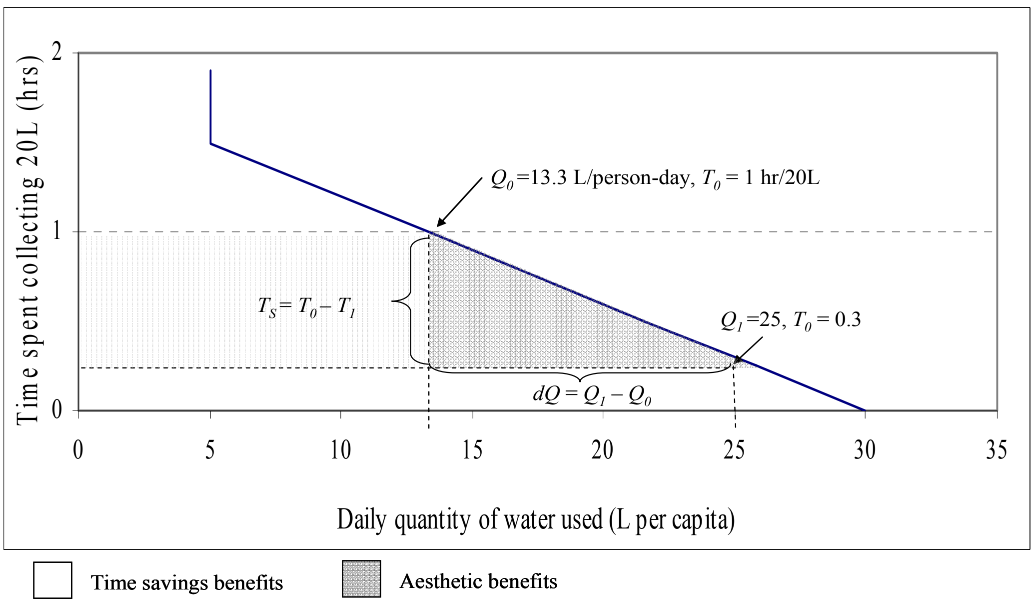

Figure 2. Demand curve for water as a function of collection time, showing different types of benefits from water project

Assume that the new hand pump provides a closer, more convenient source of water for households in the village. Having a hand pump in the village thus allows each household to spend less time collecting the same quantity of water from the improved source than from the original, traditional sources. We assume for simplicity that the village charges households a fixed monthly fee for use of the new hand pump (not a volumetric, pay-by-the-bucket tariff), so that there is an unambiguous fall in the effective price of water as a result of the installation of the new water system. One would expect that the household would use more water in response to this fall in price, and this is in fact what the available evidence suggests: households in communities with functioning public hand pumps increase the amount of water they use compared to the quantity collected when traditional sources are farther away.

It is unclear what will happen to the *total* amount of time the household spends collecting water, but a household will clearly benefit from the time savings associated with no longer needing to spend as much time acquiring the quantity of water used before the installation of the new borehole and hand pump. For purposes of illustration, assume that before the installation of the new water project the average household was collecting water from traditional sources and using 13 liters per capita per day, that is, 65 liters per household per day, or about 2 cubic meters per household per month. Assume that before the new water system was installed, the household was spending about 1 hour to collect 20 liters, or 3.25 hours per day collecting the household's daily 65 liters. These amounts are not inconsistent with observations from rural locations in Africa (Katui-Kafui, 2002). Suppose that following installation of the new hand pump and borehole, collecting 20 liters only takes 20 minutes (or about 1 hour for 65 liters). The monthly time savings for collection of 2 cubic meters of water would be about 70 hours.

The economic value of this time savings to households is likely to vary greatly depending on local labor market conditions and economic opportunities. In some small market towns the value of this time savings may approach the value of the unskilled market wage rate (Whittington et al., 1990b). In some places it may be essentially impossible to translate any of these time savings into cash. For example, in labor surplus situations and in periods when the demand for agricultural labor is low, the value of time savings from an improved water source may be the value of leisure time. This does not mean that the household is indifferent to these time savings: women may much prefer devoting this time to child care and food preparation, for example, than to collecting water. But labor market opportunities will almost certainly affect how much the household is willing to pay to obtain these time savings.

For purposes of illustration, suppose that the local wage for unskilled labor in this rural community is \$1.25 per day (US\$0.16 per hour) and that the value of the time savings from the new water system is 30% of this market wage. The monetary value of the total time savings from the water supply intervention (associated with not spending as much time to acquire the quantity of water collected elsewhere previously) would thus be US\$3.28 per household per month. In our Monte Carlo calculations we vary (1) the market wage for unskilled labor (range \$0.5–\$2/day), (2) the fraction of the value of unskilled wage rate used to estimate the value of time savings from the water project (range 0.1–0.5), and (3) the time savings on not spending as much time acquiring the quantity of water previously collected elsewhere (collection time from traditional source varies 0.1–1.9 hours/20L water, and collection time from the improved source varies 0.1–0.5 hours/20L water). The model therefore allows for the possibility of net time costs from using the improved water source, if the time spent by households collecting water from the borehole and hand pump exceeds the time spent collecting water from the original water source.

The second component of the benefits from the water supply intervention is the consumer surplus on the increased water use that occurs because of the fall in the effective price of water. We can conceptualize this as the lifestyle and aesthetic benefits that the household obtains from increased water use, although there will probably be health benefits from this increased water use as well (Whittington and Swarna, 1994). In practice, when a household moves from a per capita water use level of 10–15 liters per day to 25–30 liters per day, most of the increase in the quantity of water used is devoted to personal and household cleaning and washing. The consumer surplus on this increased water use is difficult to estimate; the contingent valuation studies cited in Part 1 of this paper would suggest that it is probably small. If these aesthetic and lifestyle benefits were 25% of the value of the time savings described above (US$3.28 per household per month), they would then be about US$0.82 per household per month. However, a portion of these aesthetic benefits may actually be health-related; there is thus a risk of double-counting. To avoid that risk we apply a downward correction, assuming that 25% of aesthetic/lifestyle benefits are actually health benefits. In our Monte Carlo simulations we also vary both the percentage of the value of the time savings used to estimate these aesthetic and lifestyle benefits (range 0–50%), and the percentage of the aesthetic benefits that are actually health-related (range 0–50%).

The third component of the benefits is the economic value of the improved health of household members. It will probably come as a surprise to those unfamiliar with the literature on the relationship between improved water and sanitation services and health outcomes, that this third component is both controversial and uncertain. It difficult to know how an improved water system will affect health outcomes in a specific location, and it is also difficult to place a monetary value on the resulting health improvements. This stems in part from the limitations with the cost of illness (COI) welfare measure itself, as described in Part 1 of this paper. Specifically, in situations where households can engage in coping or averting behaviors that reduce the risk and/or impact of disease, it is difficult to estimate how an intervention will change health outcomes and impact welfare (Bockstael and McConnell, 2007). Furthermore, in some situations households may use multiple sources of water for various purposes, depending upon seasonal availability and quality considerations; in such situations they may engage in complicated tradeoffs between time savings and health benefits that can only be understood through careful field studies (Kremer et al., 2007). We recognize these difficulties and introduce a number of parameters into our net benefit equation to attempt to characterize the various dimensions and uncertainties in health benefits.

Improved water systems are hypothesized to reduce a variety of diseases, including typhoid, cholera, and shigellosis. There are an estimated 2 million deaths annually due to such water-related diseases in developing countries, but in truth these estimates are subject to large uncertainty. Estimates of deaths from shigellosis are highly uncertain and vary between 250,000 and 1.2 million. Most health evaluations of water and sanitation interventions do not attempt to measure their effect on specific diseases or on mortality, but rather ask participants in the study about the diarrhea incidence in their households. Because most of the health intervention studies are not double-blinded, there is a risk of a placebo effect in these self-reported diarrhea data. The results of evaluations of water and sanitation interventions on diarrhea incidence vary widely in the literature. A recent meta-analysis by Fewtrell et al. (2005) reports a median reduction of about 30% from baseline diarrhea incidence.

To use this estimate of a 30% reduction in diarrhea incidence (sensitivity range 10%–50%) to estimate the economic benefits of the water supply intervention, a number of assumptions are necessary. First, one must know the baseline diarrhea incidence. In poor rural communities this can vary by more than an order of magnitude. Assume that diarrheal incidence is about 0.9 cases per person per year (range 0.5–1.4), or 4.5 cases per household. Suppose that the water intervention would reduce this by 30% to about 3 cases per household per year. The economically relevant question then becomes "What would a typical household be willing to pay to reduce diarrhea incidence from 4.5 cases per year to 3 cases per year?" Because we simply do not have a sufficient number of stated preferences studies for the interventions in Part II that would enable us to understand the extent to which WTP measures vary over time and across communities, our approach to the estimation of the health benefits for this intervention does not rely on the stated preference evidence. We proceed by separating the benefits of reduced mortality and reduced morbidity due to diarrhea. We assume a case fatality rate (CFR) of 0.08% (range 0.04%–0.12%), such that prior to the water intervention the annual risk of a household member's dying from diarrhea is about 36/10,000. The rural water supply intervention might reduce this by 30% to a risk of 25/10,000 per year. How much would this reduced risk of death be worth to a typical household in rural Africa?

One approach to estimating the value of this risk reduction is to multiply by the value of a statistical life (VSL). We assume a base case VSL of US$30,000 (Maskery et al., 2008); our range goes from $10,000–$50,000. The resulting value of the risk reduction due to the water supply intervention would then be US$33 per year, or about US$2.7 per household per month.

In addition to the mortality benefits, individuals would also receive the economic benefits of not suffering from nonfatal episodes of diarrhea. We assume that COI for a case of diarrhea is US$6 (range US$2–$10). The annual cost of illness for the average household before the water supply intervention would be about US$27; after the intervention, about $19. The US$8.10 cost savings per year from the implementation of the water supply intervention would come to about US$0.68 per month.

In our illustrative calculations, the two largest components of the benefits from the borehole and public hand pump intervention would be time savings and mortality reduction benefits, with aesthetic and morbidity benefits being considerably lower.

Comparison of Costs and Benefits (Intervention 1)

We are now in a position to compare the costs of the borehole and hand pump intervention with the estimated economic benefits, using US$ per household per month as our unit of analysis. As shown in

Table 14, the positive results from the new water system are the increases in household water use (US$0.54), time savings on the initial quantity of water used (US$3.28), the reduction in risk of death (US$2.70), and the savings in avoided cost of illness due to diarrhea (US$0.68), for a total benefit US$7.19 per household per month. Total estimated costs of the water system are US$2.13 per household per month, which implies a benefit–cost ratio (BCR) of about 3.4.

Applying the assumptions used here, it is easy to see that there will be situations in which this rural water supply intervention could be an extremely attractive economic investment (Table 15). The benefits of rural water supply projects will be highest in locations where diarrhea is high, where health care facilities are poor (and thus CFRs from diarrhea are high), and where people are walking long distances for water from traditional sources. But such locations are also likely to have high capital costs, low values of time savings, and low VSLs. The economic value of this intervention is not particularly sensitive to changes in the discount rate in the 3%–6% range.

Table 14. Base Case Results for Intervention 1: Borehole and Public Hand Pump.[a]

	Before hand pump + borehole intervention	After hand pump + borehole intervention	Change in physical units	Change in monetary units by discount rate		
Benefits				3%	4.5%	6%
Time spent collecting initial quantity of water (hrs per hh-month) [Value of time savings]	100	30	70	$3.28	$3.28	$3.28
Water use (L per hh-month) [Value of aesthetic and lifestyle benefits from increased water use]	2,000	3,750	1,750	$0.54	$0.54	$0.54
Number of nonfatal cases of diarrhea (per hh-month) [Value of reduction in morbidity]	0.38	0.26	(0.11)	$0.68	$0.68	$0.68
Risk of death from all diarrhea (per 1000 hh-month) [Value of reduction in mortality]	0.30	0.21	(0.09)	$2.70	$2.70	$2.70
Total benefits				$7.19	$7.19	$7.19
Costs						
Expenditures by all parties for new water system (per hh-month)				$(2.00)	$(2.13)	$(2.26)
Benefit–Cost Ratio				3.6	3.4	3.2
Net Benefits				$5.20	$5.07	$4.93

[a] For the results reported in this table, all parameters were set at their *base case* values as described in Table 13, except for the discount rate, which was varied between 3%, 4.5%, and 6%. The values in the cells in the three rightmost columns report the monetary value of the components of benefits and total costs on a per household per month basis.

Table 15. Intervention 1: Typology of Water Project Sites Categorized by Benefit–Cost Ratio (BCR).

Parameter [a]	Unattractive sites (BCR < 1)		Attractive sites (BCR 1 – 2.99)		Very attractive sites (BCR > 3 – 4.99)		Extremely attractive sites (BCR > 5)	
# Households	55	(18)	56	(17)	64	(16)	71	(14)
Collection time: traditional (hrs/20L)	0.48	(0.44)	0.97	(0.50)	1.16	(0.44)	1.28	(0.41)
Value of time savings / market wage for unskilled labor (%)	27	(12)	28	(11)	32	(11)	36	(10)
Reduction in diarrhea (%)	24	(11)	29	(11)	32	(11)	35	(11)
Unskilled market wage ($/day)	1.16	(0.44)	1.15	(0.42)	1.34	(0.41)	1.50	(0.37)
Diarrheal incidence (cases/person-yr)	0.84	(0.29)	0.91	(0.29)	0.91	(0.29)	0.90	(0.28)
Value of a statistical life ($)	25,195	(11,586)	27,632	(11,123)	32,916	(10,543)	37,599	(8,834)
Annual management cost ($)	538	(170)	511	(172)	491	(172)	433	(165)
People per household	4.9	(0.6)	4.9	(0.6)	5.1	(0.6)	5.2	(0.6)
Case fatality rate (%)	0.07	(0.02)	0.08	(0.02)	0.08	(0.02)	0.08	(0.02)
Collection time: improved (hrs/20L)	0.32	(0.12)	0.29	(0.12)	0.30	(0.11)	0.31	(0.11)
Water project duration (yrs)	14.3	(3.1)	14.7	(3.2)	15.3	(3.1)	15.8	(3.0)
Capital cost ($)	6,475	(869)	6,601	(868)	6,431	(854)	6,240	(821)
Program cost ($)	3,518	(867)	3,606	(859)	3,412	(859)	3,273	(833)
Percent of simulations (%)	12.8		48.7		25.6		12.8	
BCR for "mean" of subgroup [b]	1.3		2.7		4.4		6.6	

[a] Mean parameter values in first row, standard deviations in parentheses.
[b] The BCR corresponding to the case with the "mean" parameter values reported in each column, and other parameters set to base levels; it is thus possible (as in column 2) for the "mean" result to thus fall outside the range of individual results).

Figure 3 presents the distribution of benefit–cost ratios from our Monte Carlo simulation and illustrates that there are also many combinations of realistic parameter values that result in BCRs less than 1. Figure 4 shows that the benefit–cost ratios are most sensitive to variations in (1) number of households using the new borehole, (2) the collection time from the traditional source, and (3) assumptions about the value of time spent collecting water. It follows that this intervention is most likely to be successful from an economic perspective in communities where

1. Density is relatively high and many households utilize the new borehole

2. Traditional water sources are distant and thus time savings are substantial, or labor market conditions create a high economic value for the time savings.

Conversely, where these conditions fail to hold – for example, where density is low and few households utilize the new borehole, or where traditional water sources are close by and the value of time saved is low – the intervention is least likely to be successful.

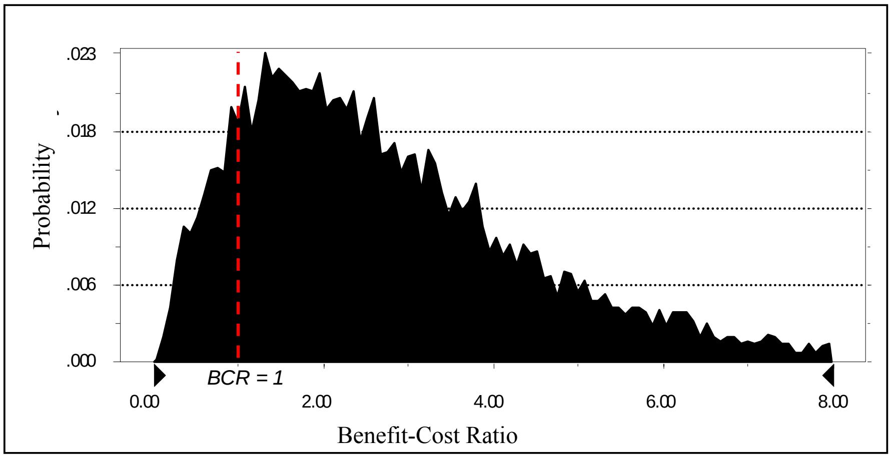

Figure 3. Intervention 1: Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions

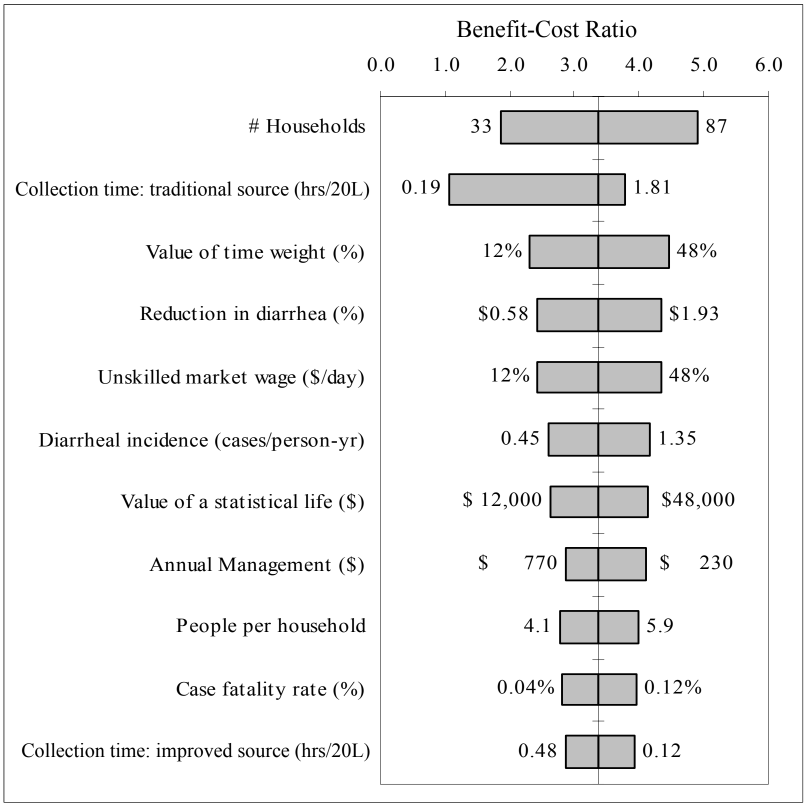

Figure 4. Intervention 1 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)

In effect, these are the types of situations for which the valuation approach we use poses the most difficulties. Wherever some proportion of intended beneficiary households are able to and would continue to use alternative sources in preference to the "improved" one, economists would expect that behavioral responses to the project would be complicated. Households might choose to continue to use lesser-quality sources of water if they are more convenient or if there are other ways of coping with low-quality water (such as investment in in-house treatment technologies or other approaches).[10] Alternatively, households might use a variety of water

[10] Limited uptake and use of improved water sources is the type of behavioral response by intended beneficiaries that has typically led to problems with supply-side interventions implemented by the

sources for different purposes or depending on the performance of these alternatives as they change with time. In situations where numerous water supply alternatives exist, the criteria by which boreholes equipped with hand pumps are evaluated must be much more sophisticated than our simple model suggests.

international donor community in the water supply sector. The shift to demand-driven planning of water and sanitation interventions seeks to avoid low priority projects from being selected.

Water and Sanitation Intervention 2 – Total Sanitation Campaigns to achieve open-defecation–free communities in South Asia

Description of the Intervention

The traditional approach to the sanitation challenge in developing countries has been to subsidize the construction of on-site latrines and, when large subsidies from donors are available, sewerage systems and wastewater treatment plants. Yet the economic and health benefits from improved sanitation require not only improved technologies for excreta disposal, but also important behavioral changes on the part of households. There are numerous innovative, low-cost technologies available for excreta disposal, virtually all of which can in theory be used hygienically. Feachem (1983) notes, "The greatest determinants of the efficacy of alternative facilities are, first, whether they are used by everyone all the time, and second, whether they are adequately maintained."[11]

Any effective sanitation solution must ensure that the needed behavioral changes occur. Surprisingly, a significant number of new, subsidized latrines are never actually used. In a recent assessment of newly provided household toilets in India, reported use rates ranged from 30% to 50%.[12] Simply providing access to improved sanitation facilities does not achieve the desired economic benefits. This type of disconnect can confound cost–benefit analyses where behavioral change is assumed but does not occur, such that returns are thus overestimated.

A Community-Led Total Sanitation (CLTS) approach has recently been developed in South Asia that focuses on mobilizing communities to achieve "total sanitation," that is, open-

[11] In Jamison et al. (2006), quoting a 1980s World Bank Technologies Advisory Group on low-cost sanitation.
[12] Usage rates of newly built toilets were estimated for programs in Andhra Pradesh (50%), Maharashtra (47%), and Himachal Pradesh (less than 30%). Use rates were reported to be higher in nonsubsidized schemes where individuals were convinced to build toilets rather than being provided with them. See Sannan and Moulik (2007).

defecation–free environments. The CLTS approach was piloted in Bangladesh in 2001; it has been claimed that within five years more than 70 million people had achieved improved sanitation through CLTS programs (Sannan and Moulik, 2007), at a cost estimated to be roughly half that of comparable interventions (Allan, 2003).[13] CLTS is now being adapted and implemented at varying scales in India, Pakistan, Nepal, Cambodia, and Indonesia. Efforts to scale up this approach have met with varied success (Water and Sanitation Program, 2005; Pattanayak et al., 2007).

The basic thrust of the CLTS model is to mobilize communities to change their behavior. Programs are designed to raise awareness of disease transmission routes, health costs, and the social benefits of sanitation, emphasizing the communal costs of open defecation that are incurred if even a small number of people fail to comply. These interventions explicitly seek to change attitudes about the social acceptability of open defecation and the advantages of convenience, privacy, and dignity associated with proper toilet usage. Banning open defecation becomes the goal, with the building of latrines treated as a means to that end. To trigger social and behavioral change, a variety of approaches have been effectively used, such as conducting "walks of shame" to open-defecation areas in the company of facilitators from local government or NGOs, or establishing children's brigades to promote and monitor the ban.

Once motivated, the community is provided with a menu of low-cost options and sometimes financial incentives to construct and maintain latrines appropriate to their circumstances and preferences. The approach is flexible and pragmatic with regard to technology choice. It emphasizes the construction of latrines from locally available, low-cost materials that meet very basic standards of safety – essentially they must be odor- and insect-free, and feces must not be visible. The "demand-driven" nature of the technological choice in this intervention

[13] Comparison is made between average costs of per family of CTLS programs in Bangladesh, relative to UNICEF estimates of average costs for pit latrines in Asia over the period 1990–2000.

is similar to that in Intervention 1 (community-managed rural water supply), and an important aspect of its cost-effectiveness.

CLTS programs have been implemented with a variety of cost-sharing arrangements and incentives. In some cases governments and/or NGOs support awareness building, motivation, and training, while households pay all the costs of latrine construction. In other programs financial incentives are provided, such as direct household subsidies (sometimes targeted to families below the poverty line) or community-focused village-level awards conveyed once open-defecation–free status has been certified.

A key challenge for interventions that seek to change personal and community behavior is to adapt and implement context-appropriate mechanisms and incentives. This leads to a range of specialized implementation modalities that complicate the task of describing "typical" programs and results. It also leads to a broad range of observed results in terms of uptake (the percentage of households that actually build a latrine as a consequence of the program) and usage (the actual usage rate of latrines once they are built) that together have a significant bearing on the benefits and costs of these interventions. Although CLTS programs are designed with the explicit goal of achieving 100% open-defecation–free villages, the best available evidence suggests that uptake rates are *on average* closer to 40%, and toilet usage rates (among "uptaking" households that have already built latrines) tend to be around 70%.[14] Highly successful interventions appear to have resulted in 100% open-defecation–free villages, but this has not been a typical result in scaling up CLTS interventions. Rather than focusing on best-case scenarios, the calculations below seek to reflect the range of plausible results that could be expected from large CLTS programs covering hundreds of villages. Table 16 summarizes the equations used in the

[14] Pattanayak et al. (2007). It should be noted that these findings were described by the authors as lower bounds due to the length of the survey period. At the time of the survey many respondents claimed that they had begun, or intended to begin shortly, the construction of in-house latrines.

calculation of benefits and costs of our model CLTS intervention;

Table 17 presents the assumed parameter values.

Table 16. Intervention 2: Equations for Cost-Benefit Analysis of Community-Led Total Sanitation (CLTS) Project

Benefits	
Time savings per hh-month (hours)	$T_{s,m} = 30 * T_s * Q * A * U * \mu / 60$
Value of time savings per hh-month ($)	$V_{ts} = T_{s,m} * (w / 8) * v_t$
Avoided morbidity per hh-month ($)	$m = (I / 12) * E * S * COI * U * \mu$
Avoided mortality per hh-month ($)	$M = (I / 12) * E * S * CFR * VSL * U * \mu$
Costs	
Capital recovery factor	$CR = r*(1 + r)^d / ((1 + r)^d - 1)$
Capital per hh-month ($)	$C_{c,m} = C_l * U * CR / 12$
Time costs per hh-month ($)	$C_{t,m} = v_t * [C_o * (w) * CR + C_t * (w / 8) * U] / 12$
Program costs per hh-month ($)	$C_{p,m} = [(C_{c,m} + C_{t,m}) / (1 - C_p)] - C_{c,m} - C_{t,m}$

Discussion of Costs Associated with Community-Led Total Sanitation Programs

In this analysis we assume a CLTS program that includes low-cost latrine building and community mobilization. Costs are categorized as (1) costs of latrine construction, (2) the value of household time associated with participation in the CLTS, and (3) program-level costs to government and/or NGOs.

Latrine costs vary widely depending on the type of latrine chosen, the materials used, and whether outside labor must be hired. Typical CLTS programs have no or few subsidies for latrine building and instead promote low-cost toilet options. We do not specify whether a subsidy is made available for latrine building here, but instead use total capital costs for latrines whether paid for by households and/or governments. The Water and Sanitation Program (2005) found an average cost of US$4 for latrines built in total sanitation programs in Bangladesh, and US$12.80 in India (with a 68% subsidy). We assume a base cost of US$8 with a range of US$4–$12 (

Table 17). The annualized cost of the investment is calculated assuming a 6-year infrastructure life and a 4.5% discount rate (for a capital cost recovery factor of 0.19), and then adjusted to arrive at a monthly cost. To calculate the total monthly investment cost to an average household, we must also recognize that not all households will actually build a latrine as a consequence of the program. Assuming an average uptake rate of 40% (with a range of 20%–60%), the cost of latrine construction per household per month is US$0.05.

Table 17. Intervention 2: Parameters Used in Cost-Benefit Analysis of CLTS Project.[a]

Symbol	Parameter	Base case	Lower limit	Upper limit	Correlated parameters
C_l	Capital cost of one latrine ($)	$8	$4	$12	Incidence (0.5), Market wage (–0.5)
C_p	Program costs per household, upfront and ongoing (% of total costs/hh)	75	65	85	Incidence (0.5), Market wage (–0.5), Life of project (0.7)
C_t	Time expenses for initial training and construction (days/hh)	10	5	15	
C_o	Time expenses for ongoing training and maintenance (hrs/hh-yr)	10	5	15	
d	Life of project (yrs)	6	3	9	Latrine cost (0.5), Household size (–0.5)
r	Real, net of inflation, discount rate (%)	4.5%	3%	6%	
S	Household size	5	4	6	
A	Number of adults in household	2	1	3	Household size (0.7)
T_s	Round trip time spent traveling to site of open defecation - status quo (min)	15	10	20	Uptake (0.5), Usage (0.7)
Q	Round trips to defecation site per person per day	1	0.75	1.25	
U	Uptake of latrines (% of households)	40%	20%	60%	Reduction in diarrhea (0.5), Program costs (0.5)
μ	Usage of latrines by adults (%)	70%	50%	90%	Capital cost (0.5), Program costs (0.5), Ongoing time expenses (0.5)
w	Market wage for unskilled labor ($/day)	$1.25	$0.50	$2.00	
v_t	Value of time savings / market wage for unskilled labor	30%	10%	50%	
I	Diarrheal incidence (cases/pc-yr) [b]	0.9	0.5	1.4	
E	% Reduction of diarrhea due to CLTS intervention	30%	10%	50%	
COI	Cost of illness ($/case)	$6	$2	$10	Market wage (0.5)
CFR	Diarrhea case fatality rate (%) [b]	0.08%	0.04%	0.12%	Capital cost (0.5)
VSL	Value of a statistical life ($)	$30,000	$10,000	$50,000	Market wage (0.7)

[a] Our uncertainty analysis does not purport to use the real probability distributions associated with these parameters but instead is aimed at assessing the range of possible situations in poor developing countries; therefore we use uniform distributions of parameters.

[b] Revised Global Burden of Disease (GBD) Estimates (WHO, 2002). Available at http://www.who.int/healthinfo/bodgbd2002revised/en/index.html. Diarrhea incidence in developing country subregions ranges 0.6–1.29 case per capita per yr (mean ~0.9) but may actually be higher or lower in some locations; CFR ranges 0.02 – 0.09.

Household time costs will include an upfront component, that is, the time spent in motivation and training meetings, as well as an ongoing time component to clean and maintain the latrine during its usable life. An upfront time commitment of 10 days was assumed per participating ("uptaking") household – those who built toilets and attended education, training, and follow-up meetings. An up-front time commitment of 3 days was assumed for the remaining households who would have been exposed to the campaign but in the end chose not to participate fully. As in intervention 1, it was assumed that the local wage for unskilled labor is US$1.25 per day (US$0.15 per hour), and 30% of that amount was used as the monetary value of household time in the program. These up-front costs were spread over the duration of the project using the 0.19 capital recovery factor (CR). For households that did build a latrine (40%), it was assumed that members spent an additional 10 hours maintaining the latrine each year. The cost to an average household in terms of the value of time spent in the CLTS program was thus US$0.05 per household per month.

Program-level "software" costs were found to range roughly from 40% to 80% of total program costs (software plus latrine costs and household contributions) in CLTS-style interventions (Water and Sanitation Program, 2005). These overhead costs for CLTS are difficult to measure and likely to be underestimated as a consequence of undervaluing volunteer and NGO input, time from higher-level government officials in guidance and conceptualization of programs, or the use of temporarily diverted local staff to assist in intensive campaigns. Here we assume software costs are 75% of total program costs, with a range of 65%–85%. Following these assumptions, the program cost per household per month is US$0.31.

Economic Benefits of Community-Led Total Sanitation Programs

The benefits of improved sanitation include health benefits and time savings associated with the convenience of an in-home latrine. Other important social benefits cited by participants in CLTS programs (but not incorporated in this analysis) include privacy, dignity, and security, particularly for women, who are often vulnerable when using secluded public areas. Aesthetic benefits might also be expected from limiting open-defecation practices within a village, but at the same time there may be aesthetic losses involved in having a latrine in the home, and in using an enclosed latrine. The value of changes in aesthetics is not addressed in this intervention.

The complexities associated with estimating the health benefits of water and sanitation investments were presented in Intervention 1, and apply equally here. Here in Intervention 2 we use comparable assumptions wherever appropriate. We assume a 30% reduction in diarrhea incidence (with a 10%–50% range) as the potential impact of the intervention, from a baseline of 7.5 cases per household per year to about 5 cases per household per year. Taking into account a 40% uptake rate and 70% usage rate (with a range of 50%–90%) for latrines, we estimate that the benefit to the *average* household will be about an 8% ($0.3 \times 0.4 \times 0.7 = 0.084$) reduction in diarrhea incidence. For nonfatal diarrhea an average cost of US$6 per episode is again assumed, which would amount to a cost savings US$0.19 per household per month. Assuming a case fatality rate of 8/10,000 and a VSL of US$30,000, the value of the averted mortality risk is US$0.78 per household per month.

Time savings for in-home sanitation were calculated by assuming that individuals otherwise walk 15 minutes round-trip (range 10–20) from their homes for this purpose each day (and make on average one such trip per day; range 0.75–1.25). Generally, the spaces used for open defecation are at the edge of villages, often near fields or railway lines. The monthly time savings for two adults with in-home sanitation would therefore be 15 hours per household per month. Given that on average only 40% of households will build latrines, and that of those who build latrines only 70% on average actually use them, we assumed 28% of the potential time savings as a benefit. Assuming again a local wage of US$1.25 per day and valuing the time savings at 30% of the market wage, the monetary value of the total expected time savings would be US$0.20 per household per month.

Comparison of Costs and Benefits of Community-Led Total Sanitation Programs

The costs and benefits of the total sanitation intervention are presented in Table 18 calculated in terms of US$ per household per month. The benefits of the program include averted mortality risks and reduced incidence of nonfatal diarrhea (US$0.95) as well as time savings associated with in-home latrines (US$0.20), for a total benefit US$1.14 per household per month. Costs associated with the program include the capital costs of latrine construction (US$0.05), the value of household time participating in the program (US$0.05), and program-level "software" costs (US$0.31), for a total of US$0.41 per household per month. This implies a simple benefit/cost ratio (BCR) of 2.8, suggesting that under circumstances similar to those assumed here, CLTS programs will very often be economically sound interventions.

Table 18. Base Case Results for Intervention 2: CLTS Project.[a]

	Without CLTS intervention	With CLTS intervention [b]	Change in physical units[b]	Change in monetary units by discount rate[c]		
Benefits				3%	4.5%	6%
Time spent by adults walking to defecation site (hrs per hh-month) [Value of time savings]	15	0	15	$0.20	$0.20	$0.20
Number of nonfatal cases of diarrhea (per hh-month) [Value of reduction in morbidity]	0.38	0.26	(0.11)	$0.19	$0.19	$0.19
Risk of death from all diarrhea (per 1000 hh-month) [Value of reduction in mortality]	0.30	0.21	(0.09)	$0.76	$0.76	$0.76
All benefits				$1.14	$1.14	$1.14
Costs						
Construction costs for latrines (per hh-month)				($0.05)	($0.05)	($0.05)
Time costs for households for CLTS (per hh-month)				($0.05)	($0.05)	($0.05)
Program-level costs for CLTS (per hh-month)				($0.29)	($0.31)	($0.32)
All costs				($0.39)	($0.41)	($0.43)
Benefit–Cost Ratio				3.0	2.8	2.7
Net benefits				$0.77	$0.73	$0.74

[a] For the results reported in this table, all parameters were set at their *base case* values as described in

Table 17, except for the discount rate, which was varied between 3, 4.5 and 6%. The values in the cells in the three rightmost columns report the monetary value of the components of benefits and total costs on a per household per month basis.

[b] Among participating households (i.e. households that build new latrines)

[c] For all households.

A Monte Carlo simulation for this intervention (Figure 5) provides a distribution of benefit–cost ratios resulting from 10,000 random draws on the parameters listed in

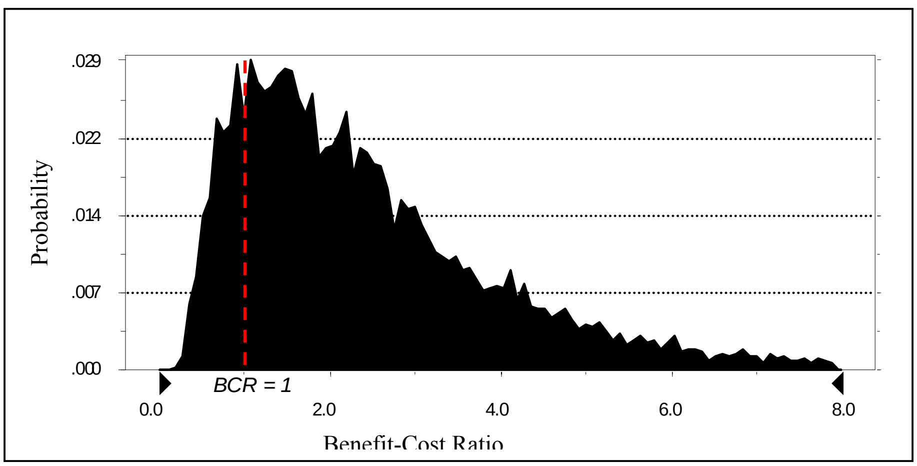

Table 17, with a range of roughly 0–8. Figure 5 shows that for most combinations of parameter values CLTS interventions return favorable BCRs. Table 19 presents the average parameter values associated with four groups of outcomes from the Monte Carlo simulations. The mean parameter values in all categories are plausible, particularly in South Asia, although they are less typical in both the unattractive and extremely attractive categories.

Figure 5. Intervention 2: Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions

A sensitivity analysis is presented to illustrate the influence of key parameters on the benefit–cost ratios for this intervention (

Figure 6). Results are most sensitive to percentage reductions in diarrhea incidence, the value of a statistical life, absolute levels of diarrhea incidence, and rates of latrine uptake. As in the case of rural water supply (Intervention 1), these investments will therefore be most beneficial where incidence of diarrhea and the value of a statistical life are both high. In contrast, the results for the CLTS are highly sensitive to the magnitude of the assumed reduction in diarrhea incidence. Unfortunately there is little robust evidence in the peer-reviewed literature on the correlation between sanitation-only investments and diarrheal disease reductions. Our assumptions are based on the best available evidence (Fewtrell et al., 2005), but other studies suggest that as villages approach open-defecation–free status the magnitude of disease reduction may rise sharply.[15] This relates to another key parameter in the sensitivity analysis: the level of uptake (percentage of households choosing to build latrines). Together this suggests that total sanitation interventions will be particularly attractive where uptake (behavior change) is highest, demonstrating the importance of the behavioral uncertainty that is embedded in benefit–cost analysis.

Table 19. Intervention 2: Typology of CLTS Project Sites Categorized by Benefit–Cost Ratio (BCR).[a]

Parameter	Unattractive sites (BCR < 1)		Attractive sites (BCR 1 – 2.99)		Very attractive sites (BCR 3 – 4.99)		Extremely attractive sites (BCR > 5)	
Reduction in diarrhea (%)	18	(7)	28	(10)	37	(9)	42	(7)
Diarrheal incidence (cases/person-yr)	0.72	(0.27)	0.87	(0.28)	1.01	(0.25)	1.13	(0.20)
Value of a statistical life ($)	28,290	(12,142)	29,304	(11,755)	30,651	(10,701)	34,171	(9,241)
CLTS Project Duration (yrs)	5.7	(2.1)	5.9	(2.0)	6.1	(1.9)	6.3	(1.8)
Uptake of latrines (% of hhs)	30	(9)	39	(11)	46	(10)	49	(8)
Program costs per household (% of total)	73	(6)	75	(6)	76	(5)	77	(5)
Case fatality rate (%)	0.07	(0.02)	0.08	(0.02)	0.09	(0.02)	0.10	(0.02)

[15] Evidence from South Asia (Sannan and Moulik, 2007) suggests that significantly greater reductions in diarrhea incidence can be achieved in villages where all excreta is hygienically confined, because bacteriological contamination and disease transmission continue to be significant even when only a small percentage of the community practices open defecation.

Usage of latrines by adults (%)	62	(10)	69	(11)	75	(10)	77	(10)
People per household	4.9	(0.6)	5.0	(0.6)	5.1	(0.6)	5.1	(0.5)
Cost of illness ($/case)	5.7	(2.3)	6.0	(2.3)	6.2	(2.3)	6.7	(2.1)
Percent of simulations (%)	15.0		55.3		20.5		9.2	
BCR for "mean" of subgroup [b]	1.0		2.4		4.4		7.5	

[a] Mean parameter values in first row, standard deviations in parentheses.
[b] The benefit–cost ratio corresponding to the case with the "mean" parameter values reported in each column, and other parameters set to base levels.

The success of CLTS programs depends heavily on tailoring project designs to specific social settings, recruiting and retaining effective "health motivators," and targeting communities that are open to change. This seems to have been the experience in scaling up CLTS-style interventions. Sharply tailored early pilot programs appear to have returned outstanding results. Yet as these programs were scaled up they did not achieve the same level of uptake and hence impact. Nonetheless, even at scale, many CLTS interventions will be economically beneficial. Where behavior can be radically changed, these interventions may be very economically attractive.

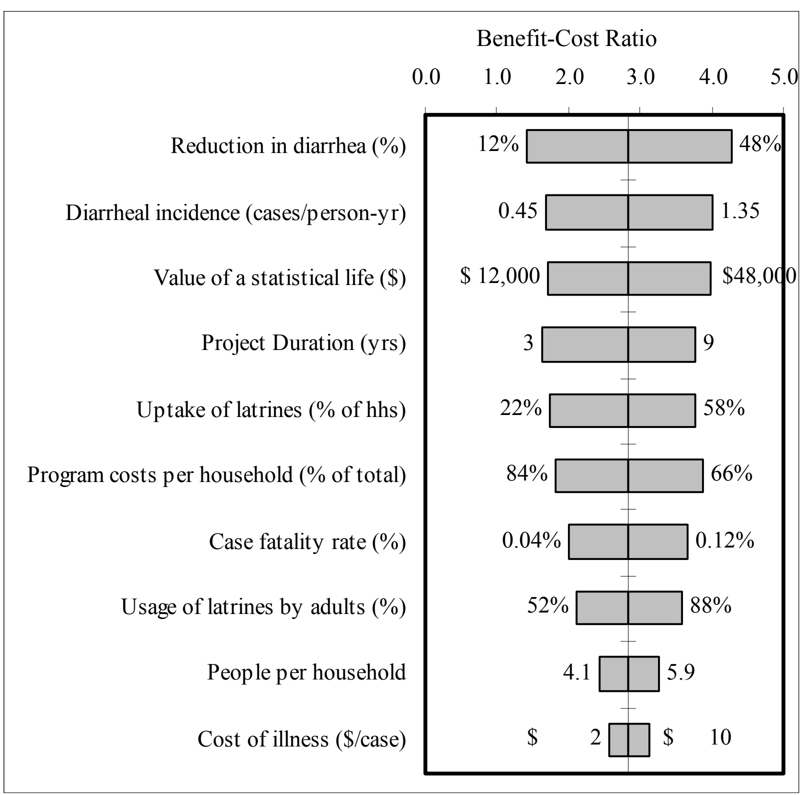

Figure 6. Intervention 2 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)

Water and Sanitation Intervention 3 – Biosand Filters for Point-of-use Household Water Treatment

Description of the Intervention

Biosand filters are one of several possible technologies that households can use in- home to remove a wide variety of contaminants, including bacteria and viruses, from their drinking and cooking water. Other point-of-use (POU) technologies include boiling, solar disinfection, chlorination, and other types of filtration. POU technologies have gained support as a result of research highlighting the role of drinking-water contamination during collection, transport, and storage. POU technologies greatly reduce the first two of those problems (Clasen and Bastable, 2003) and compare favorably with other water and sanitation interventions in field trials (Fewtrell et al., 2005; Clasen et al., 2006; Stauber, 2007a). Globally, boiling is the most prevalent and accepted means of treating water in the household. Although boiling is highly effective at removing pathogens if done for a sufficient length of time (15–20 minutes), it is today infrequently promoted, because it is expensive in terms of fuel use, often inconvenient and unpleasant for household members, prone to recontamination, and in many places environmentally harmful in terms of indoor air pollution and as a contributor to deforestation.

We selected the biosand filter for illustrative purposes; we do not argue that it is the "best" of the available POU technologies. However, the biosand filter has been demonstrated in the field to be safe and effective under a wide variety of conditions, and close to 100,000 biosand filters are now being used by households in numerous developing countries (Kaiser et al., 2002; Earwaker, 2006; Stauber, 2007a). The biosand filter uses commonly available materials, is inexpensive to install, and is convenient and simple to use. Essentially all that is required is a concrete or plastic chamber, and sand, gravel and a small section of PVC pipe (CAWST, 2007; Samaritan's Purse, 2007). Household members pour water into the top of the filter and allow time for the water to seep through the sand. Depending on the specific design of the device, biosand filters can typically provide a maximum of 30–60 liters per hour. Pathogens are removed by physical filtration and a biologically active slime layer (*Schmutzdecke*) that forms at the top of the sand column; suspended and some dissolved solids are removed by physical processes in the filter. Clean water is collected via an outlet tube at the top of the filter. The design of the filter thus ensures that there will always be water above the top of the sand bed, so that microbial activity in the *Schmutzdecke* is maintained. A biosand filter can easily provide hundreds of liters of clean water each day, more than enough for a household of typical size (about five members). The biosand filter can be installed inside or outside a house depending on site-specific conditions and household preferences.

Neither the biosand filter nor other household POU technologies resolve the difficulties associated with getting adequate quantities of water to dwellings prior to treatment. They are thus only a partial solution to households' larger problem of securing safe, clean water for use at home. POU technologies could prove beneficial, however, in two very different situations. First, in rural areas, POU technologies such as the biosand filter could be used to improve the purity of water from traditional sources that household members carry back to their homes. It would also be possible to couple a POU technology with the rural water supply described above as intervention 1 (deep boreholes and hand pumps) in order to provide added assurance of clean drinking and cooking water. In these cases, the POU device helps solve the problem of both contaminated source water and contamination of water while in transit from the source to the household. In rural and in more urbanized areas, POU technologies could be used by households that depend on water from an unreliable, low-quality piped system (either from public taps or their own private connection).

There are three primary disadvantages of the biosand filter per se. First, the top of the filter traps silt and must be cleaned periodically. This involves adding water, stirring the top layer of sand, removing it, and then "restarting" the process of *Schmutzdecke* formation at the top of the sand column. While the new layer is forming, the filter is not as effective in removing pathogens.[16] For a period of a few days after cleaning, households need to use an alternative means of purifying their water, such as chlorination or boiling, or they must store previously filtered water over an extended period. The length of time between cleanings depends on the quality of the raw water that is used and local conditions. Typically filter cleaning is required a couple of times a year. In the worst case monthly cleanings may be necessary.

Second, the biosand filter is large and takes up space in the house. In urban slums where space is at a premium, households will be reluctant to allocate the space needed for this technology. Third, once installed in a particular location, the biosand filter is very heavy and hard to move.[17] The biosand filter is thus most appropriate in rural or semi-rural areas, or in low-density urban neighborhoods.

[16] Laboratory experiments suggest that immediately following cleaning, the biosand filter removes about 50% of viruses, 80%–90% of bacteria, and >99% of parasites (Stauber, 2007a).
[17] Moving the filter is also impractical because it causes compacting of the sand, such that reinstallation (emptying the filter and refilling with sand) may be necessary.

Table 20 summarizes the equations used in the calculation of benefits and costs of the biosand filter intervention;

Table 21 presents the assumed parameter values.

Table 20. Intervention 3: Equations for Cost-Benefit Analysis of Biosand Filter.

Benefits	
Avoided morbidity per hh-month ($)	$m = \sum_{t=1}^{d} \frac{[(365 - b \cdot m) / 365] \cdot I \cdot E \cdot S \cdot COI}{12 \cdot (1+\delta)^{t-1}}$
Avoided mortality per hh-month ($)	$M = \sum_{t=1}^{d} \frac{[(365 - b \cdot m) / 365] \cdot I \cdot E \cdot S \cdot CFR \cdot VSL}{12 \cdot (1+\delta)^{t-1}}$
Costs	
Capital recovery factor	$CR = r*(1+r)^d / ((1+r)^d - 1)$
Capital + program cost per hh-month ($)	$C_{c,m} = (C_c + C_s) * CR / 12$
Household time costs per month ($)	$C_{t,m} = v_t * (w / 8) * [T_t * CR + (T_m / 60) * m] / 12$
Community maintenance program cost per hh-month ($)	$C_{0,m} = 2 * (w/8) * T_o / 12$

Table 21. Intervention 3: Parameters Used in Cost-Benefit Analysis of Biosand Filter.[a]

Symbol	Parameter	Base case	Lower limit	Upper limit	Correlated parameters
C_c	Cost of biosand filter + training + program ($)	75	60	90	Life of filter (0.5)
C_s	Transportation of filters ($)	25	15	35	CFR (0.5), Incidence (0.5), Market wage (–0.5)
T_t	Training time (hrs/hh)	8	4	12	
T_o	Operator's maintenance time (hr/hh-yr)	2	1	3	
T_m	Maintenance time (minutes/wash)	15	10	20	
m	Number of washes per year	6	2	10	
b	Days before *Schmutzdecke* regrowth	5	3	7	
r	Discount rate (%)	4.5%	3%	6%	
d	Life of filter (yr)	8	6	10	
n	# Households	60	30	90	
S	Household size	5	4	6	
w	Unskilled market wage ($/day)	1.25	0.50	2.00	
v_t	Value of time / market wage for unskilled labor	0.3	0.1	0.5	
I	Diarrheal incidence (cases/pc-yr) [b]	0.9	0.5	1.4	
E	Reduction of diarrhea (%)	0.40	0.20	0.60	Training time (0.5)
δ	Rate of disuse (% of filters per year)	2	1	3	Operator maintenance time (–0.5), Training time (–0.5)
VSL	Value of a statistical life ($)	30000	10000	50000	Market wage (0.7)
CFR	Case fatality rate (%) [b]	0.08	0.04	0.12	
COI	Cost of illness ($/case)	6	2	10	Market wage (0.5)

[a] Our uncertainty analysis does not purport to use the real probability distributions associated with these parameters, but instead is aimed at assessing the range of possible situations in poor developing countries; therefore we use uniform distributions of parameters.

[b] Revised Global Burden of Disease (GBD) Estimates (WHO, 2002). Available at http://www.who.int/healthinfo/bodgbd2002revised/en/index.html. Diarrhea incidence in developing country sub-regions from 0.6 – 1.29 case per capita per yr (mean ~0.9), but may actually be higher or lower in some locations; CFR ranges 0.02–0.09.

Discussion of Costs Associated with Programs for the Distribution of Biosand Filters

The biosand filter technology itself is extremely simple and easily scalable for use in different locations; essentially it simply requires a large container and sand. Manufacturing costs of a concrete biosand filter may be as low as US$20. However, a concrete container and sand are both heavy and bulky, and thus expensive to transport. Possible solutions to this problem include using plastic, stacking containers instead of concrete ones, or on-site construction of concrete filters. Sand may be available locally, but typically filter distribution programs prefer to haul sand with the desirable size and properties to the household to ensure optimal performance of the filter (alternatively households themselves may be required to transport the filter and sand from a distribution point to their home). Solutions to the manufacturing and delivery of the filter and sand will be location-specific depending on transportation and other cost factors; there is no simple optimal solution that will be applicable everywhere.

As with the Interventions 1 (rural water supply) and 2 (CLTS), “software” costs for biosand filters can constitute a substantial portion of total resource costs. Typically a program to introduce biosand filters would entail meetings by program staff to explain the biosand filter technology to households in the community and the potential health benefits of its use. Households also need instruction in the procedures used to clean the filters. As with the rural water supply intervention, typically one individual in the community receives additional training in the biosand filter technology in order to provide back-up technical support to households when problems arise with their filters.

For this intervention we use a range of US$60–$90 (base case $75) per biosand filter for the manufacturing and software costs, and US$15–$35 (base case $25) for transportation and delivery costs of the filter and sand. We estimate the value of the opportunity costs to the household of time spent in training and health promotion activities (8 hours, range 4–12 hours). Operation and maintenance costs are only the time required by the household for filter cleaning, and an estimated 2 hours of the community manager’s time per household per year (range 1–3 hours). We do not assign a cost to other filter operation activities (e.g., pouring the water into the filter). We assume that the average filter lasts 8 years, with a range of 6–10 years.

Economic Benefits of Biosand Filter Dissemination Programs

Our estimates of the economic benefits of the biosand filter are based solely on the improved health outcomes from the intervention. Unlike the rural water supply and total community sanitation interventions, the biosand filter intervention provides no collection time savings benefits to the household. We calculate the mortality and morbidity consequences of the intervention and assign monetary values in precisely the same manner used for interventions 1 and 2. The key difference in the calculations is in the parameter value assumed for diarrhea reduction from the intervention. For the base case we assume a 40% reduction in diarrhea incidence for the biosand filter intervention (Fewtrell et al., 2005; Clasen et al., 2006; Stauber, 2007b), with a range of 20%–60%. We assume conservatively that there are no health benefits for the five days required for regrowth of the *Schmutzdecke* (range 3–7 days) and assume an average of 6 cleanings per year (range 2–10).

Finally, as with Intervention 2 (CLTS), behavior and usage is important; the rate at which households continue to use the filters determines the benefits obtained. Other POU interventions show that diarrhea reductions are significantly diminished due to noncompliance or breakage (Clasen et al., 2006; Arnold and Colford, 2007; Brown, 2007), but research suggests that biosand usage rates remain relatively high over a number of years (Earwaker, 2006; Samaritan's Purse, 2007). .We estimate that usage declines at a constant 2% rate (range 1%–3%) each year, based on preliminary findings that 85%–90% of filters remain in use after eight years in the field (Stauber, 2007b).

Comparing the Costs and Benefits of Biosand Filter Dissemination Programs

As shown in Table 22, for our base case total household benefits from the biosand filter are about US$3.86 per month and costs are about US$1.33 per month, for a benefit–cost ratio of 2.9. Figure 7 shows that the BCR is most sensitive to the four parameters used to calculate the mortality reduction benefits: (1) the value of a statistical life, (2) percent diarrhea reduction achieved by the biosand filter, (3) the baseline diarrhea incidence, and (4) the case fatality rate from diarrhea. The morbidity reduction benefits are much smaller, just over 50% of the total costs and 20% of the total benefits.

Table 22. Base Case Results for Intervention 3: Biosand Filters.[a]

	Before biosand filter intervention	After biosand filter intervention	Change in physical units	Change in monetary units by discount rate		
Benefits				3%	4.5%	6%
Number of nonfatal cases of diarrhea (per hh-month) [Value of reduction in morbidity]	0.38	0.29	0.09	$0.77	$0.77	$0.77
Risk of death from all diarrhea (per 1000 hh-month) [Value of reduction in mortality]	0.30	0.23	0.07	$3.09	$3.09	$3.09
All benefits				$3.86	$3.86	$3.86
Costs						
Capital, training and programs (per hh-month)				($1.19)	($1.26)	($1.34)
Community maintenance program (per hh-month)				($0.05)	($0.05)	($0.05)
Household time costs (per hh-month)				($0.01)	($0.01)	($0.01)
All costs				($1.25)	($1.33)	($1.40)
Benefit–Cost Ratio				3.1	2.9	2.7
Net benefits				$2.61	$2.53	$2.45

[a] For the results reported in this table, all parameters were set at their *base case* values as described in

Table 21, except for the discount rate, which was varied between 3%, 4.5%, and 6%. The values in the cells in the three rightmost columns report the monetary value of the components of benefits and total costs on a per household per month basis.

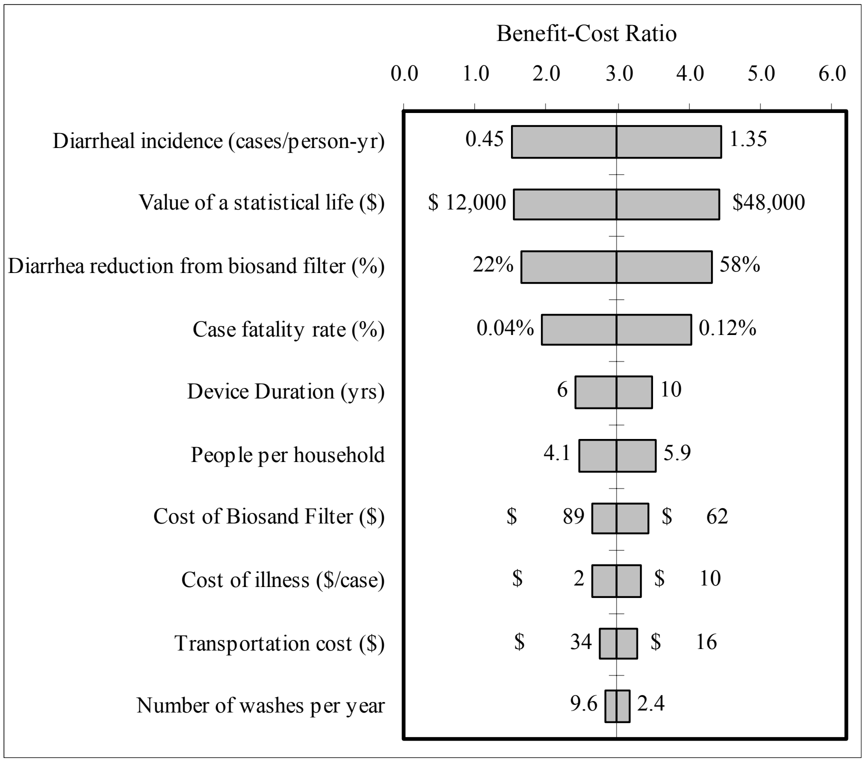

Figure 7. Intervention 3 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values)

The distribution of benefit–cost ratios shown in Figure 8 is quite similar to those for interventions 1 and 2. Some combinations of parameter values yield BCRs of < 1, but many more show BCRs greater than one. Table 23 shows that biosand filters will be extremely attractive investments where VSLs, diarrhea incidence, and the case fatality rate are all high. We would speculate, however, that locations with this combination of parameter values may be difficult to find. However, we would expect to find many locations in developing countries with parameter values similar to those shown for BCRs ranging 1–3 (“attractive sites”).

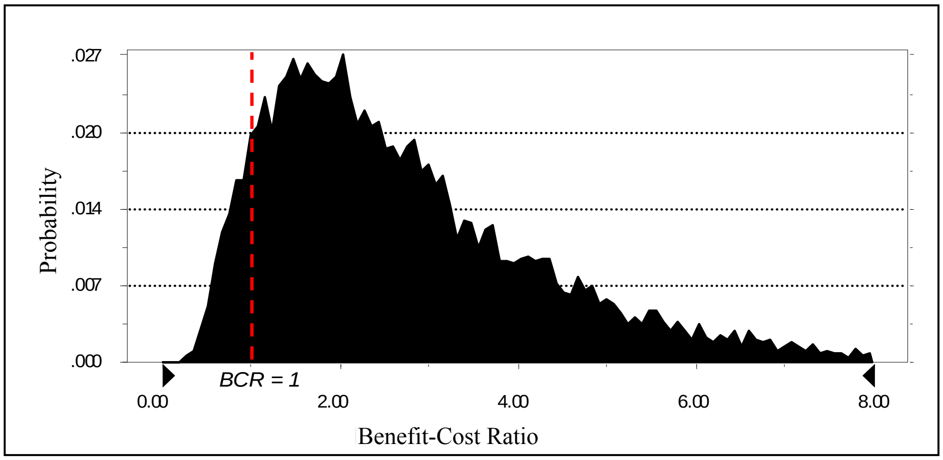

Figure 8. Intervention 3: Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions

Table 23. Intervention 3: Typology of Biosand Filter Project Sites Categorized by Benefit–Cost Ratio (BCR).[a]

Parameter	Unattractive sites (BCR < 1)		Attractive sites (BCR 1 – 2.99)		Very attractive sites (BCR 3 – 4.99)		Extremely attractive sites (BCR > 5)	
Diarrheal incidence (cases/person-yr)	0.68	(0.25)	0.84	(0.29)	0.99	(0.25)	1.11	(0.20)
Value of a statistical life ($)	22,890	(10,789)	28,335	(11,652)	32,250	(10,378)	37,030	(8,530)
Diarrhea reduction from biosand filter (%)	28	(8)	38	(11)	44	(10)	50	(8)
Case fatality rate (%)	0.06	(0.02)	0.08	(0.02)	0.09	(0.02)	0.10	(0.01)
Filter duration (yrs)	7.3	(1.3)	7.9	(1.4)	8.2	(1.4)	8.5	(1.3)
People per household	4.8	(0.6)	5.0	(0.6)	5.1	(0.6)	5.2	(0.5)
Cost of biosand filter, training and program ($/hh)	77.3	(8.2)	75.6	(8.6)	74.5	(8.7)	72.5	(8.6)
Cost of illness ($/case)	5.1	(2.2)	5.9	(2.3)	6.3	(2.2)	6.8	(2.2)
Transportation cost ($/hh)	23.5	(5.7)	24.7	(5.8)	25.7	(5.6)	26.4	(5.4)
Number of washes per year	6.3	(2.2)	6.1	(2.3)	5.8	(2.3)	5.7	(2.3)
Percent of simulations (%)	8.1		56.5		24.5		10.9	
BCR for "mean" of subgroup [b]	0.9		2.4		4.3		7.2	

[a] Mean parameter values in first row, standard deviations in parentheses.
[b] The BCR corresponding to the case with the "mean" parameter values reported in each column, and other parameters set to base levels.

Water and Sanitation Intervention 4 – Large Multipurpose dams in Africa

Description of the intervention

In recent years large multipurpose dams have been among the most controversial infrastructure projects in both industrialized and developing countries (World Commission on Dams, 2000). Proponents cite several types of direct economic benefits: hydroelectric power generation, domestic and industrial water supply, drought mitigation, recreation, irrigation, and flood control. They also claim a variety of indirect benefits (e.g., increased employment, better diplomatic relationships between riparians on international rivers, reduced risk of conflict over water resources, improved trade, and enhanced economic integration).[18] On the other hand, critics believe that these benefits are overstated or nonexistent, that the high construction and resettlement costs are underestimated, and that negative side effects, especially environmental and cultural losses, are high (Duflo and Pande, 2007). Table 24 presents a list of the types of costs and benefits typically associated with dam projects.

In the short space allotted to our discussion of this intervention, we cannot hope to explore all aspects of this debate – particularly the social and political dimensions. Nevertheless, we have selected large multipurpose dams in Africa as one of the water-related interventions for consideration in Copenhagen Consensus 2008 because we believe that there are several compelling reasons why the construction of *some* new large dams in Africa should be part of this discussion. First, many countries in Africa are short of water storage to mitigate droughts and support economic development activities; the projections from the recent Intergovernmental Panel on Climate Change suggest that this need will worsen during the century ahead as a

[18] Improved diplomatic relations and reduced conflict could result from cooperative international development of water resources infrastructure. Unilateral construction of dams could have the opposite effects.

consequence of climate change (IPCC, 2007).. As shown in Figure 9, Ethiopia has almost two orders of magnitude less water storage per person than countries in North America; South Africa has almost one order of magnitude less. In the United States and Europe, welfare may be enhanced if citizens decide that their governments should halt the construction of large dams for environmental, recreational, and cultural reasons, and even decommission some dams that may have been poorly conceived. But countries like Ethiopia face an entirely different situation. They have essentially no water storage facilities currently and are confronted with great hydrological variability, which can take a significant toll on economic growth (World Bank, 2006).

Table 24. Benefits and Costs of Large Dam Projects.[a]

Benefits	*Costs*
Irrigation water demand*	Capital investment (Dam, energy transmission infrastructure, land) *
Municipal and industrial water demand	Operation and maintenance*
Hydropower generation*	Opportunity cost of flooded land*
Downstream hydropower and irrigation water due to regularization of flow*	Reduced water availability downstream for irrigation, municipal, industrial, hydropower (including transient costs)
Flood control*	Resettlement costs for flooded habitations*
Decrease in impacts of droughts	Economic rehabilitation costs for lost livelihoods*
Creation of fishery in reservoir	Lost river fisheries
Recreational benefits around reservoir	Lost river recreation
Carbon offsets*	Catastrophic risk*
Sediment control	Ecological costs (erosion, lost plant/animal habitats, salinization)
Navigation	Public health costs (increased waterborne disease)

[a] In general, a dam project will not entail all of the costs and benefits listed in Table 24. Benefits and costs that apply to the illustrative project considered in this section are indicated by an asterisk.

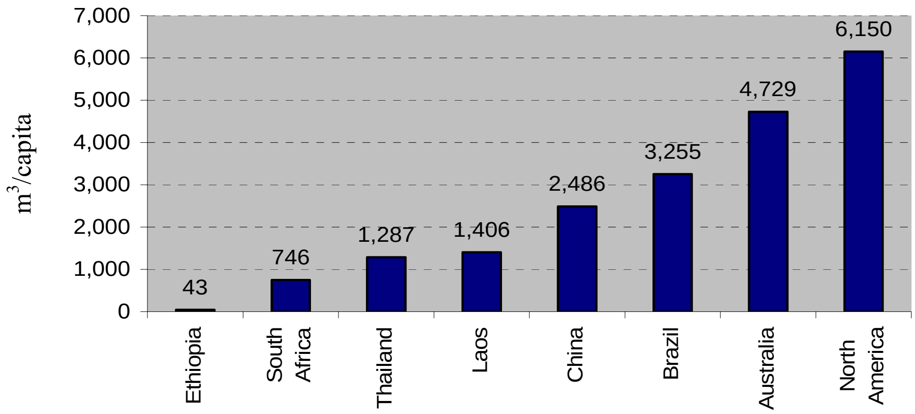

Figure 9. Water storage per person in different countries (from Grey and Sadoff, 2007)

Second, in countries where many large dams have already been built, the best sites are mostly gone: they were developed first. In such countries many of the remaining undeveloped sites have significant negative attributes. Some are in areas of great aesthetic or ecological value; some lie in earthquake prone zones; and others would, if dammed, inundate areas with large populations and thus require massive resettlement. In contrast, dams have not yet been constructed at some of the best dam sites in Africa. This would suggest that at least some of these sites in Africa are worth careful consideration. We believe that cost-benefit analysis offers one important perspective from which to judge the wisdom of such investments.

Large multipurpose dams are the most capital-intensive of the water and sanitation interventions examined in this paper, and their benefits and costs will extend much farther into the future than rural boreholes with hand pumps, biosand filters, or community-level sanitation campaigns. The majority of the costs of large dams will be incurred during construction, but the benefits, operation and maintenance costs, and some of the environmental and social costs will extend far into the future. The choice of the social rate of discount to use for valuing benefits (and costs) in the distant future is thus much more important than for the other three water and sanitation interventions reviewed above. Although this approach does not deal adequately with the shadow value of capital or the social opportunity cost of capital (see footnote 3, Part I), the objective of the cost-benefit calculations presented here is not to show the results of an in-depth, thorough project appraisal. Rather we want to direct the attention of the development community back to the economics of such large water resources infrastructure. Real discount rates in the range of 3%–6% will serve this purpose.

An additional complication associated with these calculations is that large dam projects in poor regions or countries can be the initial, "anchor" investment of a strategic, transformational economic development plan that can affect many sectors of an economy. In effect the initial investment dictates one economic development path for a region instead of another. Such investments are the most difficult to assess with the partial equilibrium tools of cost-benefit analysis, because the relative prices of many goods and services may change as a result of the economic development initiatives and also because the opportunity cost of this water resources development "path" is the benefit of the development path not chosen, which is difficult to know.

To address these valuation challenges, historically many planners and engineers have proposed that the direct benefits of dam projects be increased by the use of a Keynesian "multiplier" so that the benefits that accrue to related, ancillary businesses – and to households in the form of increased income — can be included. Recently a major World Bank report has argued in support of the use of such multipliers to estimate the total benefits of dam projects (Bhatia et al., 2005). In its simplest form, this "multiplier analysis" involves multiplying the direct economic benefits by an estimated multiplier (say 2.1) to obtain the total economic benefits of the investment.

The consensus of the economics profession is that such use of multipliers to inflate the benefits of dam investment is conceptually incorrect (Boardman et al., 2005), and we do not use this approach here. However, many of the benefits of a dam project do depend upon the completion of ancillary or associated capital investments. For example, hydropower generation from the dam will require transmission lines to carry the electricity to demand centers. If this transmission infrastructure has not yet been built, these costs will need to be incurred in addition to the costs of dam construction. Similarly, a dam may provide a controlled water supply than can be used to supply new irrigation schemes, but these irrigation schemes will need to be built, as will the infrastructure in the communities associated with them.

All of these attributes of investments in large dams serve to emphasize one of the main themes of this water and sanitation challenge paper: that the results of a cost-benefit analysis are highly contextual and site-specific. There are good and bad dam projects, and we do not attempt to reach any general conclusions about large dams. Rather we focus on a hypothetical investment in an authentic context in order to provide some illustrative calculations of the possible costs and benefits of a large dam in Africa, and to highlight some of the specific conditions that will influence these calculations. For this intervention, we present the costs and benefits at the project level; we do not feel that it is conceptually or intuitively appealing to present the benefits and costs of this intervention on a per-household basis.

The context for this hypothetical intervention is the Blue Nile gorge in Ethiopia; Sudan and Egypt are downstream riparians. This mountainous region offers numerous dam sites that appear extremely attractive from several perspectives. First, the topography is favorable for hydroelectric power generation, since there is potential for sending water at high pressure (gravity head) through power turbines, thus producing large amounts of power that could provide electricity for Ethiopia where current usage is less than 25 kWh per capita – as well as for export to both Sudan and Egypt. Second, many sites have low surface-to-volume ratios, with corresponding low evaporation losses. Third, relatively few people live in the Blue Nile gorge, and thus resettlement costs and social impacts would be low. Fourth, the land is not used for other highly productive activities, and thus the land acquisition costs would be low.[19] Fifth, although there would certainly be ecological costs associated with flooding a portion of the Blue Nile gorge, this is not an area of especially high biological diversity. Sixth, earthquake risks have been judged to be low. Seventh, the benefits of regulation to downstream riparians are high. Regulation of Nile floods in Ethiopia would benefit Sudan in several important ways. Khartoum itself would be less at risk of flood damage. Hydropower generation could be increased at Sudanese reservoirs by regulation uplift. Storage in Ethiopia could mitigate droughts in Sudan, as well as enable some expansion of irrigation. Reduction in sediment loads could extend the economic lives of Sudanese reservoirs and enable the use of less restrictive operating rules. Eighth, the hydropower that could be generated is needed in the region. Egypt, Sudan, and Ethiopia are all growing rapidly, and there is a strong market demand for electricity.

For our benefit–cost calculations we consider a single hypothetical reservoir located in the Blue Nile gorge. The results of these calculations encourage us to believe that support for large multipurpose dams in such attractive sites should definitely be back on the agenda for consideration by the international development community. But we caution that this conclusion is not a general endorsement of large dams everywhere. The equations we use for the benefit–cost calculations relative to the dam project are shown in

[19] We assume that the land will not become relatively more valuable in the future, i.e., the future opportunity cost of the land remains low.

Table 25; our parameter assumptions are listed in Table 26, and explanation of the components of costs and benefits follows.

Table 25. Intervention 3: Equations for Cost-Benefit Analysis of Large Dam.

Discounting factor in year *t*	$\delta_t = 1 / (1 + r)^{t-1}$ $\forall t = 1,\ldots, D$
Benefits	
Value of hydropower (millions of US$ in year *t*)	$H_t = \eta_{b,t} * (H_p + H_d) * v_h * (1+ \Delta v_h)^{t-8}$
Value of irrigation (millions of US$ in year *t*)	$I_t = \eta_{b,t} * (I_d * v_i) * (1+ \Delta v_i)^{t-8}$
Flood control (millions of US$ in year *t*)	$F_t = \eta_{b,t} * F*\lambda$
Value of carbon offsets (millions of US$ in year *t*)	$O_t = (\eta_{b,t} * (H_p + H_d) * p_o * \varepsilon) * (1 + \Delta v_O)^{t-8} / 10^6$
Total benefits	$B = \Sigma_t [\delta_t * (H_t + I_t + F_t + O_t)]$ $\forall t = 1,\ldots, D$
Costs	
Capital cost (US$ in year *t*)	$C_t = [\eta_{c,t} * (C_d + C_e)]$
Resettlement and economic rehabilitation (millions of US$)	$R_t = n * C_r$ if $t = 1$ $R_t = 0$ otherwise
Operation and maintenance cost (US$ in year *t*)	$M_t = C_o*(C_d + C_e) / D$ if $t > 7$ $M_t = 0$ otherwise
Cost of carbon emissions from flooding + construction (millions of US$ in year *t*)	$C_{O,t} = \eta_{c,t} * E$
Cost of catastrophic risk (US$ in year *t*)	Q_t = Cost of reconstructing dam + lost benefits
Total costs	$C = \Sigma_t [\delta_t * (C_t + C_{O,t} + R_t + M_t + Q_t)]$ $\forall t = 1,\ldots, D$

Table 26. Intervention 4: Parameters Used in Cost-Benefit Analysis of Large Dam Project.[a]

Symbol	Parameter	Base case	Lower limit	Upper limit	Correlated parameters
H_p	Hydropower generated at dam (GW-hr/yr)	8000	7000	9000	
H_d	Net gain in hydropower generated in Sudan and Egypt (GW-hr/yr)	250	-100	600	
v_h	Value of hydropower ($US/kW-hr)	0.05	0.03	0.07	
Δv_h	Annual change in value of hydropower starting in first year of operation (%, net of inflation)	0.5	0	1	
I_d	Change in timely irrigation water downstream (bcm/yr)	1.5	1	2	
v_i	Net value of timely water downstream ($US/cm)	0.075	0.05	0.10	
Δv_i	Annual change in value of timely water starting in first year of operation (%, net of inflation)	0.5	0	1	
F	Change in expected annual flood damage (millions of US$)	12	4	20	
λ	Decrease in probability of flood (%)	50	25	75	GW-hr/yr generated –-0.2)
p_o	Price of offsets (US$/ton CO_2)	20	15	25	
ε	Carbon offset factor	0.375	0.25	0.5	
Δv_O	Annual change in value of offsets starting in first year of operation (%, net of inflation)	0.5	0	1	
C_d	Capital cost of dam (millions of US$)	2500	2000	3000	
C_e	Capital cost of electrical transmission infrastructures (millions of US$)	1000	700	1300	Cost of infrastructure (0.5)
C_o	O&M expenditures (% annual capital cost)	50	35	65	Cost of infrastructure (0.5)
n	# Households displaced	10000	8000	12000	
C_r	Economic loss per displaced household (US$)	2300	1150	3450	
μ	Risk of catastrophic failure (%)	0.01	0.005	0.015	
E	Project emissions (millions of tons of CO_2)	4.5	3.5	5.5	
D	Dam project duration (yrs)	75	50	100	
d	Project delay (yrs)	2	0	4	
r	Real (net of inflation) discount rate (%)	4.5%	3%	6%	

[a] Our uncertainty analysis does not purport to use the real probability distributions associated with these parameters, but instead is aimed at assessing a range of possibilities for the illustrative case we consider in this section.

Discussion of Costs of A Large Multipurpose Dam in Africa

On the cost side we include the following components: direct construction costs of the dam and electricity transmission infrastructure, operation and maintenance costs over the economic life of the project, land acquisition costs, resettlement (compensation) costs to households currently living in the inundated area, risks of dam failure, and the cost of carbon emissions from construction and flooding of the reservoir area (with subsequent clearing of forested land, and decomposition of biomass). For the emissions from decomposition of biomass, we assume conservatively (in terms of the present value of the cost stream) that all carbon releases occur prior to the first year of reservoir filling, during construction, i.e., as land is cleared. We have not quantified costs associated with changes in ecosystem services.

We assume construction costs of US$2.5 billion over a 7-year construction period, plus an additional US$1 billion for transmission lines for electricity export. Many large construction projects experience both cost overruns and delays in completion. Only rarely do such projects finish under budget and ahead of schedule. For the purposes of the Monte Carlo simulations, we use an upper and lower bound on construction costs (US$2 billion and US$3 billion, respectively), just as we do on the other parameters in our cost-benefit calculations. In this case the lower- and upper-bound values establish a range from US$2 billion to $3 billion, and the base-case value of US$2.5 billion should be interpreted as including a "normal" cost overrun. We also allow for a construction delay of 0–4 years, with 2 years as the base case delay, for a total of nine years before any benefits begin to accrue from operation of the dam.

We assume that the annual operation and maintenance costs over the economic life of the project (75 years; range 50–100) would be 0.5% of the annual capital costs (range 0.35%–0.65%). Land acquisition costs are included in capital cost and are estimated to be about US$10 million. The compensation paid to displaced families is calculated as a multiple of average GDP per capita in Ethiopia based on costs observed in other locations around the world (Cernea, 1999). In the base case we use a multiple of 10 (range 5–15).

We include the risk of dam failure as an expected annual cost in every year over the economic life of the project, which we calculate by multiplying an estimate of the annual probability of failure (1 in 10,000 or 0.01%; range 0.005%–0.015%) times an estimate of the economic losses if dam failure were to occur. Our estimate of economic losses from dam failure is based on the cost of reconstruction plus the lost benefits over the period of reconstruction, and should be considered a lower bound since catastrophic damages from downstream flooding are not included.

Discussion of Benefits of A Large Multipurpose Dam in Africa

The main direct economic benefit of this hypothetical dam is the hydroelectric power generated, assumed to be 8000 gigawatt hours per year (range 7000–9000 GWh/yr). We assume that in the near and intermediate term these new electricity supplies will be exported to meet growing power demand in Sudan and Egypt. We thus value this hydropower generation at the cost of alternative supplies, which we estimate to be US$0.05 per kilowatt hour delivered to market (range US$0.03–$0.07). We expect that the economic value of this hydropower will grow over time in real (net of inflation) terms. We thus include a parameter to reflect this increase in the relative value of hydropower (base case 0.5%, range 0 to +1% /yr).

Other benefits include the carbon offsets from generation of carbon-neutral hydropower, the delivery of timely irrigation water and hydropower uplift downstream due to enhanced flow regulation, and downstream flood control benefits. For the carbon offsets, we assume the value to be US$20 (range US$15–25) and include the possibility of growth in the value of offsets (0.5%, range 0 to +1%/yr). In addition, hydropower generation in Sudan is estimated to increase by 600

GWh/yr (range 400–800 GWh/yr) due to the improved regulation of downstream flows that would result from a dam in the Blue Nile gorge.

The flood control benefits in Sudan are estimated as an annual benefit calculated as the expected value of reduced risk of floods times the anticipated flood damages. The reduction in the variability of flows that would result from a large hydroelectric dam in the Blue Nile gorge not only reduces flood damages in Sudan, it also increases flows during the summer, which benefit both navigation and irrigation. The value of this improved summer flow to irrigators is difficult to estimate, in part because increasing irrigation withdrawals in Sudan will correspond to some reduction in flows downstream. Determining upstream–downstream flow changes requires a system-wide analysis that takes account of the dynamics between changes in withdrawal patterns and evaporative losses, which is beyond the scope of these calculations. For purposes of illustration we assume that an additional 1.5 billion cubic meters of water would be used by Sudan annually as a result of this improved regulation (range 1–2 billion cubic meters (bcm)/yr), and that the system-wide value of this improved supply is US$0.075 per cubic meter (range $0.05–$0.10), or an annual benefit of US$150 million. We expect the relative value of this water to increase over time in real terms (base case 0.5%, range 0 to +1%/yr) as Sudanese irrigation practices undergo modernization. We assume that hydropower in Egypt would decrease by 350 GWhr/yr (range 200–500GWh/yr) as a result of these upstream withdrawals.

We do not include in our benefit estimates such difficult–to-measure outcomes as better diplomatic relationships between riparians where cooperative transboundary development is achieved, reduced risk of conflict over water resources, improved trade, and enhanced economic integration. We also do not include the benefits of sediment control, which could be substantial.

Figure 10 summarizes our assumptions about the time profile of costs and benefits associated with this dam project. We assume that the benefits from dam operation do not immediately reach 100% once the construction project is complete but instead increase over time as the reservoir fills. Economic analysis of dam projects often does not correctly account for the partial benefits that accrue during period after construction is completed while the reservoir is still filling. Ignoring the fact that benefits will be less while the reservoir is filling can substantially reduce the economic attractiveness of the investment (Block, 2006).[20]

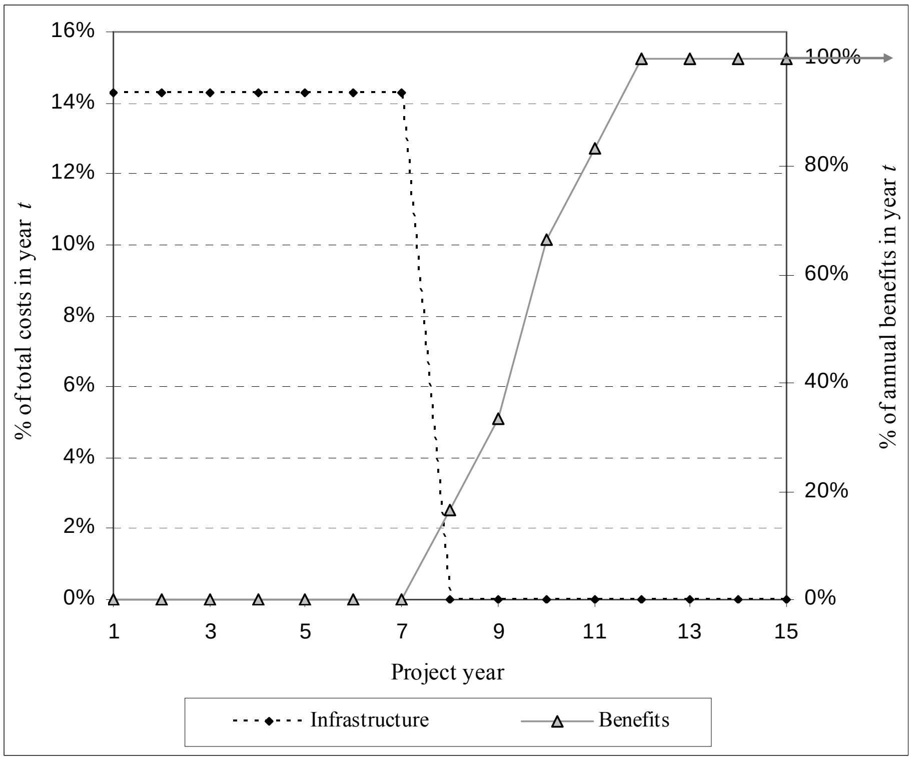

Figure 10. Intervention 4: Distribution of costs and benefits in time (η function from

[20] In fact, our calculations do not fully address the effect of filling a Blue Nile reservoir on the economic attractiveness of the investment. In order to adequately address this impact, a system-wide analysis similar to the one required for evaluating upstream-downstream changes in flow is necessary, because filling a large reservoir in Ethiopia would have impacts on dams and the water release patterns of all the reservoirs downstream of a dam in the Blue Nile gorge.

Table 25)

Comparison of Costs and Benefits of a Large Multipurpose Dam in Africa

The results for the base case show a benefit/cost ratio for the hypothetical large dam of 2.5 using a discount rate of 4.5% (Table 27). Figure 11 shows that the results are most sensitive to changes in the real discount rate, the economic value of the hydropower generated, the capital costs of the dam, and the annual rate of increase in the relative price of the hydropower generated.

Table 27. Base Case Results for Intervention 4: A Large Dam in Africa.[a]

	Physical units	Present Value of Benefit and Cost components ($US millions)		
Discount rate		3%	4.5%	6%
Benefits				
Hydropower at dam and downstream	+8250 GWhr/yr	$9643	$5958	$3907
Downstream irrigation in Sudan	+1.5 bcm/yr	$2630	$1625	$1066
Carbon offsets	3.1 million tons CO_2/yr	$1446	$894	$586
Flood benefits	50% flood reduction	$123	$77	$52
Total Benefits		$13842	$8553	$5610
Costs				
Capital	N/A	$3115	$2946	$2791
O&M	N/A	$511	$330	$225
Carbon emissions	4.5 million tons CO_2	$80	$76	$72
Resettlement	10,000 households	$22	$22	$22
Catastrophic Failure	0.01% risk of failure	$14	$10	$7
Total Costs		$3743	$3384	$3117
Benefit–Cost Ratio		3.7	2.5	1.8
Net benefits		$10099	$5170	$2493

[a] For the results reported here, all parameters were set at their base case values as described in Table 26, except for the discount rate, which was varied between 3%, 4.5%. and 6%. The values in the cells in the three rightmost columns report the present value of the components of the benefit and cost streams over the life of the project.

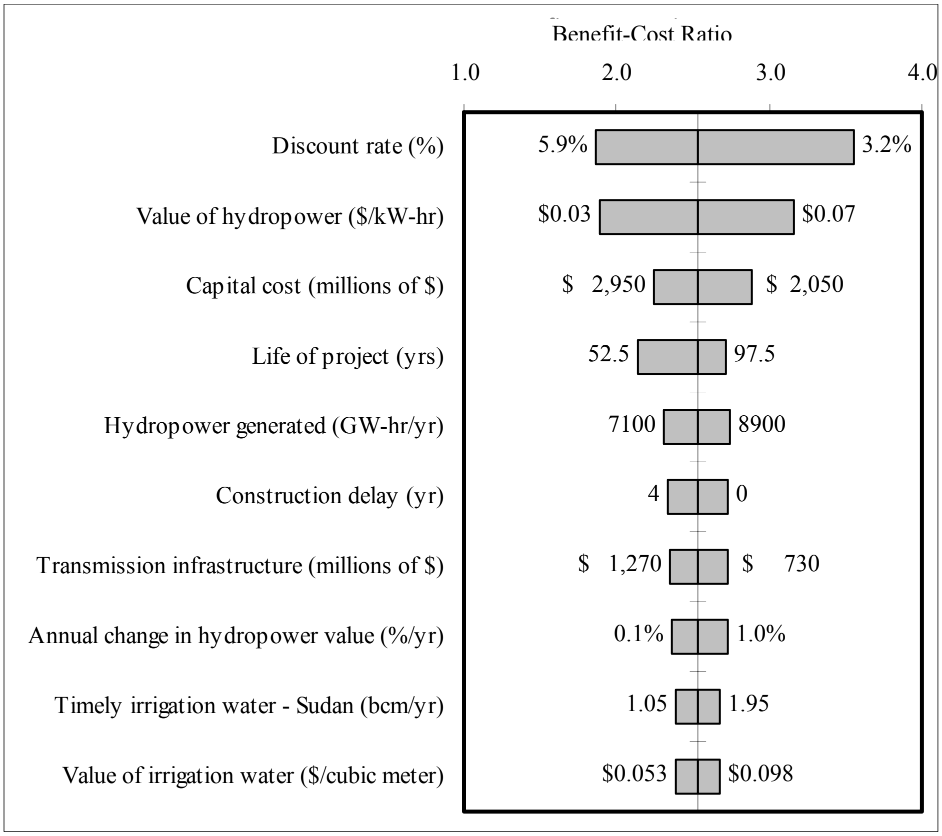

Figure 11. Intervention 4 Sensitivity Analyses: Effect of Selected Parameters on Benefit–Cost Ratio (BCR) (90% confidence intervals, holding other parameters at base case values).

Figure 12 represents the frequency distribution of the benefit/cost ratios from the Monte Carlo calculations. This frequency distribution suggests that this hypothetical large dam is extremely attractive from an economic perspective, even without including many of the more difficult-to-measure benefits (e.g., reduced risk of conflict over water resources, increased trade, and economic cooperation). The frequency distribution in Figure 12 is conceptually different from those presented for the first three water and sanitation interventions in the sense that the spatial location of the investment is much more precisely specified: the large dam is located at a site with the characteristics of the Blue Nile gorge of Ethiopia. For the other interventions, we used ranges for parameter values that one would expect to find throughout developing countries. The frequency distribution of benefit–cost ratios in Figure 12 thus does not show such a wide range; almost all of the BCRs are positive. These economic results thus appear more attractive than those for the other three interventions because the mass of the distribution is centered on high benefit–cost ratios.

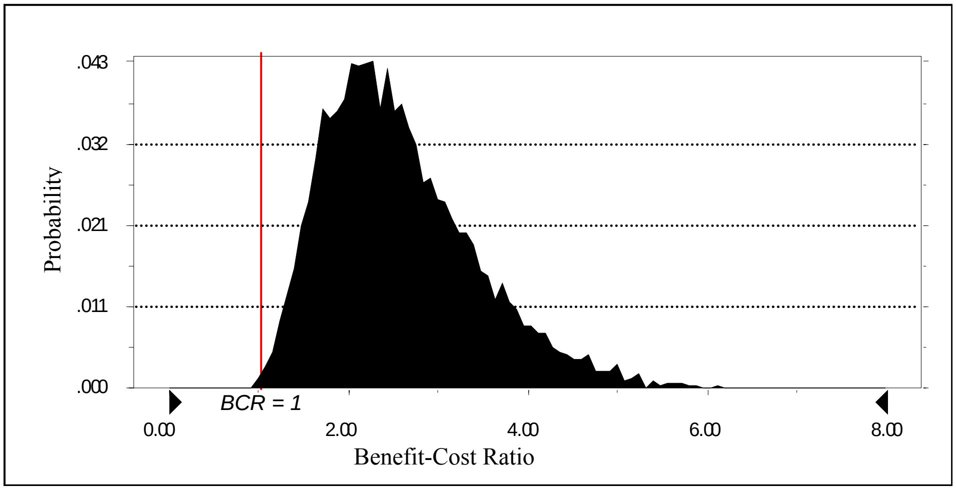

Figure 12. Distribution of Benefit-Cost Ratio (BCR) Outcomes from Monte Carlo Simulation (10,000 draws) with Uniform Parameter Distributions

Table 28 presents the mean values of the most important parameters for four groups of outcomes from the Monte Carlo simulations: those with BCRs (a) < 1, (b) 1–2.99, (c) 3–4.99, and (d) ≥ 5. As shown, in order for the intervention to have a BCR of < 1, essentially everything would have to go wrong. The hydropower generated would have to be less than expected, and its value would have to be low and not increase in value over the economic life of the project. The dam construction would have to run over budget and experience delays to completion. Most importantly, the social rate of discount would have to be higher than in our base case. But the combinations of parameter values that result in a BCR of <1 occur in only 0.1% of the outcomes from the Monte Carlo simulation.

Table 28. Intervention 4: Typology of Dam Project Outcomes Categorized by Benefit–Cost Ratio (BCR).[a]

Parameter	Unattractive (BCR < 1)	Attractive (BCR 1–2.99)	Very attractive (BCR > 3–4.99)	Extremely attractive (BCR > 5)
Real discount rate (%)	5.79 (0.21)	4.78 (0.79)	3.81 (0.59)	3.27 (0.25)
Value of hydropower (US$/kWh)	0.033 (0.003)	0.047 (0.011)	0.057 (0.009)	0.062 (0.006)
Capital cost (millions of US$)	2,835 (136)	2,547 (281)	2,392 (272)	2,203 (194)
Life of project (yr)	59.6 (7.6)	73.5 (14.5)	79.1 (13.4)	89.0 (8.6)
Hydropower generated (GWh/yr)	7692 (486)	7959 (574)	8103 (561)	8317 (530)
Construction delay (yr)	3.8 (0.6)	2.1 (1.4)	1.7 (1.4)	1.6 (1.5)
Transmission infrastructure cost (millions of US$)	1,155 (130)	1,022 (171)	944 (165)	862 (128)
Annual change in hydropower value (%/yr)	0.4 (0.3)	0.5 (0.3)	0.6 (0.3)	0.7 (0.3)
Percent of simulations (%)	0.1	72.2	26.3	1.3
BCR for "mean" of subgroup [b]	0.92	1.88	3.42	4.92

[a] Mean parameter values in first row, standard deviations in parentheses.
[b] The benefit–cost ratio corresponding to the case with the "mean" parameter values reported in each column, and other parameters set to base levels. The BCR can therefore lie outside the range predicted by the average values listed here, as in the extreme right column.

Our cost-benefit results show that a large dam under conditions like those in the Blue Nile gorge of Ethiopia would be an extremely attractive economic investment. Although we did not quantify the costs associated with changes in ecosystem services, these would have to be high to change this conclusion. In presenting this analysis we do not comment on the political feasibility (and associated process costs) of such an investment. Nor have we touched on the distribution of benefits and costs. How the benefits and costs of large dam development can be shared is a matter for negotiation and ultimately requires trust and regional cooperation.

Our results suggest that there may be very good sites for large multipurpose dam investments in Africa, and that support for these interventions deserves the consideration and engagement of the international community.

Discussion of the Costs and Benefits of the Four Water and Sanitation Interventions

In the second part of this challenge paper we have examined four water and sanitation interventions: (1) rural water supply programs providing poor rural communities in Africa with deep boreholes and public hand pumps, (2) "total sanitation" (CLTS) campaigns to halt open defecation in South Asia, (3) the biosand filter, a specific point-of-use (POU) water disinfection technology for household water treatment, and (4) a large, multipurpose dam in Africa. The first three interventions differ from the fourth in two related ways: they do not require the large capital cost of a network infrastructure, and they are best conceptualized as a prototype of a project that could be repeated in as many locations as needed. By contrast, the fourth intervention is a project that can be done once in a specific location. The probabilistic simulation analysis that we have performed thus has a different interpretation for the first three interventions than for the fourth.

The difference in interpretation hinges on the distinction between uncertainty and variability. With every intervention, there is inevitably some uncertainty regarding the appropriate parameter values to be used in the cost–benefit assessment. But an additional consideration arises for the first three interventions, namely variability: these interventions are intended for application in many separate locations. Even if the parameter values were known with certainty for any one location, these values necessarily vary with the circumstances of the different locations. Hence in these three cases the simulation analysis also characterizes the variability across applications in different locations. Another way of making this point is to say that if we knew the relevant parameter values with certainty (which, of course we do not), whereas there would be a single estimate of net benefit for the fourth intervention, a large dam at a particular site in Africa, there could not be a single global estimate of net benefit for the other interventions – boreholes, CLTS campaigns, and household treatment with biosand filters – because they each take place in many different locations with potentially large differences in individual circumstances. Hence one cannot say that a (for example) a sanitation campaign always has the same given net benefit regardless of the circumstances in which it is employed. The net benefit clearly depends on the specific circumstances.

Our simulation analysis for the first three interventions thus serves to identify the combination of circumstances – the combination of parameter values – that characterize a successful economic outcome and, also, the combination conducive to an unsuccessful outcome. In this final section of our water and sanitation challenge paper, we summarize and compare the results of the cost–benefit calculations of the first three interventions and then compare these three with the fourth. Table 29 lists the 8 parameters that (1) were used in the benefit–cost model for the first three water and sanitation interventions, and (2) were assumed to have the same values in each of the interventions. Table 30 lists 10 parameters that had important effects on the benefit–cost ratios of one or more of the interventions. For example, the parameter "reduction in diarrheal disease" was used in the cost-benefit calculations for all three interventions and had an important influence on the BCR of all three. However, from the available empirical evidence, we assumed that the biosand filter intervention would result in a larger reduction in diarrheal incidence than either the deep borehole plus hand pump or the CLTS intervention. Similarly, the duration of the intervention was a parameter in all three interventions, but a different base case parameter value was used for each intervention.

Table 29. Parameters with the Same Values in Each of the Three Community Water and Sanitation Interventions and Base Case Assumptions.

Parameter	Base case (range)	Units
Household size	5 (4–6)	people
Market wage for unskilled labor	1.25 (0.5–2.0)	US$/day
Value of time / market wage	0.3 (0.1–0.5)	None
Diarrhea incidence	0.9 (0.5–1.4)	cases/person-yr
Cost of illness	6 (2–10)	US$/case
Case fatality rate	0.08 (0.04–0.12)	%
Value of a statistical life	30,000 (10,000–50,000)	US$/statistical life
Discount rate	4.5 (3–6)	%

Table 30 illustrates some important differences between the interventions. The benefits from the rural water supply intervention are assumed to last longer (15 years) than those for the biosand filter intervention (8 years) or the CLTS intervention (6 years). On the other hand, annual operation and maintenance costs for the rural water intervention are significantly higher than for the biosand filter and CLTS interventions. The initial capital cost for the rural water supply intervention is also higher than for the biosand filter and CLTS interventions.

Table 30. Parameters with the Greatest Effects on the Benefit–Cost Ratios: Comparison of Assumed Values (with Ranges) Across the Three Community Water and Sanitation Interventions.

Parameter	Borehole + Hand Pump		CLTS		Biosand Filter	
Reduction in diarrheal disease (%)	30	(10–50)	30	(10–50)	40	(20–60)
Duration of intervention (yrs)	15	(10–20)	6	(3–9)	8	(6–10)
Upfront investment: program + capital	$10,000	(7,000–13,000)	~$55/hh	(4–12)[a]	$100/hh	(75–125)[a]
Training time (hr/hh)	N/A		10	(5–15)[b]	8	(4–12)
Operation and maintenance costs (US$/yr)	600	(250–950)	0	(None)	0	(None)
Operation and maintenance time (hr/yr)	See above		10	(5–15)	3.5	(1.5–5.5)
Time spent, traditional situation	1 hr/20L	(0.1–1.9)	15 min/d	(10–20)	N/A	
Time spent, improved situation	0.3	(0.1–0.5)	0	(None)	N/A	
Usage	100		70	(50–90)	–2%/yr	(1–3)
Uptake	N/A		40	(20–60)	N/A	

[a] For both the CLTS and the biosand filter intervention, program costs represent the major fraction of the investment; the latrines and biosand filters cost roughly $8 and $20 per unit, respectively.
[b] Only for participating households; nonparticipating households assumed to spend 3 hours (range 2–4 hrs).

The three interventions also differ in important dimensions not shown in Table 30. The biosand filter intervention has the advantage that the benefits from household treatment are entirely under an individual household's control. Collective action by the community is not required. In contrast, the rural water supply intervention requires the active, continuing involvement of a village water committee in the management of the borehole and hand pump to ensure long-term successful performance. In fact, some proponents see this institutional aspect of the rural water intervention as an advantage rather than a limitation, because village water committees may learn to organize and work together to achieve other common goals. The CLTS intervention requires considerable collective action at the beginning of the program, but potentially less after household toilets are constructed. However, little is known about how latrine usage rates change over time in the absence of ongoing community management programs.

Table 31 summarizes the components of the benefits and costs in terms of US$ per household per month, and the benefit–cost ratios for each of the three interventions for the base case parameter values (assuming a discount rate of 6%). As shown, all three interventions have very attractive BCRs. The rural water supply intervention has the largest (3.4), followed by the biosand filter (2.9), then CLTS (2.8).[21] We do not consider the differences in BCR across these interventions to be of much significance given the approximate nature of the calculations. There are, however, important differences in the various components of benefits (Figure 13) and costs (Figure 14) across the three interventions. This has implications for where these interventions will be most attractive.

The rural water supply intervention is the most expensive (US$2.26 per household per month), with larger up-front capital costs (Figure 14) than the biosand filter or CLTS interventions. But it also yields the largest benefits (US$7.19 per household per month). Most of the benefits from rural water supply in the base case come from the value of time savings and the value of reduced mortality. Thus the rural water intervention is attractive from an economic

[21] Note that in Table 31 the monthly household benefits for the borehole plus public hand pump intervention are over $7, and thus approach the low end of the range of costs for technologies for network services. However, the borehole plus hand pump intervention is most likely to be an economically attractive investment in places where time savings are substantial, and people do not have easy access to alternative sources. In such locations the costs of network infrastructure are likely to be higher than the costs presented in Tables 1 and 2 because such sites would generally be rural, with low population densities, and there would be few economies of scale in providing network services. In urban areas where economies of scale are possible, boreholes and hand pumps would typically yield few if any time savings benefits, and the health savings would be greatly diminished because people have other water options and nearby health services.

perspective because it has the potential to deliver both health benefits and time savings. CLTS does result in some time savings, but not to the same extent as the rural water intervention in our base case. The benefit–cost ratio of the rural water intervention has been dramatically improved in the past decade by the presence of low-cost Chinese contractors operating in Africa.

Table 31. Comparison of the Components of the Benefits and Costs of the Four Water and Sanitation Interventions (US$/hh-month).[a]

Benefit–Cost Category	Rural water	CLTS	Biosand Filter	Large dam
Benefits				
Time savings	3.28	0.20	0	
Quantity/aesthetic	0.54	0	0	
Morbidity	0.68	0.19	0.77	
Mortality	2.70	0.76	3.09	
Total Benefits	7.19	1.14	3.86	
Costs				
Capital, training and program	1.43	0.37	1.34	
Maintenance costs	0.83	0	0.05	
Household time costs	0	0.05	0.01	
Total Costs	2.26	0.43	1.40	
Net Benefits	4.93	0.74	2.45	
Benefit–Cost Ratio (BCR) [b]	3.2	2.7	2.7	1.8

[a] Assuming 6% discount rate.
[b] BCRs for the first three water and sanitation interventions do not pertain to any specific location in developing countries; instead they represent outcomes given the average, base case parameter values described in Part II of this paper. In contrast, the BCR for the large dam intervention does pertain to one specific, illustrative project location.

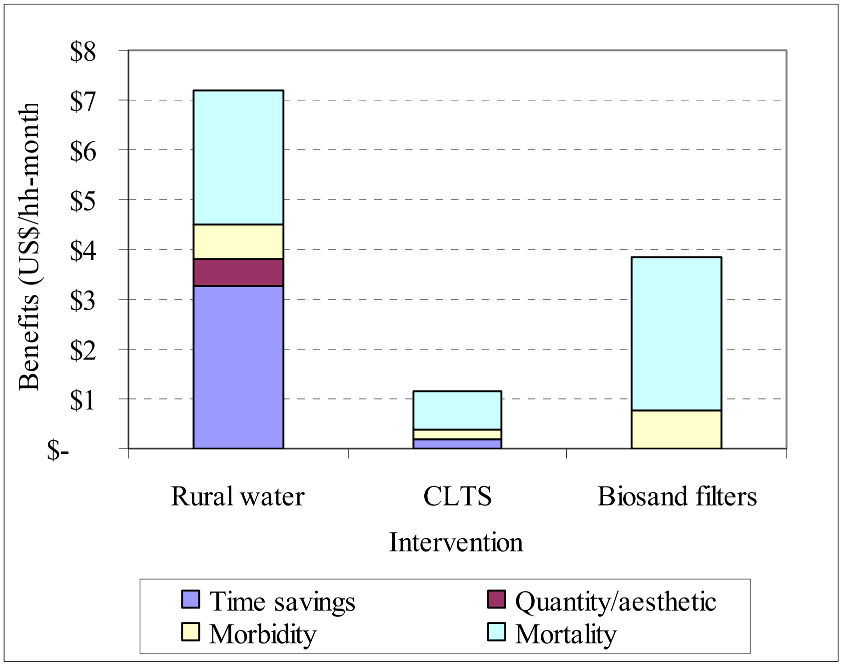

Figure 13. Components of the Benefits of Three Water and Sanitation Interventions: Base Case Parameter Values

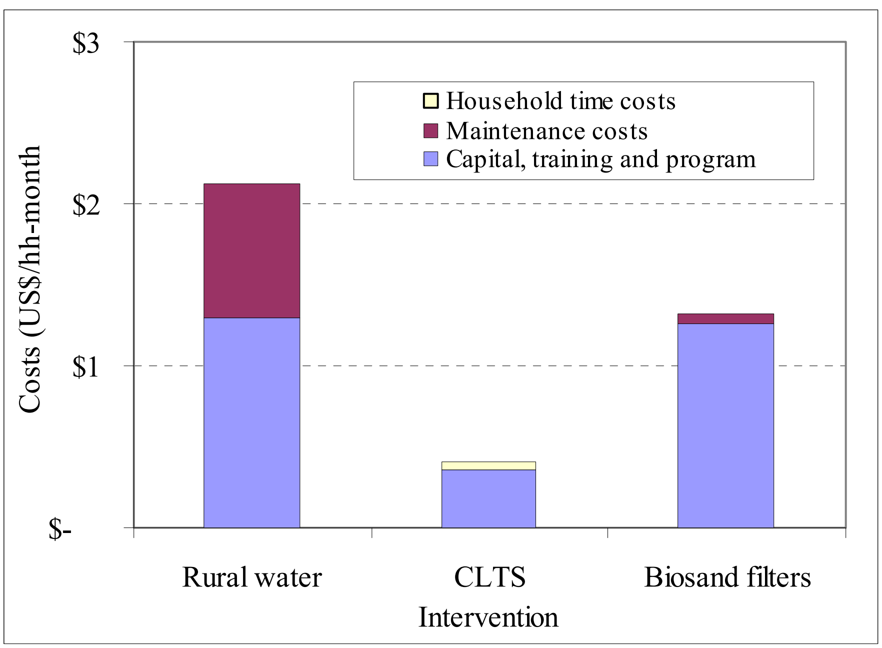

Figure 14. Components of the Costs of Three Water and Sanitation Interventions: Base Case Parameter Values

The majority of the benefits of CLTS (67%) and the biosand filter (80%) are in the form of reduced mortality. For all three interventions, the value of the reduced mortality benefits is heavily influenced by the assumed value of the VSL parameter. The economic value of reduced morbidity (avoided costs of illness) is a small percentage of the total benefits for all three interventions: 9% for rural water, 17% for CLTS, and 20% for the biosand filter (Figure 13). We emphasize, however, that the avoided COI measure of economic benefits does not account for pain and suffering, and that both these measures of health benefits suffer from shortcomings when behavioral responses to illness such as coping and averting expenditures reduce the risk of disease.

Figure 15 shows the frequency distribution of the benefit–cost ratios for all three water and sanitation interventions from the Monte Carlo simulations; Figure 16 shows the same information in the form of cumulative frequency distributions. Both figures illustrate the apparent similarity of the three interventions. The biosand filter intervention has the fewest combinations of parameter values for which the BCR is < 1. The rural water intervention has the largest number of combinations of parameter values with high BCRs. However, it is again important to emphasize that these frequency distributions do not correspond with the frequency of outcomes for real locations (communities) in developing countries, but rather are the result of our assumed combinations of parameter values. The planning challenge is to find locations in the real world with high BCRs like those shown in Figures 15 and 16 for each of the three interventions, and to avoid locations with BCRs < 1. A location that is particularly favorable for one intervention may or may not be for another. It may also be difficult to determine which sites are favorable or unfavorable due to a paucity of data for the key parameters in our cost-benefit calculations. Particularly for calculations of mortality benefits, there is great uncertainty surrounding the four key parameters (VSL, case fatality rates, diarrheal incidence, and percentage reduction in diarrheal incidence due to an intervention) for any specific location or region. But the large number of combinations of parameter values with positive BCRs should give planners wide latitude for action in the face of such uncertainty.

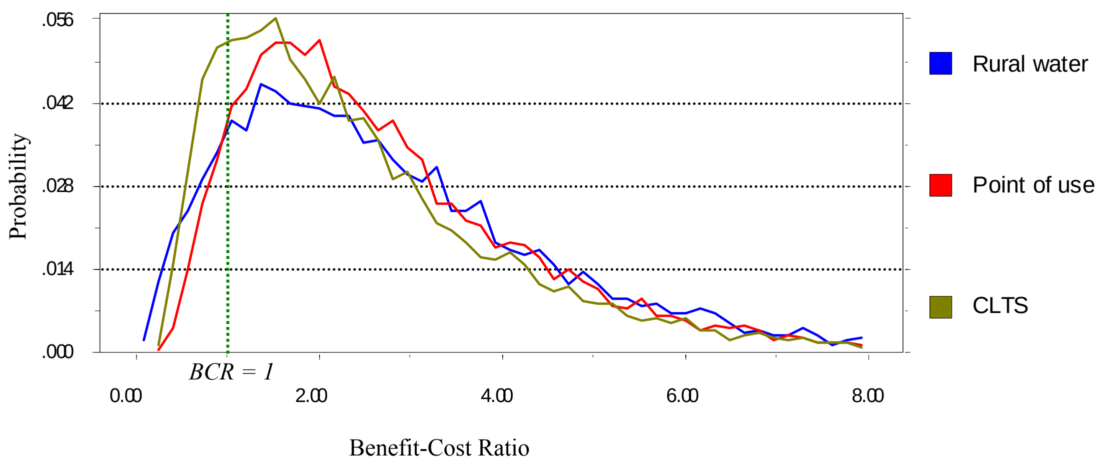

Figure 15. Frequency Distribution of the Benefit–Cost Ratios for the Three Water and Sanitation Interventions

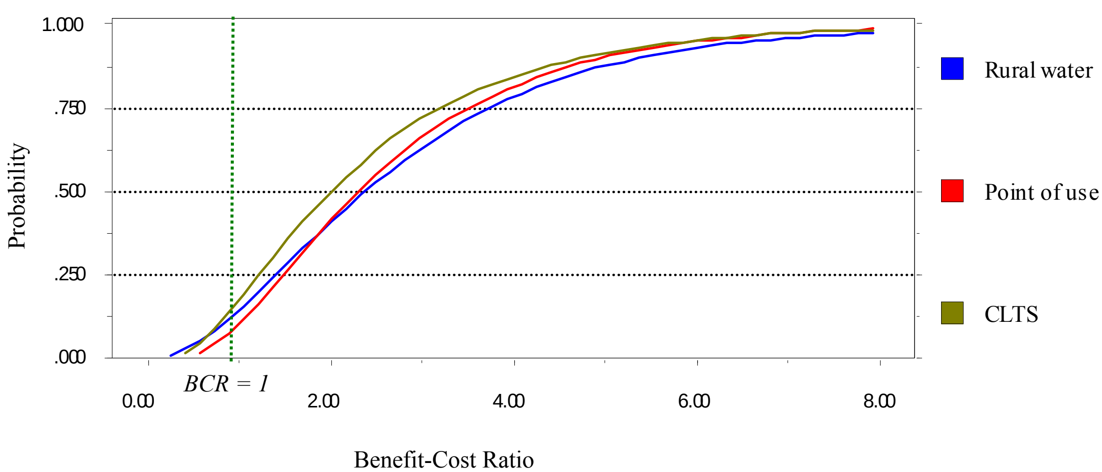

Figure 16. Cumulative Frequency Distribution of the Benefit–Cost Ratios (BCRs) for Three Water and Sanitation Interventions

On the other hand, this large uncertainty on key parameters is a strong argument to maintain the demand-driven focus of the rural water intervention, and to extend it to both the biosand filter and the CLTS interventions. Sizeable community and household cash contributions to finance all three interventions can serve as important "demand filters" to ensure that after people receive the health education and other "software" messages designed by planners, the people themselves are convinced that these interventions will prove valuable in their local circumstances. Our benefit–cost calculations suggest that there will be places where each of the three water and sanitation interventions should not be undertaken. Demand filters are an important means of identifying such communities and avoiding investing in interventions where they are not needed or desired.

The rural water supply intervention has the advantage that the distance households are walking to traditional sources to collect water and the time spent queuing at water points are much more easily observable than VSLs, case fatality rates, diarrheal incidence, and percentage reduction in diarrheal incidence due to an intervention. On the other hand, the economic value of these time savings is difficult to estimate. The presence of water vendors in an area with high water collection times from traditional sources is tangible, compelling evidence that some households are willing to pay to avoid the time spent collecting water from traditional sources. Similarly the absence of widespread water vending can often be interpreted as evidence that households cannot pay much for such time savings.

Both the rural water and the biosand filter interventions appear to be scalable to large numbers of communities in developing countries. The biosand filter has the advantage that it can be used by households in both rural and (low density) urban areas. Deep boreholes with hand pumps are not likely to be attractive in large urban settlements because of the risks of (1) contaminated groundwater, and (2) falling water tables (if large numbers of households in close proximity rely on wells). Even in rural areas, the use of deep boreholes is limited by groundwater and geologic (drilling) conditions. This is not true of the biosand filter, which can be used essentially anywhere except very high-density urban settlements (where finding space for the filters may be difficult).

The CLTS intervention has been shown to be scalable in South Asia. It is unclear how this intervention might work in Africa or Latin America, but there is no reason to be pessimistic in this regard. Sanitation and hygiene promotion messages should be adaptable to local cultures. Table 31 also shows the benefit–cost ratio for the base case for the fourth intervention, a large multipurpose dam in the Blue Nile gorge in Ethiopia. Although in the base case the BCR of this large dam investment is less than for the first three interventions, it is still extremely attractive from an economic perspective. We would not conclude that this fourth intervention should receive a lower priority than the first three simply on the basis of this simple comparison of base case results in Table 31. The scalability of these investments is too different and the variability in the results too site-specific to make global statements about the desirability of one type of intervention over another.

Concluding Remarks

In Part I our findings suggest that the high costs and unique characteristics of network water and sanitation investments make them especially challenging projects for many communities in developing countries. Some, but not all, water and sanitation network infrastructure projects will pass a rigorous economic test. In cities in rapidly growing economies, we expect the benefits of many projects, properly estimated, to exceed the costs. In other cases, however, the economic reality will be more nuanced and the attractiveness of specific water and sanitation investments in network infrastructure less clear-cut.

We believe that all four of the interventions discussed in Part II (rural boreholes and hand pumps, community-led total sanitation, point-of-use treatment with biosand filters, and large dams in Africa) hold considerable promise for improving the economic livelihoods and health conditions of hundreds of millions of people in developing countries. None of these interventions, however, is a panacea. The success of each intervention will depend on the specific context in which it is implemented. The social context matters, as well as the physical and economic contexts, particularly where behavioral change is required for positive outcomes. We believe that the first three, non-network interventions discussed in Part II should be viewed as intermediate, not long-term solutions to the water and sanitation problems of rapidly urbanizing societies in developing countries. Governments and donors should let people themselves decide whether such non-network options are preferable to waiting for network solutions to their water and sanitation problems. The fourth intervention, large dams in Africa, deserves renewed attention.

In communities where economic growth proceeds, we have little doubt that households and firms will ultimately want the advantages of large-scale, piped network infrastructure for the delivery of modern water and sanitation services, and they will struggle to finance these highly capital-intensive investments – a struggle that played out in the U.S. over much of the nineteenth century and beyond, as described above. With time, however, the benefits of these water and sanitation investments may grow. There is limited evidence that investments in municipal water and sanitation services actually *cause* economic growth, but the sequencing of significant water investments could possibly set in motion path dependent patterns of development that will change the expected returns to, and hence incentives for, subsequent investments in other sectors of the economy. Moreover, there is a strong association between household income and the provision of both piped water and sewer services. Higher-income households definitely want improved water and sanitation services, and, as incomes grow, the demand for such services grows. So even in the absence of a causal relationship, the benefit stream of water and sanitation services becomes more valuable as economic growth proceeds.

This paper demonstrates the extremely broad range of interventions that can be classified in the 'water and sanitation' sector. The breadth of these options, the range of their potential returns, and the strong dependence on the specific circumstances of each project's design and implementation underscore the fact that there can be no single benefit-cost ratio for water and sanitation. No sectoral-level analysis can replace rigorous, project-level economic analysis. Each water and sanitation investment is unique and must be designed for its specific context and judged on its specific merits.

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