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Household Water Resources and Rural Productivity in Sub-Saharan Africa: A Review of the Evidence

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Abstract

The benefits and costs of providing a safe, convenient, and reliable water supply to households in the developing world have been the subject of a vast and wide-ranging research effort for at least four decades. Despite the quantity of studies carried out, relatively little is known about a number of key aspects of household water use. In particular, the productivity cost to households of having an inadequate water supply, measured in terms of the quantity and quality of labor lost as a result, has rarely been examined carefully. There is also relatively little known about water use in rural areas, as most research has focused on the developing world's rapidly expanding cities. Among the regions of the world, both of these research gaps are most acute for sub-Saharan Africa, the region whose population is the most rural and has the least access to an improved water supply.

This paper reviews and summarizes the results of studies of household water use in rural areas of sub-Saharan Africa that offer clues to the effects of household water resources on rural productivity. Findings are presented on the extent of household access to safe water supplies, household water use, the costs of water-related diseases, the time costs of collecting water from distance sources, and the costs and benefits of interventions to improve household water supplies. Most studies indicate that household water use in sub-Saharan Africa averages only about 10 liters/person/day, far less than is needed for proper hygiene practices. Water-related diseases account for between 10 percent and 12 percent of all morbidity and mortality in sub-Saharan Africa. Households (and primarily women) spend an average of 134 minutes/day collecting water, and time saved by bringing water supplies closer to households is likely to dominate estimates of the benefits of improving rural water supplies. Data on the current and future costs of water-related diseases; the opportunity cost of time spent collecting water and lost to sickness or caring for the sick; and what kinds of water supply, sanitation, and hygiene interventions, in what sequence, produce the greatest health benefits are poor, and further research on these issues is needed.

Keywords: sub-Saharan Africa, domestic water supply, water-related disease, household labor allocation, rural productivity.

JEL codes: I12, R20, Q25

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Household Water Resources and Rural Productivity in Sub-Saharan Africa: A Review of the Evidence

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1. Introduction

The benefits and costs of providing a safe, convenient, and reliable water supply to households in the developing world have been the subject of a vast and wide-ranging research effort for at least four decades. Most of this research has focused on the relationship between water and disease, the efficacy of water supply projects in improving health, and the financing of water supply infrastructure.

Despite the quantity of studies carried out, relatively little is known about a number of key aspects of household water use. In particular, the productivity cost to households of having an inadequate water supply—measured in terms of the *quantity and quality of labor lost as a result*—has rarely been examined carefully. There is also relatively little known about water use in rural areas, as most research has focused on the developing world's rapidly expanding cities. Among the regions of the world, both of these research gaps are most acute for sub-Saharan Africa—the region whose population is the most rural and has the least access to an improved water supply.

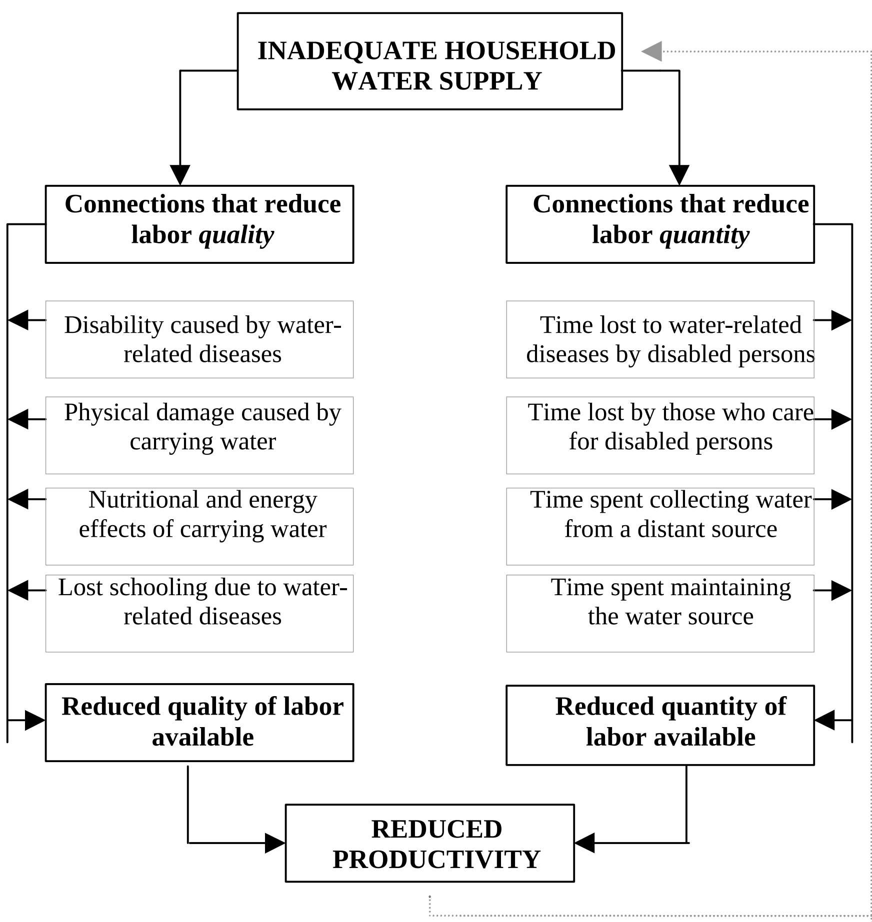
This paper reviews and summarizes the results of studies of household water use in rural areas of sub-Saharan Africa that offer clues to the effects of household water resources on rural productivity. We attempt to consider all the possible ways that household water supplies could affect productivity and to present whatever evidence on these links is available. The purpose of the review is to identify which of the connections between water supply and productivity are likely to be most important for rural households in Africa and to indicate where further field research is needed most.

The rest of this paper is organized as follows. This section continues with a brief description of the links between household water supplies and productivity and of the scope of our review. The next two sections summarize current data on access to safe water in rural areas of sub-Saharan Africa and on household water use. Section 4 then discusses the health costs of rural water supplies, combining information on the burden of water-related diseases in Africa, the productivity costs of these diseases, and the impact of water supply interventions. The costs of collecting water from distant sources are examined in Section 5. Section 6 reviews the cost and cost-effectiveness of water supply interventions. The paper concludes with a summary of our findings and recommendations for further research.

Links between household water supplies and productivity

The productivity implications for households of not having an adequate supply of water for domestic uses (drinking, cooking, dishwashing, bathing, laundry, and cleaning) can fairly comfortably be separated into two general categories: the costs to households of water-related diseases, and the costs associated with the collection of water from a distant source. Figure 1 illustrates the most important paths that lead from a household's water supply to the health and water collection costs it incurs to the quantity and quality of labor available for the household to employ for productive activities.

Figure 1: Connections between household water supplies and labor availability



Sections 4 and 5 of this paper explore what is known about each of these links in detail.

Scope of the review

As noted above, our review focuses on the connections between household water supply and the quantity and quality of labor available in rural areas of sub-Saharan Africa. Most of these connections link water supply either to health costs or to the costs of collecting water from a distant source, and these are the issues that this paper addresses.

A third set of issues—those specific to sanitation services—are generally beyond the scope of this paper, but they are closely related to questions of household water supply. Improvements in water supply and sanitation services often cannot be considered in isolation from one another. Sanitation will be discussed in this paper whenever evidence is found on "water supply and sanitation" as an inseparable unit and when we consider the efficacy and cost-effectiveness of water supply improvements and sanitation improvements as alternative means of reducing the burden of water-related diseases. Sanitation data will also occasionally be provided for comparison. Our review did not include a thorough search for evidence on sanitation and productivity in sub-Saharan Africa, however, and this paper should not be regarded as a reference on this topic.

The review had other limitations that should be noted. We looked only at research conducted in sub-Saharan Africa. Besides omitting sanitation, we made no attempt to consider agricultural or industrial water supplies, urban areas, institutional issues, water supply technology, financing of water supply infrastructure, water pricing, or political issues. Materials reviewed were identified through a search of the English-language published and gray literature available to us from our location at a U.S. university. We did not have access to research carried out in Africa by African universities, government agencies, or research centers unless the results were published in an international journal or by an international organization.

The unit of analysis on which this paper concentrates is the household. The question of what constitutes a "household" is open to debate, especially when the geographic area of interest is an entire continent. Berman et al. (1994) provide a good explanation of why the household is the most appropriate level of analysis, though not the only relevant one, for work on public health. They note, "we feel that household processes are becoming more critical as determinants of impact as health interventions increasingly rely on behavior change to produce benefits. There is ample evidence of success in providing access to health-improving inputs but failure in their appropriate use …. [The household] is the unit to which many public health interventions are addressed, often depending on the internal processes of households for their success." The household is also the relevant unit when considering the cost of disease in terms of the quantity and quality of labor available, since households often replace the labor of sick workers with that of other household members. Following the advice of Berman et al. (1994), we will define the household on the basis of the functional criterion that is of interest to us: domestic water supply. For the purpose of this paper, a household is a group of people who secure their water for drinking, cooking, washing, etc. from a common source and from one or more common carriers of water.

Before moving into the review, it is important to emphasize the small number of studies that met the criteria for our search. Information on household water supply and productivity in rural areas in Africa is limited to a handful of original studies, which continue to be cited and recycled in the literature.[1] Foremost among them is *Drawers of Water* (White, Bradley, and White 1972), which reported the results of a data collection effort spanning 34 sites in three countries over three years. *Drawers of Water* remains the most comprehensive and compelling account available of the economics of water use in rural Africa. It figures prominently in the review that follows, as do a handful of smaller studies that build upon its findings.[2]

2. Access to Water for Rural African Households

Based on the most recent data available—which in many cases are not very recent—approximately 250 million people in rural areas of sub-Saharan Africa lack a safe and accessible water supply. This constitutes some 67 percent of the total rural population. Sanitation coverage is even poorer: 81 percent of the rural population do not have sanitation facilities.

Table 1 summarizes available data on a country-by-country basis. It includes urban and sanitation figures for comparison purposes. Access to a safe water supply ranged from a reported low of 8 percent among the rural population of Congo to a reported high of 92 percent in Mauritius. For several countries, the most recent figures date from the early or mid 1980s.

[1] The exception to this is studies of the immediate health impacts of individual water supply investment projects, of which there are many.

[2] The International Institute for Environment and Development (IIED) in London is currently revisiting the *Drawers of Water* sites in eastern Africa as part of a study entitled "Domestic Water Use and Environmental Health in East Africa: Three Decades After *Drawers of Water*." Results of this study are not yet available.

Table 1: Access to safe water and sanitation in sub-Saharan Africa

Country name	Safe water				Sanitation	
	Year of most recent data	Rural population with access	Percent of rural population with access	Percent of urban population with access (a)	Year of most recent data	Percent of rural population with access
Angola	1988	1,144,245	18	75	1988	20
Benin	1993	1,948,162	63	82	1993	7.2
Botswana	1993	526,084	53	100	1993	41
Burkina Faso	1988	1,879,443	26	50	1988	5
Burundi	1993	3,045,384	55	97	1993	47
Cameroon	1993	1,713,229	24	71	1993	21
Cape Verde	1990	64,199	34	75	1990	9.7
Central African Republic	1988	245,854	14	29	1985	9
Chad	1982	1,136,684	30	27	1994	16
Comoros	1982	142,585	52	99	1990	80
Congo	1993	86,333	8	94	1993	7
Congo Dem. Rep. (Zaire)	1988	4,031,957	16	62	1988	9
Cote d'Ivoire	1993	5,563,359	73	97	1982	20
Djibouti	1990	13,611	14	27	1990	50
Equatorial Guinea	1993	108,465	48	10	1993	52
Eritrea	no data available					
Ethiopia	1993	9,277,942	20	90	1985	5
Gabon	1993	161,256	30	80	1993	66.8
Gambia, The	1993	678,827	86	87	no data available	
Ghana	1993	4,815,482	46	76	1993	11
Guinea	1993	2,295,395	51	78	1993	10
Guinea-Bissau	1993	378,374	47	18	1993	19
Kenya	1993	8,059,048	43	74	1993	35
Lesotho	1990	576,003	40	90	1990	30
Liberia	1988	346,657	25	50	1988	0.5
Madagascar	1990	889,406	10	55	1990	3
Malawi	1993	3,297,919	41	91	1993	68
Mali	1993	1,713,716	25	42	1990	30
Mauritania	1993	905,402	86	49	1988	18.1
Mauritius	1988	564,651	92	100	1988	96
Mozambique	1993	1,766,069	17	44	1993	12
Namibia	1993	351,481	37	97	1993	15
Niger	1990	3,350,924	54	58	1988	4.2
Nigeria	1993	7,192,916	11	69	1993	44.5
Reunion	no data available					
Rwanda	1985	3,444,653	60	55	1985	60
Sao Tome & Principe	1990	39,885	61	100	1990	7
Senegal	1985	1,068,896	27	63	1982	2

Country name	Safe water				Sanitation	
	Year of most recent data	Rural population with access	Percent of rural population with access	Percent of urban population with access (a)	Year of most recent data	Percent of rural population with access
Seychelles	1993	21,061	80	99	1993	99
Sierra Leone	1988	532,936	20	85	1988	20
Somalia	1985	1,391,247	22	57	1985	5
South Africa	1993	13,830,232	70 (b)	70(b)	1994	12
Sudan	1993	14,086,913	73	89	1993	44.5
Swaziland	1993	251,301	42	80	1985	25
Tanzania	1993	9,677,232	45	65	1993	83.4
Togo	1990	1,349,468	54	64	1990	10
Uganda	1988	1,637,104	12	45	1988	10
Zambia	1993	2,006,037	43	76	1993	34
Zimbabwe	1993	4,748,321	65	99	1993	50

Source: World Health Organization (1996a)

Notes:
(a) Figures for urban water access are for years other than those listed for Equatorial Guinea (1990), Mali (1990), Niger (1993), Sierra Leone (1990), and Togo (1993).
(b) Percent coverage includes both rural and urban areas in South Africa.

The data in Table 1 are officially reported figures from each country's government or the relevant WHO regional office and are widely cited as a measure of the magnitude of the domestic water supply problem. Some of the figures—such as the reported 73 percent access to safe water in rural Sudan—should raise concerns about data quality. In addition to problems with the accuracy of the data, information for many countries is well over a decade old, and significant changes—either improvement or deterioration—have occurred in many cases. In Chad, for example, the most recent "official" WHO estimate of safe water access in rural areas is from 1982 and is 30 percent; twelve years later, in 1994, the estimate from another WHO database was 17 percent. Alternative estimates from other United Nations databases are generally a little more recent than the "official" figures. According to the WHO, a new set of data were collected by 1997 and will be published in late 1998 (WHO 1996a).

Even if the data are accurate, their practical value is limited, because aggregate data on water supply coverage do not specify what level of service constitutes "adequate access to safe water." The WHO states that its data refer to the "proportion of the population with access to an adequate amount of safe drinking water in a dwelling or located within a convenient distance from the user's dwelling." An adequate amount is specified as 20 litres of safe water per person per day, while "reasonable access implies that the housewife does not have to spend a disproportionate part of the day in fetching water for the family's needs." A distance of 200 meters is regarded as a convenient distance. "Safe water" includes untreated water from protected boreholes, springs, and wells, but not generally from lakes or streams (World Health Organization 1996a).

The range of household water supplies that fall under the definition of "safe and accessible water supply" is thus quite broad, and it includes many situations that do not produce the health and time-saving benefits implied by "safe water." As the discussion of water usage below indicates, a communal standpipe that supplies water of good quality but is located 200 meters from the user's dwelling may confer relatively few health benefits. A nearby but non-functioning or unreliable tap would also have disappointing results. If a definition of an "accessible water supply" that better reflects what households regard as accessible were used, the percentage of the rural population in sub-Saharan with access to a safe water supply would decrease significantly (Sharma et al. 1996), in some cases very close to zero.[3]

The expansion of safe water supplies in rural areas of sub-Saharan Africa is not keeping pace with rural population growth in many countries. Table 2 uses available data to indicate trends in access. Whenever possible, we analyzed the eight-year period from 1985 to 1993, but for many countries the period considered is only 3-5 years. We did not include data from before 1982. Due to the differences in the time period, the change in the absolute number of rural residents without access to a safe water supply cannot simply be summed across countries to arrive at a regional estimate. Table 2 does suggest, however, that many countries are losing ground in the effort to reduce the number of people in rural areas who rely on a distant and/or unsafe water supply. The percentage of the rural population *without* access to safe water increased in 10 countries, remained the same in 2, and decreased in 27. Due to population growth, the absolute number of people in rural areas without access increased in 20 countries and decreased in just 19.

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[3] Sanitation access suffers from the same problem. Access to sanitation is defined as "At least adequate excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta. Suitable facilities range from simple but protected pit latrines to flush toilets with sewerage" (WHO 1996). As a result, "In Uganda, for example, pit latrines are counted as sanitary, and the latest Demographic and Health Survey (DHS) shows 80% of households with access. But if pit latrines are not counted, the level of access shrinks to a mere 3%" (Unicef 1997).

Table 2: Changes in rural population *without* safe water since the mid-1980s

Country name[a]	Years		Rural population		Rural population *without* safe water			
			Total	Percent change over period	Total	Percent of total rural population	Percent change over period	Absolute change over period
Angola	*From*	1985	6,042,265		5,148,010	85		
	To	1988	6,356,917	5%	5,212,672	82	1%	+64,662
Benin	*From*	1985	2,636,036		2,398,793	91		
	To	1993	3,087,420	17%	1,139,258	37	-53%	-1,259,535
Botswana	*From*	1985	865,375		242,305	28		
	To	1993	992,612	15%	466,528	47	93%	+224,223
Burkina Faso	*From*	1985	6,982,566		5,167,099	74		
	To	1988	7,228,628	4%	5,349,185	74	4%	+182,086
Burundi	*From*	1985	4,503,000		3,512,340	78		
	To	1993	5,537,061	23%	2,491,678	45	-29%	-1,020,662
Cameroon	*From*	1985	6,415,211		4,490,648	70		
	To	1993	7,138,454	11%	5,425,225	76	21%	+934,577
Cape Verde	*From*	1985	207,700		164,083	79		
	To	1990	190,501	-8%	126,302	66	-23%	-37,781
Central African Rep.	*From*	1982	1,561,141		1,483,084	95		
	To	1988	1,756,097	12%	1,510,243	86	2%	+27,159
Congo	*From*	1985	1,017,450		946,229	93		
	To	1993	1,079,158	6%	992,825	92	5%	+46,596
Congo Dem. Rep. (Zaire)	*From*	1985	22,848,421		21,706,000	95		
	To	1988	25,199,732	10%	21,167,775	84	-2%	-538,225
Cote d'Ivoire	*From*	1988	6,755,446		1,553,753	23		
	To	1993	7,621,040	13%	2,057,681	27	32%	+503,928
Djibouti	*From*	1985	87,193		68,882	79		
	To	1990	95,855	10%	82,244	86	19%	+13,361
Ethiopia	*From*	1985	38,364,750		22,251,555	58		
	To	1993	46,389,709	21%	37,111,767	80	67%	14,860,212
Gabon	*From*	1988	487,703		243,851	50		
	To	1993	537,521	10%	376,265	70	54%	+132,413
Gambia, The	*From*	1985	594,510		398,322	67		
	To	1993	789,334	33%	110,507	14	-72%	-287,815
Ghana	*From*	1985	8,543,740		5,100,613	60		
	To	1993	10,468,440	23%	5,652,958	54	11%	+552,345
Guinea	*From*	1988	4,101,670		3,506,928	86		
	To	1993	4,500,774	10%	2,205,379	49	-37%	-1,301,549
Guinea-Bissau	*From*	1985	725,634		457,149	63		
	To	1993	805,051	11%	426,677	53	-7%	-30,472
Kenya	*From*	1985	16,057,591		12,685,497	79		
	To	1993	18,741,972	17%	10,682,924	57	-16%	-2,002,573
Lesotho	*From*	1985	1,314,255		1,130,259	86		
	To	1990	1,440,008	10%	864,005	60	-24%	-266,255

Country name[a]	Years		Rural population		Rural population *without* safe water			
			Total	Percent change over period	Total	Percent of total rural population	Percent change over period	Absolute change over period
Liberia	*From*	1985	1,334,793		1,014,443	76		
	To	1988	1,386,629	4%	1,039,972	75	3%	+25,529
Madagascar	*From*	1985	7,898,135		6,539,656	83		
	To	1990	8,894,064	13%	8,004,658	90	22%	+1,465,002
Malawi	*From*	1985	6,440,448		4,707,968	73		
	To	1993	8,043,705	25%	4,745,786	59	1%	+37,819
Mali	*From*	1988	6,180,918		5,130,162	83		
	To	1993	6,854,865	11%	5,141,149	75	0%	+10,987
Mauritania	*From*	1985	1,091,388		916,766	84		
	To	1993	1,058,950	-3%	153,548	15	-83%	-763,218
Mauritius	*From*	1985	593,720		11,874	2		
	To	1988	613,752	3%	49,100	8	313%	+37,226
Mozambique	*From*	1988	10,620,061		9,345,654	88		
	To	1993	10,388,639	-2%	8,622,570	83	-8%	-723,084
Namibia	*From*	1990	921,669		645,168	70		
	To	1993	949,948	3%	598,467	63	-7%	-46,701
Niger	*From*	1985	5,499,794		3,618,864	66		
	To	1990	6,171,130	12%	2,820,206	46	-22%	-798,658
Nigeria	*From*	1985	57,322,044		40,125,431	70		
	To	1993	65,390,144	14%	58,197,228	89	45%	+18,071,797
Sierra Leone	*From*	1985	2,571,294		2,365,590	92		
	To	1988	2,664,679	4%	2,131,743	80	-10%	-233,847
Somalia	*From*	1982	5,834,400		4,667,520	80		
	To	1985	6,323,848	8%	4,932,601	78	6%	+265,081
Sudan	*From*	1988	17,940,228		14,352,182	80		
	To	1993	19,297,141	8%	5,210,228	27	-64%	-9,141,954
Swaziland	*From*	1985	515,338		479,264	93		
	To	1993	598,336	16%	347,035	58	-28%	-132,229
Tanzania	*From*	1985	17,946,728		9,511,766	53		
	To	1993	21,504,961	20%	11,827,728	55	24%	+2,315,962
Togo	*From*	1985	2,225,580		1,646,929	74		
	To	1990	2,517,665	13%	1,168,197	46	-29%	-478,733
Uganda	*From*	1985	12,734,734		11,206,566	88		
	To	1988	13,642,537	7%	12,005,432	88	7%	+798,866
Zambia	*From*	1985	4,101,422		2,788,967	68		
	To	1993	4,665,203	14%	2,659,166	57	-5%	-129,801
Zimbabwe	*From*	1985	6,222,612		5,600,351	90		
	To	1993	7,305,109	17%	2,556,788	35	-54%	-3,043,563

Source: World Health Organization (1996a)

Notes:

(a) No time series data are available for Chad, Comoros, Equatorial Guinea, Rwanda, Sao Tome and Principe, Senegal, and Seychelles. These countries are excluded from the table.

3. Household Water Use in Sub-Saharan Africa

Both of the major issues investigated in this paper—the health effects of rural water supplies and the costs of carrying water from distant sources—depend in large part on the quantities of water used in the household for drinking, cooking, bathing, and domestic hygiene. As noted above, the WHO estimates that 20 liters of safe water per person per day is "the amount needed to satisfy metabolic, hygienic and domestic requirements" (World Health Organization 1996). The basis for this standard is not obvious, given the very different climates and terrains of different parts of the world. On average, though, 20 liters per person per day should probably be considered the minimum that is needed. Gleick (1998) estimates that 25 liters per day is enough for personal consumption and sanitation, but that another 25 liters per day is needed for bathing and food preparation, producing a total daily requirement of 50 liters per person. In industrialized countries, daily per capita water use far exceeds this, sometimes by more than an order of magnitude. Switzerland, which uses the least water per capita of all the industrialized countries, has an average daily per capita use of 110 liters; the comparable figure for Japan is 342 liters and for the United States 668 liters (World Bank 1997b). If households were to use their domestic water supply to irrigate kitchen gardens or support livestock, two activities that provide nutritional and income benefits, far more than 50 liters/person/day would likely be required.

We found several published studies that estimated the quantity of water used by rural African households that obtain water from a source away from the household. Four of these used direct observation or other reliable field methods to gauge the total quantities obtained (Cairncross and Cliff 1987; Esrey, Habicht, and Casella 1992; Lindskog and Lundqvist 1989; White, Bradley, and White 1972). These are grouped together as the "best available studies" at the start of Table 3. Table 3 also contains the results of several other studies, including some that were not available to us but are cited in White, Bradley, and White (1972).

Table 3: Water use in rural areas of sub-Saharan Africa

Study	Location	Sample size and source of data	Average per capita daily use (liters)	Minimum (liters)	Maximum (liters)	Comments
Best available studies						
Cairncross and Cliff (1987)—village with a centrally located standpipe	Namaua village, Mueda, Mozambique	338 person-days over four days; direct observation of quantities carried	11.1	8.0	15.9	Source was about 300 m from households and required a 10-20 minute roundtrip. Minimum and maximum are averages for all people observed on a single day.
Cairncross and Cliff (1987)—village using a standpipe in a distant village	Itanda village, Mueda, Mozambique	329 person-days over four days; direct observation of quantities carried	4.1	1.3	6.8	Source was 4 km away and required a 5-hour roundtrip. Minimum and maximum are averages for all people observed on a single day.
Esrey, Habicht, and Casella (1992)	20 villages in Lesotho, of which 10 had communal taps or handpumps and 10 relied on traditional sources	119 mothers of infants; interviews using pictures of water containers of different sizes conducted in two 5-week periods in July-Aug 1984 (dry season) and Jan-Feb 1985 (wet season)	9.6 in the dry season; 7.8 in the wet season (no variation between sources)		35	Some households increased their per capita water usage between the dry season and the wet season (average change from 5.7 to 12.7 liters/capita/day), while others decreased their per capita usage between seasons (average change from 10.5 to 6.6 liters/capita/day). No explanation is given for these changes (distance to source is a possible explanation). The presence or absence of a latrine did not affect water usage. Authors report that the pictorial method of estimating daily water use has been found to be very accurate.

Study	Location	Sample size and source of data	Average per capita daily use (liters)	Minimum (liters)	Maximum (liters)	Comments
Lindskog and Lundqvist (1989)	11 villages in Zomba District in southern Malawi	539 households; regular interviews to determine number of trips to source and measurements of carrying vessels one year before (1983-84) and one year after (1984-85) communal taps were provided	9.7 before taps were provided; 15.3 after taps were provided			Text states that average use before intervention was 12.8 liters/capita/day, but data show an average of 9.7. The average distance to the source (well, river, or spring) before the intervention was 420 m (range 0-1300 m). After-intervention figure includes households that did not use the taps. For those that did (43% of the sample), the average distance to the new source was 270 m.
White, Bradley, and White (1972)—rural households without piped water	12 sites in Kenya, Uganda, and Tanzania	307 households; direct observation of quantities carried	9.7	1.4	48.5	Data in table are only for rural households, none of which has piped water connections; study also provides water use data for urban connected and non-connected households.
Other studies						
Imo State Evaluation Team (1989)	2 control villages and 3 intervention villages in Imo State, Nigeria (intervention was construction of communal boreholes)	24 households from control villages and 24 households from intervention villages; detailed water collection surveys (but no specific methodology indicated for estimating volumes used)	12 before and after intervention			No significant difference in per capita water use was observed between control and intervention villages. A new unprotected spring formed near the control villages during the study period, giving the control and intervention villages approximately similar collection times.
Nakagawa et al. (1994)	Kakamega and Bungoma districts, Kenya	287 households; source of estimates and methodology not stated in study	40		80	Kakamega and Bungoma are in the highlands and receive substantial rainfall. Most households relied on well water or borehole water.
Nakagawa et al. (1994)	Kitui district, Kenya	49 households; source of estimates and methodology not stated in study	20		40	Kitui is in a dry area. The source of the water is not reported clearly in the study.

Study	Location	Sample size and source of data	Average per capita daily use (liters)	Minimum (liters)	Maximum (liters)	Comments
Noda et al. (1997)—piped water use only (not total use)	Mwachinga village, Kwale District, Coast Province, Kenya	All village residents who had contact with river water; village records of standpipe water use	0.84	0	16.34	Only use of standpipe water was surveyed. Most villagers used river water for bathing, laundry, etc. and had frequent contact with river water.
Sangodoyin (1993)	Ogbomoso North and South Local Government Areas, Oyo State, Nigeria	100 women; interviews with questions on water use (respondents estimated volumes)	25 (estimated)	<20	>50	Only ranges of use are provided. 46% of respondents used <20 liters per capita per day; 45% used 20-50 liters per capita per day; 9% used 50-100.
Young and Briscoe (1987)	Eastern Zomba district, Malawi	797 households whose children were treated at health clinics in 1985; interviews with mothers (respondents estimated volumes)	31-32			Study was carried out mainly during the rainy season, when unprotected water sources are abundant and convenient.
Reported in White, Bradley, and White (1972)						
FAO Land & Water Survey (1967)	Kordofan, Sudan	unknown	9-16			No details of these studies are provided; the original studies are not available to us.
Fenwick (undated)	Zaina, Kenya	unknown	7			
Nash (1948)	Anchau District, Nigeria	unknown	23-27			
Warner (1969)	Tanzania	26 villages	5-26			

The four "best available studies" suggest that a rough average for the use of water in rural areas is on the order of 10 liters per person per day. There is very great variation, however, between countries, between villages, and even between households within the same village. Zimbabwe, for example, had an average per capita daily use of 48.2 liters in 1990, while in Mali the average per capita daily use was just 8 liters (Gleick 1998). Within villages, household size is one of the most accurate predictors of per capita water use. White, Bradley, and White (1972) and Lindskog and Lundqvist (1989) found that per capita use consistently decreased as the number of people in the household increased. In eastern Africa, households with 4-5 members averaged a little over 10 liters/person/day, while those with more than 12 members averaged just 7 liters/person/day. In Malawi, two-person households used at least 20 liters/person/day, while those with eight members never exceeded 10. While some of the difference can be attributed to economies of scale in domestic hygiene, a limit to the number of adult women available to carry water (often just one) is probably the main reason for the lower per capita use in larger households. Lindskog and Lundqvist (1989) observe, "This means that water consumption per household varies much less than water consumption per capita."

In any case, one of the conclusions that we can draw from Table 3 is that if African villages are to meet the 20-liter/person/day WHO standard for an adequate water supply, average water use by rural households will have to double.

4. Human Health and Rural Water Supplies

The dangers to the health of Africans from inadequate household water supplies are vividly described by White, Bradley, and White (1972) in a memorable (though perhaps overstated) passage from *Drawers of Water*:

> An African housewife gets up in the morning and soon begins to fetch water. She walks through the thicketed savannah to the water source. This is the habitat of tsetse flies and she is exposed to their unpleasant bites and the risk of sleeping sickness. She reaches the water source in a valley bottom and has to wait her turn. This is the habitat of disease-bearing mosquitoes and of a different tsetse fly more efficiently transmitting sleeping sickness. The stream contains snails transmitting bilharziasis if it is sluggish, or breeds the vectors of onchocerciasis if it is rapid, or may contain guinea worm larvae if it is a mere muddy hole. She collects the water, which today bears a highly dilute load of human excreta and may contain typhoid bacilli or hepatitis virus. She returns, past the tsetse flies, to her home...She prepares the family's main meal. The scarcity of water discourages the washing of hands before the meal and makes washing-up after the

> last meal perfunctory. Some decayed food may be left on the utensils. Some unboiled water is drunk by her thirsty family, who pick up the germs from it.

Although this passage was written in 1972, the dangers it describes remain a pervasive part of life for many rural African women. In this section, we will review the disease and nutrition impacts of inadequate household water supplies and the health benefits that can be expected from improving those supplies.

a. Classification of water-related diseases

A large share of the total burden of disease in rural areas of sub-Saharan Africa is associated in some way with the presence or absence of water—its presence in the landscape and its absence, in terms of sufficient quantities or acceptable quality, in the household. Virtually all of the literature on water, sanitation, and health since the 1970s follows a disease classification system developed by David Bradley and presented in detail in White, Bradley, and White (1972). Bradley classified water-related diseases on the basis of their transmission routes from the environment to humans, rather than on the taxonomic characteristics of the pathogens, as is traditional in medical science. The strength of Bradley's system is that it indicates almost immediately the types of interventions that are likely to be effective in reducing the incidence of water-related diseases. According to Kolsky (1993), this system "has by and large set the agenda for thought about water interventions and diarrhoea for the last 20 years, precisely because it focused on the objects of such interventions."

Bradley's system contains four classes of infectious diseases that are in some way related to water:

1. *Waterborne diseases* are the classic causes of water-related epidemics. In sub-Saharan Africa, they include cholera and typhoid. These diseases are transmitted by consuming contaminated water.

2. *Water-washed diseases* are those that result from using insufficient quantities of water for personal or domestic hygiene. What matters most for these diseases is the quantity of water used, not its quality.[4] Many are diseases of the skin and eyes, but, as is discussed in more detail below, diarrhoeal diseases are also frequently water-washed.

[4]The definition provided in White, Bradley, and White (1972) is those infections "whose incidence or severity can be reduced by augmenting the availability of water without improving its quality" (p. 169).

3. *Water-based diseases* are caused by pathogens that require aquatic organisms as hosts during some part of their life cycle. These diseases are transmitted through repeated contact with or ingestion of contaminated water, for example through bathing or washing clothes. The two main water-based diseases in sub-Saharan Africa are schistosomiasis and dracunculiasis (guinea worm disease).

4. Finally, *diseases with water-related insect vectors* are those that are spread by insects that breed in or near water, like malaria and onchocerciasis ("river blindness").

Because almost all the endemic diarrhoeal diseases that take such a heavy toll on health in sub-Saharan Africa are transmitted through the faecal-oral pathway and are very often water-washed, rather than waterborne, Feachem (1977) and Cairncross (1996) propose that the "waterborne diseases" category be replaced with one for "faecal-oral diseases" that can be either waterborne or water-washed. Skin and eye diseases that are strictly water-washed remain in a category of their own, as do water-based diseases and those with water-related insect vectors. Below are some of the common diseases in each class, using the combined Bradley-Feachem classification system (Bradley 1977; Feachem 1977).

Faecal-oral (may be waterborne or water-washed)	*Low infective dose*: cholera, typhoid *High infective dose*: diarrhoeal diseases, amoebic and bacillary dysentary, ascariasis, gastroenteritis, infectious hepatitis, paratyphoid, enteroviruses (some), hookworm
Water-washed (strictly)	*Skin and eye infections*: trachoma, skin sepsis and ulcers, scabies, conjunctivitis, leprosy, yaws *Other*: insect and arachnid-borne typhus
Water-based	*Penetrating skin*: schistosomiasis (bilharzia) *Ingested*: dracunculiasis
Water-related insect vectors	*Breeding in water*: malaria, onchocerciasis, yellow fever, filariasis, dengue, arboviral infections (some) *Biting near water*: trypanosomiasis (sleeping sickness)

Throughout the remainder of this paper, we will present information on water-related diseases in the order of the categories above.[5]

[5] A brief description and discussion of each these diseases, as well as those primarily affecting the developed world, can be found in Hunter (1997).

b. Burden of water-related diseases in sub-Saharan Africa

The most recent data available on the burden of water-related diseases in sub-Saharan Africa are from 1990 and are summarized in Tables 4-6.[6] They include estimates of the incidence or prevalence of major water-related diseases (Table 4); [7] the toll these diseases take in terms of several different physical measures (Table 5); and the share of all mortality and morbidity attributable to poor water supply, sanitation, and hygiene (Table 6). The data in Tables 4-6 include both rural and urban areas of sub-Saharan Africa.

Table 4 presents basic statistics on the annual incidence or prevalence of major water-related diseases for which data are available. Three diseases have by far the highest rates of incidence or prevalence: diarrhoeal diseases, malaria, and schistosomiasis. As Table 4 shows, all three of these diseases, along with ascariasis, disproportionately affect children.

[6] The term "burden of disease" is routinely used in the literature to describe the sum of damages caused by disease. Anand and Hanson (1995) observe that socioeconomic conditions can offset or exacerbate these damages and should therefore be taken into account if we are to calculate the actual net "burden" imposed by disease. In this paper, we will follow the standard practice of using "burden" to refer to what is actually the quantity or extent of disease.

[7]Prevalence is the total number of cases occurring in a given period (e.g., a year) as a percentage of the average number of persons in the population during the period. Incidence is the number of new cases during the period as a percentage of the average number of persons in the population. In practice, incidence figures tend to be used when the duration of a case is brief, whereas prevalence is reported when cases tend to last more than one period.

Table 4: Incidence or prevalence of water-related diseases in sub-Saharan Africa, 1990

Disease	Annual incidence or prevalence (number)	Annual incidence or prevalence (rate per 100,000 pop.)	Proportion of total incidence or prevalence affecting children aged 0-14
Faecal-oral			
Diarrhoeal diseases (incidence)	653,126,000	127,995	87%
Ascariasis/high intensity infection (prevalence)	2,991,000	586	84%
Hepatitis B and C (incidence)	245,000	48	21%
Water-washed			
Leprosy (prevalence)	317,000	62.1	21%
Trachoma/blindness (prevalence)	473,000	93	0%
Trachoma/low vision (prevalence)	547,000	107	0%
Water-based			
Schistosomiasis (prevalence)	181,015,000	35,474	52%
Dracunculiasis (prevalence)	330,000	n.a.	n.a.
Water-related insect vectors			
Malaria (incidence)	186,175,000	36,485	74%
Trypanosomiasis (prevalence)	267,000	52.3	25%
Onchocerciasis/blindness (prevalence)[a]	355,000	69.6	<1%
Onchocerciasis/itching (prevalence)	5,771,000	1,131	23%
Onchocerciasis/low vision (prevalence)	476,000	93.3	<1%
Lymphatic filariasis/Bancroftian lymphoedema (prevalence)	4,751,000	931	10%

Source: Murray and Lopez (1996b), except for dracunculiasis (WHO 1997)

Notes:

(a) Although it remains relatively prevalent, onchocerciasis has been the target of a successful eradication effort in a number of West African countries. Of the 17.5 million people whom the African Programme for Onchocerciasis Control reported to be infected in 1997, fewer than 15 percent live within the seven-country Onchocerciasis Control Program area. Most of the rest are concentrated in Nigeria, Chad, Cameroon, the Central African Republic, and Sudan, where approximately 235,000 people are blind as a result of the disease and 40,000 new cases of blindness occur each year (APOC/WHO 1997). It is not clear why the prevalence estimates for onchcerciasis in Table 4 are not consistent with those reported by the APOC.

Many recent estimates of the burden of diseases report their findings in terms of disability-adjusted life years, or DALYs. The DALY approach was developed by the World Bank and the World Health Organization as a method for comparing the consequences of different diseases (World Bank 1993). DALYs are calculated as follows. For mortality impacts, years of life lost are defined as the difference between life expectancy in a developed-country population and actual age at death due to the disease in question. Each year of life lost is assigned a relative value. The relative values rise from zero at birth, peak at age 25, and decline thereafter. The years of life lost thus valued are discounted (using a 3 percent rate) and summed to determine the number of DALYs lost due to premature death. The procedure is similar for morbidity impacts, with the principal differences being that the calculations involve the estimated duration of the disease, which might be measured in days instead of years, and "severity weights" for converting the time spent ill or disabled to equivalent life-years lost. Severity weights range from 0 to 1 and reflect the relative impact of a disease on a person's ability to carry out normal daily activities. The shape of the relationship between relative values of a year of life and age and the factors that are considered in determining the severity weights for morbidity impacts indicate that DALYs strongly (though not exclusively) reflect forgone current and future earnings, i.e. long-run productivity.

Table 5 reports the burden of individual water-related diseases in terms of deaths, years lived with a disability, and DALYs. The DALY methodology yields a different ranking of disease burden than does the simple incidence or prevalence approach taken in Table 4. For example, although the incidence of diarrhoeal diseases is more than three times the incidence of malaria, the number of DALYs is virtually the same for the two diseases. The explanation is that the number of deaths caused by the diseases, which is nearly the same, dominates the DALY calculation. This also explains why the burden of disease from schistosomiasis in terms of DALYs is only about a tenth as great as that from malaria, even though the prevalence of schistosomiasis nearly matches the incidence of malaria.

To the extent that faecal-oral and water-washed diseases are the water-related diseases whose incidence or prevalence is most likely to be reduced by improvements in household water supplies, the figures in Table 5 suggest that water supply improvements could potentially cut the DALY total for water-related diseases in sub-Saharan Africa by nearly half. To the extent that DALYs mirror long-run productivity impacts, the long-run productivity gains would be great. The tendency of many water-related diseases to strike children more heavily than adults, however, has two consequences for the usefulness of DALYs in thinking about *current* impacts on labor quality and quantity in Africa. First, due to the discounting and age-weighting in the DALY methodology, burden of disease figures stated in DALYs are heavily influenced by lost *future* years of healthy life. This causes DALYs to tend to overstate losses in current productivity. Second, while most actual illness is concentrated in children, it takes an immediate toll on the labor availability of adults, through the time required to care for sick children. The DALY approach does not capture this impact, which we will discuss in detail later in this section.

Table 5: Burden of water-related diseases in sub-Saharan Africa, 1990

Disease	Deaths	Share of total deaths (from all causes)	Years lived with a disability	Share of total years lived with a disability (from all causes)	DALYs	Share of total DALYs (from all causes)
Faecal-oral	**887,100**	**11.2%**	**1,104,000**	**1.7%**	**31,139,000**	**10.6%**
Diarrhoeal diseases	887,100	11.2%	662,000	1.0%	30,356,000	10.4%
Ascariasis	n.a.	0.0%	419,000	0.6%	440,000	0.2%
Hookworm	n.a.	0.0%	97,000	0.1%	108,000	<0.1%
Hepatitis	n.a.	0.0%	14,000	<0.1%	235,000	<0.1%
Water-washed	**n.a.**	**0.0%**	**1,110,000**	**1.6%**	**1,241,000**	**0.4%**
Trachoma	n.a.	0.0%	901,000	1.3%	901,000	0.3%
Leprosy	n.a.	0.0%	209,000	0.3%	227,000	0.1%
Skin diseases	n.a.	0.0%	n.a.	0.0%	113,000	<0.1%
Water-based[(a)]	**21,000**	**0.26%**	**2,887,000**	**4.3%**	**3,490,000**	**1.20%**
Schistosomiasis	21,000	0.26%	2,887,000	4.3%	3,490,000	1.20%
Water-related insect vector	**890,100**	**11.2%**	**5,221,000**	**7.8%**	**34,111,000**	**11.63%**
Malaria	805,300	10.1%	4,708,000	7.0%	31,504,000	10.8%
Trypanosomiasis	55,100	0.7%	147,000	0.2%	1,782,000	0.61%
Onchocerciasis	29,700	0.4%	182,000	0.3%	641,000	0.22%
Lymphatic filariasis	n.a.		184,000	0.3%	184,000	<0.1%

Source: Murray and Lopez 1994

Notes:

(a) Data on dracunculiasis are not available. Although this disease remains a serious threat in some areas, it has been eliminated in much of sub-Saharan Africa (and elsewhere) by the Global Dracunculiasis Eradication Campaign. An estimated 2.25 million people worldwide were infected in 1986, most of them in Africa; by 1996 the total estimated number of people infected in the world had dropped to about 330,000 (Kim, Tandon, and Ruiz-Tiben, 1997). Of the remaining cases, some 78 percent are in Sudan, and virtually all are in sub-Saharan Africa. The absence of dracunculiasis from burden of disease data may reflect its waning importance as a health concern, although 330,000 infected people does constitute a major local health burden.

The types of data presented in Table 5 can be aggregated to produce estimates of the overall burden of disease that can be attributed to poor water supply, sanitation, and hygiene in sub-Saharan Africa. Murray and Lopez (1996a) generated such estimates, which are shown in Table 6.

Table 6: Physical measures of health damages attributable to poor water supply, sanitation, and personal and domestic hygiene in sub-Saharan Africa, 1990

Measure of health damage	Number attributable to poor water supply, sanitation, and hygiene in Sub-Saharan Africa	Share of total health damages from all causes in Sub-Saharan Africa	Corresponding share in "Established market economies"
Deaths	875,600	10.7%	0.0%
Life years lost	28,781,000	12.7%	0.0%
Disabled life years	1,088,000	1.6%	0.2%
DALYs	29,870,000	10.1%	0.1%

Source: Murray and Lopez (1996a)

The estimates of damages attributable to poor water supply, sanitation, and hygiene in Table 6 do not include diseases that are water-related but are not primarily attributed to poor household water supply and sanitation, such as malaria. They also appear to exclude strictly water-washed diseases and schistosomiasis, as well as injuries sustained in the process of collecting water from a distant source.[8] For this reason, they tend to understate the share of deaths and disabilities attributable to water supply, sanitation, and hygiene. If the data in Table 5 for faecal-oral diseases, water-washed diseases, and schistosomiasis are aggregated, the proportion of total damages attributable to this risk factor rises to 11.5 percent of deaths, 7.6 percent of years lived with a disability, and 12.2 percent of DALYs.

On the other hand, the share of health damages in sub-Saharan Africa that can be attributed *solely* to a poor *water supply*, and not to poor sanitation, poor hygiene practices, or some combination of the three, is surely much less than these estimates indicate. That is, the 10.7 percent share of total deaths, the 12.7 percent share of total life years lost, and other figures in Table 6 are best interpreted as upper bounds on the impacts of poor water supplies alone.

c. Cost of water-related diseases

The total long-run economic cost to a household of ill health can be disaggregated into at least eight components (adapted from Paul and Mauskopf 1991 and Freeman 1993). Four of these

[8] A review of the unpublished background paper that Murray and Lopez (1996a) cite as the source of the risk factor estimates in Table 6 suggests that only diarrhoeal diseases, intestinal helminths, and dracunculiasis are included in the estimates, although this is not certain.

components are incurred by the household when the disease occurs, while four are incurred in the future.[9]

Current costs

i) The direct and indirect costs of defensive or averting measures taken to reduce the risk of death and disease (e.g. boiling water, immunizations).
ii) The direct financial costs of medical care, including hospital or clinic fees, transport, room and board at hospital, medications, etc.
iii) The loss in current household labor availability due to death and disease, including the time of the sick individual and the time of one or more caregivers. Time losses include time at home, at the treatment center or pharmacy, and traveling to and from the treatment center or pharmacy. For caregivers, time losses might also include traveling to and from the home of the sick individual.
iv) Pain and suffering experienced by the sick individual and his or her family.

Future costs

v) The loss in future productivity due to chronic morbidity effects (i.e. long-term disability).
vi) The loss in future productivity due to reductions in children's learning abilities and/or time available for schooling.
vii) The loss in future productivity due to premature mortality of children and adults.
viii) For premature mortality, welfare losses beyond the value of discounted future earnings (Freeman 1993).

Components (i) and (ii) are typically labelled direct costs, while all the others are regarded as indirect costs. It is important to recognize that component (vii), which values human life from the standpoint of future earnings alone and is known as the human capital approach, dramatically understates welfare-based measures of the benefits of reducing mortality risks. Component (viii) captures these additional welfare benefits, which reflect the additional value that individuals place on their lives, above and beyond the amounts they earn.

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[9] The list of costs presented in this section is a variation on the standard cost-of-illness (COI) framework used by health economists. In the standard COI framework, the main division is between direct and indirect costs, rather than between current and future costs. The same individual costs appear in the COI framework, however. It should also be noted that our list includes only costs that are borne by the individual or household.

The cost information that is available for sub-Saharan Africa pertains primarily to component (iii): *morbidity-induced decreases in current household productivity* caused by reductions in the quantity or quality of labor available for activities that benefit the household. Estimates solely of component (iii) greatly underestimate the total long-run productivity impacts of water-related diseases, for two main reasons: the much larger number of life years lost compared to disabled life years (Table 6); and the large share of illness occurring in children (Table 4). Component (iii) does give an indication of the current labor impacts of disease, however, and it is necessarily our focus.

The results of a number of studies that estimate the productivity costs of current morbidity are summarized in Table 7. Several comments will help explain the information in this table.

- In these studies, indirect costs are reported in terms of either the days, the quantity, or the value of lost production—and are therefore very difficult to compare with one another. Information provided in the studies was not sufficient to allow us to convert the reported "costs" into comparable units.

- A few studies also estimate the direct financial costs of medical care (component (ii)) and the cost of future losses in productivity due to premature mortality (component (vii)), and these results are also included in the table.[10] We did not find any studies that attempt to capture either future losses due to reductions in children's learning ability or time for school (component (vi)) or the pain and suffering component of the total cost of ill health (component (iv)), and we found only one estimate of the cost of averting or defensive measures taken to avoid the health effects of water-related diseases (component (i)), for malaria (Ettling et al., 1994).

- The table includes several studies of the costs of malaria and onchocerciasis. As noted earlier, these diseases are not primarily associated with household water use, but instead with water in the external environment, where the mosquito vectors of malaria and the black fly vectors of onchocerciasis breed. There are two reasons for including information on these

[10] As Table 7 indicates, the relative magnitudes of current direct and indirect costs associated with current morbidity appears to be country-specific. Sauerborn et al. (1995) found that two thirds of the total current cost of illness in Burkina Faso results indirectly from time losses due to current morbidity. Shepard et al. (1991) reached the same conclusion for malaria costs in Chad. On the other hand, Ettling et al. (1994) concluded that the direct costs of malaria treatment in Malawi were almost twice the indirect costs (though their sample included urban areas), and Sauerborn et al. (1991) found that current indirect costs of current malaria morbidity in Burkina Faso were only 38 percent of direct costs.

diseases in the table. First, given the scant quantitative information available on the costs of any disease in sub-Saharan Africa, it makes sense to consider all available evidence, some of which may be transferable to other diseases. Second, transmission of these diseases can be affected by household water supplies in several ways. On the one hand, poorly-maintained water supplies (pumps without proper drainage, leaking tanks, etc.) can increase the incidence of malaria by providing additional breeding sites for mosquitoes.[11] On the other hand, the provision of on-site household piped water connections reduces the need to store water in the household, which may in turn eliminate mosquito breeding sites. For onchocerciasis, the passage from White et al. (1972) quoted at the beginning of this section implies that collecting water from a stream increases exposure to onchocerciasis, and this may well be so. We found no qualitative or quantitative information on the extent of any of these effects in sub-Saharan Africa, however.

- We found no research on the current productivity costs of the diseases that are most closely related to household water supply and have the highest incidence of all of the water-related illnesses—diarrhoeal diseases. Although the diarrhoeal diseases mainly strike young children, the time that adults spend caring for children during their 568 million bouts of diarrhoeal diseases each year must be significant (Table 4).

- Finally, although all of the studies in the table claimed to address the productivity costs of disease, some of them ultimately provided little or no useful information. We included them in this review for the sake of completeness and to demonstrate the difficulty of quantifying the effects of disease on productivity. We did not include studies that described the costs of disease qualitatively but did not provide quantitative data.

[11] According to Dr. Andrew Spielman at the Harvard School of Public Health, "African malaria vectors tend to breed in very small accumulations of vegetation-free water, as in the run-off of a poorly drained pump or spigot. I recall investigating a hand-pump that the Peace Corps installed in the courtyard of an open village hospital in Chad. No drainage was provided, and an inch or two of water accumulated around the pump. Lots of *gambiae* developed there and derived much blood from the patients who slept nearby" (Spielman, personal communication, May 11, 1998).

Table 7: Current indirect costs of water-related diseases in sub-Saharan Africa

Study	**Location**	**Source of data/ sample size**	**Current indirect costs (lost productivity due to current morbidity)**	**Comments**
Faecal-oral diseases				
Gastroenteritis—Ghana Health Assessment Project Team (1981)	Ghana	Census data, national statistics on medical care, survey data, all from 1975	0.97 healthy life days lost/capita/ year. Additional 13.5 healthy life days lost/capita/year due to premature mortality.	Only severe diarrhoea episodes are included. The average duration of the disease is assumed to be 14 days. Time lost is by incapacitated persons only; time of caregivers is not accounted for. All gastroenteritis is assumed to afflict children aged 0-4 years, who made up 20% of the population and thus each lost approximately 5 healthy days/year. The population of Ghana in 1975 was 9,835,000.
Water-washed diseases				
Trachoma—Ghana Health Assessment Project Team (1981)	Ghana	Census data, national statistics on medical care, survey data, all from 1975	1.40 healthy life days lost/capita/year.	Time lost is by incapacitated persons only; time of caregivers is not accounted for. The population of Ghana in 1975 was 9,835,000.
Skin infections—Ghana Health Assessment Project Team (1981)	Ghana	Census data, national statistics on medical care, survey data, all from 1975	2.82 healthy life days lost/capita/year.	Time lost is by incapacitated persons only; time of caregivers is not accounted for. The population of Ghana in 1975 was 9,835,000.
Water-based diseases—Schistosomiasis				
Audibert (1986)	Mayo Danai region, Cameroon (SEMRY I and SEMRY II irrigation projects)	Surveys of 37-50 households on SEMRY I fields and 65-108 households on SEMRY II fields and rice company records (1978-82 data)	Estimated that a 4.9% decrease in rice output would result from a 10% increase in the prevalence of *Schistosoma haematobium*.	The mean prevalence of schistosomiasis was 13.8% among adults and 14.5% overall (standard deviations 0.223 and 0.212 respectively).

Study	Location	Source of data/ sample size	Current indirect costs (lost productivity due to current morbidity)	Comments
Collins et al. (1976)	Guneid township, Sudan	Medical exams of 194 cane cutters who were uninfected or infected without symptoms; direct measurement of output for 2 days	Infection status did not affect mean weight of cane cut per worker per day.	Because the study excluded workers who were infected and showing symptoms, it does not reflect the full effects of schistosomiasis infection on productivity. The severity of schistosomiasis increases with exposure. As a result, infected workers, who are typically more experienced than uninfected workers, are also likely to be more productive, masking the effects of the infection.
Fenwick and Figenschou (1972)	Irrigated sugar estate near Moshi, Tanzania	Sugar plantation records of output and bonuses earned by 63 uninfected and 74 infected workers	Uninfected cane workers cut 3% more cane than infected workers.	Infected workers without treatment earned 11% less than uninfected workers; infected workers with treatment earned 7% less than uninfected workers. (Earnings did not match production due to a complicated bonus formula.)
Foster (1967)	Irrigated sugar estate near Moshi, Tanzania	Survey of *S. mansoni* infectious status of 400 men aged 20-30 years (200 cane cutters and 200 irrigators); attendance and output records from estate	No difference in the quantity of cane cut per shift was found between infected and uninfected workers. Infected irrigators missed an average of 7.47 shifts/month, v. 4.78 for uninfected irrigators (difference for cane cutters was not significant).	The survey excluded workers who had received treatment for schistosomiasis and were thus likely the most seriously disabled. Increased absenteeism among irrigators represented the equivalent of 9 full-time workers (from a total irrigation of workforce of 400). 80% of the irrigation workforce was infected. No explanation is given for the differences between cane cutters and irrigators.
Ghana Health Assessment Project Team (1981)	Ghana	Census data, national statistics on medical care, survey data, all from 1975	1.42 healthy life days lost/capita/ year. Additional 2.94 healthy life days lost/capita/year due to premature mortality.	Time lost is by incapacitated persons only; time of caregivers is not accounted for. The population of Ghana in 1975 was 9,835,000.
Parker (1992)	Omdurman aj Jadida village, Gezira/Managil irrigation scheme, Sudan	11 infected and 11 uninfected women observed by author for one day during cotton picking season	Disease status had no significant effect on quantity of cotton picked or time spent on domestic chores; infected women spent somewhat less time in the fields, but this did not affect their output, as they worked more quickly.	The sample size for this study (11 pairs of women observed for one day) was very small.

Study	Location	Source of data/ sample size	Current indirect costs (lost productivity due to current morbidity)	Comments
Water-based diseases—Dracunculiasis				
Brieger and Guyer (1990)	Idere town, Oyo State, Nigeria	Interviews of 20 farmers who had suffered from guinea worm disease in 1987-88	Average gross loss in crop yields per farmer due to acreage not planted was $332 per year. Net loss was not stated.	The average duration of disability was 3.9 months (117 days) (range 1-7 months). 85% were bedridden for some period of time. The authors note that the timing and duration of an illness largely determined farmers' losses, such that a simple "days lost" estimate is not a meaningful measure of productivity effects. Per capita income for the region was $125.
Kim, Tandon, and Ruiz-Tiben (1997)	Global, primarily sub-Saharan Africa	Review of 12 studies on the duration of guinea worm cases	Median of 8 weeks (56 days) of productive time lost to infected person per case of infection (range 2-16 weeks).	Because guinea worm infection is seasonal and coincides with the period of peak demand for agricultural labor, the economic impact of dracunculiasis was relatively severe.
Watts, Brieger, and Yacoob (1989)	Idere town, Oyo State, Nigeria and Asa and Moro Local Government Areas, Kwara State, Nigeria	Interviews of 42 women infected with guinea worm, of whom 12 provided income data	Average duration of disability was 9 weeks (63 days). 67% were bedridden or only able to hobble short distances; the rest were able to limp or walk. Income-generating activity ceased for 37 of the 42 women surveyed. Among those who reported income data, the average loss was almost U.S. $75 per case.	Less time was spent on child care and housework by infected women. Average per capita income in the study area was U.S. $125.
Diseases with water-related vectors—Malaria				
Audibert (1986)	Mayo Danai region, Cameroon (SEMRY I and SEMRY II irrigation project)	37-50 households on SEMRY I fields, 65-108 households on SEMRY II fields (1978-82 data)	Disease did not affect quantity of rice produced.	Author speculates that the episodic and seasonal nature of malaria attacks makes it difficult to find evidence of their effect on productivity.
Ettling and Shepard (1991)	Malawi (nationwide)	National aggregate medical records and wage data	$0.58/capita/year. Additional $1.67/capita/year for lost future production and $0.63/capita/year for direct costs of treatment.	Total cost of $2.88 is equivalent to 7 days of individual production in rural areas. Time is assumed to have a value of 85% of the average rural wage rate. This assumption is not explained.

Study	Location	Source of data/ sample size	Current indirect costs (lost productivity due to current morbidity)	Comments
Ettling et al. (1994)	Malawi (nationwide)	1531 households; 1992 nationwide survey	$12.75/household/year including adult illness and child care, equal to 2.6% of annual household income. Additional $19.83/household/year for direct costs of treatment and additional $2.55/household/year for malaria prevention.	Sample includes both urban and rural areas. Total costs ranged from 32% of annual income for very low income households to 4.7% for low to high income households. Households lost an average of 25 days per year to malaria, including adult illness and time spent on child care. Adult time spent caring for sick children averaged 1.17 days per child case.
Ghana Health Assessment Project Team (1981)	Ghana	Census data, national statistics on medical care, survey data, all from 1975	14.95 healthy life days lost/capita/ year. Additional 17.62 health life days lost/capita/year due to premature mortality.	Time lost is by incapacitated persons only; time of caregivers is not accounted for. Malaria accounted for 10.2% of all healthy life days lost in Ghana. The population of Ghana in 1975 was 9,835,000.
Nur (1993)	Gezira area, Sudan	Survey data and laboratory tests of 250 households with 256 malaria cases.	9.1 days/household/year lost to agricultural production (including total and partial incapacity of workers and time spent caring for the sick).	Most of the labor was lost by adult men. It was entirely substituted for by labor of women and children, so that agricultural production remained constant at the household level. Notes that an additional significant cost of disease is time spent fulfilling social obligations to visit the sick.
Sauerborn et al. (1991)	Solenzo District, Burkina Faso	1985 household survey of 626 households (average household size 10.3)	$0.10/capita/year including adult illness and time spent on child care. Additional $0.79/capita/year for lost future production and $0.26/capita/year for direct costs of treatment.	Total cost of $1.15/capita/year was equivalent to 3.7 days of output. Adult time loss was assumed to be 1 day per mild adult case, 5 days per severe adult case, 0.33 days per mild child case, and 1.67 days per severe child case.
Shepard et al. (1991); Shepard et al. (1990)	Mayo-Kebbi District, Chad	National aggregate data on disease incidence and 1985 survey data on treatment costs and value of time	$0.02/capita/year. Additional $0.57/capita/year for lost future production and $0.01/capita/year for direct costs of treatment.	Total cost of $0.60/per capita/year was equivalent to 5 days of individual production. Adult time loss was assumed to be 3.5 days/adult case and 2 days/child case.

Study	Location	Source of data/ sample size	Current indirect costs (lost productivity due to current morbidity)	Comments
Diseases with water-related vectors—Onchocerciasis				
Clark (1990), reported in Aron and Davis (1993)	Rubber plantation in Liberia	Plantation production and payroll records and lab tests to determine workers' infection status. Sample size unknown.	No effects found.	The disease studied was a non-blinding strain with milder symptoms than the blinding strain. The study was designed to measure the productivity effects of a drug to control the disease. Workers' productivity and use of health care services was assessed before and after distribution of the drug. No information is provided on the efficacy of the drug in treating the disease or on differences in productivity between infected and uninfected workers.
Ghana Health Assessment Project Team (1981)	Ghana	Census data, national statistics on medical care, survey data, all from 1975	1.93 healthy life days lost/capita/ year by all ages.	Time lost was by incapacitated persons only; time of caregivers is not accounted for.
Kim et al. (1997)	Teppi coffee plantation, southwest Ethiopia	Plantation records and clinical examinations of 235 permanent plantation workers, of whom 229 were men and 6 were women.	Workers with severe infections worked 1.9 fewer days per month than uninfected workers and earned 17% less income per month (due to number of days worked and output per day). The daily wage of severely infected workers was reduced by 16% and of moderately infected workers by 10%.	The disease studied was onchocercal skin disease, which is the non-blinding form of the disease. Wages were paid according to output produced, so daily wages corresponded directly to productivity. Older males experienced the greatest losses (no explanation is given for this).
Other diseases				
All illnesses—Sauerborn et al. (1995)	Nouna zone, northwest Burkina Faso	Interviews of 566 households.	\$126.97/household/year, almost evenly divided between time loss of incapacitated person and time loss of caretaker. Additional \$57.69/household/year (3.7% of household income) for direct costs of treatment.	Estimates included all illnesses, including those not related to water, but schistosomiasis, malaria, and diarrhea are cited as among the most common illnesses. Time was valued at the wage rate for a replacement worker, which is likely to be an overestimate. A follow-up study found that only 7% of the households did hire replacement workers. The rest relied on substitute labor from within the household (Sauerborn et al. 1996).

The evidence on links between disease and productivity summarized in Table 7 is, in the words of Over et al. (1992), "weak and conflicting." Some studies show a substantial cost, such as the nearly three healthy life days per capita per year lost to skin infections in Ghana. Others, such as Parker (1992), show no effect at all. For various reasons, most of which involve data quality and the difficulty of controlling for confounding variables, all of the studies in the table are likely to overestimate or underestimate the productivity costs of illness in one way or another. The half dozen studies that compare the actual output of infected workers to that of healthy workers (e.g. several of the schistosomiasis studies) are probably the most reliable. They come to conflicting conclusions, however. Of the five that focus on schistosomiasis, three found no difference in output between infected and uninfected workers, a fourth estimated an output loss of 3 percent for infected workers, and the fifth estimated a 4.9 percent loss in output per 10 percent increase in disease prevalence.

Among the other studies, few account for differences in the severity of disability caused by a disease—one day of infection is often assumed to entail one full day of lost production. The related issue of the quality of labor provided, rather than the quantity, is similarly overlooked. Only one of the studies takes into account the often substantial time loss by those who care for the sick, which Sauerborn et al. (1995) found to be almost exactly equal to the time lost by the sick persons themselves, thereby doubling the total loss of time due to disease. Most of the studies ignore the seasonality of demand for agricultural labor, implying that the cost of a day lost to illness is the same year-round. And most assume that people suffer only one infection at a time, so that the entire loss in productivity can be attributed to the disease under consideration. This is unlikely always to be the case (Paul and Mauskopf 1991).

Finally, and perhaps most important, few of the studies summarized in Table 7 consider the costs of disease from the perspective of the entire household. A day of agricultural labor lost due to illness suffered by a particular individual does not necessarily result in a net loss of one day of agricultural labor by the household. The reason is simply that households make adjustments by reallocating the total household labor supply. Actions taken by households to reduce the negative effects of illness have been termed "coping" (Over et al. 1992; Evans and Jamison 1994). Table 8 presents the results of two studies that documented the extent of coping in rural sub-Saharan Africa. If the results of these studies apply to rural households throughout sub-Saharan Africa, they suggest that substitution of household labor greatly reduces the agricultural production costs of disease.[12] For this reason, studies that assume that the losses in labor quality or quantity caused by disease can be estimated by applying a simple elasticity of output with respect to agricultural labor[13] or that individual time losses can be extrapolated to a society as whole[14] are likely to overestimate agricultural productivity losses.

Table 8: Extent of household substitution for lost labor

Study	Location	Sample size	Results	Comments
Sauerborn, Adams, and Hien (1996)	Burkina Faso	30 illness episodes among 51 households interviewed, of which 27 caused the loss of at least one full day of work	Household labor was substituted in 89% of cases. Households used free community labor in 7% of cases, hired labor in 11%, and changed their labor-capital mix in 7%. Study states that households that could not hire outside labor lost production, but the loss is not quantified.	Composition of substitute labor is not specified, except as follows: "In the case of lost field production, household members who had not participated in agriculture before the illness event were mobilized. Children less than 10 years old, those who had retired from field work or participated in other activities were called to the field."
Nur (1993)	Gezira area, Sudan	250 households/ 256 malaria cases	All agricultural labor hours lost to malaria were compensated by family members (9,716 hours lost due to total and partial disability were replaced by 10,272 hours of other family members' time).	Output was sustained at the same level, though more labor was used. 55% of the labor lost due to disease was among adult men; women and children provided 95% of the substitute labor (58% women, 37% children).

Coping is not free, however. The time that an adult or child in rural Africa spends replacing the agricultural labor of a sick worker is taken away from education, from childcare, from important domestic tasks like cooking, fetching water and fuelwood, and cleaning, from other agricultural or non-agricultural labor, and from leisure and rest. Estimates of the overall productivity costs of illness must take into account the opportunity cost to the household as a whole—that is, of the time of not only the sick person, but also of the household members who provide care and compensate for the lost labor (Over et al. 1992). It is likely that the opportunity cost of total household time lost directly and indirectly to illness is often quite high. As Nur (1993) observed,

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[12] The results obtained by Parker (1992) suggest that individuals can also "cope" by shifting their work patterns—for example by working fewer hours per day but maintaining production by working more quickly.

[13] For example, Kim, Tandon, and Ruiz-Tiben (1997) assume that agricultural output increases by 0.66 percent for every 1.0 percent increase in labor input.

[14] For example, Shepard et al. (1991) applied the average cost per case of malaria in 1987 from four case studies to the total incidence of malaria in sub-Saharan Africa and concluded that the per capita cost of malaria in the region was $2.34 in 1987. They projected this cost to increase to $2.92 per capita in 1995. This would represent about 0.6 percent of the 1995 per capita GDP of $490 (World Development Report Indicators 1997).

"The result was that output was maintained, but at considerable cost to other persons and their activities (schooling, household activities) within the family." The value of time in rural African households will be discussed in the next section.

d. Nutritional costs of a poor water supply

Inadequate access to a safe water supply harms the nutritional status of households in three ways. One of these, the loss of the energy expended collecting water from a distant source, will be addressed in the next section. A second connection between water supply and nutrition is through the availability of water for cooking food. Cairncross and Cliff (1987) found that households with access to a nearby water supply used almost three times more water for cooking than households whose water source was several kilometers away. They explained, "Villagers of Itanda [the village with a distant water source] claimed in several interviews that they cooked little, and only once a day, because of the lack of water. Healthy adults may be able to make up the deficiency by eating uncooked cassava, fruit etc., but small children, and elderly people lacking teeth, cannot do this...." We did not find any estimates of the extent to which malnutrition is exacerbated by inadequate water for cooking.

The third way in which a poor household water supply affects nutrition is through the impacts of water-related diseases. Intestinal parasites that compete with the host for food and diarrhoeal diseases that diminish the body's ability to absorb nutrients cause widespread stunting and wasting among children (World Bank 1993).[15] Huttly et al. (1990), for example, found that in three Nigerian villages that received an improved water supply (boreholes), the proportion of children classified as wasted decreased from 6.7 percent to 2.8 percent. The proportion of children classified as stunted did not decline, however.[16]

e. Direct evidence on the health benefits of improved water supplies

Hundreds of studies carried out all over the world have attempted to quantify the health benefits secured by giving households access to an improved water supply, better sanitation services, hygiene education, or all three. Some are pre-intervention and post-intervention evaluations of the same households; others compare control and intervention households that are otherwise

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[15] A child who is wasted has a weight-for-height ratio below a specified percentage of a reference value; a child who is stunted has a height-for-age ratio below a specified percentage of a reference value.
[16] Strauss and Thomas (1998) provide a thorough review of the literature on nutrition and labor productivity.

similar to one another. A host of methodological flaws have been identified in most, if not all, of these studies (see, e.g., Esrey et al. 1991, Cairncross 1996). The difficulty of controlling for confounding variables, distinguishing among the discrete components of combined water supply and sanitation projects, and collecting accurate data from a sufficiently large sample over a long enough period of time in remote locations makes the reliability of most of these studies suspect. In this section we review evidence from sub-Saharan Africa on the health benefits that have been secured from water supply projects and on the relative value of interventions to improve water quality, water quantity, sanitation facilities, and hygiene practices.

The numbers most frequently cited for estimating the health benefits of improved water supply and sanitation projects are those generated by Esrey et al. (1991) in a global review of studies on this topic. That review produced median estimates of expected reductions in six diseases: ascariasis, diarrhoeal diseases, dracunculiasis, hookworm, schistosomiasis, and trachoma. Of the 144 studies reviewed, 105 contained data that allowed reductions in disease prevalence to be calculated; 42 of these were considered to be methodologically rigorous and were analyzed separately. The results of the review are summarized in Table 9.

Table 9: Median reductions in disease expected from water supply and sanitation projects

Disease	Better studies (42)			All studies (105)		
	Number of studies	Median reduction in prevalence (%)	Range (%)	Number of studies	Median reduction in prevalence (%)	Range (%)
Diarrhoeal morbidity	19	26	0-68	49	22	0-100
Diarrhoeal mortality	0	n.a.	n.a.	3	65	43-79
Child mortality	6	55	20-82	9	60	0-82
Schistosomiasis	3	77	59-87	4	73	59-87
Dracunculiasis	2	78	75-81	7	76	37-98
Hookworm	1	4	n.a.	9	4	0-100
Ascariasis	4	29	15-83	11	28	0-83
Trachoma	7	27	0-79	13	50	0-91

Source: Esrey et al. (1991)

The results of both the better studies and all the studies indicate very large median reductions in disease. The implications for improved water supplies in rural sub-Saharan Africa are difficult to infer, however. The studies reviewed by Esrey et al. (1991) included both water supply and sanitation projects and were carried out all over the world and in both urban and rural areas.

Only between a quarter and a third looked at households in sub-Saharan Africa—the exact number is not clear—and not enough information is provided to calculate results from Africa-based studies or from rural studies alone.

Our own review of some the Africa-specific studies included in Esrey et al. (1991) and a few subsequent ones provides less clear evidence of the benefits of water supply projects. We summarize the principal results of these studies in Table 10.[17] Deriving general conclusions from these results is very difficult. The studies do, however, tend to indicate lower health benefits than the broader set of studies reviewed by Esrey et al. (1991). Several could not discern any effect of the intervention, while others found contradictory effects or only small improvements as a result of the intervention.

[17] Interventions to reduce incidence of dracunculiasis were not included, as this disease is nearing eradication in sub-Saharan Africa. We also excluded projects aimed at reducing malaria incidence, as malaria is not primarily a problem of poor household water supply.

Table 10: Effects on health of water supply interventions in rural areas of sub-Saharan Africa

Study	Location and intervention	Sample size and methodology	Results	Comments
Diarrhoeal diseases				
Esrey et al. (1988)	Lesotho; addition of communal taps and pumps fed by springs or boreholes dispersed throughout villages	247 children aged 1-5 years in ten villages with continually functioning taps or pumps for a least one full year before study began; interviews with mothers, weighing and measuring of children, and examination of stool samples during three five-week periods in 1984-85.	The diarrhoea rates of 125 children who used the improved water supply exclusively were found to be somewhat higher than the diarrhoea rates of 122 children who used both the improved and traditional water supplies, based on mothers' reports to interviewers of the source of water used for drinking and cooking and mothers' recall of diarrhoea cases. For infants (aged 0-12 months), average rates for exclusive users were –2.0 to +12.1% higher than for mixed users. For children (aged 1-5 years), average rates for exclusive users were 2.1 to 4.5% higher.	No clear explanation of these results is given. Authors speculate that mothers' recall of diarrhoea cases might not have accurate, as infection rates of various pathogens as determined by stool examinations were 33-53% lower for exclusive users than for mixed users. Other confounding variables are also proposed. (For example, some exclusive users might have used *less* water per capita than mixed users because of the need to carry all water from a potentially distant tap, resulting in poorer hygiene.)
Huttly et al. (1990)	Imo State, Nigeria; construction of communal boreholes	935 households in three intervention villages and 470 households in two control villages; household questionnaires administered twice-yearly for 3.5 years, direct measurements of children, daily interviews on diarrhoea status of children.	No clear difference was found in the incidence or prevalence of diarrhoea between intervention and control villages. Within the intervention villages, the only factors consistently correlated with diarrhoea prevalence rates were borehole distance, level of reliance on borehole water, and time required to collect water. A water collection time of >120 minutes/household/day was associated with a 291% increase in risk of diarrhoea in children aged 0-4; those with households >250 m from a borehole had a 23% greater risk of diarrhoea.	Authors speculate that other changes in the control and intervention villages over the course of the study made it difficult to detect differences in diarrhoea rates between control and intervention villages. Per capita water use did not increase as a result of the intervention, suggesting that the decrease in diarrhoea prevalence associated with shorter water collection times results from allowing women to spend more time on childcare and hygiene and/or less storing of water in the household, and not from using more water. Authors note, "Results from a small sample of households showed that water became heavily contaminated during collection and storage, regardless of the quality at source."

Study	Location and intervention	Sample size and methodology	Results	Comments
Mason, Patterson, and Loewenson (1986)	Chiweshe communal land, Zimbabwe; provision of boreholes and communal taps	253 children in a village with communal taps (1 tap per 42 residents) and 413 children in a village using traditional sources; interviews with the children and examination of faecal samples.	The prevalence of intestinal protozoans was generally higher among children using taps than among those using traditional sources. *Giardia lamblia* prevalence was 11.6% for children using traditional sources and 20.2% for children using taps. 35.1% of children using traditional sources had no intestinal protozoa, while only 31.6% of children using taps had no intestinal protozoa.	Authors cannot explain why piped water was associated with higher prevalences of intestinal protozoa. No information was gathered on per capita water usage or on the quality of water from the two kinds of sources.
Child growth				
Esrey et al. (1988)	Lesotho; addition of communal taps and pumps fed by springs or boreholes dispersed throughout villages	247 children aged 0-5 years in ten villages with continually functioning taps or pumps for a least one full year before study began; interviews with mothers and weighing and measuring of children during three five-week periods in 1984-85.	The 125 children who used the improved water supply exclusively gained an average of 118 g more weight and grew 0.236 cm taller than the 122 children who used both the improved and traditional water supplies over a six-month period, based on mothers' reports to interviewers of the source of water used for drinking and cooking. Most gains were among children aged 1-5 years, not infants. Gains over five years (by extrapolation) would be 2.3 kg and 4.4 cm per child.	An earlier study found that children from villages that did not receive an improved water supply grew better than either the exclusive or "mixed" users in the intervention villages. Authors note that households that used improved water supplies exclusively may have differed in other ways from "mixed" users, such as control over village resources. For infants, advantages of using improved water supply disappeared when water quantity was controlled, possibly because almost all infants are breastfed.
Huttly et al. (1990)	Imo State, Nigeria; construction of communal boreholes	935 households in three intervention villages and 470 households in two control villages; household questionnaires administered twice-yearly for 3.5 years, direct measurements of children, daily interviews on diarrhoea status of children.	In the intervention villages, the proportion of children with weight-for-height below 80% of a reference value (wasted) decreased by 54% from 1984 to 1985 (wet season data). In the control villages, the proportion of children classified as wasted increased by 42% over the same time period. No change was found in the proportion of children classified as stunted.	

Study	**Location and intervention**	**Sample size and methodology**	**Results**	**Comments**
Lindskog, Lindskog, and Gebre-Medhin (1987)	Chingale, Malawi; introduction of communal taps within 400 meters of each household	Approximately 572 children in 539 households with children under 5 years old in 11 villages; questionnaires, observation, and measurement of children one year before (1983-84) and one year after (1984-85) the intervention.	No significant differences in child growth rates were found before and after the intervention.	The link between an improved water supply and higher child growth rates requires that child morbidity be decreased by the new water supply. The study found that child growth correlated closely with total morbidity and incidence of diarrhoeal diseases. Total morbidity, but not diarrhoeal disease incidence, decreased during the second half of the year following the intervention, but this did not affect growth rates. Only 46% of children used the piped water during the second half of the year following the intervention. Water usage/capita did not increase substantially.
***Schistosomiasis*[(a)]**				
El Kholy et al. (1989)	Msambweni area, Kwale District, Coast Province, Kenya	114 households in 4 villages where communal boreholes were constructed in 1984; interviews of adults and parasitologic examinations of children and adults before and after borehole construction	No significant reduction in the prevalence or incidence of *S. haematobium* was found following construction of the boreholes.	79% of households used the boreholes for water for drinking, cooking, and washing dishes, (another 19% used other "safe" sources, such as water from vendors, entailing nearly complete reliance on safe sources for water for these purposes). 72% of households continued to use of marshes, ponds, and other traditional sources for laundry, however, and 23% for bathing. Authors speculate that the boreholes are likely to have reduced the incidence of faecal-oral diseases, but exposure to schistosomiasis did not decline enough to diminish the prevalence of the disease.
Mason, Patterson, and Loewenson (1986)	Chiweshe communal land, Zimbabwe	253 children in village with communal taps (1 tap per 42 residents) and 413 children in a village using traditional sources; interviews with the children and examination of faecal samples.	Prevalence of *S. mansoni* parasites was 4.8% among children using traditional sources and 0.8% among those using taps; prevalence of *S. haematobium* was 4.4% for traditional sources and 0.4% for taps.	Percentage of children with no intestinal helminths (including schistosomiasis and *Hymenolepsis nana*) was 87.4% for children using traditional sources and 96.8% for children using taps. No information was collected about quantities of water used, use of alternative sources, etc.

Study	Location and intervention	Sample size and methodology	Results	Comments
Noda et al. (1997)	Mwachinga village, Kwale District, Coast Province, Kenya; construction of communal standpipes near the center of the village	1,460 village residents; direct observation of river water contact before and after construction of the standpipes and village records of standpipe water use.	Prevalence of schistosomiasis before water supply intervention was 68.2%. Prevalence of schistosomiasis after intervention was not assessed because a mass chemotherapy campaign was carried out at the same time that the standpipes were constructed. After standpipes were constructed, the number of people using river water decreased by 35.1%, total frequency of river water contact by 44.1%, and total amount of contact by 25.4%. Decreases varied between men and women and among age groups. The drop in the number of people using the river accounted for most of the decrease in frequency and amount of contact. Only people who used more than 2.74 liters of standpipe water per person per day (>1000 liters/person/year) reduced their contact with river water significantly.	Average consumption of standpipe water was 0.84 liters/person/day (=307 liters/person/year) (range 0-16.3 liters/person/day). Consumption of standpipe water was correlated with distance to standpipe. 65% of households were more than 0.5 km from the standpipes and 30% were more than 1 km from the standpipes.
Morbidity (all causes)				
Fenwick (undated), reported in Carruthers (1973)	Zaina irrigation scheme, Kenya; provision of piped chlorinated water (presumably communal standpipes)	Sample size and methodology not specified.	The days of illness per child from March to September decreased from 9.4 in 1961 to 4.7 in 1965 in Zaina and increased from 6.2 to 7.3 for children in a control village. The days of illness per adult from March to September increased from 3.28 to 3.71 in Zaina and from 2.70 to 3.15 in the control village.	Other changes brought about by the Zaina irrigation scheme, including more health care personnel and better housing, may have been partially responsible for the improvements in children's health. Author (Carruthers) noted that in both Zaina and the control village, adults were sick for only about half a day per month, and that "even if piped water removed all sickness, the gain to the labor force would be less than half a man day per month." (This did not include adult time spent caring for sick children.)

Notes:

(a) Hunter (1997) reviewed several other studies of schistosomiasis in sub-Saharan Africa. Most were focused on the relationship between water exposure and infection rates, which was consistently positive, or on the effect of various treatments. None appeared to examine the effect of water supply changes on disease rates.

All of the studies described in Table 10 involved the provision of communal standpipes located at least half a kilometer, on average, from the households that used them. The interventions thus typically reduced but did not eliminate the need to carry water and store it in the household, where it could have been re-contaminated, or to use traditional sources for laundry and bathing, which might have provided routes for infection. These issues will be discussed further later in this section.

f. Water supply versus sanitation

The review by Esrey et al. (1991) also provided some information on the relative benefits of water supply, sanitation, and hygiene projects. It grouped studies of diarrhoeal disease reductions according to the kind of intervention considered, as shown in Table 11.

Table 11: Median reduction in diarrhoeal morbidity expected from different types of interventions

Intervention (object of improvement)	**Number of rigorous studies for which morbidity reduction calculations could be made**	**Median reduction in diarrhoeal morbidity (%)**
Water quality only	4	15%
Water quantity only	7	20%
Water quantity and quality	2	17%
Sanitation only	5	36%
Water and sanitation	2	30%
Hygiene only (handwashing, etc.)	6	33%

Source: Esrey et al. (1991)

Although the figures in Table 11 are based on a relatively small number of studies, they suggest that if the object of an intervention is to reduce diarrhoeal morbidity, increasing the quantity of water used is more important than improving its quality. Table 11 suggests even more strongly that improved sanitation services and hygiene practices are the most important interventions of all. This last conclusion might not be justified, however. The health benefits of improved sanitation services and hygiene practices may be difficult to achieve if an adequate water supply has not been secured first. The "object of improvement" in Table 11 is defined as the item that was added by the intervention, and other facilities might already have been in place when the intervention was made. For example, a "sanitation only" intervention might have improved sanitation facilities for households that already had access to improved water supplies.

A more recent study, also by Esrey (1996), more carefully controlled for quality of existing services. The purpose of the study was "to examine whether incremental improvements in water and sanitation services result in incremental improvements in health." The data were drawn from USAID's 1992 Demographic and Health Surveys. Forty-eight percent of the sample was located in four sub-Saharan African countries: Burundi, Ghana, Togo, and Uganda. Each of the 11,992 rural children included in the study was classified as having a water supply that was unimproved (traditional water source), intermediate (communal tap, pump, or well), or optimal (household piped water connection); and sanitation services that were unimproved (no facilities), intermediate (pit latrine), or optimal (flush toilet or other water-based system). Results of the study are summarized in Table 12.

Table 12: Effects of incremental water supply and sanitation improvements on children's health

Water supply	Sanitation	Sample size (sample size for sub-Saharan Africa countries)	Diarrhoea, difference in prevalence from unimproved water and unimproved sanitation	Height-for-age, difference in Z-score from unimproved water and unimproved sanitation	Weight-for-age, difference in Z-score from unimproved water and unimproved sanitation	Weight-for-height, difference in Z-score from unimproved water and unimproved sanitation
Unimproved	Unimproved	1,628 (733)	0	0	0	0
Unimproved	Intermediate	2,510 (1,958)	-1.6%	+.059	+.072	+.058
Unimproved	Optimal	162 (10)	-1.1%	+.254	+.288	+.170
Intermediate	Unimproved	2,908 (756)	-1.7%	-0.14	+.017	+.060
Intermediate	Intermediate	2,985 (2,179)	-1.5%	+.126	+.115	+.057
Intermediate	Optimal	572 (0)	+1.7%	+.224	+.215	+.107
Optimal	Unimproved	462 (14)	+0.4%	+.010	+.083	+.113
Optimal	Intermediate	445 (45)	+0.7%	+.234	+.221	+.118
Optimal	Optimal	320 (26)	-1.6%	+.630	+.543	+.193

Source: Esrey (1996)

From this information, Esrey (1996) concluded, "Improved sanitation appears overwhelmingly to confer broader and larger benefits to health than improved water supplies." This conclusion is consistent with the global evidence of greater efficacy of sanitation projects in Table 11 and the African evidence of limited impact of water supply projects in Table 10. Based on his conclusion, Esrey argued that investment in sanitation facilities, rather than water supply, should be the priority for improving children's health.

The results of this study are potentially very important for African policy-makers who are trying to improve the health of their nations' children and the productivity of present and future adults. Further investigation seems to be warranted before definite conclusions are drawn however, for at least four reasons:

1. The sample size for the sub-Saharan African countries for some of the level-of-service combinations is quite small. A household that has its own piped water connection but no sanitation facilities at all would seem to be a rare object in much of rural Africa—and a household with a water-based sanitation system but a traditional water source even rarer. Even the small number of households reporting these combinations in the survey casts doubt on the accuracy of the data (Cairncross and Kolsky 1997).

2. As the author noted, the data set used in the study indicated only the presence or absence of different levels of water supply and sanitation infrastructure. Several critical details are omitted:

   i) the condition of the infrastructure (a reliably working tap or pump versus one that is broken or provides water at too low a pressure to be convenient)

   ii) the extent of use of the infrastructure (exclusive use by everyone in the household or some continued use of unimproved facilities)[18]

   iii) the manner of use of the infrastructure (quantity of water used, potential for re-contamination during storage, prevalence of proper hygiene practices).

   Without these details, there is no way of knowing whether the modest or negligible benefits conferred by improved water supplies stemmed from increasing the quality of water used, increasing its quantity, or freeing up time that could then be devoted to child care, or if the benefits would have been greater had the condition, extent of use, and manner of use of the infrastructure been taken into account.

3. Self-selection by households that choose to have intermediate or optimal water supply or sanitation may be producing misleading results. In a comment on Esrey (1996), Cairncross

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[18] In rural Malawi, for example, Lindskog, Lindskog, and Gebre-Medhin (1987) noted, "Even if latrines were present, young children, who are the main propagators of gastro-intestinal infections, did not use them."

and Kolsky (1997) noted that households that have optimal sanitation facilities also tend to have good hygiene practices, and that it might be those good hygiene practices that lead a household both to install sanitation facilities and to reduce its incidence of diarrhoeal diseases. Esrey (1997) observed, however, that this point and the preceding one, if true, would have the effect of understating the real difference in child health between different levels of water supply and sanitation, reinforcing his results rather than calling them into question.

4. A final reason for being skeptical about Esrey's conclusion that improved sanitation services have a greater impact on health than improved water supplies is that most of the estimated impacts in the last four columns of Table 12 are not significantly different from zero at a 5 percent significance level, the level that Esrey cited in the paper. *None* of the impacts in the case of diarrhoea is statistically significant, and all the impacts are very small in magnitude. This suggests that there is no significant difference in effectiveness among the different interventions, at least within the sample analyzed. This could be a real result (there really is no difference), or it could be a consequence of poorly measured data on the prevalence of diarrhoeal disease.

   If the latter is the case, we might expect the anthropometric data, which are based on direct measurements, to be more reliable. Figures 2-4 show the statistically significant impacts for the three anthropometric health indicators. They indicate that the provision of *optimal* services of *either* water or sanitation, whether separately or in tandem, generates health benefits relative to unimproved and intermediate services. Both water and sanitation investments can generate health benefits if they are provided separately, especially if they are provided at optimal levels, but the greatest benefits come from joint provision of the two services at optimal levels.

   The evidence reviewed in this section does not indicate any clear conclusion about the relative values of water supply and sanitation investments for improving human health and productivity. What does seem clear is that optimal service levels provide much greater health benefits than intermediate levels; that improving both water supply and sanitation generates greater benefits that focusing only on one or the other; and that achieving any benefits at all from the kinds of interventions described in Table 10 cannot be taken for granted.

Figure 2: Changes in weight-for-height Z-scores at different levels of water supply and sanitation (statistically significant impacts only)

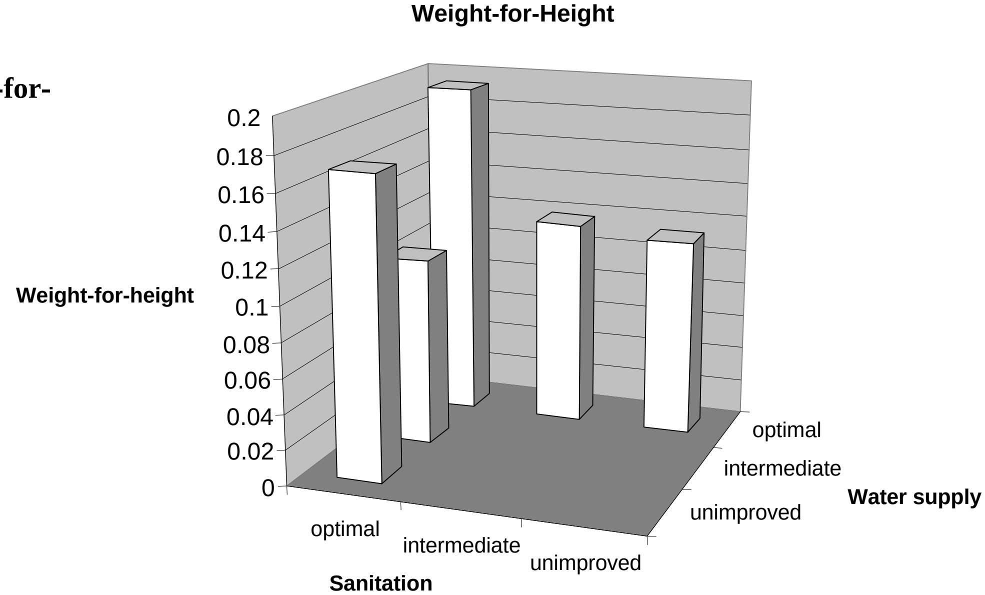


Figure 3: Changes in height-for-age Z-scores at different levels of water supply and sanitation (statistically significant impacts only)

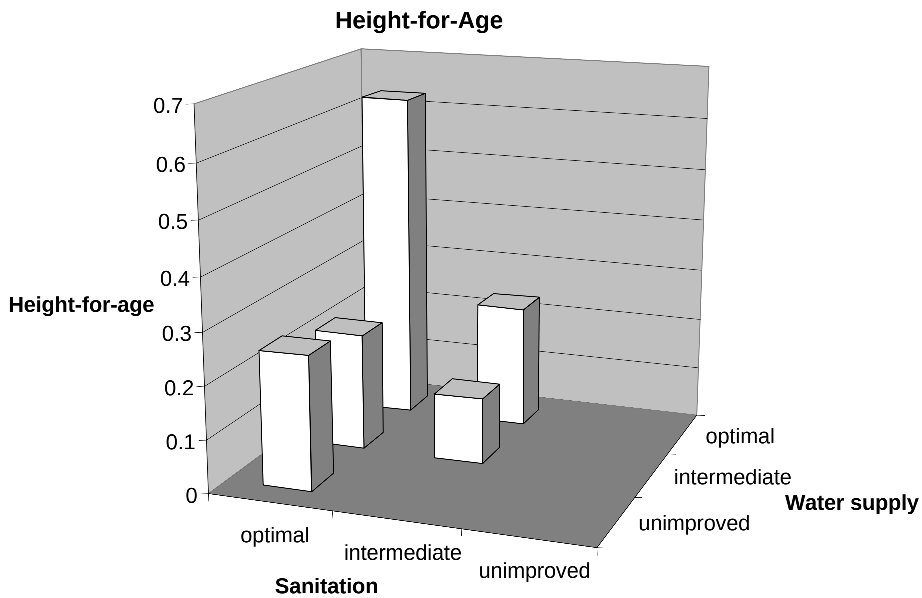
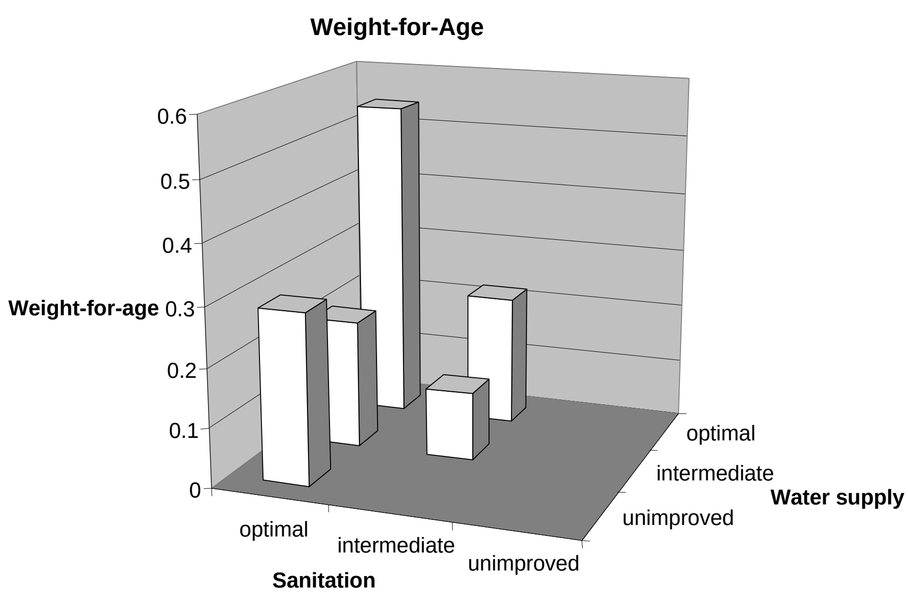


Figure 4: Changes in weight-for-age Z-scores at different levels of water supply and sanitation (statistically significant impacts only)



g. Water quantity, hygiene, and health

Since the publication of *Drawers of Water* in 1972, research on the effects of water supply on health has fairly consistently concluded that increasing the quantity of water used in the household is more important than improving its quality. Because faecal-oral diseases have multiple transmission routes—hands, food, and dishes, as well as drinking water—they are more likely to be water-washed than waterborne. If a household has only a small quantity of water to use, it is likely that all aspects of hygiene—from bathing to laundry to washing of hands, food, and dishes—will suffer. A typical observation is that of Cairncross (1988), who commented, "... an increasing weight of evidence, much of it from rural Africa, has accumulated that the endemic paediatric diarrheoas of poor communities are largely water-washed, as they are not substantially affected by water quality improvements when hygiene and access to water are unchanged."

We did not find any research in sub-Saharan Africa to support or refute what would seem intuitively to be the case: that daily access to at least a few liters of water per person beyond the minimum required for physical survival is a prerequisite for achieving major, sustained improvements in hygiene practices. The WHO's standard of 20 liters/person/day assumes this to be the case.[19] At the same time, it seems equally logical that, since almost all households have access to some water for hygiene, more effective use of that water should cause some reduction in the transmission of faecal-oral diseases.

The last row of Table 11 reports the results for child health of education and outreach programs aimed at improving households' hygiene practices. Researchers have consistently observed significant reductions in diarrhoeal morbidity as a result of more and better handwashing, for example (Kolsky 1993; Birmingham et al. 1997).[20] Feachem (1984) reviewed three studies of hygiene interventions, none from sub-Saharan Africa, and found reductions in diarrhoea incidence ranging from 14 to 48 percent, largely from better handwashing practices. He noted, however, that "the effectiveness of hygiene education may depend ... upon the presence of [improved water supply and sanitation] facilities."[21] Varley (1996) argued that hygiene

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[19] The minimum water intake required for survival in tropical areas is estimated at 1.8-3.0 liters/person/day (White, Bradley, and White 1972).

[20] In a study of the epidemiology of dysentary in Burundi, for example, Birmingham et al. (1997) found that not washing hands before preparing food accounted for 30 percent of dysentary cases.

[21] Evaluating the efficacy of hygiene education is also made more difficult by the need to observe hygiene behavior throughout the day over long periods of time. In a study of hygiene practices in Zaire, for example, Manun'Ebo et al. (1997) found that agreement between the frequency of handwashing reported by 274 mothers and the frequency of handwashing observed by researchers was "little better than might

“software” (education and outreach) alone, in the absence of improved “hardware” (water supply and sanitation infrastructure), can reduce the incidence of diarrhoea by 15 percent.

Whether better hygiene results from improving household water supplies depends, of course, on what households do with additional water when they obtain it. As Esrey (1996) observed, “Access to and use of improved water and sanitation facilities are not synonymous.” An evaluation of a comprehensive water supply and hygiene education program in rural Ghana that provided boreholes and handpumps, for example, found no differences in risky hygiene practices between intervention and non-intervention villages, despite presumably improving residents’ access to water (Akuoko-Asibey and McPherson 1994). On the other hand, a study in a large city in Burkina Faso found a strong correlation between the location of the water source and hygiene practices: mothers in compounds with taps were three times more likely to wash their hands following child defecation than mothers in compounds relying on public standpipes (Curtis et al., 1995). The authors of this study identified a number of possible confounding factors, but they concluded

> ...if improved access to domestic water supplies produces health benefits, this may be because better access to water leads to improved hygiene behavior. This study did not allow us to distinguish whether the observed improvements in hygiene practices were due to mothers conforming to higher standards of hygiene when better water supplies were available or because mothers who spent less time collecting water has more time available in which to practice safer behavior.

We found one study that offered some detailed information on water quantity and hygiene practices in rural sub-Saharan Africa. Cairncross and Cliff (1987) found that households in Mozambique with a centrally-located water source used an average of 11.1 liters/capita/day, while those relying on a distant source averaged only 4.1 liters/capita/day (Table 3). Table 13 shows the amounts of water households in the two villages allocated to various activities. The far right column indicates that more than half of the additional water was used for bathing adults and children. Water for bathing children, nearly nonexistent when the water source was distant, rose to 13 percent of the total.

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be expected by chance.” Practices that respondents regarded as “desirable” were generally over-reported, although handwashing before feeding children was under-reported.

Table 13: Volumes of water used for different purposes by households with near and distant water sources in Mozambique[(a)]

Activity	Households with distant water source (n=90 person-days)		Households with centrally-located water source (n=95 person-days)		Difference in use between households with different water sources	
	Liters per capita per day	Share of total	Liters per capita per day	Share of total	Liters per capita per day	Share of total
Drinking	0.21	6%	0.36	3%	0.15	2%
Cooking	0.67	21%	1.93	16%	1.26	14%
Washing dishes and food	0.50	15%	1.36	11%	0.86	9%
Bathing adults	0.80	25%	4.75	39%	3.95	44%
Bathing children	0.04	1%	1.23	10%	1.19	13%
Washing clothes	0.54	17%	2.64	21%	2.10	23%
Production (animals, drinks, etc.)	0.48	15%	0.03	0.3%	(0.45)	n.a.
Total	3.24		12.30		9.06	

Source: Cairncross and Cliff (1987)

Notes:
(a) Information was obtained from twice-daily interviews. The totals in Table 13 do not match those for the same study in Table 3 due to the smaller sample size and different methodology used to obtain the data in Table 13. As the authors note, the totals are quite similar.

To the extent that the findings in Table 13 reflect practices throughout the region, they suggest that better hygiene does result when households obtain larger quantities of water. This implies—though certainly does not guarantee—some reduction in the prevalence of faecal-oral and water-washed diseases. Even for diseases that are classified as "strictly water-washed," however, the relationship between disease prevalence and access to a water supply is not straightforward. Trachoma is a case in point. We did not find any research on the efficacy of water supply interventions in reducing trachoma, but the studies summarized in Table 14 provide some evidence on this question.

Table 14: Trachoma prevalence and water supply

Study	Location	Sample size and methodology	Results	Comments
Cairncross and Cliff (1987)	Namaua and Nimu villages, Mueda, Mozambique	100 households per village; interviews, observations, and ophthalmological examinations	The prevalence of trachoma was 19% in Namaua, whose standpipe was about 300 m from most households and where per capita daily water use was 14 liters. The prevalence of trachoma was 38% in Nimu, whose water source required a 90-minute roundtrip and where per capita daily water use was 8 liters.	According to the authors, "The lower trachoma prevalence in Namaua may not result from the water supply. The lower prevalence of stages III and IV [in Namaua], for which the difference is still significant at 1%, could hardly be accounted for by a water supply which had been functioning for only a little over 2 years. A possible cause may lie in the much dustier environment in Nimu."
Majcuk (1966), reported in Prost and Negrel (1989)	Sudan	478 people; random sample	The prevalence of trachoma was 32% among people who bathed daily and 70% among people who bathed less than every day.	
Tielsch et al. (1988)	Lower Shire River Valley, Malawi	5,356 children under age 6; interviews and ophthalmological examinations	The prevalence of trachoma was 34.2% for children when the primary water source was < 5 minutes away, 39.7 % when the source was 5-30 minutes away, 48.8 % when it was 31-60 minutes away, and 57.8 % when it was > 60 minutes away.	The reported frequency of facewashing had very little effect on the prevalence of trachoma. No data were collected on quantities of water used.
West et al. (1989)	Kongwa, Tanzania	1938 households; interviews and ophthalmological examinations	The proportion of households in which all children had trachoma was 37% for those whose water source was < 30 minutes away, 49% for those whose source was 30-120 minutes away, and 50% for those whose source was >120 minutes away. The prevalence was the same in villages that had a "constructed" water supply and those that did not.	The risk of trachoma was only marginally associated with the quantity of water brought into the house or with the proportion of children with clean faces, and there was no relationship between these two latter variables. Water quality did not affect prevalence.
Zerihun (1997)	Jimma Zone, Ethiopia	1601 randomly selected households; ophthalmological examinations which also recorded distance to water source	The prevalence of trachoma decreased as the time to the water source increased. Prevalence was 19.7% for those whose water source was <16 minutes away, 17.8% for those whose source was 16-30 minutes away, and 12.7 percent for those whose source was >30 minutes away.	No explanation is offered for these results. Data were not collected on quantities of water used or hygiene practices.

While it does appear that trachoma prevalence diminishes as the water source is brought closer to the home and water consumption presumably increases, the evidence in Table 14 is far from conclusive. The causal links between the location of the water source and the disease—from water source to quantities collected to personal hygiene practices to disease transmission—are missing or uncertain. Without them, it is difficult to draw any general conclusions about whether simply reducing the distance to the water source is an effective way to fight trachoma.

Before looking more closely at the relationship between the quantity of water used and the distance to the water source, one issue of water quality, rather than quantity, merits attention. The link between an improved water supply and reduced incidence of faecal-oral diseases can be disrupted by the contamination of water that is stored in the household. Storage of water is necessary if the source is even a short distant away—only households that have their own on-site piped water connections are likely not to have to store water at all. Several studies have found that water from "safe" communal sources (boreholes, springs) becomes unsafe before it reaches its final user. We found one study that tested water at the source and in the household in sub-Saharan Africa. In Malawi, Lindskog and Lundqvist (1989) discovered that the fecal coliform and fecal streptococci counts of water collected from all sources (wells, river, springs, and taps) increased significantly during storage—fecal coliform by as much as 41 percent for piped water and fecal streptococci by up to 33 percent for river water. The quality of stored water was best in households that used the same container for drawing and storing water—which meant that the container was rinsed frequently—rather than keeping at home a separate storage container that was easily contaminated by users and rarely washed. Huttly et al. (1990) came to similar conclusions in Nigeria about diarrhoeal disease rates and the likelihood of water contamination during storage, as noted in Table 10. If these findings reflect conditions elsewhere in the region—and given that the high cost of fuelwood precludes boiling water to destroy bacteria for most households—then reducing the incidence of faecal-oral diseases is likely to require changes in storage practices.[22]

[22] The opposite conclusion was reached by VanDerslice and Briscoe (1993), who carried out a study of water storage practices, water quality, and infant health in an urban area in the Philippines. They argued that family members develop some immunity to the family's "internal" pathogens and that other transmission pathways for diarrhoeal pathogens are far more important than storage of water. Storing water was not a major risk factor for the infants in the study, but using contaminated water sources was. The authors concluded from this that investments in improving the quality of water at the source should take precedence over improving water storage practices.

h. Water quantity and distance to the source

Despite the cautionary notes in the previous section, if the key to reducing faecal-oral and water-washed diseases is indeed to increase the quantity of water used, then it is vital to know how to achieve increased usage. Understanding the relationship between distance and quantity is critical if the goal of an intervention is to increase water usage. On this relationship will rest the value of continuing to provide closer but still distant communal sources, rather than incurring the extra cost of providing household connections. Table 15 summarizes the scant evidence available on this question in sub-Saharan Africa, which amounts to just a handful of studies in addition to those by White, Bradley, and White (1972) and Cairncross and Cliff (1987) cited above.

Few studies have measured the actual quantity of water used directly, and many do not separate out the effects of improved quality and increased quantity. Those that have focused on quantity have consistently found that per capita usage increases substantially (i.e. above the 20 liter/person/day threshold) only when the water source is located inside the household or compound, such that the distance to the source is effectively zero. One of the important contributions of *Drawers of Water* (1972) was to suggest that the addition of a closer but still distant water source, such as a centrally-located standpipe or well, will not necessarily increase household water use. White, Bradley, and White (1972) found that if water must be carried, the quantity brought home varies little for sources between 30 meters and 1000 meters from the household.

Table 15: Water use v. distance to source

Study	Location	Sample size	Results	Comments
Cairncross and Cliff (1987)	Namaua and Itanda villages, Mueda, Mozambique	338 person-days in Namaua; 329 person-days in Itanda	Households with source 300 m away used an average of 11.1 liters/capita/day. Households with source 4 km away used an average of 4.1 liters/capita/day.	Water use estimated by direct observation.
Jacobsen et al. (1971), reported in Carruthers (1973)	Zaina irrigation scheme, Nyeri District, Kenya	Unknown	"Persons close to water outlets used quantities greatly exceeding more distant consumers. Some 37 percent of Zaina consumers could no longer estimate their consumption as it was too high." Daily per capita consumption for those who had household piped water connections ranged from 25 to 120 litres.	No other details of the study are provided. Original study was not available to us.
Imo State Evaluation Team (1989)	2 control villages and 3 intervention villages in Imo State, Nigeria	24 households from control villages and 24 households from intervention villages	Quantity of water used per capita did not change with the introduction of new sources (boreholes, spring) that reduced the collection time from 4-6 hours to 36-45 minutes.	No details are provided on the methodology for estimating water use.
Lindskog and Lundqvist (1989)	11 villages in Zomba District in southern Malawi	539 households	Following the installation of communal taps that reduced average distance to the water source from 410 m for all households to 270 m for the approximately 43 percent of households that used the taps, average water use/capita/day for all households increased from 9.7 liters to 15.5 liters.	Water use increased for all households, not just those that used the new taps. The authors attribute this to the increased awareness of the links between water use and health resulting from villagers' involvement in installing the taps. ("The significant intervention was obviously the participation in the work for the project, not the hardware as such.")
Warner (1973), reported in White (1977)	Tanzania	Unknown	Following the installation of improved water supplies that reduced (but not to zero) the distance to the source, water use increased but only by a few litres per capita per day.	No other details of the study are provided. Original study was not available to us.
White, Bradley, and White (1972)	12 rural sites in Kenya, Uganda, and Tanzania	307 households	Per capita water collection remained roughly constant at about 9 liters/capita/day for sources located anywhere from about 30 m to 1.6 km from the household. Below 30 m use was greater; above 1.6 km it was less.	Water use estimated by direct observation.

The failure of water usage to increase as the distance to the source falls from 1000 meters to 30 meters is surprising. White, Bradley, and White (1972) offered one possible explanation: the size of the container that is customarily used to carry water often determines household water usage. They speculated that the number of trips made to the water source, whatever its distance, is often determined by the household's daily work schedule, and that container size is typically a matter of local custom. To the extent that this is the case, then it is no surprise that water usage does not increase when the distance to the source is reduced from 1 km to half a kilometer. Those carrying water simply save the time instead.

Another source of uncertainty in measuring water usage is laundry. African households whose water source is more than a few meters away often take their laundry, and sometimes their children and themselves, to the source for washing, rather than bringing the water home. In this case the quantity of water used and the quantity carried to the house are not identical. White, Bradley, and White (1972) found that households located very close to the source (within 200 meters or so) or very far from the source (more than 1.6 km) are slightly more likely to take laundry to the source, while the medium-range households are more likely to carry water home for laundry.

On the basis of evidence such as that presented in Table 15, Cairncross (1988) concluded

> As the time required to collect a bucket of water is reduced, water use increases progressively until it reaches a plateau at about thirty minutes, equivalent to a walking distance of 1 km each way, to and from the water source. Within this range, bringing the water source closer to the home does not lead to increased consumption. Collection of water at a public standpipe, well, or pump is therefore likely to cause increased water consumption only if the previous source of water was over a kilometer away.

The implication of Cairncross's conclusion is that investment in rural water supply should either improve access for those whose current source is more than 1 km away or provide household connections to households whose current source is within 1 km. In other words, additional improvements to nearby (but still distant) communal sources should not be the priority (Cairncross 1988; Carruthers 1973; Churchill 1987). Most research on the costs and benefits of rural water supply improvements focuses on this "intermediate" level of service, however.

A final consideration for the problem of how to increase water usage involves the tradeoff between water quantity and women's time, which we will consider in the next section. Levine

(1989) made the following observation: “Inasmuch as increased availability of water may have a positive impact on infant/child morbidity and mortality because it frees women to attend more to their children’s needs, it would be unwise to try to convince women to do the reverse: to spend more time each day carrying water when this would reduce an already limited amount of time for breastfeeding and childcare.” We did not find any discussion of this tradeoff in the literature, perhaps because interventions that increase per capita water use always bring the water source closer to the home, allowing women to collect more water without spending more time.

5. The Costs of Collecting Water

Almost all water for household use in rural areas of sub-Saharan Africa is carried by women and girls, who often begin carrying small containers of water when they are very young children. In a study of the Chiduku Communal Area in Zimbabwe, Mehretu and Mutambirwa (1992) found that women and girls account for 90.8 percent of the total time spent collecting water (61.1 percent by wives, 25.5 percent by daughters, and 3.7 percent by other women and girls). The rest is shared among the husband, sons, and other men and boys. Lindskog and Lundqvist (1989) observed that water is carried “almost exclusively” by women and older girls. Makule (1997) cites a UNDP study from the Arusha area of Tanzania that found that women and girls bore responsibility for water collection in 75 percent of households interviewed; boys (13 percent) and men (9 percent) were responsible in most of the rest.[23] Most studies of water supply in sub-Saharan Africa take for granted that almost all water is carried by women and girls. In the absence of other detailed breakdowns, we will assume that the figures from Chiduku are typical of the region.

When water for household use must be collected from a source away from the household, women and girls incur three kinds of costs: health damages resulting from the physical process of carrying water; the expenditure of energy on carrying water; and the opportunity cost of time spent fetching water. A simple calculation is useful for getting a feel for what is physically involved in carrying water—what one might call the “drudgery” element. If average water use is roughly 10 liters/person/day, the population is evenly divided between males and females, all water is carried by women and girls, and approximately half of the women and girls in a household actually do carry water on any given day, then each carrier is responsible for fetching

[23] Figures did not add up to 100 percent in the study.

some 40 liters of water per day—or 40 kilograms' worth (90 lbs). This would need to increase to 80 kg per carrier per day to achieve the WHO usage standard of 20 liters/capita/day.[24]

a. Health costs of collecting water

The health of women and girls who fetch water from a source away from the household is threatened in three general ways: (i) by exposure to water-based diseases at the source (e.g. schistosomiasis) and diseases with insect vectors at or near the source;[25] (ii) by exposure to accidents, drowning, attack, and assault at and on the way to and from the water source; and (iii) by skeletal injuries caused by carrying heavy loads repeatedly over long periods of time. While these threats to women's and girls' health sound intuitively quite serious—and widespread, considering the great number of households that rely on distant water sources and the great amount of water carried—we did not find any studies that attempt to quantify them, for sub-Saharan Africa or elsewhere.

Dufaut (1988) provided a qualitative description of a range of injuries that can result from carrying water on the head or back. In sub-Saharan Africa, where water is most often carried on the head, limitation of flexion and increased incidence of arthrosis (degenerative rheumatism) appear to be the most common injuries. More severe injuries, including injuries to the vertebral column among adults and scoliosis among children, can result from carrying water on the back or hip, which is done in some parts of the region.

b. Energy costs of collecting water

We found three studies that estimated the toll of carrying water on African women's energy supply. These estimates are summarized in Table 16.

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[24] This assumes, of course, that water use could be doubled without providing household piped water connections—an unlikely circumstance.

[25] Fetching water is not likely to increase exposure to malaria, however, because the anopheline mosquito vectors of malaria are nocturnal and generally bite indoors (Spielman 1998).

Table 16: Energy used carrying water

Study	Location	Sample size	Results	Comments
Mehretu and Mutambirwa (1992)	Chiduku Communal Area, Zimbabwe	331 households	Each carrier expended an average of 217 calories per day carrying water. Average daily calorie intake in Zimbabwe was 2132, so carrying water required approximately 10.18% of the carrier's total daily intake.	Estimate of energy used is based on observed time to the source and an average caloric expenditure for one hour of carrying water of 243. The WHO recommended daily intake for women is 2100-2400 calories.
Unicef (1991), reported in Makule (1997)	Tanzania	unknown	Women and girls used about 260 calories to carry a 20-liter container of water from a source 1 km away. This is equivalent to 10% of the daily calorie intake of an adolescent.	No other details of this study are provided.
White, Bradley, and White (1972)	12 rural sites in Kenya, Uganda, and Tanzania	307 households	Water carriers used an average of 240 calories per day carrying water (range 0-1930). Average daily calorie intake for eastern Africa was 2840, so carrying water required an average of 8.45% of the carrier's total daily intake (range 0-67.96%).	Estimate of energy used is based on the observed distance and gradient to source times an average caloric expenditure for one hour of carrying water of 189-265, depending on load size. If energy use for sleep (840 calories/day) is excluded, carrying water requires an average of 12% of the carrier's total daily intake.

The average estimate in Table 16 is on the order of 10 percent of daily calorie intake. We did not find any analyses of the health consequences of expending such a large share of daily energy intake on carrying water.[26]

In addition to noting the nutritional implications of using 8-10 percent of daily caloric intake on carrying water, White, Bradley, and White (1972) calculated the cost of these calories in terms of local staple food prices. We will update their calculation using current price and income data for Kenya. One kilogram of maize meal, the staple grain in eastern Africa, yields 3500 calories. In rural western Kenya, maize meal currently costs about $0.46 (27.5 Kenya shillings) per kilogram. The maize meal needed to provide the average daily 240 calories burned in carrying water therefore costs about U.S. $11.36 per year. This can be compared to the local wage rate

[26] The strenuous work involved in carrying water probably contributes to anemia, which afflicts 40 percent of non-pregnant African women and 63 percent of pregnant African women (Dufaut, 1988). Elmendorf and Isely (1982) argue that the loss of 9 or 10 percent of daily calorie intake leaves pregnant and lactating women with dangerously low caloric reserves, but they do not detail the health consequences of low caloric reserves for mothers and infants.

for unskilled agricultural labor of approximately $0.17/hour (10.0 Kenya shillings) (Gugerty 1998) or to Kenya's average per capita GNP in 1995 of $280 (World Bank 1997b), bearing in mind that rural incomes are likely to be somewhat less than the national average.

The cost of the calories burned carrying water is very much a lower bound on the total costs of carrying water, as it suggests that the opportunity cost of women's time is zero. The next section reviews the evidence on how much time it takes to collect water and how this time is valued.

c. Time costs of collecting water

To determine the opportunity cost of the time that a household spends securing water for domestic use, we must know both the amount of time that is spent and the value that should be placed on that time. Some estimates are available for the first of these parameters. Data are scarce on the second.[27]

Table 17 summarizes what is known about the amount of time households and women spend walking to the water source, queuing, drawing the water, and walking home with it.

[27] In addition, different kinds of water supplies might require different amounts of time for maintenance. It is possible that the time a households saves when a water supply is provided nearer to the house is partially offset by the time required to maintain the supply (e.g. repairing or clearing a well). We found no information on this issue in the literature.

Table 17: Time spent collecting water

Study	Location	Sample size	Average time spent collecting water (minutes/day)	Comments
Bevan, Collier, and Gunning (1989)—Central Province	Central Province, Kenya	342 households (average household size 6.3)	56 for women 20-29 years; 77 for women 30-49 years; 69 for women 50+ years	Average time spent carrying water by all ages (0-50+) was 16.8% of total reported time for women and 3.22% of total reported time for men. Time reported in the survey was less than half of a full waking day (i.e. much time remains unaccounted for). [a]
Bevan, Collier, and Gunning (1989)—Nyanza Province	Nyanza Province, Kenya	441 households (average household size 7.3)	75 for women 20-29 years; 103 for women 30-49 years; 87 for women 50+ years	Average time spent carrying water by all ages (0-50+) was 26.3% of total reported time for women and 4.46% of total reported time for men. Time reported in the survey was less than half of a full waking day (i.e. much time remains unaccounted for).
Cairncross and Cliff (1987)—village with central standpipe	Namaua village, Mueda, Mozambique	118 person-days	25/carrier	The source was a standpipe about 300 m from households. Each trip to the source took 10-20 minutes. See Table 13 for a breakdown of the use of time.
Cairncross and Cliff (1987)—standpipe in a distant village	Itanda village, Mueda, Mozambique	100 person-days	131/carrier	The source was a standpipe 4 km away in another village and always crowded. Each trip took approximately 5 hours. See Table 13 for a breakdown of the use of time.
Feachem et al. (1978), reported in Cairncross (1988)	Lesotho (unspecified rural location)	39 person-days	17/carrier (range 7-33)	See Table 14 for a breakdown of the use of time by women in households of various sizes.
Fruzzetti (1985)	8 villages in Blue Nile Province, southeastern Sudan	unknown (each village had 50-300 households, but number surveyed is not stated)	100/woman (range 17-200)	Only the average for each village is provided; 100 minutes/woman is an average of these averages. Information was obtained through surveys. The sources of water and the distance to the sources are not stated.
Huttly et al. (1990)—before intervention	2 control villages and 3 intervention villages in Imo State, Nigeria	470 households in control area and 935 households in intervention area	260/household for control area; 360/household for intervention area	During the dry season, 45% of households in the intervention area and 33% in the control area spent more than 6 hours/day collecting water. During the wet season, most households used rainwater or temporary ponds, reducing water collection times to zero.

Study	Location	Sample size	Average time spent collecting water (minutes/day)	Comments
Huttly et al. (1990)—after intervention and formation of new source in control villages	2 control villages and 3 intervention villages in Imo State, Nigeria	470 households in control area and 935 households in intervention area	36/household for control area with new source; 45/household for intervention area	The intervention was the construction of boreholes in the intervention villages (approximately 1 borehole: 440 population). According to Blum et al. (1987), 23% of households were located <250 m from a borehole, 26% from 250-499 m, 35% from 500-999 m, 12% from 1-2 km, and 3% > 2 km. During the study, a new unprotected spring formed near the control villages. Following the introduction of the new sources (boreholes and spring), 92% of households in the intervention area and 89% in the control area spent less than 120 minutes/day collecting water in the dry season. Water use per capita did not change between seasons or before and after the new sources were introduced.
Jacobsen et al. (1971), reported in Carruthers (1973)	Zaina irrigation scheme, Nyeri District, Kenya	unknown	100/household	3-4 persons per household participated in water-collecting. No further details of the study are provided; original study not available.
McSweeney (1979)	Zimtenga, Burkina Faso	unknown	38/woman (0 for men)	Based on direct observation of daily time budgets for the first 14 hours of the day. Also found that women allocate an average of 587 minutes/day to all productive activities, v. 453 minutes/day for men, who allocate more time to personal and social activities (meals, rest, visiting, education, etc.).
Mehretu and Mutambirwa (1992)	Chiduku Communal Area, Zimbabwe	331 households	54/carrier or 88/household in the dry season	Source was an average of 0.57 km (dry season) or 0.53 km (rainy season) away. The average distance to a water source in Zimbabwe is almost twice the distance in Chiduku. Households made an average of 2.4 trips to the source/day, with an average of 1.63 persons carrying water per trip (dry season).
Sangodoyin (1993)	Ogbomoso North and South Local Government Areas, Oyo State, Nigeria	100 women	58/woman (estimated) (range <30 to >120)	Estimated average distance to source was 537 m. Distance was <100 m for 15% of respondents; 100-500 m for 58%; 500m-1km for 10%; and >1km for 17%.
West et al. (1989)	Kongwa, Tanzania	1938 households	90/one-way trip to source; 180 per roundtrip (estimated)	The time required to walk each way to the nearest source was < 30 minutes for 20% of the households, 30-120 minutes for 44%, and > 120 minutes for 36%.

Study	Location	Sample size	Average time spent collecting water (minutes/day)	Comments
White, Bradley, and White (1972)	12 rural sites in Kenya, Uganda, and Tanzania	277 households	46/household (range 3-264)	The authors observe that the mean is relatively low because data were gathered during the rainy season when ephemeral sources are available.
Whittington et al. (1990)	Ukunda, Kenya	39 households	8.79/roundtrip to source (range 3.30-14.50)	Ukunda is a large village that is well served by water vendors and water kiosks, such that relatively few households depend on traditional sources (open wells). Source was one of several water kiosks located in the village. 20 liters of water were collected on each trip; assuming 2.5 trips/household/day, the time spent per day was 22 minutes.

Notes:

(a) Time budgets based on recall of how individuals used their time might not be terribly accurate. McSweeney (1979) found that recall budgets failed to account for 44 percent of women's working time as measured by direct observation.

Average values in Table 17 range from 17 to 103 minutes/carrier/day, with some carriers spending as little as 7 minutes or as much as 264 minutes (four and a half hours) per day. Among the studies that estimated time spent per carrier, a simple average (not weighted by sample size, which is not known for every study) is 60 minutes/carrier/day. For households, the average is 134 minutes/day.

It should be noted that if a trip made to collect water has other purposes as well—a visit to town or a neighbor, work in the fields, taking animals to graze, etc.—then the figures reported in Table 17 above are overestimates of the time spent collecting water. For example, if a woman must both work in the fields and carry water on any given day and her fields and the water source lie in the same direction, then at least some of the time spent walking to and from the water source would not be saved even if the household obtained its own piped water connection. We did not find any studies that took multi-purpose trips into account in calculating the time costs of carrying water.[28]

[28] Mehretu and Mutambirwa (1992) allude to the possibility of double-counting due to multi-purpose trips, but they do not offer any estimates of its extent.

In thinking about how many of the hundreds of minutes women and girls currently spend collecting water could be saved and reallocated to other activities, it is important to keep in mind that bringing the water source closer to the house would be expected to induce the household to use more water per capita, because it reduces the effective price of the water. The net time saved would then depend on how many additional trips to the source are made, which would in turn depend on the price elasticity of water demand (Churchill 1987). Although water usage is generally inversely related to distance to source, the relationship is not a smooth one, as Table 15 indicated.

Very few attempts have been made to determine the opportunity cost of the many minutes or hours per day that rural Africans spend collecting water. One, in Mozambique, compared the daily time budgets for women in two villages, one with a centrally-located water source and one dependent on a distant water source (Cairncross and Cliff 1987). Results are summarized in Table 18.

Table 18: Time budgets for women in two villages in Mozambique

Activity	**Distant source (minutes per day)**	**Centrally-located source (minutes per day)**	**Difference in time allocated by women using centrally-located source (minutes per day)**
Fetching water	131	25	-106
Housework	126	161	+35
Grinding grain	84	98	+14
Agricultural production	154	160	+6
Rest and leisure (eating, social, personal hygiene, meetings, etc.)	385	433	+48
Total	880	877	n.a.
Sample size (person-days observed)	110	118	n.a.

Source: Cairncross and Cliff (1987)

Most of the time that women using the centrally-located water source saved was divided between housework, including grinding grain (46 percent), and rest and leisure (45 percent). Very little was allocated to agricultural production. The authors note that they carried out their study during the dry season, however, when the demand for agricultural labor was low.

A similar study in Lesotho observed the different uses of time in households with varying numbers of women among whom household responsibilities could be shared (Feachem et al., 1976, reported in Cairncross, 1988). The results, which indicate how women spend time saved from housework and fetching water, are summarized in Table 19. Although the sample size is quite small, a shift in time allocation from housework and fetching water to "rest and leisure" activities (including childcare) is evident. While there is some increase in the time spent on agricultural production, it is modest.

Table 19: Time budgets for women in different-sized households in Lesotho

Activity	**Time per woman when household has 1 woman (A)**		**Time per woman when household has 2 women (B)**		**Time per woman when household has 3 women (C)**		**Time per woman when household has 6 women (D)**		**Difference between (A) and (D)** (In minutes per day)
	In min. per day	As percent of total time observed per day	In min. per day	As percent of total time observed per day	In min. per day	As percent of total time observed per day	In min. per day	As percent of total time observed per day	
Fetching water	33	4%	10	1%	15	2%	7	1%	-26
Housework	537	64%	478	56%	375	46%	287	31%	-250
Agricultural labor	34	4%	70	8%	44	5%	94	10%	+60
Rest and leisure (eating, social, personal hygiene, meetings, classes, etc.)	238	28%	291	34%	376	46%	524	57%	+286
Total	842	100%	849	100%	810	100%	912	100%	n.a.
Sample size (person-days observed)	5		14		18		12		n.a.

Source: Feachem et al. (1978), reported in Cairncross (1988)

Carruthers (1973) reported similar findings from the Zaina irrigation scheme in Kenya, where water collection time per household was reduced by about 100 minutes per day.

> The Zaina investigators gained the impression that this time was put mainly to use within the household in activities that had in any event to be carried out, such as cooking, cleaning and washing. It was noticeable that the household had more time for social activities and data was collected which verified this. Very little additional time was spent by those with a water supply upon agricultural work. It was the household which benefited rather than the crops.

The results of these three studies suggest that most time saved from carrying water is devoted to housework, including cooking and hygiene, and to rest, social, and personal activities (i.e. the entire set of non-market activities). Presumably one reason that more time is spent on personal and household hygiene is that bringing the source closer to the house, or having more carriers in the household, makes more water available for hygiene, in addition to more time. This might have indirect effects on the quantity and quality of labor available by reducing the incidence of water-washed diseases.

It is not clear why so little incremental time is spent working in agriculture. Imperfect labor markets that limit wage labor opportunities for women might play a role, as might cultural or social norms regarding women's activities. These may be transitional constraints that will diminish as households adjust to spending less time collecting water, or they may be permanent. Labor might also not be the limiting input for agricultural production in some parts of the region. It is likely, for example, that the availability of irrigation water and fertilizer limit opportunities for agriculture in many areas, and that women often do not have equal access to credit, technology, and land (Larson and Frisvold 1996; Prah 1997). Labor is a limiting input in at least some areas, however (Sella 1989). We did not review the literature on the marginal value of agricultural labor in sub-Saharan Africa.[29]

Churchill (1987) argues that rural women typically do have opportunities for income-earning activities, such as food processing and petty trading, and that an hour saved from carrying water could reasonably be valued at the marginal amount that could be earned from spending an extra hour on such activities. Ocloo (1997) reports that some 30 percent of Ghanaian women engage in food processing and petty trading. Churchill (1987) also notes that even in rural communities where no formal water vending exists, most households have the option of paying someone—a neighbor child, for example—to fetch water, and he suggests that time spent carrying water might also be valued at the neighbor child's wage rate.

We found only one study that calculates directly the monetary value of time spent collecting water in a rural site in sub-Saharan Africa. Whittington et al. (1991) compared the water source choices of sixty-nine households in Ukunda, Kenya, a large village on the coast. Residents of Ukunda could choose among three sources of water for domestic use: water vendors (requiring no time but the most expensive of the three options); water kiosks (requiring some time but

[29] Curtis et al. (1995) cite an unpublished study in Angola that found that time saved from collecting water was re-allocated to agricultural activities and leisure, not to housework. No quantitative data are provided, however.

considerably less expensive than vendors); and open wells (typically requiring the most time but free of charge). Since all three options were available to all the households and the quality of water was similar, the upper and lower bound values households placed on their time were revealed by their choice of water source. The study found that most households valued the time they spent collecting water at very close to the individual household's actual income per hour worked, which was considerably above the market wage rate for unskilled labor. Results for vendors and kiosks are summarized in Table 20. The sample size for households that chose open wells was too small to provide reliable results.

Table 20: Value of time spent collecting water in Kenya

Source	Number of households	Mean time required to source (minutes)	Hourly value of time based on choice of water source	Hourly value of time imputed by average household income
Water vendor	17	0	US$ 0.41-0.57 (lower bound range)	US$ 0.56
Water kiosk	39	8.8	US$ 0.12-0.64 (lower and upper bounds; midpoint US$ 0.38)	US$ 0.35

Source: Whittington et al. (1991)

In addition to concern about their small sample size, Whittington et al. (1990) point out two possible problems with their results. First, Ukunda is a very large village—almost a town—and is located in a resort region, where there are more opportunities for wage labor than in most rural areas. Time might therefore have a greater market value in Ukunda than elsewhere in Kenya. On the other hand, the Ukunda survey was carried out in the summer, which is off-season for tourists. Wage rates are lower during the off-season.

There seems to be no published research on the value of the time African women spend on housework and on social, rest, and leisure activities. Many of the activities classified as housework, rest, and leisure certainly contribute to improved family health and community welfare, however, and therefore to productivity. For example, women spend much of their rest and leisure time with their children. Research from other parts of the world indicates that children are better nourished when their mothers have more time available for food preparation and breastfeeding (Cairncross 1988). Lindskog and Lundqvist (1989) comment that "the severe constraint on mother-child contact time may be the major limiting factor in giving an infant sufficient food." Moreover, to the extent that important public health interventions, such as the promotion of better hygiene practices, family planning, etc., require behavioral changes in the household, ensuring that women have some “leisure” time available for health education and practice is also a priority.[30]

Despite the absence of quantitative estimates of the value of time, one fact is beyond dispute. However women choose to use the additional time, sparing them from a few minutes to several hours a day of a physically demanding and sometimes dangerous chore clearly improves their welfare. It might also improve their status within the household and community, as more time and energy becomes available for education, higher-status work, and civic activities (World Health Organization 1995).

d. Direct evidence on the time-related benefits of improved water supplies

We did not find any studies that focused specifically on the success of water supply interventions in reducing the time required to collect water from a distant source. Time saved is easier to calculate than are health benefits, since it can be observed directly and/or estimated from the reduction in distance to the new water source. Two of the studies in Table 15 (Imo State Evaluation Team 1989; Warner 1973) found that the quantity of water collected increased only modestly or not at all when the distance to the source decreased, indicating that time was reallocated to other activities. Table 17 reports similar findings. In Mozambique, Cairncross and Cliff (1987) observed that women in a village with a centrally located water supply spent 25 minutes per day collecting water, while those in a similar village with a distant source spent 131 minutes per day. In Nigeria, Huttly et al. (1990) determined that the time cost to households of collecting water fell from 360 minutes per day to 45 minutes per household per day when boreholes were constructed in the villages.[31]

It thus seems that water supply interventions do generally succeed in reducing the time costs of collecting water, provided that the new source is closer to the households than the old one. The range of time spent collecting water is so wide, however, that any estimate of the amount of time that could be saved by providing a new water source should be based on data from the specific

[30] Boardman et al. (1996) observe that almost all empirical work on the value of leisure time has focused on estimating how people value the time lost traveling from one place to another (e.g. commuting to work). They cite a median estimate of the value of commuting time based on non-North American studies of 38 percent of the wage rate.

[31] Bevan et al. (1989, see Table 15.10) present regression results indicating that an in-house water tap increases “total household productive working time” (agricultural and wage labor and time spent on own business) by about 280 hours per year in rural Kenyan villages, but the coefficient on the in-house tap variable was not statistically significant at the 5 percent level.

locality where the new source is to be placed. For example, providing on-site piped water connections for households in Itanda village, Mueda, Mozambique would save about 800 hours/woman/year (the equivalent of 57 14-hour days) (Cairncross and Cliff 1987), but the same piped water connections for households in Zimtenga, Burkina Faso would save only about 230 hours/woman/year (the equivalent of 16.5 14-hour days) (McSweeney 1979).

A few caveats about time savings recur in the literature. First, in principle a household might choose to spend the same amount of time and collect more water, rather than saving the time, although the empirical evidence reviewed above suggests that this is rarely the case in practice. Second, due to increased demand, a new communal source might not reduce queuing time, and could even increase it. And third, time will not be saved if households choose not to use the new source because it is unreliable, poorly located, or difficult to use or provides water that is not to the household's liking. White, Bradley, and White (1972) identified four general factors that an African woman might consider in choosing her water source: perceived water quality; technology available for obtaining the water (pump, tap, etc.); cost of obtaining the water (time, water charges); and the source's social setting (other people who may or may not be encountered en route to or at the source, etc.). Of the water sources that rural households chose not to use, 48 percent were rejected for cost (time) reasons, 41 percent due to perceptions of poor water quality, 10 percent due to technology, and 1 percent for social reasons. Estimates of how much farther women were willing to walk to avoid a source they perceived to be of poor quality are not provided, however.[32]

6. The Cost and Cost-Effectiveness of Improving Water Supplies

The preceding sections reviewed the evidence on the health and time costs of inadequate water supplies in rural areas of sub-Saharan Africa. In this section, we summarize what is known about the cost and cost-effectiveness of interventions to improve water supplies.

a. Cost of water supply improvements

We found a few studies that report the average cost of rural water supply and sanitation projects. Table 21 summarizes the information in them. One of the studies (Sharma et al. 1996) is for sub-

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[32] Blum et al. (1987) found that choice of source was also highly seasonal. In three villages where boreholes had been constructed in Imo State, Nigeria, 90 percent of households used the boreholes as their main or only water source in the dry season, while in the wet season 64 percent used rainwater as their main source.

Saharan Africa, while the others report averages for many parts of the world. Given the very different conditions and costs in different regions of sub-Saharan Africa, the interpretation of these cost estimates is not entirely clear, but they do provide a starting point for thinking about the costs involved in providing improved supplies.[33] Additional data in the study by Sharma et al. (1996) not shown in Table 21 indicate that the cost of new World Bank water supply and sanitation projects in urban and rural areas of sub-Saharan Africa has increased steadily over the past thirty years. In Senegal, for example, the construction cost per m^3 of water supplied, in 1993 U.S. dollars, was approximately $0.60 in 1979 and $1.80 in 1994, while the cost in Ghana rose from about $0.50 per m^3 in 1974 to $1.05 in 1994. It is likely that the cost increases are driven largely by rising costs in urban areas, however. The authors identify larger distances to water sources, more expensive technologies, and barriers to efficient allocation of water among users as the main reasons for this trend. The study does not indicate whether the increasing costs also reflected changes in the quality of service.

[33] Churchill (1987) provides illustrative cost estimates for different technologies in a "prototype" village. His estimates appear generally consistent with those in Table 21.

Table 21: Costs of rural water supply and sanitation infrastructure projects

Service	Construction cost/capita	Lifetime (years)	Annual construction cost/capita (10% discount rate)	Annual maintenance cost/capita[a]	Annual total cost/capita (to nearest $)[b]
Esrey, Feachem, and Hughes (1985), in 1982 U.S. dollars—WHO worldwide data					
Communal tap or handpump	$60	20	$7	$3	$10
Sanitation (unspecified level; probably pit latrines)	$19	10	$3	$1	$4
Water supply and sanitation	$79		$10	$4	$14
Okun (1987), in 1983 U.S. dollars— WHO worldwide data					
Communal tap or handpump (20 liters/capita/day)	$39 (range $8-200)	20	$4.58	$0.48/$m^3$ (range $0.20-$1.18), or $3.50/capita assuming 20 liters (7.3m^3)/capita/day	$8
Sanitation (unspecified level; probably pit latrines)	$30 (range $8-300)	10	$4.88	n.a.	$5
Water supply and sanitation	$69		$9.46	$3.50	$13
Sharma et al. (1996), assumed to be in 1993 U.S. dollars—World Bank data for Africa					
Water supply (communal tap or handpump)	$80	10	$13.02	not specified	$13
Sanitation (pit latrines)	$40	10	$6.51	not specified	$7
Water supply and sanitation	$120		$19.53		$20
World Health Organization (1996b), assumed to be in 1992 U.S. dollars— WHO worldwide data					
Water supply (unspecified level, probably communal tap or handpump)	$50	not specified, assumed to be 10	$8.14	not specified	$8.14
Sanitation (unspecified level, probably pit latrines)	$30	not specified, assumed to be 10	$4.88	not specified	$4.88
Water supply and sanitation	$80		$13.02		$13.02

Notes:
(a) The cost of using the infrastructure—walking to and from it, queuing, etc.—is not included in these estimates.
(b) The cost of hygiene education and the overhead of the government agencies providing the services are not included in these estimates.

Although none of these estimates are current, those provided by Sharma et al (1996) appear to be the most recent and relevant. In the remainder of this paper, we will use the figures in this study: $20/capita/year for intermediate level water supply and sanitation, and $13/capita/year for water supply alone.

The cost estimates in Table 21 are for communal taps or handpumps. The cost of providing on-site household piped water connections, which might be necessary to achieve many of the benefits discussed in earlier sections, is higher than that of providing communal service, but how much higher is unclear. Okun (1987) cites data suggesting that providing a household connection is approximately 50 percent more expensive per capita than providing communal standpipes connected to piped water systems. For urban areas, Esrey, Feachem, and Hughes (1985) show annual per capita costs for household connections at about 82 percent more than for public taps. Given the dispersed settlement patterns in many rural areas, it seems likely that the cost increment could be considerably higher for rural areas than those indicated above. For the analysis that follows, we will assume that on-site household piped water connections in rural areas would cost twice as much as communal sources, or about $26/capita/year.

b. Cost-effectiveness of water supply improvements

Taking for granted the health and time benefits of improved rural water supplies, the critical question for African policymakers and international organizations is whether improving rural water supplies is the least expensive way to achieve the benefits. The few analyses of this question we found focused on only one discrete benefit (e.g. reducing the incidence of diarrhoeal diseases). We did not find any studies that attempted to assess the cost-effectiveness of the entire package of benefits that are generated by improved water supplies. This proviso should be kept in mind in considering the evidence presented below.

Reducing the incidence of diarrhoeal diseases is a high priority of most African governments, and data are available on the costs of various options for achieving this goal. Using the estimate of $20/capita/year to provide both water supply and sanitation services, and assuming a median reduction in diarrhoeal morbidity due to water supply and sanitation of 26 percent (Table 9) and the 1990 incidence rate of 1.28 cases of diarrhoea/person/year (Table 4), we obtain a cost of approximately $60 per case prevented, in 1993 U.S. dollars. Using the annual total cost estimate for water supply and sanitation services from Esrey, Feachem, and Hughes (1985) in Table 21 ($14/capita/year), we obtain a cost of about $42 per case prevented. As this estimate is in 1982, not 1993, U.S. dollars, so it is not surprising that it is lower than the estimate derived from the data in Sharma et al. (1996).

These estimates can be compared to the costs of other interventions to reduce diarrhoea, which are presented in Table 22. The figures in Table 22 are in 1982 U.S. dollars, so for comparison to water and sanitation improvements we use the estimate of $42/case prevented. At this unit cost, water supply and sanitation improvements are comparable to promoting breastfeeding as a cost-effective way of reducing diarrhoeal morbidity, but they are far more expensive than several other interventions.

Table 22: Cost-effectiveness of interventions for reducing diarrhoea

Intervention[1]	**Cost per case of diarrhoea prevented (1982 U.S. $)**	
	Median	Range
Promoting breastfeeding	$45	$10-75
Rotavirus immunization	$5	$3-30
Cholera immunization	$174	$90-1,450
Measles immunization	$7	$3-60
Promoting personal and domestic hygiene	$10	$5-500

Source: Martines, Phillips, and Feachem (1993)

Notes:
(1) No cost information was available for another intervention, improving weaning practices.

Varley (1996) compared the costs of preventing diarrhoeal morbidity and mortality using different combinations of "hardware" (intermediate level water supply and sanitation infrastructure) and "software" (improved hygiene practices such as handwashing and proper disposal of waste, achieved through education and outreach). The data were for an urban area in Africa and reflected only the costs borne by the government. Table 23 summarizes the results. Assuming that the ranking of interventions in urban areas holds for rural areas, even if the actual costs differ for each intervention,[34] the figures in Table 23 imply that improving the hygiene practices of those who already have an improved water supply is the most cost-effective way to prevent diarrhoeal morbidity and mortality. Given that two thirds of the population of rural sub-Saharan Africa lacks a "pre-existing" improved water supply and that adding hardware alone is twice as expensive per case of diarrhoea prevented as combining hardware and software,

[34] Given the low population density and dispersed settlement patterns in rural areas, this assumption might not be accurate.

however, Table 23 underscores the value of supplementing new water supply and sanitation infrastructure projects with hygiene education programs.

Table 23: Cost-effectiveness of adding "hardware" or "software" to reduce diarrhoea (urban area of sub-Saharan Africa)

Intervention (a)	Expected reduction in incidence of diarrhoea	Cost per case averted	Cost per death averted	Cost per DALY saved
Software added to pre-existing hardware(b)	40% (range 30%-50%)	$2.2 (range $0.2-$11.2)	$523.2 (range $43.4-$2,627.0)	$15.7 (range $1.3-$78.9)
Software and hardware added	40%	$45.3	$10,654.7	$320.0
Only hardware added	15%	$112.3	$26,433.2	$794.0
Only software added (no pre-existing hardware)	15%	$4.1	$966.1	$29.0

Source: Varley (1996)

Notes:

(a) Hardware is assumed to cost $72/household/year. Software is assumed to cost $3/household/year. It is likely that the high cost of hardware results from using urban estimates, rather than rural.

(b) Endpoints of cost ranges reflect optimistic and pessimistic assumptions about the efficacy and cost of the intervention.

We did not find any studies that evaluated the cost-effectiveness of improved water supplies as a means of saving time. If saving time is the sole objective, then other investments might well make more sense. McSweeney (1979) found that women at a rural site in Burkina Faso spent an average of 108 minutes per day pounding grain, leading Cairncross (1988) to observe, "If the objective of water supplies is to free women's time from an onerous chore, the same objective might be met more cheaply by providing a grain mill." Similarly, providing an alternative source of fuel, thereby relieving women of the time-consuming task of collecting fuelwood, might be less expensive in some regions than improving water supplies, in addition to taking pressure off remaining forested areas where many people now collect fuelwood. Gathering fuelwood took slightly more time than collecting water in villages in Sudan (Fruzzetti 1985) and perhaps in Malawi (Lindskog and Lundqvist 1989), but it took less than half the time required for collecting water in Zimbabwe (Mehretu and Mutambirwa 1992) and Burkina Faso (McSweeney 1979). Determining the most cost-effective way to save women's time must clearly be done on a site-by-site basis.

Perhaps the right conclusion to draw from the evidence available on the costs of rural water supplies is that investing in water supply infrastructure might not be the most cost-effective way to achieve any *single* benefit (though it might). As noted above, the challenge for evaluating water supply investments is to think about the *package of benefits* that is likely to result—and, in turn, to place water supply investments within the context of the broader program of private and public investments that is needed to improve rural welfare.

7. Conclusions and Recommendations for Future Research

a. Summary of findings of the review

In the preceding sections, we presented as much quantitative data as we could find on the connections between household water supply and productivity in rural areas of sub-Saharan Africa. In this section, we will summarize the data as best we can, with the purpose of determining which of the connections are likely to be most important and indicating where further field research is needed most.

<u>Water Access and Use</u>

Access to water for rural households	Official data suggest that approximately 67 percent of the rural population lacked a safe and accessible water supply as of the early 1990s. There is great variation among individual countries. Many estimates are from the early or mid 1980s, and the number of people in rural areas without access appears to be increasing. The definition of a safe and accessible water supply includes distant and/or non-functioning water sources that do not confer many of the benefits implied by the phrase "safe and accessible." The data are therefore likely to overstate water supply access, perhaps significantly. We did not find any more detailed information on water supply coverage.
Water use	The four "best available" studies we found suggest an average per capita daily use of about 10 liters. The range is great, however, varying from 1.3 to 48.5 liters/capita/day just within these four studies. Variation is substantial among different regions of sub-Saharan Africa, as well as between villages and households within the same regions. Average per capita use in rural Africa appears to be far below the WHO standard for an adequate household water supply of 20 liters/capita/day, which can probably be taken as a low estimate of what households need. None of the studies took into account the use of water at the source for laundry and bathing, however. Households may collect and take home less water than they actually use. Nevertheless, it seems safe to conclude that per capita water use is too low to maintain the level of personal and domestic hygiene needed for good health.

Human Health and Rural Water Supplies

Burden of water-related diseases

Approximately 10.7 percent of deaths and 10.1 percent of DALYs were attributable to poor water supply, sanitation, and hygiene in 1990. Almost all of the deaths and about 85 percent of the DALYs are due to diarrhoeal diseases. 87 percent of diarrhoea cases strike children age 0-14.

The burden of disease that can be attributed specifically to poor water supplies, rather than to poor sanitation or poor hygiene, or all three, is not known. Because of the weighting factors they incorporate, DALYs are not a useful unit for estimating current labor losses due to disease. We did not find any estimates of the total amount of adult time lost to illness (including sick adults and caretakers for sick children).

Labor quality and quantity costs of water-related diseases

Very little household-level information is available. We did not find any studies on the productivity losses associated with diarrhoeal diseases. Studies of the cost of schistosomiasis found no or very modest reductions in output among infected workers. Studies of malaria estimated significant numbers of days lost to malaria/year. Other studies were inconclusive.

Most studies on the cost of disease that considered indirect costs used the local wage rate (or some assumed percentage of it) or aggregate information on labor inputs and agricultural outputs to estimate the value of time lost to disease. We did not find any studies that considered the total current productivity costs of one or more water-related diseases from the perspective of the household. Sauerborn et al. (1995) attempted to do this for households in rural Burkina Faso, but time is valued at the wage rate in this study, and this is likely to overestimate costs significantly.

In the two studies that addressed the question of household substitution of labor, (Sauerborn, Adams, and Hien 1996; Nur 1993) households substituted other members' time to compensate for most or all of the time lost to agricultural production due to illness. Most substitution was by women and children. Coping appears to be an effective way to maintain agricultural production provided that other members of the household are not already fully engaged in agricultural or higher-value work. The opportunity cost of coping, in terms of time lost to education, housework, childcare, etc., is likely to be high, however.

Nutritional costs of a poor water supply

Domestic water supplies affect nutrition through the use of water for cooking and the impacts of water-related diseases. No quantitative data were found on the former; the latter are considered below. The one study that measured volumes of water used for different purposes (Cairncross and Cliff 1987) found that water use for cooking nearly doubled when households had access to a nearby water supply. We found no evidence to confirm that lack of water for cooking is or is not an important cause of malnutrition or disease.

Direct evidence of the health benefits of improved water supplies

A meta-analysis of studies of the efficacy of water supply and sanitation projects in reducing disease found average reductions of 26 percent in diarrhoeal morbidity, 55 percent in child mortality, 77 percent in schistosomiasis, and 27 percent in trachoma (Esrey et al. 1991). Individual studies from sub-Saharan Africa do not appear to bear these figures out, however. Many water supply and/or sanitation projects in Africa produced few or no improvements in health.

Two general conclusions seem to be justified from the studies from sub-Saharan Africa, as well as other analyses reviewed in this paper. First, an improved water supply is only one element of the package of interventions that may be needed to reduce the burden of water-related diseases, because simply providing a safer or more convenient source of water does not ensure that households will use the source exclusively, use enough water, utilize adequate sanitation facilities, or practice proper hygiene. Second, all of the studies we found of the health impacts of improved water supplies looked at communal taps or pumps, which typically reduced the time required to collect water but did not eliminate it. We did not find any research to indicate whether providing households on-site piped water would achieve more of the expected health benefits.

Water supply vs. sanitation and hygiene

A number of studies from various parts of the world suggest that interventions to improve sanitation facilities and/or hygiene practices are more effective in reducing diarrhoea morbidity and mortality than are those that improve water supplies. We did not find any research from sub-Saharan Africa that separated out the effects of water supply, sanitation, and hygiene improvements. Improving sanitation facilities appears to be a critical element in efforts to reduce the impact of faecal-oral diseases, but it has little value in combating other kinds of water-related diseases, which may be important from a productivity standpoint.

It seems likely that there is some threshold level of water use (and thus threshold of access to a safe water source) that is a prerequisite for achieving proper hygiene practices, which are the key link between household water supply and faecal-oral diseases, but this threshold is not known. The condition, extent of use, and manner of use of water supply and sanitation infrastructure is not taken into account in studies like Esrey (1996), and this limits the usefulness of their conclusions.

The evidence reviewed in this paper does not indicate any clear conclusion about the relative values of water supply and sanitation investments for improving human health and productivity. What does seem clear is that optimal service levels provide much greater health benefits than intermediate levels and that improving both water supply and sanitation generates greater benefits that focusing only on one or the other.

Water quantity, hygiene, and health

Improvements in hygiene practices (e.g. handwashing) have consistently been found to reduce the incidence of faecal-oral diseases. Evidence on how to achieve these improvements in sub-Saharan Africa is ambiguous, however. One study in Mozambique (Cairncross and Cliff 1987) found that as per capita water use rises, the amounts of water used for bathing both children and adults increase dramatically. Several studies of trachoma, however, found only weak connections between the quantity of water collected, hygiene practices, and disease rates. A study in Malawi (Lindskog and Lundqvist 1989) found that even when water is taken from a protected source, there is evidence that it often becomes contaminated during storage.

Water quantity and distance to source

Most studies that collected information on quantities of water used and distance to source generally bear out the original finding of White, Bradley, and White (1972) that per capita water use is roughly constant when the source is between about 30 m and 1.6 km away. Per capita usage seems to increase moderately, e.g. from 9.7 to 15.5 liters/day in Chingale, Malawi (Lindskog, Lindskog, and Gebre-Medhin 1987), as the source is brought nearer to the house, but large increases, above the 20 liter/capita/day standard, occur only when there are on-site piped water connections. Because many households choose to bathe and/or do laundry at the source, rather than carrying water home for these purposes, the amount of water collected and the amount used are not always identical.

One explanation offered of why per capita water use is roughly constant in the middle-distance range is that the number of water collection trips and the size of water containers is determined largely by the household schedule and by local custom. Understanding how households decide how much water to use and the relationship between distance and quantity is crucial to achieving many of the health benefits expected from investments in water supply.

<u>Costs of Collecting Water</u>

Health costs of collecting water

Almost all water is collected by women and girls. Collecting water from a distant source appears to impose a number of health costs on women and girls, but we found no studies that quantified these costs. It is possible that more information on this topic exists in the literature on rural health provision.

Energy costs of collecting water

Three studies in eastern and southern Africa found that women and girls who carry water expend an average of 8-10 percent of their total daily calorie intake on this activity. We did not find any quantitative estimates of the cost in terms of health, growth, cognitive abilities, etc. that the expenditure of this many calories imposes on water carriers.

Time spent collecting water

There are quite a few studies that report the average amount of time that women or households spend carrying water per day. Averages for the studies range from 17 to 103 minutes/carrier/day, with some carriers spending as little as 7 minutes or as much as 264 minutes per day. A simple average for the studies is 60 minutes/carrier/day or 134 minutes/household/day.

Value of time

We found almost no quantitative estimates of the value of the time households spend collecting water (or lose to illness or caring for the sick). Three studies that examined what women who spend less time carrying water do with the saved time found that most of it is allocated to housework, social and leisure activities, and rest; relatively little is allocated to agricultural work. Households in Ukunda, Kenya that chose to purchase water from vendors or kiosks, rather than use more distant wells, valued the time needed to collect water at approximately their own hourly household income (Whittington et al. 1990).

It is clear that the time women spend collecting water has value, but little or no information is available that allows us to evaluate this time from a productivity standpoint. It would be useful to know why so little of the time saved when the distance to the source is reduced is allocated to agricultural production. Without a better understanding of the value of time of different members of rural households and the constraints on how time can be allocated, it may be nearly impossible to value the productivity benefits of improving household water supplies.

Evidence of the time benefits of improved water supplies

The evidence from sub-Saharan Africa suggests that water supply interventions do generally succeed in reducing the time costs of collecting water, provided that the new source is closer to the households than the old one. When centrally-located water sources were provided, the time spent carrying water in villages in Mozambique and Nigeria fell by 106 minutes/carrier/day and 315 minutes/household/day, respectively. The range of time spent collecting water is so wide, however, that any estimate of the amount of time that could be saved by providing a new water source will have to be based on data from the specific locality where the new source is to be placed. The same intervention (e.g. a borehole in the center of a village) could produce very different benefits in different locations.

Cost and Cost-Effectiveness of Water Supply Improvements

Cost of rural water supply

We found only one fairly recent estimate of the average cost of providing "intermediate" level water supply and sanitation facilities in sub-Saharan Africa—$20 per person per year (1993 U.S. dollars) (Sharma et al. 1996). This is about 4 percent of the annual per capita GNP for the region of $490. Costs appear to be increasing rapidly, though this may be less true of rural areas than of cities. Given the variation in conditions and costs in different parts of sub-Saharan Africa, it is not clear that average cost estimates for the entire region have any meaning.

Cost-effectiveness of improving water supplies

If the cost estimates for providing improved water supply and sanitation facilities discussed above are realistic, it appears that investment in this infrastructure is in many cases a cost-effective way to reduce diarrhoeal morbidity and mortality. Improving hygiene practices among people who already have an intermediate level of water supply and sanitation infrastructure is a less expensive way to prevent faecal-oral diseases than is investing in new infrastructure, but this will not be relevant for the large fraction of rural people who rely on traditional water sources and have no sanitation facilities. We did not find any research on the cost-effectiveness of water supply investments for preventing other water-related diseases or for saving time.

Providing better access to a safe water supply generates a wide range of potential benefits to individuals, households, and communities. For any one benefit—preventing transmission of schistosomiasis, saving women's time, etc.—there may be less expensive solutions for some locations and some population groups. It seems likely that different investment decisions will be made if the cost-effectiveness of water supply improvements in providing a single benefit, such as a reduction in diarrhoeal morbidity among children, is the main criterion for investment, rather than if the whole package of benefits is taken into account.

b. A back-of-the-envelope benefit-cost analysis

Poor and ambiguous as the data are on almost all aspects of household water supply and productivity in rural Africa, it may still be useful to pull together some of the information contained in this paper into a crude comparison of benefits and costs. The purpose is simply to provide some indication of the magnitude of some of the most important time-related benefits of improving access to water for rural households, to estimate how great the other benefits will have to be to justify investments in providing an "intermediate" level of water supply (communal standpipes or handpumps) and sanitation services (pit latrines) to the entire rural population, which comprises 69 percent of the total population of sub-Saharan Africa.

On the benefits side, we will include only three: time saved collecting water; time saved caring for children who are ill with diarrhoea; and time saved from adult schistosomiasis. In each case, we will look only at adult time. Using the data in Tables 1 and 17, we will assume that half of the rural women aged 15-64 who do not have access to a safe water supply each spend one hour per day collecting water. Following the intervention, we will assume that the time spent collecting water drops to half an hour per carrier per day. We will assume that the quantity of water collected also increases, as this may be necessary to achieve the health benefits discussed in the following paragraph, but that the extra volume of water can be collected within the half hour allotted.

We will also apply the incidence data in Table 4 to the population that does not have access to a safe water supply, and we will assume (arbitrarily) that for each child case of diarrhoea, a woman devotes four extra hours to child care. We will also assume (again arbitrarily) that for each adult case of schistosomiasis, one day of productive time is lost per year. Finally, based on the information in Table 9, we will assume that our intervention will reduce the incidence of diarrhoea by 26 percent and the prevalence of schistosomiasis by 77 percent.

All of these assumptions are intended to be conservative (low) estimates, to avoid overstating the benefits of improved water supplies and sanitation. The relevant figures for rural areas of sub-Saharan Africa per year are then as follows:

Table 24: Calculation of time benefits from improved water supplies and sanitation

Collecting water	
Number of rural women aged 15-64 (World Bank 1997a)	106,225,946
Proportion of women who carry water per day (estimate)	50%
Proportion of households lacking access to an intermediate level of water supply before intervention (from Table 1)	67%
Number of rural women who carry water and will benefit from intervention	35,585,692
Time spent carrying water per carrier per day before intervention (from Table 17)	60 minutes
Intervention	Provide an intermediate level of water supply to entire rural population
Proportion of households lacking access to an intermediate level of water supply after intervention	0%
Time spent carrying water per carrier per day after intervention (estimate)	30 minutes
Time saved per carrier per day by intervention	30 minutes
Time saved per carrier per year (assuming a 14-hour waking day, 365 days/year)	13.04 person-days
Total person-years saved per year	1,271,335
Caring for children ill with diarrhoea	
Cases of child diarrhoea in rural areas per year (from Table 4)	392,071,530
Amount of women's time required per child case (estimate)	240 minutes
Proportion of households lacking access to an intermediate level of water supply before intervention (from Table 1)	67%
Intervention	Provide an intermediate level of water supply to entire rural population
Proportion of households lacking access to an intermediate level of water supply after intervention	0%
Expected reduction in incidence of diarrhoeal diseases after intervention (from Table 9)	26%
Number of cases of child diarrhoea prevented by intervention	68,298,859
Total person-years saved per year (assuming a 14-hour waking day, 365 days/year)	53,462
Reductions in adult schistosomiasis prevalence	
Prevalence of adult schistosomiasis in rural areas per year (from Table 4)	59,952,000
Amount of adult time lost per case per year	1 day
Proportion of households lacking access to an intermediate level of water supply before intervention (from Table 1)	67%
Intervention	Provide an intermediate level of water supply to entire rural population
Proportion of households lacking access to an intermediate level of water supply after intervention	0%
Expected reduction in incidence of schistosomiasis after intervention (from Table 9)	77%
Number of adult cases of schistosomiasis prevented by intervention	30,929236
Total person-years saved per year (365 days)	84,738

The total number of person-years saved each year by our intervention is approximately 1.4 million.

The estimates from Sharma et al. (1996) in Table 21 indicate that the total cost of bringing rural households to an intermediate level of water supply is $13.02/capita/year and to an intermediate level of sanitation is $6.51/capita/year. The rural population of sub-Saharan Africa in 1995 was 402,477,000, of whom 269,660,000 (67%) had less than intermediate level of water supply and 326,006,000 (81%) had less than an intermediate level of sanitation. The total annual cost of the intervention would thus be approximately $5.63 billion per year. For the 1.4 million person-years saved each year by our intervention to cover this cost, time would have to be valued at approximately $4,021 per person-year, or about $11 per day. To justify the investment in the intervention, the value of the many other benefits of improved water supplies and sanitation (reduced pain and suffering from illness, lesser risk of mortality, lower costs of medical care, improved health and status of women, etc.) would thus have to be at least equal to the difference between the actual value of the time saved and the cost of the intervention, as calculated above.

Two variations on this calculation are also interesting. First, we could omit the health benefits entirely and focus only on the value of the time saved from collecting water. This would avoid the cost of sanitation infrastructure, while still securing most of the time benefits. In this case, each person-year of time saved would have to be valued at approximately $2,762, or about $7.50 per day, to justify the intervention.

A second variation is to provide all households with an on-site piped water connection ("optimal" level of service), as well as omitting the health benefits, as in the first variation. This would eliminate the time spent collecting water for all rural households, not just reduce it for those who currently have less than an intermediate level. In addition to the time saved by the original intervention, all households would thus save an extra 30 minutes per day. The total annual time savings will then be 3,168,226 person-years. If we assume that the cost of installing on-site connections is twice that of communal services, each person-year would have to be valued at $1,654, or $4.53/person-day, to justify the intervention.[35] On-site connections are of course also likely to generate significantly greater health benefits than communal services, provided that the water provided is of high quality and the supply system dependable. Our calculations thus concur with the conclusions of Churchill (1987), who wrote

> One of the most significant observations that comes out of a study of the cost functions [of supply water services in rural areas] is how large a part of total costs

[35] To place this cost in context, it is worth recalling that the hourly wage rate for unskilled agricultural labor in western Kenya is currently approximately $0.17, generating an average daily wage of about $1.70 for a ten-hour work day (Gugerty 1998).

> are haul costs whenever water has to be carried any distance. In a typical situation where a handpump is used, for example, the haul costs can account for over two-thirds of total costs when certain assumptions about value of time are followed, with capital and maintenance costs the remainder. This holds true even for very low costs of labor or values of time and suggests that whenever per capita incomes of rural populations are much over $250, it will seldom pay to invest in systems that involve headloading of water.

c. Priorities for future research

The preceding review brings to the fore a number of issues on which we have little or no data and which are central to evaluating the benefits and costs of improving rural water supplies in sub-Saharan African. Those we consider to be the most important are identified below.

Human health and rural water supplies

- Despite a great deal of research, we still do not have a good understanding of what kinds of water supply, sanitation, and hygiene interventions, in what sequence, produce the greatest health benefits. Since any individual study of this issue will almost certainly suffer from one or another unavoidable methodological flaw, our best approach may be to continue to accumulate studies in the hope of gaining a better understanding of the factors that influence the success of interventions.

- The research on how to increase the quantity of water used by rural households is ambiguous. To achieve quantity-related health benefits, we need to know if there are any alternatives to providing on-site piped water connections for increasing usage and to learn more about the relationship between distance to source, number of trips made, container size, and quantities used.

- Although some research has been done, we still know very little about the costs of ill health in rural African communities. A better understanding of how disease affects household welfare now and in the future is needed if the benefits of water supply interventions are to be evaluated. Since time loss is one of the major components of the cost of disease, it is particularly important to learn more about the opportunity cost of time for those who substitute for labor lost to disease or spend time caring for sick family members.

- A related topic that needs further research is how households allocate water to different purposes within the household. Increasing the quantity of water collected will have few health benefits if it is not used efficiently.

- We found no published research on the benefits of providing on-site household piped water connections in rural areas. This may be because such connections are rare, but it might also reflect a belief that widespread provision of individual household connections is not a realistic aim and therefore does not warrant study. The studies reviewed here, however, suggest that the health- and time-related benefits of on-site connections are likely to outweigh by far those of communal taps or pumps. If this is the case, further research is indeed warranted.

- It would also be interesting to determine whether any additional health benefits are generated when clusters of households (those whose members tend to have frequent contact with one another) all increase their water usage, beyond what any one household would realize on its own.

- Finally, it would be useful to know how much of the rural population's total exposure to malaria, onchocerciasis, schistosomiasis, and other vector-borne diseases is associated with collecting water for household use, and whether the incidence or prevalence of these diseases would decrease (or possibly increase) if households had on-site piped water connections.

The costs of collecting water

- We know almost nothing about the value that households and individuals place on the time they spend collecting water from a distant source. Churchill (1987) demonstrates that the choice of water supply technology is very sensitive to assumptions about the value of time. Without a better understanding of the opportunity costs of time, it will be difficult to estimate the net benefits of moving water supplies closer to people's homes.

- There are a number of options for saving the time of rural Africans. We do not know the cost-effectiveness of these options. It is likely that at least some cost-effective alternatives to water supply infrastructure improvements do exist, although they may do less to reduce the "drudgery" aspect of rural women's daily work routines.

- It appears that relatively little of the time women save when a water source is brought closer to their homes is allocated to agricultural work. It would be useful to know why this is and if other opportunities for participating in the labor market are available.

- Finally, virtually all estimates of the time spent collecting water have been made shortly after a communal tap or handpump replaced a more distant traditional source. No information is available about the time saved by on-site household connections or about the allocation of time to different activities after the new source has been in place and functioning for several years or decades, allowing households a chance to adjust their labor allocations.

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