THE OPERATION AND MAINTENANCE OF WATER SUPPLY SYSTEMS IN DEVELOPING COUNTRIES

A Cost Study

A Report Submitted
for WASH Activity No. 348

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1.0 INTRODUCTION

The issue of potable water supplies in developing countries has received increased attention during recent decades. Numerous water development projects have been established, most recently in response to the International Drinking Water Supply and Sanitation Decade. Despite sizeable investment efforts directed toward water supply improvements, a large portion of third world populations remain without adequate access to safe drinking water, especially in rural areas.

General problems associated with the on-going international water crisis include: 1) funding limitations; 2) lack of trained personnel; 3) inadequate cost recovery policies; and 4) insufficient allowances for the operation and maintenance costs of water supply systems. This report focusses on the fourth problem, particularly the magnitude of operation and maintenance (O&M) costs for community water supply systems in developing countries.

Water development investments have emphasized the construction and installation of water systems, thereby placing a higher priority on capital rather than recurrent cost items within project budgets. Due to neglected operation and maintenance considerations, water supply systems are subject to disrepair and breakdown. As a result, many countries receiving water development assistance suffer from a large percentage of nonfunctioning systems. Unreliable water systems consequently reduce the potential benefits derived from and community support for water supply improvements.

The need for more attention to the O&M aspects of water supply improvements is clear. A solution to the problem is much less obvious. Bastemeijer and Visscher (1986) identify the following three approaches to the O&M dilemma facing rural water consumers:

1) **technical**, involving either highly reliable (though often expensive) "maintenance free" pumps, or more simple designs which can be maintained at the village level.

2) **organizational**, ranging from a single village caretaker to a three-tier maintenance system combining village operators with mobile repair teams.

3) **systematic**, a combination of the previous two approaches with additional emphasis on relevant environmental and social factors.

Before these approaches can be properly evaluated, additional preliminary research is required. An assessment of O&M costs associated with various water technology options is an important first step. Total project cost, including O&M costs, plays a large role in identifying appropriate systems for a specific community. Moreover, O&M costs will affect the community's ability and willingness to pay for the project as well as influence cost recovery policies. This is especially true when a significant portion of the project cost is paid by the recipient community.

Water project O&M is discussed in numerous publications; however, specific cost information is limited. The lack of real data appears to be due to a combination of inadequate field data collection activities and an uncoordinated information network among water development agencies. The O&M data base is slowly increasing and data collection efforts are improving as a result of more concerted investigations conducted by the World Bank, several United Nations agencies (UNDP, UNICEF, and UNDTCD), the International Reference Centre for Community Water Supply and Sanitation (IRC), and other organizations involved with water supply improvements in developing countries.

Accurate O&M costs are difficult to find, and available data is often incomplete. For these reasons, O&M cost estimates, typically calculated as a percentage of project capital cost, tend to be imprecise. More meaningful O&M cost information first requires a better understanding of O&M procedures along with improved data collection. In the meantime, it is useful to examine currently available O&M costs at regional and country levels. While this study is not intended to provide a means of discerning precise O&M costs, it offers general figures which are useful in evaluating the present O&M cost situation for water supply systems and area also helpful in defining future research needs.

2.0 PURPOSE OF REPORT

The objective of this report is to complete the following tasks:

- determine the availability of O&M cost information for water supply systems in developing countries;
- provide general O&M cost analyses for a variety of water supply technologies with an emphasis on those used in rural areas;
- determine the general magnitude of O&M costs required by various water supply technology options;
- identify important factors which influence O&M costs;
- identify research needs for the continued investigation of O&M costs.

Reliable O&M cost information is scarce and rarely compiled in a standardized format. One of the purposes of this study is to identify O&M information sources and collect cost data directly from these sources. Then by arranging the gathered data according to system technology, specific cost analyses can follow. Water system technologies evaluated in this study include: hand, diesel, electric, and gravity powered systems. Once individual technologies have been evaluated, the different systems will be analyzed comparatively. Based on the information (or lack thereof) generated from the previous sections of the report, areas of additional research needs will be determined.

3.0 BACKGROUND INFORMATION

The definition of "operation and maintenance" is necessarily broad, because the activities and expenses associated with O&M for different situations vary significantly. Donaldson (1984) defines "operations" as the actions required to enable the system to deliver water of a desired quantity and/or quality. "Maintenance" involves the preservation of the system elements' capabilities to carry out their task throughout their design life. In this study, it is assumed that O&M costs for a water supply system include all financial costs required to provide a reliable and satisfactory supply of water from the system. These costs are recurrent rather than single capital expenses and expressed as an annual amount in most cases.

The maintenance of water systems tends to be overlooked more often than operational aspects, perhaps as a result of the unpredictable nature of maintenance requirements. System maintenance can be divided into either preventive or corrective measures. According to Cairncross and others (1980), corrective maintenance is practiced more often than preventive. While preventive maintenance may initially appear to be more expensive than corrective maintenance, long term considerations tend to favor the preventive approach. This is based on the assumption that system breakdown and down time could be reduced and possibly eliminated if an appropriate preventive maintenance regime is followed. For these reasons the preventive approach is intuitively appealing, but more research is required before any single maintenance procedure is deemed clearly superior.

Several reports investigating water system O&M have preceded this study. The IRC has published a paper entitled "Maintenance Systems for Rural Water Supplies" as a part of their Occasional Paper Series. The paper discusses several important topics pertaining to system maintenance from the perspectives of water project feasibility, management, and evaluation. The authors determine the need for: 1) systematic evaluations of maintenance practices and requirements; 2) community-based management systems; and 3) more complete investigations of project preparation and assessment.

The Water Supply and Urban Development Department of the World Bank has recently completed a publication entitled Community Water Supply: The Handpump Option. The book provides detailed information on numerous handpump designs which have been field tested in a variety of developing countries. While O&M considerations for handpumps are addressed, specific cost analyses are not covered. The World Bank study also provides evidence that a community-based organization of O&M is preferable to a more centralized approach. The community oriented approach is referred to as Village Level Operations and Maintenance (VLOM) and is ardently promoted within World Bank/UNDP water development projects throughout the developing world. The VLOM concept has been adopted by many other water development groups as well.

An earlier WASH Technical Report (No. 35), Assessment of the Operations and Maintenance Component of Water Supply Projects, outlines the primary considerations relevant to the planning, organization and evaluation of water system O&M. Much of the report is in a questionnaire format which can be used as a checklist for water project planning criteria.

Another WASH Technical Report (No. 48), Estimating Operations and Maintenance Costs for Water Supply Systems in Developing Countries, was in preparation while this cost study was underway. It outlines a logical cost estimation procedure and is described in more detail below.

Additional reports examine a variety of water supply technologies and related institutional considerations. These reports and other related publications are not discussed here, but are listed in the Bibliography.

4.0 O&M COSTS CALCULATIONS

There are numerous factors which can affect O&M costs. These factors include but are not limited to:

- project location (country and region within country);
- climate and geophysical environment;
- system technology and scale;
- system age and operational status;
- O&M management and organization;
- availability and cost of items such as:
  - transportation
  - labor
  - chemicals
  - energy
  - replacement parts;
- debt service, depreciation and administrative expense[1].

Each of these factors will vary among individual projects. It is therefore difficult to accurately extrapolate O&M costs beyond the site specific level. For instance, it would be incorrect to assume that O&M costs for a certain pumping system in a developed country would be comparable to the costs encountered for the same system in a less advanced country, as several of the above factors would differ significantly. Yet due to the scarcity of specific O&M cost estimates, such substitutions are not uncommon. Many researchers contend that broad general estimations are often unavoidable, especially in the early stages of project planning. But given the likelihood of either over- or understating actual O&M cost requirements, the impact on project financial feasibility must also be considered.

WASH Technical Report (No. 48), Estimating Operations and Maintenance Costs for Water Supply Systems in Developing Countries, describes a detailed procedure for water system O&M cost estimation. Project planners and engineers who use the manual must collect sufficient data on the systems engineering configuration, corrective and preventive maintenance

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[1] Debt service and depreciation expense are recurrent costs and are occasionally included in O&M cost figures.

requirements, detailed information on O&M responsibilities and institutional aspects as well as local costs of labor, materials, chemicals, utilities, transport and other inputs. Once these variables have been accounted for, a reasonably accurate O&M cost estimate can be prepared.

Schulz and Okun (1984) suggest that reliable cost estimates can be based on any of the following techniques:

- cross sectional studies of cost data for similar systems established in similar environments;
- general cost curves based on based on similar systems located throughout a country;
- general predictive cost functions developed for similar situations.

Each of these techniques offers a means of predicting general cost figures which can be used to assist development officials in determining the acceptability of O&M costs in relation to project budgets and guidelines.

O&M cost functions can be used to indicate the cost of O&M for a water system, often in terms of the annual cost as a function of the annual water produced.[2] An annual cost function is typically expressed in the form of:

$$C_{O\&M} = C_0 Q^b$$

where: $C_{O\&M}$ = annual O&M cost, ($)

C_0 = annual cost corresponding to Q = 1, ($)

Q = annual water production, (m^3)

b = exponent, economy of scale indicator

This cost function can be alternatively expressed in terms of unit cost where:

$$\text{Cost per m3} = C_0 Q^{b-1}$$

The economy of scale factor, b, provides additional information concerning project planning. The b value indicates the economy of scale associated with a system as follows:

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[2] The volume of water delivered by a system can be in the form of either the volume supplied to consumers or the volume initially produced. These two measures may differ due to system loss and/or leakage. For the purposes of this report, volume is measured as that produced, because many of the costs relate most directly to water production.

if $b < 1$ then: economies of scale exist $(b-1 < 0)$

$b > 1$ diseconomies of scale exist $(b-1 > 0)$

$b = 1$ no economies of scale exist $(b-1 = 0)$

While the analytical tools for O&M cost estimation do exist, the prerequisite information remains limited. Until actual cost data become more available, the response to O&M needs will continue to be reactive rather than predictive. In order to facilitate progress within the water development sector of developing countries, improvements in project planning and management must occur. These improvements dictate more and better field information.

5.0 METHODOLOGY

This project, designated as WASH Activity 348, consists of three phases: 1) data collection, 2) data analysis, and 3) a final report.

The data collection stage involved mailed requests, library searches, and other inquiry. Over seventy five letters were mailed directly to water utilities, consultancies, bilateral and multilateral donor organizations, and other groups active in water development in developing countries. The letters requested O&M cost data and related project reports or publications. Libraries at the Universities of North Carolina at Chapel Hill, North Carolina State, and Duke along with the Joint Bank-Fund Library and the World Bank's Sectoral Library were thoroughly researched for information pertaining to O&M and water supply development. Direct contact was made with various individuals and World Bank personnel followed by two visits to the Bank.

The data received were manipulated using Lotus 1-2-3 spreadsheet software. These data were arranged in two different formats, depending on the detail of the available information (See Appendices). Data were then analyzed according to system types and country. All dollar amounts found in the text of this report have been converted into and/or reexpressed in 1986 dollars (US), based on the Producer Price Index for All Commodities, for accurate cost comparisons. All original cost figures are presented in the Appendices. Unless noted otherwise, all O&M cost figures represent annual amounts.

6.0 INITIAL RESULTS

The results of written requests for O&M information were less than hoped for. Of the more than 75 letters sent out, there were approximately 30 responses, a return rate of roughly 40%. Significant amounts of data were obtained from agencies in Morocco,and Sri Lanka. Most respondents indicated that data were either uncollected or unavailable. In some cases, responses were followed up with further inquiry of details concerning O&M information which had been provided.

Library searches resulted in general information regarding O&M of water supply systems. The cost figures which were available tended to be non-specific. This is indicative of the overall O&M cost data situation. The information generated from the library searches were primarily useful as background information for this report.

Visits to the World Bank were productive in providing detailed O&M cost information, particularly for African and Asian countries, and particularly for handpump systems. One report (Burnett 1984) summarized World Bank efforts to collect O&M cost data and was particularly useful.

7.0 O&M COSTS OF WATER SUPPLY SYSTEMS

Each type of water delivery system requires a different set of activities to keep the system operational and properly maintained. Generally, the principal components of O&M costs for water supply systems are labor, transport, chemicals, materials, and energy. The composition of available labor (expatriate or local), extent of transportation required for O&M activities, and availability and cost of energy supplies and spare parts (either of domestic or foreign origin) vary widely among projects, causing significant differences in O&M costs. Therefore, there are no absolute cost figures which can be universally applied to water supply projects as predictive measures.

Due to the variable nature of O&M costs, cost estimates should be analyzed with clear recognition of their deficiencies. Actual incurred costs are highly dependent on site-specific conditions. However, while it is incorrect to assume that O&M costs for different projects will be equivalent, it is useful to evaluate both the average and the range of O&M costs for several different projects utilizing similar water supply technologies. This approach allows project planners to better forecast O&M costs prior to project implementation. The forecast will only be as accurate as the available data. Therefore, it is appropriate to examine available data and compare them with other available estimates.

This section provides analysis of O&M costs as selected from several sources. The systems evaluated include: handpumps, gravity flow systems with distribution, systems with electric pumps and distribution, and schemes with diesel pumps. The systems are initially discussed individually and later as a group. O&M costs are analyzed according to system type, country and region. For all systems, data were most prevalent for Africa and Asia. A brief description of each of the systems is followed by general cost analyses. Detailed information regarding these data can be found in the Appendices.

The World Bank (Burnett, 1984) has collected a considerable amount of water supply O&M information, particularly in Africa and Asia. A table of O&M costs for several different types of water supply systems are shown in Table 1 on the next page.

Table 1

ANNUAL PER CAPITA RECURRENT COSTS FOR
WATER SYSTEMS IN AFRICA AND ASIA

(1984 Dollars (US))

SYSTEM TYPE		AVERAGE	RANGE
DUGWELL, Handpump			
	Africa	$0.70	$0.20-$1.40
	Asia	(-)	(-)
BOREHOLE, Handpump			
	Africa	$0.80	$0.20-$1.40
	Asia	$0.40	$0.10-$0.90
DUGWELL			
	Africa	$0.00	$0.00-$2.00
	Asia	$0.00	(-)
RAIN CATCHMENT			
	Africa	$0.00	(-)
	Asia	$0.10	$0.00-$2.00
SPRING (+distrib.)			
	Africa	$3.00	$0.00-$6.00
	Asia	$0.20	$0.00-$4.00
BOREHOLE, Electric Pump			
(+storage)	Africa	$5.40	$4.90-$5.90
	Asia	$0.60	$0.10-$1.20
BOREHOLE, Electric Pump (+storage, +distrib.)			
	Africa	$6.20	$4.10-$8.00
	Asia	$1.50	$0.70-$2.30
BOREHOLE, Diesel Pump			
(+storage)	Africa	(-)	(-)
	Asia	$1.80	(-)
GRAVITY, (+distrib.)			
	Africa	$1.40	$0.90-$1.80
	Asia	$1.00	$0.90-$1.10
PIPED, Surface			
	Africa	$6.90	(-)
	Asia	$1.80	(-)

Notes: Recurrent costs do not include any annualized capital cost items.
(-) indicates no available data.

Source: Burnett, Nick. 1984. "Rural Water Supply Handpumps Project Report on Cost Analysis Work", UNDP Project INT/81/026, World Bank, Draft Report, Tables 1 and 2.

7.1 Handpumps

The UNDP/World Bank Handpumps Project was established in 1981 to identify reliable water supply systems with low capital and recurrent costs. Conclusions from project research thus far indicate that handpumps provide an economically attractive and manageable option for the majority of poor small rural communities. In addition to demonstrating low costs, the relatively simple design of most handpumps facilitates maintenance at the village level. Once applied more extensively, village level operations and maintenance (VLOM) is expected to result in further reductions in recurrent costs.

Data from the World Bank and other respondents has been assembled in Appendix A, and summarized in Table 2. It is obvious from the table that both capital and annual O&M costs are much higher in Africa than in Asia. The same is true on a per capita basis. The higher capital cost in Africa can probably be attributed to increased dependence on imported pumps. Careful study of the annual O&M cost data shows that material and labor costs are on the same order of magnitude for the two continents, but transport costs in Africa are far higher. This result supports the growing movement towards VLOM in that region.

Table 2. SUMMARY OF STUDY RESULTS FOR HANDPUMP SYSTEMS (1986 $)

	ASIA	AFRICA
# OF DATA POINTS	14	25
CAPITAL COST		
Average	$341	$1,219
Range	$135-$802	$647-$1917
CAPITAL COST/CAPITA		
Average	$1.56	$3.92
Range	$0.45-$3.50	$1.72-$10.00
ANNUAL O&M COST		
Average	$60	$145
Range	$6-$300	$24-$383
ANNUAL O&M COST/CAPITA		
Average	$0.23	$0.53
Range	$0.05-$0.97	$0.05-$1.23
O&M COST/CAPITAL COST		
Average	26.2%	16.5%
Range	2.5%-112%	1.7%-53.2%

Per capita O&M costs for handpump systems from the World Bank and the results from this study (which include the same World Bank data) are compared in Table 3 below.

Table 3. PER CAPITA O&M COSTS FOR HANDPUMP SYSTEMS (1986 $)

HANDPUMP SYSTEM +	INFORMATION SOURCE	REGION	AVERAGE	RANGE
Dugwell	World Bank	Africa	$0.70	$0.19-$1.35
Borehole	World Bank	Africa	$0.78	$0.19-$1.35
Various	Study Results	Africa	$0.53	$0.05-$1.23
Borehole	World Bank	Asia	$0.40	$0.10-$0.87
Various	Study Results	Asia	$0.23	$0.05-$0.97

The study results show a similar range, but a slightly lower average cost indicating that our additional data points had a lower cost than the original World Bank data set.

In the absence of other precise O&M data, planners often estimate O&M costs as a percentage of system capital cost. This ratio was computed for our data, as shown in Table 2. The ratio was lower in Africa (16.5%) than in Asia (26.2%), which can mostly be attributed to higher capital costs in Africa. In both Africa and Asia, very wide ranges were found for this ratio. O&M cost estimates for handpumps based solely on such percentage figures appear to be questionable and should not be applied without careful consideration. Direct estimates of annual O&M cost would be preferable.

7.2 Gravity Systems

Given appropriate geographic conditions and a perennial source of spring or surface water, gravity fed water supply systems can provide a suitable means of water delivery. Many gravity systems, such as those established in Malawi since the early 1970's, have proven to be quite successful. There are possible problems involved in utilizing surface water in that water supplies are subject to contamination and subsequent quality concerns. For this reason, water treatment systems are often considered necessary and constructed at an additional cost to the distribution system. Water storage may also be required in order to attain sufficient head and volume for distribution purposes. Reliance upon gravity rather than mechanical pumping systems offer the potential of reduced maintenance requirements; however, water treatment and storage facilities add to the capital and recurrent costs of gravity systems. Chemical costs, in particular, are incurred.

Data collected from Indonesia, Sri Lanka, and Malawi are shown in

Appendix B, and summarized in Table 4. Additional World Bank data is also given in Appendix B.

Table 4. SUMMARY OF STUDY RESULTS FOR GRAVITY SYSTEMS (1986 $)

		ASIA	Malawi
# OF DATA POINTS		10	5
WATER VOLUME PRODUCED	Average	512,000	(-)
	Range	15,000-1,740,000 m3/yr	
CAPITAL COST	Average	$77,600	$117,200
	Range	$30,300-$158,000	$9,000-$187,000
CAPITAL COST/CAPITA	Average	$26.85	$3.64
	Range	$5.14-$48.04	$1.78-$6.56
ANNUAL O&M COST	Average	$44,700	$5,300
	Range	$1,700-$150,000	$2,700-$10,200
ANNUAL O&M COST/CAPITA	Average	$1.01	$0.26
	Range	$0.58-$2.28	$0.10-$0.72
O&M COST/CAPITAL COST	Average	5.5%	10.0%
	Range	2.1%-12.0%	1.9%-33.4%
O&M COST PER m3	Average	$0.07	(-)
	Range	$0.014-$0.141	

The capital costs and annual O&M costs for gravity systems are much larger than for handpumps, because of the much greater size of these systems. In addition, per capita values are higher, in Asia. In Malawi per capita values for gravity systems are actually lower than handpumps in Africa. These low costs in Malawi give some explanation for the successful projects there.

Per capita O&M costs for gravity systems for this study and for World Bank data are compared in Table 5.

GRAVITY SYSTEM (+)	INFORMATION SOURCE	REGION	AVERAGE	RANGE
Distribution	World Bank	Asia	$0.97	$0.87-$1.06
Distribution	Study Results	Asia	$1.01	$0.58-$2.28
Distribution	World Bank	Africa	$1.30	$0.87-$1.74
Distribution	Study Results	Malawi	$0.26	$0.10-$0.72

For Asia, the study results show a similar average cost per capita, but a much wider range. Our results show that costs in Malawi are well below other African costs.

The O&M cost per cubic meter of water produced is also a useful comparative measure. In addition to the data in Table 4, the Asian Development Bank (ADB) has compiled a table of such costs for nineteen Asian countries (See Appendix E). The ADB average cost figures for gravity systems are compared to the study results in Table 6.

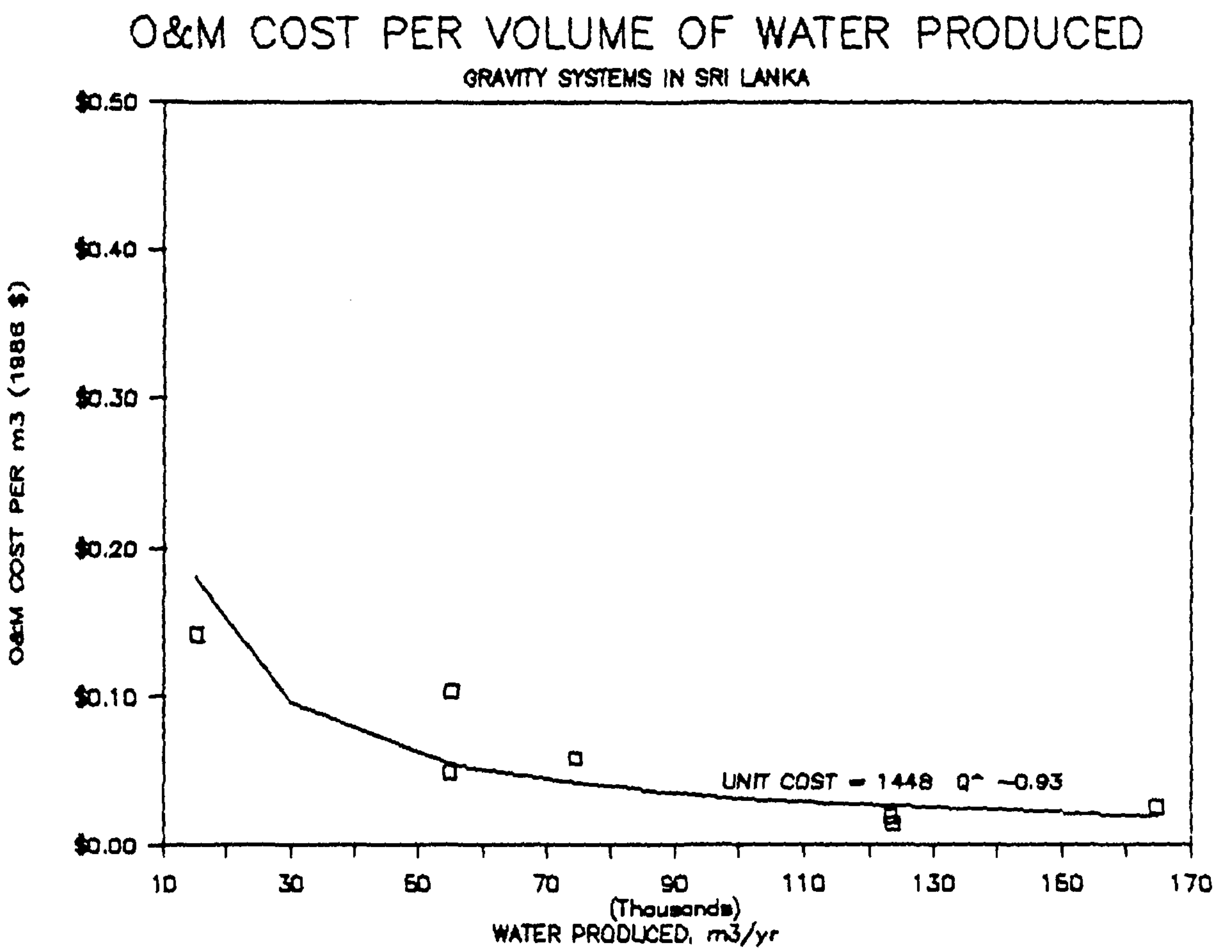
Table 6. O&M COST PER CUBIC METER OF WATER PRODUCED (1986 $)

GRAVITY SYSTEM (+)	INFORMATION SOURCE	REGION	AVERAGE	RANGE
Distribution + Treatment	ADB	Asia	(-)	$0.07-$0.14
Distribution + Treatment	Study Results	Asia	$0.07	$0.01-$0.14

The range of per cubic meter costs determined in this study is wider than that of the ADB cost range, which can perhaps be explained due to scale effects.

A cost function for O&M cost per cubic meter was derived to examine the question of scale. Figure 1 shows a plot of gravity systems in Sri Lanka only. The fit of the cost function regression was good (r^2=0.74). There are very large economies of scale (b=0.07). For Sri Lanka, the ADB estimates a range of O&M costs per cubic meter of $0.04 - $0.15, which closely corresponds to the range in Figure 1.

Figure 1



O&M COST PER VOLUME OF WATER PRODUCED
GRAVITY SYSTEMS IN SRI LANKA
O&M COST PER m3 (1988 $)
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
UNIT COST = 1448 Q^ -0.93
10
30
50
70
90
110
130
150
170
(Thousands)
WATER PRODUCED, m3/yr

7.3 Electric Systems

Electric pumping for water systems is usually limited to areas where reliable electric power already exists, primarily in towns and cities. Such systems vary greatly in size and complexity. They can pump water from boreholes or surface water sources. Larger systems will have storage and distribution networks, but smaller systems may simply have a tank and single standpost. The extent of treatment required will vary from none or simple chlorination, common on borehole systems, to more extensive treatment common with systems using surface water. The maintenance requirements for these systems will vary depending greatly on the engineering configuration and scale. Electric pump systems will have a large energy cost component.

World Bank data, in Appendix C, provide information for the O&M costs of borehole/electric pump/storage systems either with or without distribution. Additional data from Sri Lanka, in Appendix C, is summarized in Table 7.

Table 7. SUMMARY OF STUDY RESULTS FOR ELECTRIC PUMP SYSTEMS (1986 $)

	Sri Lanka	AFRICA
# OF DATA POINTS	35	
WATER VOLUME PRODUCED		
Average	169,000	
Range	2,700-1,310,000	
CAPITAL COST		
Average	$210,000	
Range	$8000-2,000,000	
CAPITAL COST/CAPITA		
Average	$24.78	
Range	$3.17-$134	
ANNUAL O&M COST		
Average	$11,383	
Range	$780-$75,000	
ANNUAL O&M COST/CAPITA		
Average	$2.12	
Range	$0.50-$7.28	
O&M COST/CAPITAL COST		
Average	18.0%	
Range	1.2%-72.8%	
O&M COST PER m3		
Average	$0.15	
Range	$0.028-$1.17	

The capital cost per capita for electric systems appear somewhat similar to the Asian gravity systems, but the O&M cost per capita is twice the gravity systems. Also, the O&M cost per cubic meter for electric systems is about twice that for gravity schemes.

World Bank figures are compared with the study results in Table 8, below, showing slightly higher figures in our study.

Table 8. PER CAPITA O&M COSTS FOR ELECTRIC SYSTEMS (1986 $)

ELECTRIC SYSTEM (+)	INFORMATION SOURCE	REGION	AVERAGE	RANGE
Storage	World Bank	Africa	$6.23	$4.73-$7.73
Storage	World Bank	Asia	$0.61	$0.10-$1.16
Storage + Distribution	World Bank	Africa	$3.96	(-)
Storage + Distribution	World Bank	Asia	$1.40	$0.68-$2.22
Storage + Chlorination + Distribution	Study Results	Sri Lanka	$2.12	$0.50-$7.28

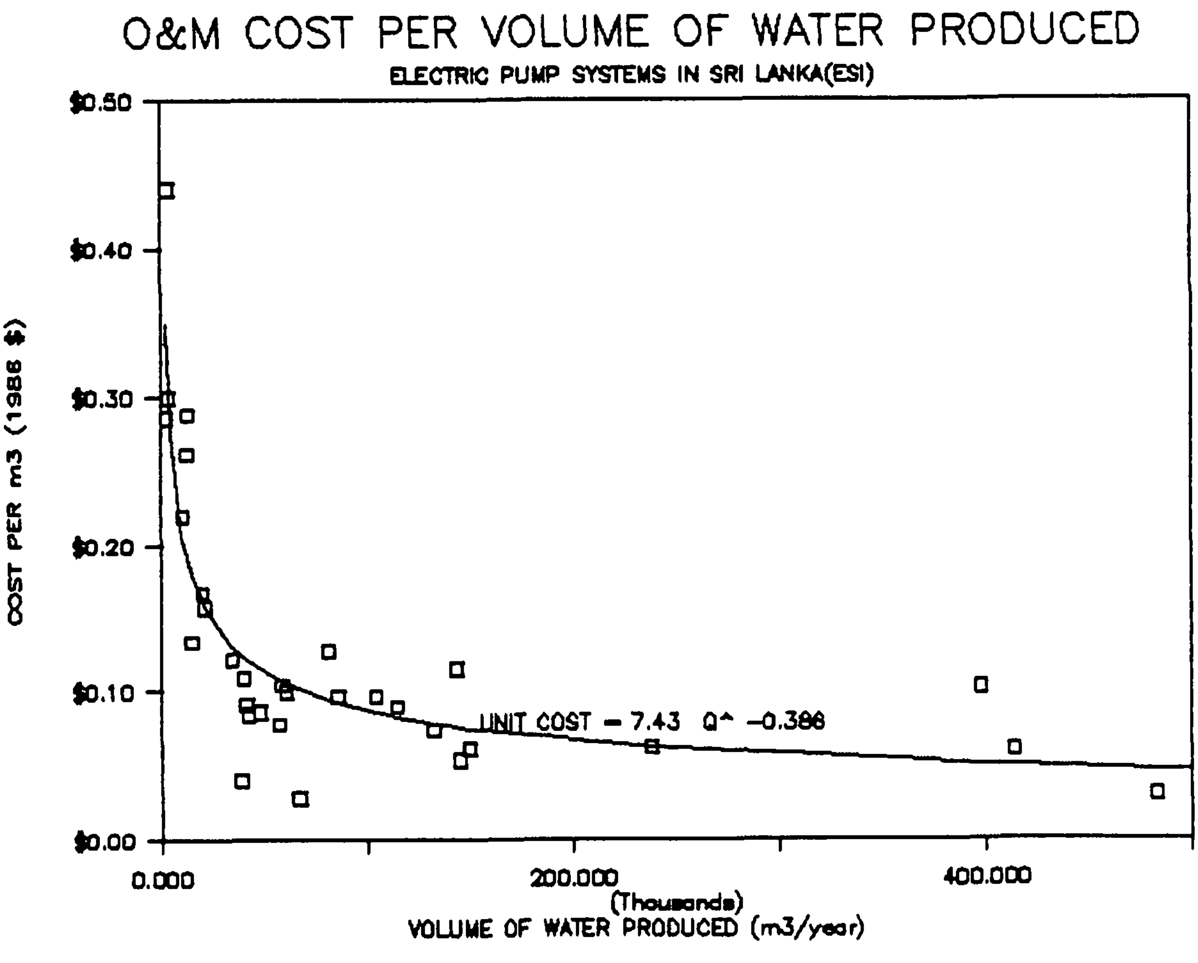
There are also differences between the study results for the O&M cost per cubic meter of water produced for Sri Lanka systems and those determined by the ADB (Appendix E). These cost figures are presented in Table 9.

Table 9. O&M COST PER CUBIC METER OF WATER PRODUCED (1986 $)

ELECTRIC SYSTEM (+)	INFORMATION SOURCE	REGION	AVERAGE	RANGE
Borehole + Distribution	ADB	Sri Lanka	(-)	$0.02-$0.06
Borehole + Treatment + Distribution	ADB	Sri Lanka	(-)	$0.03-$0.10
Borehole + Chlorination + Distribution	Study Results	Sri Lanka	$0.15	$0.028-$1.17

The very broad range of O&M costs in our study results can be better understood by examining the effect of scale on these costs. A graph of O&M costs per cubic meter of produced water plotted against the volume of water produced for electric systems is shown in Figure 2[3]. The fit of the curve is good (r^2=0.62). The economies of scale are clearly evident (b=0.614), although they are less marked than in gravity systems in Sri Lanka. Beyond the 50,000 cubic meter production level, costs consistently occur within the $0.03 to $0.10 range. This is the same as determined by the ADB. So while smaller scale electric systems in Sri Lanka exhibit a wide range of O&M costs, systems producing more than 50,000 cubic meters annually appear to be more predictable and in agreement with ADB findings.

Figure 2



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[3] The graph excludes the points where cost per cubic meter equals $1.17 and total volume produced equals 1,310,021 meters per year so that the remaining points can be more easily distinguished.

7.4 Diesel Systems

Diesel systems provide an additional method of providing water to communities dependent upon groundwater supplies. Similar to electric systems, diesel pumping may also involve concurrent investments in storage and distribution facilities. Unlike the other systems previously discussed, diesel systems often require more constant attention for refueling and other O&M activities. Unpredictable fuel prices and supplies can cause diesel system O&M costs to fluctuate and thereby complicate planning for O&M management and organization. Therefore, the price and availability of fuel are important considerations in determining the propriety of diesel powered pumping systems.

Information regarding diesel systems is detailed in Appendix D. and summarized in Table 10. The data obtained for this study pertain to several countries located throughout Africa. Most of the systems analyzed do not have any significant water distribution system, but most all have storage. Although not elaborated in the data, those with distribution have higher capital and O&M costs.

Table 10. SUMMARY OF STUDY RESULTS FOR DIESEL PUMP SYSTEMS (1986 $)

	ASIA	AFRICA
# OF DATA POINTS		38
WATER VOLUME PRODUCED		
Average		26,700
Range		1,200-147,000
CAPITAL COST		
Average		$6,200
Range		$3,200-$16,000
ANNUAL O&M COST		
Average		$2,540
Range		$120-$12,250
ANNUAL O&M COST/CAPITA		
Average		$4.27
Range		$1.94-$7.30
O&M COST/CAPITAL COST		
Average		53.2%
Range		12.4%-94.1%
O&M COST PER m3		
Average		$0.21
Range		$0.01-$1.17

Population figures are not available for many of the systems evaluated, so per capita data is limited. Of the 38 systems analyzed, only 9 had sufficient information to calculate annual per capita costs. Although the data are deficient for purposes of comparison, the available averages and ranges of per capita O&M costs for diesel systems are shown in Table 11.

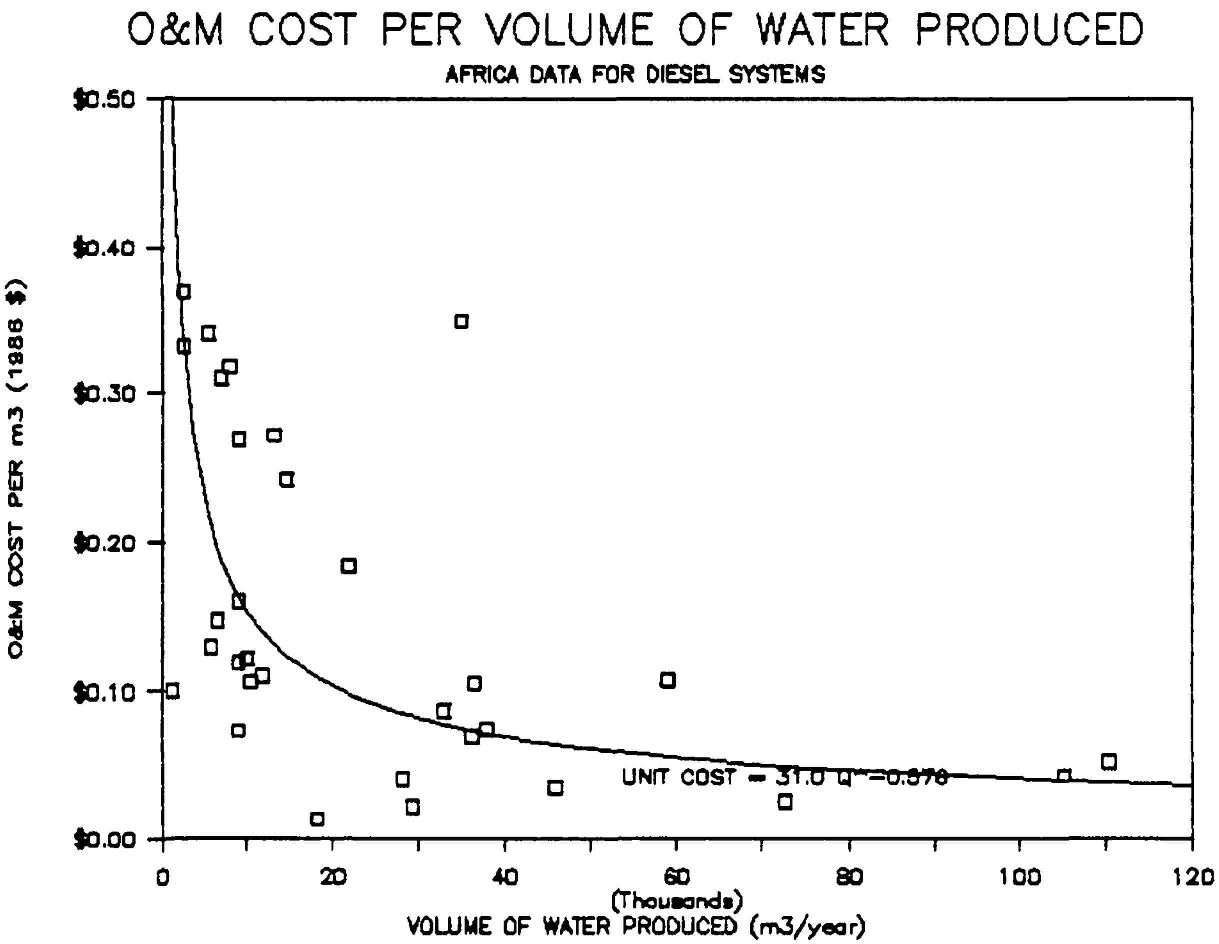
Table 11. PER CAPITA O&M COSTS FOR DIESEL SYSTEMS (1986 $)

DIESEL SYSTEM (+)	INFORMATION SOURCE	REGION	AVERAGE	RANGE
Storage	World Bank	Asia	$1.74	(-)
Storage	World Bank	Africa	(-)	(-)
(Various)	Study Results	Africa	$4.27	$1.94-$7.30

As was the case for electric systems, a graph of annual O&M cost per volume of water provides better analytical cost information. The graph[4] for diesel systems is shown in Figure 3. Again, the graph indicates that economies of scale exist (b=0.424). The fit of the cost function was only moderately good, (r^2=0.5), probably due to a wide variability of costs at the smaller scales.

[4] Once again, the outermost values along each axis have been omitted in order to better distinguish the remaining points.

Figure 3


O&M COST PER VOLUME OF WATER PRODUCED
AFRICA DATA FOR DIESEL SYSTEMS
O&M COST PER m3 (1988 $)
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
UNIT COST = 31.0 Q^-0.578
0
20
40
60
80
100
120
(Thousands)
VOLUME OF WATER PRODUCED (m3/year)

8.0 O&M COST COMPARISON OF WATER SUPPLY SYSTEMS

This section combines information found in previous sections in order to compare the various costs of water supply systems. These are primarily average figures which are not intended to be representative of all water development projects. However, they do permit general cost comparisons of the systems.

Given uniform data sets, different technologies can be compared. Unfortunately the limited data collected only allow limited comparisons. In Sri Lanka, however, coherent data were obtained and analyzed for gravity and electric pump systems. Cost functions for these two systems are compared in Figure 4. Clearly gravity systems have a lower unit O&M cost over the range considered. Such ample, uniform data are, however, not widely available.

The ranges of average per capita O&M costs by system and region are shown in Table 12. (Averages from this study and World Bank data were used to compile Table 12).

Table 12. RANGES OF AVERAGE PER CAPITA O&M COSTS BY SYSTEM AND REGION (1986 $)

SYSTEM	REGION	RANGE
Handpump	Africa	$0.53 - $0.78
	Asia	$0.29 - $0.40
Gravity + Distribution	Africa	$0.26 - $1.30
	Asia	$0.97 - $1.01
Electric + Distribution	Africa	$3.96 - $6.23
	Asia	$1.40 - $2.12
Diesel	Africa	$4.27
	Asia	$1.74

This same information is presented in bar graph form in Figures 5. While the cost ranges do overlap in some cases, each system type appears to occupy a distinct space, thus providing a rough approximation of O&M cost requirements. Available information suggests that of the systems evaluated, handpumps represent the least cost technology, followed by gravity systems which are less expensive than electric systems. The O&M cost range for diesel systems is narrow due to a lack of data and is therefore inconclusive. However, diesel systems do seem to be among the more expensive options.

Figure 4

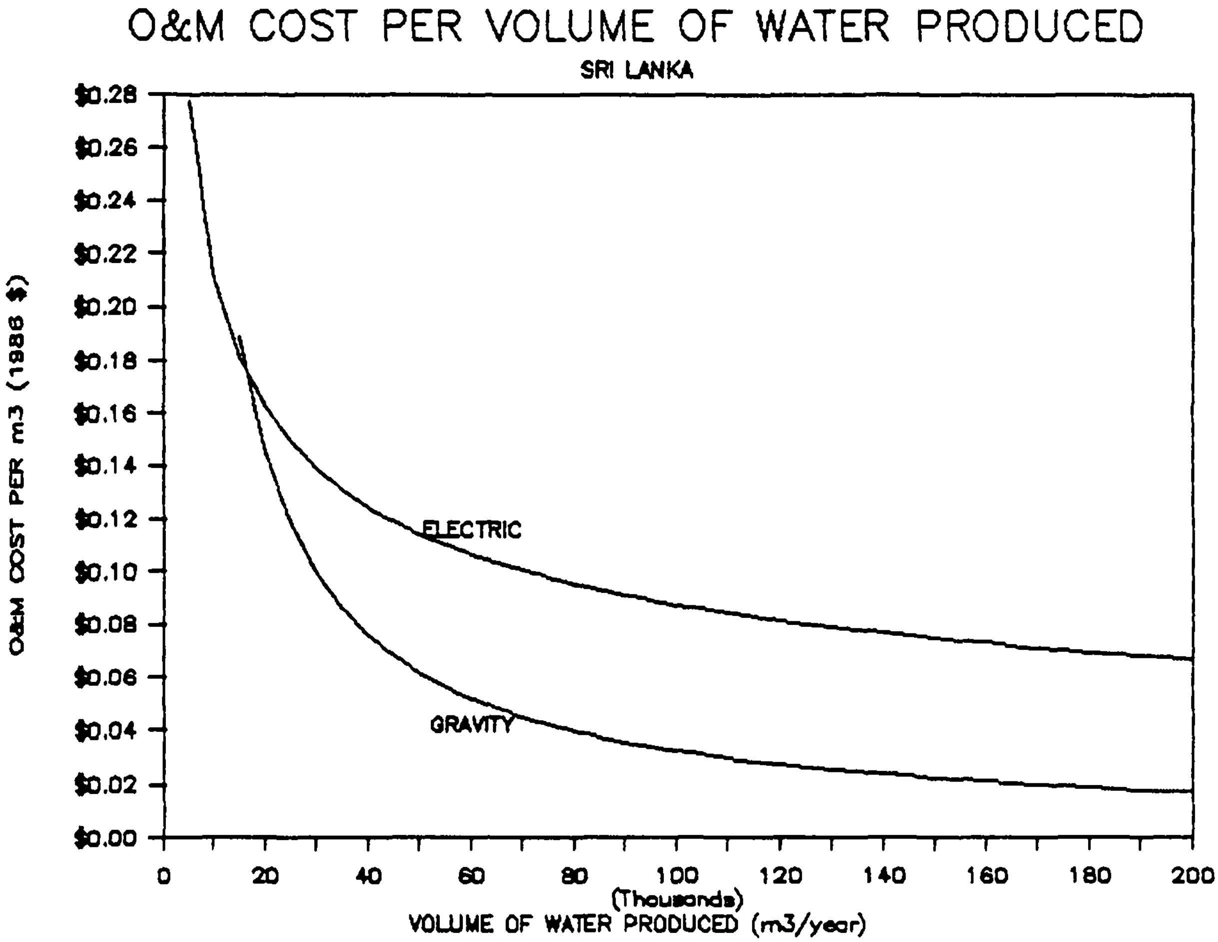
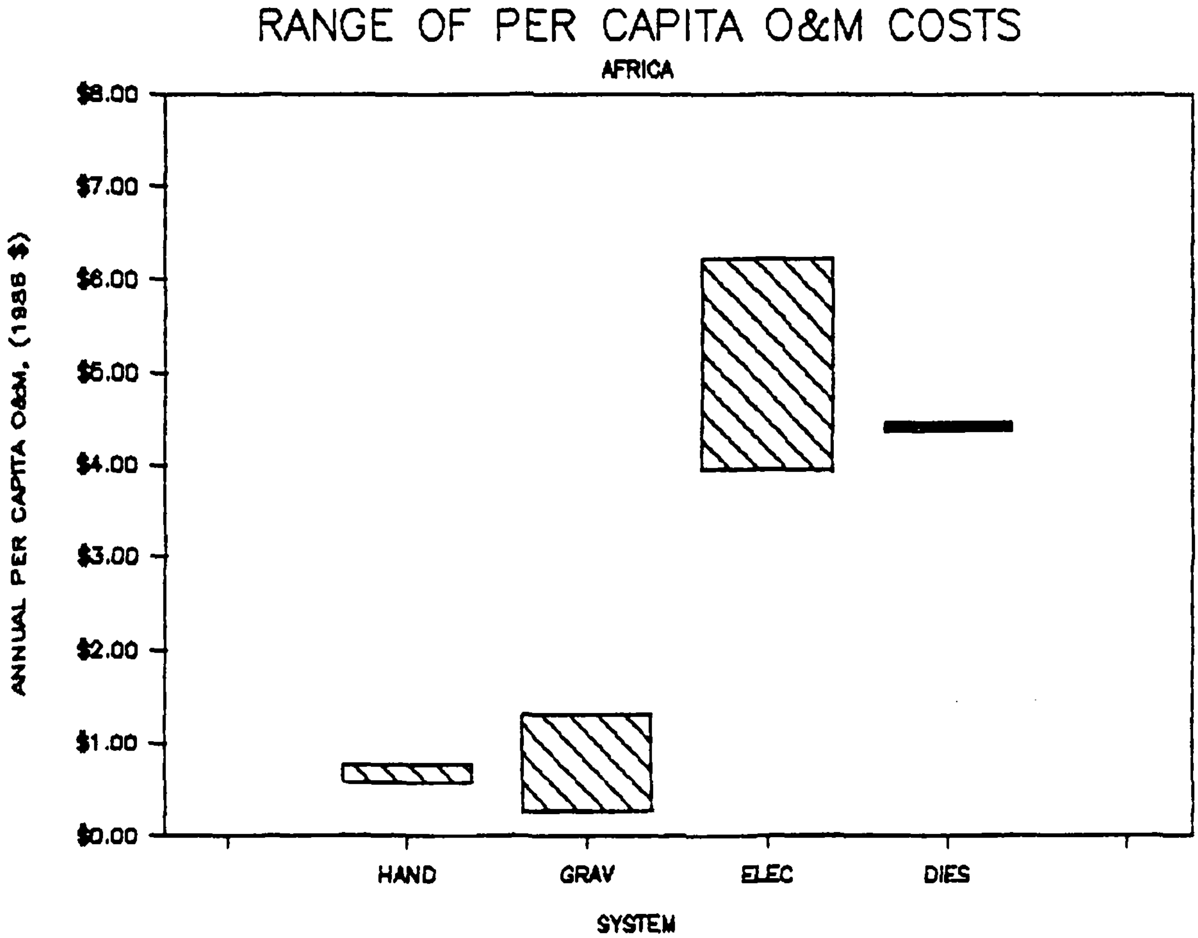
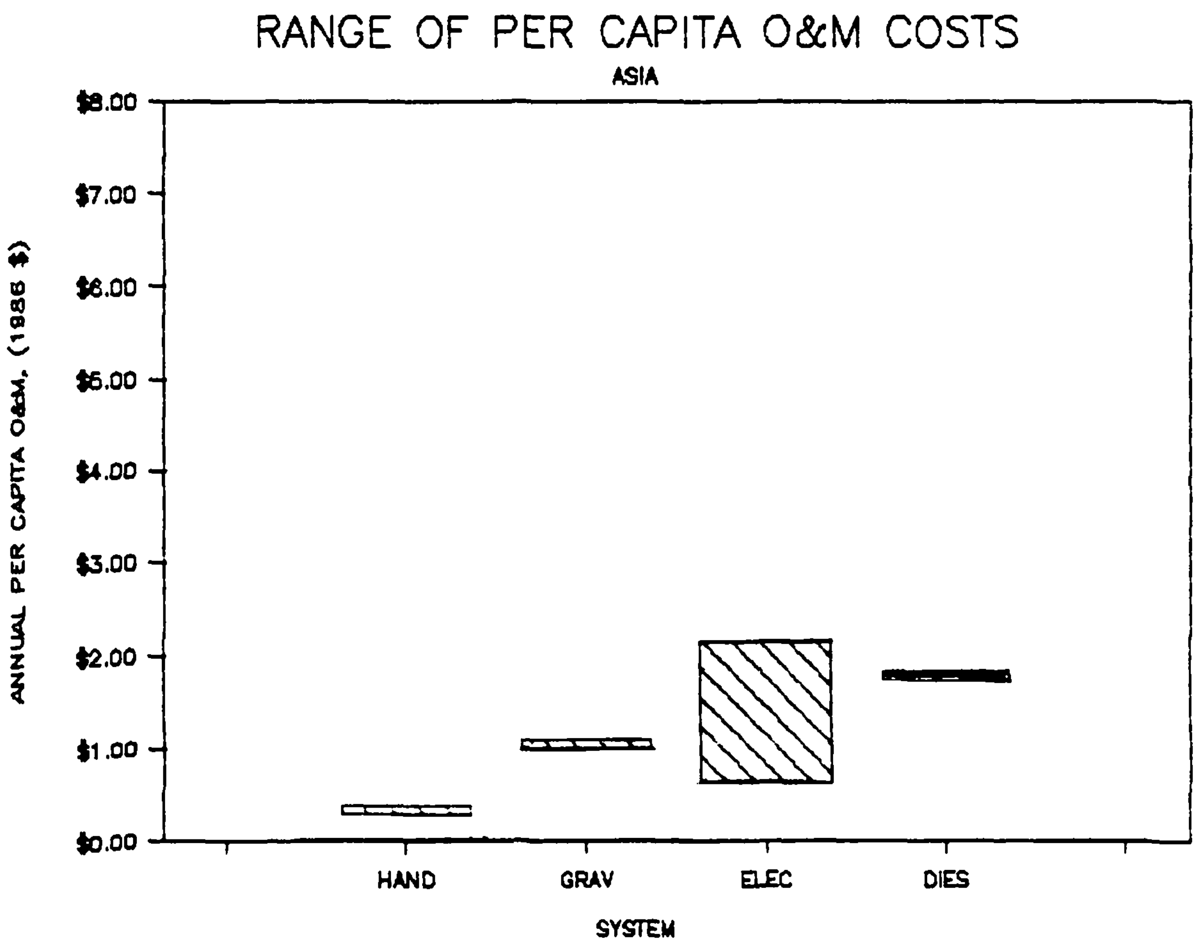

O&M COST PER VOLUME OF WATER PRODUCED
SRI LANKA
O&M COST PER m3 (1988 $)
$0.28
$0.26
$0.24
$0.22
$0.20
$0.18
$0.16
$0.14
$0.12
$0.10
$0.08
$0.06
$0.04
$0.02
$0.00
ELECTRIC
GRAVITY
0
20
40
60
80
100
120
140
160
180
200
(Thousands)
VOLUME OF WATER PRODUCED (m3/year)

Figure 5


RANGE OF PER CAPITA O&M COSTS
AFRICA
ANNUAL PER CAPITA O&M, (1988 $)
$8.00
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
HAND
GRAV
ELEC
DIES
SYSTEM


RANGE OF PER CAPITA O&M COSTS
ASIA
ANNUAL PER CAPITA O&M, (1988 $)
$8.00
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
HAND
GRAV
ELEC
DIES
SYSTEM

A summary of the average O&M costs per cubic meter for all system types is shown in Table 13. The figures for handpump systems represent a hypothetical calculation based on a daily per capita use of 20 liters. The same rough ranking of handpump, gravity, electric, and diesel systems is evident.

The average costs provide a means of ranking the systems; however, these figures must be viewed carefully. The effect of scale, and other technical factors can lead to very wide ranges of unit water costs. The technologies are best compared as cost functions with scale (as for Sri Lanka above) but there is insufficient data to make such comparisons.

Table 13. RANGES OF PER CUBIC METER COSTS FOR ALL REGIONS (1986 $)

SYSTEM	RANGE	AVERAGE
Handpump*	$0.007 - $0.17	$0.05
Gravity	$0.01 - $0.14	$0.07
Electric	$0.03 - $1.17	$0.14
Diesel	$0.01 - $1.17	$0.21

* Assuming production yields 20 lpd per handpump

9.0 CONCLUSIONS

Water supply system O&M costs are important yet relatively unknown components of water development projects. While O&M costs do vary among different system technologies, the costs cannot currently be accurately estimated for site specific applications.

The O&M cost figures found in this report apply only to very broad regions and are therefore inappropriate for purposes of specific estimation. The data do suggest, however, that certain trends do exist thus allowing the general trends and relative magnitudes of O&M costs to be compared. Handpumps, for example, appear to represent the least cost system available. Data for handpump systems are also more available than other systems perhaps because handpumps have received greater emphasis during recent years. Gravity systems demonstrate the next lowest O&M costs. Distinctions between electric and diesel systems are less clear primarily due to a lack of data for diesel systems.

The most evident point concerning O&M for water supply systems is the limited amount of actual cost data. This is an obvious and significant constraint for O&M cost studies, but the lack of data has even greater implications. As the responsibility for O&M is increasingly borne by individual communities, without a better ability to estimate O&M costs, these communities are burdened by unknown costs. Until more is known about O&M costs of water supply systems, current and future water development projects face a precarious existence.

10.0 FUTURE RESEARCH NEEDS

One of the purposes of this report is to identify research needs for the O&M of water supply projects in developing countries. The report provides only a small sample of actual O&M costs. The limited amount of data retrieved for this study reflects the general lack of currently available information. Rather than overemphasize the numbers generated in this and previous studies, it is perhaps more important to consider the direction of future O&M investigations. General research needs are briefly discussed below.

More and better O&M cost information. The awareness of and provision for O&M cost requirements are still in a formative stage for most water supply projects in developing countries. Improved data collection efforts by local water utilities and donor agencies is a necessary prerequisite for improved cost estimation. The Appendices contains several significant data gaps. Until such gaps are more completely filled, O&M cost estimations will also remain incomplete and speculative.

Comprehensive and cost-effective data collection. The funding and time required to improve the O&M data situation are in short supply relative to the extensive and urgent need for water supply improvements in developing countries. These financial and time constraints will result in certain compromises for the collection and analysis of O&M data. Therefore, it is essential to consider methods of investigation which will efficiently determine the most useful information. Cross sectional analysis of appropriate water supply technologies, involving representative environments (physical and social) and O&M management regimes, provide a viable approach to the problem.

Consistent data collection. Given the diversity of project and system types and the numerous organizations involved in water supply development, comparable information is needed to provide accurate cost studies. A standard O&M questionnaire or report form would promote more reliable cost measurements and estimations.

An O&M information network among water development organizations. Despite efforts directed toward this need, O&M studies remain uncoordinated. Without more collaboration, certain O&M investigations are left undone while others are redundant. An information pool would increase the availability of O&M data and thereby promote a more concerted global effort.

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APPENDIX A

Handpump Systems

PER CAPITA COST DATA FOR HANDPUMP SYSTEMS IN AFRICA

(1984 Dollars (US))

COUNTRY	SYSTEM	CAPITAL	RECURRENT	REC/CAP
BURKINA FASSO	Dugwell +Handpump	$ 15.20	$ 0.40	2.6%
SIERRA LEONE	Dugwell +Handpump	$ 25.90	$ 0.90	3.5%
TANZANIA	Dugwell +Handpump	$ 7.30	$ 0.20	2.7%
WEST AFRICA	Dugwell +Handpump	$ 55.20	$ 1.40	2.5%
GHANA	Borehole +Handpump	$ 41.80	$ 1.20	2.9%
MALI	Borehole +Handpump	$ 40.80	$ 0.20	0.5%
SENEGAL	Borehole +Handpump	$ 24.00	$ 0.90	3.8%
SIERRA LEONE	Borehole +Handpump	$ 57.10	$ 0.90	1.6%
SUDAN	Borehole +Handpump	$ 8.30	$ 0.60	7.2%
TANZANIA	Borehole +Handpump	$ 13.10	$ 0.20	1.5%
TOGO	Borehole +Handpump	$ 44.20	$ 1.10	2.5%
WEST AFRICA	Borehole +Handpump	$ 51.00	$ 1.40	2.7%
Dugwell +Handpump	AVERAGE	$ 25.90	$ 0.73	2.8%
	STD DEV	$ 18.16	$ 0.47	0.4%
	STD/AVG	0.70	0.64	0.13
	MINIMUM	$ 7.30	$ 0.20	2.5%
	MAXIMUM	$ 55.20	$ 1.40	3.5%
Borehole +Handpump	AVERAGE	$ 35.04	$ 0.81	2.8%
	STD DEV	$ 16.67	$ 0.42	1.9%
	STD/AVG	0.48	0.51	0.67
	MINIMUM	$ 8.30	$ 0.20	0.5%
	MAXIMUM	$ 57.10	$ 1.40	7.2%

Source: Burnett, Nick. 1984. "Rural Water Supply Handpumps Project Report on Cost Analysis Work", UNDP Project INT/81/026, World Bank, Draft Report, Tables 1 and 2.

PER CAPITA COST DATA FOR HANDPUMP SYSTEMS IN ASIA

(1984 Dollars (US))

COUNTRY	LOCATION	SYSTEM	CAPITAL	RECURRENT	REC/CAP
INDIA	Madhya Pradesh	Deep Borehole +Handpump	$ 5.30	$ 0.20	3.8%
INDIA	Orissa	Deep Borehole +Handpump	$ 7.00	$ 0.20	2.9%
INDIA	Tamil Nadu	Deep Borehole +Hand Pump	$ 6.50	$ 0.20	3.1%
INDIA	West Bengal	Deep Borehole +Handpump	$ 3.00	$ 0.10	3.3%
INDONESIA		Deep Borehole +Handpump	$ 8.20	$ 0.50	6.1%
PHILIPPINES		Deep Borehole +Handpump	$ 4.40	$ 0.80	18.2%
THAILAND		Deep Borehole +Handpump	$ 20.90	$ 0.90	4.3%
INDONESIA		Shallow Borehole +Handpump	$ 3.30	$ 0.30	9.1%
Deep Borehole +Handpump		AVERAGE	$ 7.90	$ 0.41	5.9%
		STD DEV	$ 5.54	$ 0.30	5.1%
		STD/AVG	0.70	0.72	0.86
		MINIMUM	$ 3.00	$ 0.10	2.9%
		MAXIMUM	$ 20.90	$ 0.90	18.2%

Source: Burnett, Nick. 1984. "Rural Water Supply Handpumps Project Report on Cost Analysis Work", UNDP Project INT/81/026, World Bank, Draft Report, Tables 1 and 2.

O&M COST DATA FOR HANDPUMP SYSTEMS

ASIA

COUNTRY	PROJECT LOCATION	PUMP TYPE	SOURCE	DATE	POPULA. SERVED	CAPITAL COST	CAPITAL COST (1986 US$)	CAPITAL COST PER CAPITA (1986 US$)	O&M COST/ TRANSP.
BANGLADESH			SKAT	1982	100	$200	$200	$2.00	
BANGLADESH		New No. 6	Hofkes	1984					
BURMA			SKAT	1982	150	$200	$200	$1.34	
INDIA			SKAT	1982	500	$800	$802	$1.60	
INDIA	Tamil Nadu	Mark II	Hofkes, UNICEF	1984					
INDIA	Tamil Nadu	Mark II	World Bank	1984	250	$370	$357	$1.43	$11
INDIA	Orissa	Mark II	World Bank	1984	200	$270	$261	$1.30	$6
INDIA	Madhya Prades	Mark II	World Bank	1984	350	$280	$270	$0.77	$13
INDIA	West Bengal	Mark II	World Bank	1984	260				$0
NEPAL			SKAT	1982	100	$200-$500	$200-501	$2-$5	
PHILIPPINES	Pampanga	Eureka	World Bank	1984	300	$140	$135	$0.45	$14
PHILIPPINES	Pampanga	Takasago	World Bank	1984	300	$510	$493	$1.64	$15
THAILAND	North East	Various	Hofkes	1983	224				$10
THAILAND		Various	Hofkes	1984					
			COUNT	14	11	9	9	9	7
			AVERAGE		249	$347	$341	$1.56	$10
			STD DEV		111	$191	$191	$0.81	$5
			STD/AVG		0.45	0.55	0.56	0.52	0.49
			MINIMUM		100	$140	$135	$0.45	$0
			MAXIMUM		500	$800	$802	$3.50	$15

AFRICA

COUNTRY	PROJECT LOCATION	PUMP TYPE	SOURCE	DATE	POPULA. SERVED	CAPITAL COST	CAPITAL COST (1986 US$)	CAPITAL COST PER CAPITA (1986 US$)	O&M COST/ TRANSP.
BENIN			World Bank	1984					
BOTSWANA	Dikgonye Thebe		ARD	1985		$1,974	$1,917		
BOTSWANA	Hukuntsi		ARD	1985		$1,427	$1,386		
BOTSWANA	Tlhareseleele		ARD	1985		$805	$782		
BOTSWANA	Sengwoma		ARD	1985		$812	$788		
BURKINA FASO	(Dugwell)	Volanta	World Bank	1984	500	$890	$860	$1.72	$137
BURKINA FASO	Yatenga	Vergnet	World Bank	1986					
CAMEROON	North-FSAR	Various	CARE-Cameroon	1986		$1,736	$1,736		
CAMEROON	North-CARE	Mono/R&M	CARE-Cameroon	1986		$1,660	$1,660		
GHANA	Upper Region		SKAT	1982	200	$300-$2000	$301-$2004	$1.50-$10.00	
GHANA			Hofkes	1984					
GHANA (1)	(Borehole)	Mark II	World Bank	1984	300	$720	$696	$2.32	$103
GHANA (2)	(Borehole)	Various	World Bank	1984	350	$850	$821	$2.35	$27
IVORY COAST	(SODECI)	ABI/Vergnet	Hofkes, WB	1984					
MALAWI		MALDEV/other	Hofkes	1984					
MALAWI	Livulezi		World Bank	1985	250	$1,390	$1,350	$5.40	$6
MALI			World Bank	1984	500	$1,840	$1,777	$3.55	$32
SIERRA LEONE	(Dugwell)		World Bank	1984	250	$1,260	$1,217	$4.87	$29
SUDAN			World Bank	1984	350	$670	$647	$1.85	$100
TANZANIA			SKAT	1982	200	$1,500	$1,503	$7.52	
TANZANIA	Shinyanga		Hofkes	1982					$56
TANZANIA	Centralized		Hofkes	1983					
TANZANIA	Decentralized		Hofkes	1983					
TANZANIA	(Dugwell)	Nira	World Bank	1984	200				$13
TOGO		Vergnet	World Bank	1984	300				$132
			COUNT	25	11	15	15	9	10
			AVERAGE		309	$1,246	$1,219	$3.92	$63
			STD DEV		104	$424	$421	$1.93	$47
			STD/AVG		0.34	0.34	0.35	0.49	0.75
			MINIMUM		200	$670	$647	$1.72	$6
			MAXIMUM		500	$1,974	$1,917	$10.00	$137

O&M COST DATA FOR HANDPUMP SYSTEMS

ASIA

YEAR	LABOR	REPAIR & MAINTENANCE	ADMINIS.	OTHER	TOTAL O&M COST/YEAR	% SYSTEMS IN OPER.	TOT.O&M COST @100% OPER.	TOT.O&M COST @100% OPER. (1986 US$)	PER CAPITA O&M COST (1986 US$)	O&M COST AS % OF CAPITAL
	O&M COST/YEAR									
					$5	80.0%	$6	$6	$0.06	3.1%
					$6-$10		$6-$10			
					$8		$8	$8	$0.05	3.8%
					$20	85.0%	$24	$24	$0.05	2.9%
					$35		$35	$34		
	$21	$5		$0	$37	78.0%	$47	$46	$0.18	12.8%
	$11	$21		$2	$40	95.0%	$42	$41	$0.20	15.6%
	$41	$9		$2	$67	98.0%	$68	$66	$0.19	24.4%
	$11	$2		$0	$13	90.0%	$14	$14	$0.05	
					$7		$7	$7	$0.07	1.4%-3.5%
	$71	$71			$157		$157	$152	$0.51	112.1%
	$144	$144			$300		$300	$290	$0.97	58.8%
	$28	$4	$9	$5	$57		$57	$56		
					$60		$60	$58		
	7	7	1	5	14	6	14	13	10	9
	$47	$36	$9	$2	$58	87.7%	$60	$58	$0.23	26.2%
	$44	$49		$2	$77	7.4%	$77	$74	$0.28	34.8%
	0.94	1.35		1.02	1.33	0.08	1.29	1.28	1.19	1.33
	$11	$2	$9	$0	$5	78.0%	$6	$6	$0.05	2.5%
	$144	$144	$9	$5	$300	98.0%	$300	$290	$0.97	112.1%

AFRICA

YEAR	LABOR	REPAIR & MAINTENANCE	ADMINIS.	OTHER	TOTAL O&M COST/YEAR	% SYSTEMS IN OPER.	TOT.O&M COST @100% OPER.	TOT.O&M COST @100% OPER. (1986 US$)	PER CAPITA O&M COST (1986 US$)	O&M COST AS % OF CAPITAL
	O&M COST/YEAR									
					$114		$114	$111		
					$176		$176	$171		8.9%
					$85		$85	$83		6.0%
					$181		$181	$176		22.5%
					$91		$91	$88		11.2%
	$51	$10		$0	$196	95.0%	$206	$199	$0.40	23.2%
									$0.05	
					$186		$186	$186		10.7%
					$87		$87	$87		5.2%
					$70	90.0%	$78	$78	$0.39	3%-26%
					$75-$90		$75-$90	$72-$87		
	$199	$52		$11	$368	96.0%	$383	$370	$1.23	53.2%
	$76	$34		$6	$140	84.0%	$167	$161	$0.46	19.6%
					$126		$126	$122		
					$20-$30		$20-$30	$19-$29		
	$5	$3	$10	$0	$24		$24	$23	$0.09	1.7%
	$31	$21		$0	$84		$84	$81	$0.16	4.6%
	$109	$67		$18	$222		$222	$214	$0.86	17.6%
	$95	$19		$0	$212	70.0%	$303	$293	$0.84	45.2%
					$120	90.0%	$133	$134	$0.67	8.9%
	$25	$29			$111		$111	$111		
					$130-$200		$130-$200	$128-$198		
					$95		$95	$94		
	$7	$17		$0	$38	90.0%	$42	$41	$0.20	
	$61	$123		$10	$323		$323	$312	$1.04	
	10	10	1	9	24	7	24	24	12	15
	$66	$37	$10	$5	$138	87.9%	$145	$142	$0.53	16.5%
	$55	$34		$6	$83	8.1%	$90	$87	$0.37	14.3%
	0.84	0.90		1.27	0.60	0.09	0.62	0.61	0.70	0.87
	$5	$3	$10	$0	$24	70.0%	$24	$23	$0.05	1.7%
	$199	$123	$10	$18	$368	96.0%	$383	$370	$1.23	53.2%

APPENDIX B

Gravity Systems

PER CAPITA COSTS FOR GRAVITY SYSTEMS IN AFRICA AND ASIA

Source: Burnett, World Bank   Date: 1984   (In 1984 US$)

AFRICA

COUNTRY	SYSTEM	CAPITAL	RECURRENT	REC/CAPITAL
CAPE VERDE	Gravity (surface) +distri.	$ 73.30	$ 1.80	2.5%
SIERRA LEONE	Gravity (surface) +distri.	$ 42.00	$ 0.90	2.1%
	AVERAGE	$ 57.65	$ 1.35	2.3%

ASIA

COUNTRY	SYSTEM	CAPITAL	RECURRENT	REC/CAPITAL
INDIA	Gravity (surface) +distri.	$ 24.00	$ 0.90	3.8%
PAPUA NEW GUINEA	Gravity (surface) +distri.	$ 13.70	$ 1.10	8.0%
	AVERAGE	$ 18.85	$ 1.00	5.9%

GRAVITY SYSTEM O&M COST DATA

ASIA

COUNTRY	PROJECT LOCATION	SYSTEM TYPE	DATA SOURCE	DATE	POPULAT. SERVED	TOT. VOLUME PRODUCED (m3/yr)	VOLUME PRODUCED (lt/cap/day)	INITIAL CAPITAL COST	CAPITAL COST PER CAPITA	TRANSP.
INDONESIA	Sukabumi	Gravity	DHV	1983	173,500	1,240,000	20			
INDONESIA	Sukabumi	Gravity	DHV	1984	176,600	1,530,000	24			
INDONESIA	Sukabumi	Gravity	DHV	1985	179,700	1,740,000	27			
SRI LANKA	Gonagaldeniya	Grav/Chlor	ESI	1986	1,200	15,229	35	$57,644	$48.04	
SRI LANKA	Kannantota	Grav/Chlor	ESI	1986	4,200	54,850	36	$30,339	$7.22	
SRI LANKA	Nivitagale	Grav/Chlor	ESI	1986	2,500	55,209	61	$88,518	$35.41	
SRI LANKA	Deliowita	Grav/Chlor	ESI	1986	7,000	74,500	29	$35,978	$5.14	
SRI LANKA	Aranyake	Grav/Chlor	ESI	1986	4,000	123,185	84	$111,361	$27.84	
SRI LANKA	Ukuwela	Grav/Chlor	ESI	1986	3,000	123,610	113	$61,391	$20.46	
SRI LANKA	Pelmadulla	Grav/Chlor	ESI	1986	3,600	164,752	125	$157,940	$43.87	
		COUNT	10		10	10	10	7	7	
		AVERAGE			55,530	512,134	55	$77,596	$26.85	
		STD DEV			79,283	659,752	37	$41,987	$15.63	
		STD/AVG			1.43	1.29	0.67	0.54	0.58	
		MINIMUM			1,200	15,229	20	$30,339	$5.14	
		MAXIMUM			179,700	1,740,000	125	$157,940	$48.04	

AFRICA

COUNTRY	PROJECT LOCATION	SYSTEM TYPE	DATA SOURCE	DATE	POPULAT. SERVED	TOT. VOLUME PRODUCED (m3/yr)	VOLUME PRODUCED (lt/cap/day)	INITIAL CAPITAL COST	CAPITAL COST PER CAPITA	TRANSP.
MALAWI	Lufira/Kar.	Gravity	WASH	1986	32,700	(1985 est.)		$186,986	$5.72	
MALAWI	Ng'onga	Gravity	WASH	1986	4,200	(1985 est.)		$9,027	$2.15	
MALAWI	Mchinji	Gravity	WASH	1986	26,600	(1985 est.)		$53,087	$2.00	
MALAWI	Sumulu	Gravity	WASH	1986	23,500	(1985 est.)		$154,210	$6.56	
MALAWI	Mulanje West	Gravity	WASH	1986	102,700	(1985 est.)		$182,688	$1.78	
		COUNT	5		5			5	5	
		AVERAGE			37,940			$117,200	$3.64	
		STD DEV			33,754			$72,582	$2.06	
		STD/AVG			1			0.62	0.57	
		MINIMUM			4,200			$9,027	$1.78	
		MAXIMUM			102,700			$186,986	$6.56	

GRAVITY SYSTEM O&M COST DATA (CONTD.)

ASIA									
O&M COST/YEAR						TOTAL O&M COST/YEAR	PER CAPITA O&M COST($)	O&M COST PER m3	O&M AS % OF CAPITAL COST
LABOR	ENERGY	CHEM.	ADMIN.	MAINT.	OTHER				
$105,138	$842	$140	$16,283	$13,476	$14,037	$149,916	$0.86	$0.121	
$79,386	$1,011	$2,023	$19,720	$9,708	$12,843	$124,691	$0.71	$0.081	
$83,762	$1,935	$5,990	$20,272	$26,815	$10,228	$149,002	$0.83	$0.086	
$1,677	$0	$29		$445		$2,151	$1.79	$0.141	3.73%
$2,044	$0	$323		$284		$2,651	$0.63	$0.048	8.74%
$4,922	$27	$332		$417		$5,699	$2.28	$0.103	6.44%
$3,748	$0	$172		$413		$4,332	$0.62	$0.058	12.04%
$2,139	$34	$165		$3		$2,342	$0.59	$0.019	2.10%
$1,382	$0	$302		$43		$1,726	$0.58	$0.014	2.81%
$3,657	$46	$387		$175		$4,265	$1.18	$0.026	2.70%
10	10	10	3	10	3	10	10	10	7
$28,785	$390	$986	$18,758	$5,178	$12,369	$44,678	$1.01	$0.070	5.51%
$40,189	$629	$1,754	$1,765	$8,529	$1,591	$63,524	$0.55	$0.042	3.46%
1.40	1.62	1.78	0.09	1.65	0.13	1.42	0.55	0.60	0.63
$1,382	$0	$29	$16,283	$3	$10,228	$1,726	$0.58	$0.014	2.10%
$105,138	$1,935	$5,990	$20,272	$26,815	$14,037	$149,916	$2.28	$0.141	12.04%

AFRICA									
O&M COST/YEAR						TOTAL O&M COST/YEAR	PER CAPITA O&M COST($)	O&M COST PER m3	O&M AS % OF CAPITAL COST
LABOR	ENERGY	CHEM.	ADMIN.	MAINT.	OTHER				
				$7,830		$7,830	$0.24		4.19%
				$3,019		$3,019	$0.72		33.44%
				$2,658		$2,658	$0.10		5.01%
				$2,878		$2,878	$0.12		1.87%
				$10,250		$10,250	$0.10		5.61%
				5		5	5		5
				$5,327		$5,327	$0.26		10.02%
				$3,129		$3,129	$0.24		11.78%
				0.59		0.59	0.93		1.18
				$2,658		$2,658	$0.10		1.87%
				$10,250		$10,250	$0.72		33.44%

APPENDIX C

Electric Systems

PER CAPITA COSTS FOR ELECTRIC PUMP WATER SYSTEMS

Source: Burnett, World Bank Date: 1984 (In 1984 US $)

AFRICA

COUNTRY	SYSTEM	CAPITAL	RECURRENT	REC/CAPITAL
CAPE VERDE	Borehole (electric) +storage, +distri.	$48.40	$8.00	16.5%
SIERRA LEONE	Borehole (electric) +storage	$25.20	$4.90	19.4%
	Borehole (electric) +storage, +distri.	$39.20	$4.10	10.5%
	AVERAGE w/o distrib.	$25.20	$4.90	19.4%
	AVERAGE w/ distrib.	$43.80	$6.05	13.5%

ASIA

COUNTRY	SYSTEM	CAPITAL	RECURRENT	REC/CAPITAL
BURMA	Borehole (electric) +storage	$25.30	$1.20	4.7%
INDIA	Borehole (electric) +storage	$22.00	$0.40	1.8%
INDIA	Borehole (electric) +storage	$21.00	$0.10	0.5%
SRI LANKA	Borehole (electric) +storage	$31.70	$0.80	2.5%
INDIA	Borehole (electric) +storage, +distri.	$22.80	$0.70	3.1%
INDIA	Borehole (electric) +storage, +distri.	$29.00	$1.00	3.4%
INDIA	Borehole (electric) +storage, +distri.	$28.00	$1.80	6.4%
SRI LANKA	Borehole (electric) +storage, +distri.	$35.10	$2.30	6.6%

		CAPITAL	RECURRENT	REC/CAPITAL
Borehole (electric) +storage	AVERAGE	$25.00	$0.63	2.4%
	STD DEV	$4.18	$0.41	1.5%
	DEV/AVG	0.17	0.66	0.65
	MINIMUM	$21.00	$0.10	0.5%
	MAXIMUM	$31.70	$1.20	4.7%
Borehole (electric) +storage, +distri.	AVERAGE	$28.73	$1.45	4.9%
	STD DEV	$4.37	$0.63	1.6%
	DEV/AVG	0.15	0.44	0.33
	MINIMUM	$22.80	$0.70	3.1%
	MAXIMUM	$35.10	$2.30	6.6%

ELECTRIC PUMP WATER SYSTEM O&M COST DATA

ASIA

COUNTRY	PROJECT LOCATION	SOURCE	DATE	POPULAT. SERVED	TOTAL VOL. PRODUCED (m3/year)	PER CAPITA VOLUME (l/cap/day)	INITIAL CAPITAL COST	CAPITAL COST PER CAPITA	TRANSPORT	LABOR
SRI LANKA	Padeniya	ESI	1986	300	2,726	25				$519
SRI LANKA	Udagame	ESI	1986	300	3,359	31				$965
SRI LANKA	Buluwela	ESI	1986	1,000	3,791	10				$972
SRI LANKA	Samurdigama	ESI	1986	800	4,980	17				$1,147
SRI LANKA	Andigama	ESI	1986	2,000	10,857	15				$1,052
SRI LANKA	Wannigama	ESI	1986	500	12,866	70				$2,112
SRI LANKA	Ambanpola	ESI	1986	2,100	13,528	18	$71,385	$33.99		$2,419
SRI LANKA	Minigamuwa	ESI	1986	1,000	15,219	42	$37,227	$37.23		$1,018
SRI LANKA	Anamaduwa	ESI	1986	1,500	20,552	38	$17,489	$11.66		$2,884
SRI LANKA	Pannala	ESI	1986	2,300	21,487	26	$103,509	$45.00		$2,669
SRI LANKA	Nikaweratiya	ESI	1986	8,000	34,575	12	$178,463	$22.31		$1,589
SRI LANKA	Piliyandala	ESI	1986	2,500	38,975	43	$7,924	$3.17		$1,092
SRI LANKA	Alawwa	ESI	1986	3,600	40,189	31	$35,978	$9.99		$3,432
SRI LANKA	Bataleeya	ESI	1986	1,000	41,308	113	$133,847	$133.85		$1,353
SRI LANKA	Giriulla	ESI	1986	1,800	42,423	65	$11,065	$6.15		$1,096
SRI LANKA	Ogodapola	ESI	1986	8,000	48,183	17	$33,373	$4.17		$2,537
SRI LANKA	Rambodagalle	ESI	1986	2,000	57,916	79	$14,099	$7.05		$2,325
SRI LANKA	Wennappuwa	ESI	1986	6,500	58,854	25	$78,524	$12.08		$2.960
SRI LANKA	Wariyapola	ESI	1986	4,000	60,626	42	$117,429	$29.36		$3.491
SRI LANKA	Dankotuwa	ESI	1986	3,800	66,720	48	$28,197	$7.42		$725
SRI LANKA	Dambulla	ESI	1986	7,000	81,751	32				$6,025
SRI LANKA	Galgamuwa	ESI	1986	4,000	85,810	59	$24,093	$6.02		$3.855
SRI LANKA	Malawana	ESI	1986	5,000	104,489	57	$22,129	$4.43		$3,227
SRI LANKA	Ehiliyagoda	ESI	1986	6,000	114,646	52	$40,939	$6.82		$6.826
SRI LANKA	Kahawatta	ESI	1986	6,000	132.776	61	$23,736	$3.96		$6,505
SRI LANKA	Ruwanella	ESI	1986	9,900	143,634	40	$76,739	$7.75		$8,428
SRI LANKA	Yatiyantota	ESI	1986	3,000	145,255	133	$10,708	$3.57		$4,258
SRI LANKA	Galagedara	ESI	1986	7,500	150,077	55				$4,422
SRI LANKA	Horana	ESI	1986	10,000	238,647	65	$1,252,811	$125.28		$8,537
SRI LANKA	Avissawella	ESI	1986	10,000	398,451	109				$11,225
SRI LANKA	Matale	ESI	1986	46,000	414,295	25	$2,070,172	$45.00		$5,221
SRI LANKA	Mawanella	ESI	1986	12,000	483,453	110	$209,873	$17.49		$8,181
SRI LANKA	Balangoda	ESI	1986	15,000	603,025	110	$175,965	$11.73		$14,671
SRI LANKA	Udunwara-Yat	ESI	1986	30,000	899,508	82				$8,072
SRI LANKA	Ratnapura	ESI	1986	20,000	1,310,021	179	$479,352	$23.97		$36.896
	COUNT	35	35	35	35	35	25	25	0	35
	AVERAGE			6,983	168,713	55	$210,201	$24.78		$4,934
	STD DEV			9,025	275,706	39	$454,112	$33.45		$6,381
	STD/AVG			1.29	1.63	0.70	2.16	1.35		1.29
	MINIMUM			300	2,726	10	$7,924	$3.17		$519
	MAXIMUM			46,000	1,310,021	179	$2,070,172	$133.85		$36.896

NOTE: ALL COSTS EXPRESSED IN 1986 US$

ASIA

O&M COST/YEAR (1986 US$)									
REPAIR	ENERGY	CHEM	ADMIN	MAINT	OTHER	TOTAL O&M COST/YEAR	PER CAPITA O&M COST ($/year)	O&M COST PER m3 ($/m3)	O&M AS % OF CAPITAL COST
	$167	$1		$95		$781	$2.60	$0.286	
	$440	$15		$56		$1,476	$4.92	$0.439	
	$96	$67				$1,135	$1.13	$0.299	
		$5		$4,674		$5,827	$7.28	$1.170	
		$65		$1,267		$2,385	$1.19	$0.220	
	$478	$46		$734		$3,370	$6.74	$0.262	
	$199	$838		$448		$3,904	$1.86	$0.289	5.47%
	$946	$17		$50		$2,030	$2.03	$0.133	5.45%
	$325	$130		$87		$3,426	$2.28	$0.167	19.59%
	$432	$29		$237		$3,368	$1.46	$0.157	3.25%
	$907			$1,697		$4,193	$0.52	$0.121	2.35%
	$121	$323		$38		$1,575	$0.63	$0.040	19.88%
	$764	$196				$4,392	$1.22	$0.109	12.21%
	$1,961	$62		$382		$3,759	$3.76	$0.091	2.81%
	$2,159	$111		$183		$3,549	$1.97	$0.084	32.08%
	$1,048	$366		$198		$4,149	$0.52	$0.086	12.43%
	$1,524	$372		$282		$4,502	$2.25	$0.078	31.93%
	$1,483	$1,449		$209		$6,101	$0.94	$0.104	7.77%
	$1,971	$483		$61		$6,006	$1.50	$0.099	5.11%
	$853	$155		$149		$1,883	$0.50	$0.028	6.68%
	$3,777	$255		$321		$10,378	$1.48	$0.127	
	$3,698	$451		$246		$8,249	$2.06	$0.096	34.24%
	$2,700	$445		$3,670		$10,041	$2.01	$0.096	45.37%
	$2,443	$784		$186		$10,238	$1.71	$0.089	25.01%
	$2,435	$381		$469		$9,790	$1.63	$0.074	41.25%
	$7,168	$215		$608		$16,419	$1.66	$0.114	21.40%
	$3,333			$206		$7,797	$2.60	$0.054	72.82%
	$4,235	$401		$101		$9,158	$1.22	$0.061	
	$5,592	$279		$370		$14,779	$1.48	$0.062	1.18%
	$15,985	$592		$13,103		$40,905	$4.09	$0.103	
	$14,349	$5,468				$25,037	$0.54	$0.060	1.21%
	$5,938	$370		$56		$14,544	$1.21	$0.030	6.93%
	$11,125	$1,268		$2,688		$29,751	$1.98	$0.049	16.91%
	$38,945	$1,263		$579		$48,859	$1.63	$0.054	
	$28,683	$1,442		$7,638		$74,659	$3.73	$0.057	15.58%
0	33	33	0	32	0	35	35	35	25
	$5,039	$556		$1,284		$11,383	$2.12	$0.154	17.96%
	$8,353	$961		$2,662		$15,316	$1.57	$0.196	16.95%
	1.66	1.73		2.07		1.35	0.74	1.27	0.94
	$96	$1		$38		$781	$0.50	$0.028	1.18%
	$38,945	$5,468		$13,103		$74,659	$7.28	$1.170	72.82%

APPENDIX D

Diesel Systems

DIESEL SYSTEMS O&M COST DATA

COUNTRY	PROJECT LOCATION	SOURCE	DATE	ENGINE	HEAD (m)	HOURLY OUTPUT m3/hr	LOADING	OVERALL EFFI-CIENCY	HOURS PER DAY	WATER VOLUME PRODUCED (m3/yr)	POPULA. SERVED	WATER VOLUME PRODUCED (lpd)
KENYA	Karamani(Small)	IT Power	1986	Lister LT1	10	2.6	9.0%	7.7%	2.7	2,608		
KENYA	Maturu II	IT Power	1986	Lister HA3	30		9.1%	4.3%	3.5	5,856		
KENYA	Nyumba IV	IT Power	1986	Lister HR2	100		10.6%	8.0%	5.7	10,025		
KENYA	Karamani(Big)	IT Power	1986	Lister 8/1	45		24.0%	11.3%	5.0	36,209		
BOTSWANA	Malotwana	ARD	1986	Lister SR1	48	3.2	15.0%	8.0%	3.1	3,650		
BOTSWANA	Bonwapitse	ARD	1986	Lister ST1	58	7.7	48.0%	15.0%	2.5	6,935	600	31.7
BOTSWANA	Mmankgodi	ARD	1986	Lister LT1	82	2.7	33.0%	10.0%	8.1	8,030		
BOTSWANA	Oodi	ARD	1986	Lister 8/1	101	3.9	27.0%	14.0%	9.3	13,140		
BOTSWANA	Mogobane	ARD	1986	Lister ST1	74	8.7	67.0%	20.0%	11.5	36,500	1980	50.5
RWANDA		CARE	1986		100					2,555	467	15.0
ETHIOPIA	Adami Tulu		1986	5kw		18.0			7.0	45,990		
MOROCCO	El-Attaouia	CDER	1985	Lister	9				6.0			
MOROCCO	Pepin. Hortimex	CDER	1985	Ford	40				8.0			
MOROCCO	El-Idrissi	CDER	1985	Lister	14	6.5	7.6%	4.5%	0.5	1,186		
MOROCCO	Abattoir du Souk	CDER	1985	Farymann	19	12.5	42.8%	10.0%	0.3	1,369		
MOROCCO	Mzouda	CDER	1985	Armstrong	95	3.6	18.5%	4.3%	1.5	1,971	500	10.8
MOROCCO	Mejatt	CDER	1985	Lister	59	14.4	27.9%	7.1%	0.5	2,628	250	28.8
MOROCCO	Douar Khalifa	CDER	1985	Petter	21	3.0	5.3%	1.3%	5.0	5,475		
MOROCCO	Arba Tighedoune	CDER	1985	Petter	25	18.0	23.9%	6.7%	1.0	6,570	200	90.0
MOROCCO	Lakhouil	CDER	1985	Ford	42	8.3	8.6%	2.5%	3.0	9,062		
MOROCCO	Guemassa	CDER	1985	Lister	60	12.5	32.7%	7.6%	2.0	9,125	200	125.0
MOROCCO	Rguiguia	CDER	1985	Petter	37	16.7	36.3%	7.8%	1.5	9,125	180	138.9
MOROCCO	Timzgadioune	CDER	1985	Simef	38	12.5	37.8%	9.6%	2.0	9,125		
MOROCCO	Mohamed	CDER	1985	Lister	35	23.1	68.3%	15.3%	1.3	10,523		
MOROCCO	Zaouiat Saaidia	CDER	1985	Petter	53	21.6	68.8%	11.6%	1.5	11,826	550	58.9
MOROCCO	El-Guerne	CDER	1985	Lister	32	6.0	8.1%	2.2%	6.7	14,607		
MOROCCO	Ouled El-Rmedia	CDER	1985	Petter	22	25.0			2.0	18,250		
MOROCCO	Abid	CDER	1985	Deutz	48	15.0	17.9%	3.6%	4.0	21,900		
MOROCCO	Ait Nacer	CDER	1985	Petter	18	19.3	50.6%	6.8%	4.0	28,105		
MOROCCO	Lagmah	CDER	1985	Petter	15	32.0	40.6%	12.1%	2.5	29,200		
MOROCCO	Ben Wadi	CDER	1985	Ford	50	18.0	16.2%	9.1%	5.0	32,850		
MOROCCO	Oul-Hachmi	CDER	1985	Lister	40	24.0			4.0	35,040		
MOROCCO	Haj Mohamed	CDER	1985	Lister	24	26.0	26.7%	5.3%	4.0	37,960		
MOROCCO	Si Mohamed	CDER	1985	Ford	33	27.0	13.4%	9.0%	6.0	59,130		
MOROCCO	Oudia	CDER	1985	Petter	17	24.0	58.9%	6.9%	8.3	72,708		
MOROCCO	Roserie Hortime	CDER	1985	Ford	32	32.0	15.4%	8.5%	9.0	105,120		
MOROCCO	Bouzidia	CDER	1985	Petter	27	21.6	42.1%	7.4%	14.0	110,376		
MOROCCO	Rguiguia	CDER	1985	Petter	13	36.6	26.9%	3.8%	11.0	146,949		
COUNT	37	37	38	37	37	32	32	32	37	36	9	9
AVERAGE					42.3	15.8	29.3%	8.2%	4.7	26,713	547	61.1
STD DEV					26.1	9.5	18.6%	4.1%	3.4	33,421	530	44.3
STD/AVE					0.617	0.60	0.63	0.50	0.72	1.25	0.97	0.73
MINIMUM					9.0	2.6	5.3%	1.3%	0.3	1,186	180	10.8
MAXIMUM					101.0	36.6	68.8%	20.0%	14.0	146,949	1980	138.9

DIESEL SYSTEMS O&M COST DATA

CAPITAL COST	ANNUAL O&M COST: LABOR	MAINT.	REPAIRS & PARTS	FUEL	CHEM.	TRANSP.	TOTAL O&M COST/YEAR	TOTAL O&M COST/YEAR (1986 US$)	PER CAPITA O&M COST ($/year) (1986 US$)	TOTAL O&M COST/m3 (1986 US$)	TOTAL O&M COST PER m HEAD cents/m3/m (1986 US$)	O&M COST AS % OF CAPITAL
	$338	$238	$100	$250			$926	$965		$0.37	3.70	
	$231	$50	$13	$438			$732	$755		$0.13	0.43	
$9,750	$275	$63		$875			$1,213	$1,213		$0.12	0.12	12.4%
	$394	$656	$100	$1,276			$2,426	$2,527		$0.07	0.16	
$3,242							$2,042	$2,042		$0.56	1.17	63.0%
$3,751							$2,153	$2,153	$3.59	$0.31	0.54	57.4%
$3,833							$2,554	$2,554		$0.32	0.39	66.6%
$4,748							$3,566	$3,566		$0.27	0.27	75.1%
$4,079							$3,838	$3,838	$1.94	$0.11	0.14	94.1%
$16,000	$2,400	$317		$285			$3,002	$3,002	$6.43	$1.17	1.17	18.8%
$4,200		$240	$175	$1,200			$1,615	$1,615		$0.04		38.5%
		$80	$1,067	$876			$2,023	$1,964				
		$320	$944	$3,997		$267	$5,528	$5,368				
		$29	$39	$37		$18	$123	$119		$0.10	0.73	
	$667	$27	$22	$26			$742	$720		$0.53	2.77	
	$667	$117	$44	$428			$1,257	$1,220	$2.44	$0.62	0.65	
	$667	$19		$214			$899	$873	$3.49	$0.33	0.56	
		$53	$833	$876		$160	$1,923	$1,867		$0.34	1.62	
	$667	$56		$276			$998	$969	$4.85	$0.15	0.59	
		$320	$639	$1,533		$20	$2,512	$2,439		$0.27	0.65	
	$667	$96	$27	$714			$1,503	$1,460	$7.30	$0.16	0.27	
	$667	$24		$427			$1,117	$1,085	$6.03	$0.12	0.32	
	$667	$20					$687	$667		$0.07	0.19	
	$667	$80	$78	$243		$80	$1,147	$1,114		$0.11	0.30	
	$667	$20	$111	$535			$1,333	$1,294	$2.35	$0.11	0.21	
		$288	$1,111	$2,203		$29	$3,631	$3,526		$0.24	0.75	
		$80	$6	$148		$20	$254	$247		$0.01	0.06	
		$480	$778	$2,855		$29	$4,142	$4,022		$0.18	0.39	
		$121	$267	$730		$64	$1,182	$1,148		$0.04	0.23	
		$27	$56	$365		$200	$647	$628		$0.02	0.14	
		$240	$833	$1,784		$69	$2,927	$2,842		$0.09	0.17	
		$373	$6,000	$5,840		$400	$12,613	$12,247		$0.35	0.87	
		$160	$1,000	$1,728		$29	$2,917	$2,832		$0.07	0.31	
			$4,181	$2,141		$214	$6,536	$6,346		$0.11	0.33	
		$71	$54	$1,777			$1,902	$1,847		$0.03	0.15	
		$365		$3,919		$400	$4,684	$4,548		$0.04	0.14	
	$667	$680	$89	$4,542			$5,978	$5,804		$0.05	0.19	
	$667	$27		$4,698			$5,391	$5,235		$0.04	0.28	
8	16	32	25	32	0	15	38	38	9	36	35	8
$6,200	$686	$179	$743	$1,476		$133	$2,596	$2,544	$4.27	$0.21	0.60	53.2%
$4,177	$469	$180	$1,364	$1,535		$130	$2,318	$2,250	$1.85	$0.23	0.74	26.2%
0.67	0.68	1.00	1.84	1.04		0.98	0.89	0.88	0.43	1.06	1.24	0.49
$3,242	$231	$19	$6	$26		$18	$123	$119	$1.94	$0.01	0.06	12.4%
$16,000	$2,400	$680	$6,000	$5,840		$400	$12,613	$12,247	$7.30	$1.17	3.70	94.1%

APPENDIX E

Asian Development Bank O&M Cost Data

Water Supply Projects
Production Cost Per Cubic Meter (¢/cum)
(in 1985 prices)

Type of System / DMCs	Dug Well with Hand Pump	Shallow Drilled Well with Hand Pump	Deep Borehole Well with Distribution System and Untreated Water	Deep Borehole Well with Distribution System and Treated Water	Surface Water with Gravity Feed Distribution and Treated Water	Surface Water with Pumped Distribution System and Treated Water
Bangladesh	1 - 3	2 - 3	3 - 6	4 - 8	6 - 11	11 - 13
Bhutan	1 - 2	1 - 5	2 - 8	6 - 10	6 - 10	10 - 15
Burma	1 - 2	1 - 2	2 - 5	3 - 6	5 - 8	4 - 10
Hong Kong	2 - 3	2 - 4	3 - 11	7 - 10	7 - 10	7 - 12
India	1 - 2	1 - 2	1 - 5	2 - 5	2 - 6	5 - 8
Indonesia	1 - 2	1 - 2	2 - 6	3 - 12	10 - 15	6 - 16
Korea	1 - 3	2 - 4	2 - 10	5 - 15	10 - 20	5 - 25
Laos	1 - 4	1 - 4	4 - 7	4 - 10	4 - 10	10 - 15
Malaysia	1 - 2	1 - 5	3 - 10	5 - 15	5 - 15	5 - 18
Maldives	2 - 3	2 - 3	3 - 5	4 - 15	6 - 15	8 - 17
Nepal	1 - 2	1 - 2	1 - 6	5 - 12	5 - 12	11 - 19
Pakistan	1 - 3	1 - 3	3 - 8	8 - 10	8 - 15	12 - 18
Papua New Guinea	1 - 2	2 - 5	2 - 10	6 - 20	10 - 25	10 - 30
Philippines	2 - 3	2 - 3	3 - 9	9 - 15	9 - 18	12 - 20
Singapore	1 - 2	2 - 6	3 - 11	10 - 12	10 - 15	15 - 18
Solomon Islands	2 - 3	2 - 3	2 - 4	4 - 10	6 - 13	13 - 15
Sri Lanka	1 - 2	1 - 4	2 - 6	3 - 10	4 - 15	11 - 23
Thailand	1 - 2	2 - 3	3 - 10	10 - 20	10 - 20	10 - 25
Vietnam	1 - 3	2 - 3	3 - 11	5 - 15	5 - 15	9 - 21
Average Range	1 - 3	2 - 3	2 - 8	6 - 12	7 - 14	9 - 18