COSTS OF ALTERNATIVE WATER SUPPLY AND SANITATION SERVICES IN BRAZIL

by

Donald T. Lauria

Keith A. Demke

SUMMARY

1. In many developing countries, it is not possible to use the conventional water supply and wastewater systems of the economically advanced countries because they are too expensive. Instead, cheaper facilities are required such as public standposts for water supply and pit privies for sanitation. Little is known, however, about the savings that can be obtained with these systems, which is an obstacle to their use. Consequently, a case study was made for the town of Rio Casca in the state of Minas Gerais, Brazil, to investigate the costs of alternative levels of water supply and sanitation service.

2. Rio Casca recently received a new water system through the efforts of COPASA, the state water supply planning agency, and additional facilities are not needed. However, available maps and data for this town constitute a valuable source of information which is one of the reasons Rio Casca was selected for study. The present and future design populations are 6,000 and 10,800, respectively, and the future service area is about 83 ha. Average household size is 6 which implies 1800 connections for the future design population. The town is divided by a river and has irregular topography.

3. Five different levels of water supply and sanitation service were investigated:

Level	Average Demand (lcd)	Maximum Daily Demand (m^3/d)	Water Distribution Facilities	Sanitation Facilities
I	25	405	Standpost	Latrines
II	50	810	Yard Tap	Soakaway
III	100	1620	Sanitary Core	Septic Tank
IV	100	1620	Sanitary Core	Small Sewers
V	200	3240	Full Plumbing	Conventional

For Level I, 27 standposts each with service radius of about 100 m were selected, and ventilated pit privies were used for sanitation. For Level II, yard hydrants at each house were provided for water supply, and pour flush

toilets with soak pits were used for sanitation. For Level III, a single kitchen tap and shower (called a sanitary core) were used for water supply, and a septic tank with drainfield was used for sanitation. Level IV also used a sanitary core for water supply and a septic tank for on-site sanitation; however, the drainfield was replaced by small bore street sewers, with sewage lagoons for treatment. Finally, Level V assumed multiple house taps for water supply and conventional waterborne sewerage and lagoons for wastewater. Minimum sewer sizes for Levels IV and V were 100 mm and 150 mm, respectively, and minimum design velocities were 0.3 m/s and 0.6 m/s, respectively.

4. For each of the above service levels, a separate water supply and sanitation design was prepared. It was assumed that none of the existing facilities in Rio Casca was incorporated in these designs, nor were any facilities carried from one level of service to another. The water distribution and wastewater collection networks were designed using the computer to assure that pipes were accurately sized.

5. Because of differences in design flows, required capacities of the raw and finished water pumping stations, the treatment plants, and distribution storage tanks doubled from Level I to Level II, from II to III, and from III to V. Also, sewage pumping station and treatment plant capacity doubled from Level IV to V.

6. The pipe characteristics in the water and sewer networks for the alternative designs were as follows:

	I	II	III	IV	V
Water					
Length (m)	5200	10,800	10,800	10,800	10,800
Average Diameter (mm)	43	37	45	45	57
Sewer					
Length (m)	--	--	--	10,000	10,000
Average Diameter (mm)	--	--	--	120	165
Average Depth (m)	--	--	--	1.8	2.4

Average diameter (depth) is the sum of the product of length and diameter (depth) for all pipes in the network divided by total length.

7. The above table shows that water network pipe length approximately doubled by using house connections instead of standposts. The variation in average water pipe diameter was fairly small; for all but the highest level of service, 50 mm diameter pipe "on the average" was adequate. Actually, between 20% and 30% of total water main length in each case exceeded 50 mm. The increases in average sewer diameter and excavation depth were primarily due to use of higher minimum pipe sizes and design velocities.

8. Per capita construction costs in US$ based on the design population of 10,800 were determined at each level of service. The results are as follows:

	US$/Capita				
	I	II	III	IV	V
Water	12	29	45	45	74
Sanitation	12	25	50	77	88
Total	24	54	95	122	162

9. The breakdown of total per capita costs by percentage among system components is as follows:

	Percent of Total Construction Cost				
	I	II	III	IV	V
Upstream Water	26	18	15	12	14
Water Distribution	22	13	10	8	9
On-Site Water	0	23	22	17	23
On-Site Sanitation	52	46	53	39	24
Sewage Collection	0	0	0	17	21
Sewage Treatment	0	0	0	7	9

Upstream water facilities include source development, raw and finished water pumping, transmission, and treatment. Water distribution facilities include the network and storage tank (and standposts in the case of Level I). On-site water facilities include connections and water-using appliances, and on-site sanitation includes house connections (for Levels IV and V) and disposal facilities.

10. Annual operation and maintenance (O&M) costs and present value O&M costs on a per capita basis are shown below. Present value (P.V.) costs are based on a period of 20 years and an interest rate of 10%.

	I	II	III	IV	V
Annual O&M Water, ($/yr/cap)	0.31	0.63	1.10	1.10	1.95
P.V. O&M Water, ($/cap)	2.59	5.37	9.35	9.35	16.57
Annual O&M Sanitation, ($/yr/cap)	1.25	0.63	0.63	1.26	0.97
P.V. O&M Sanitation, ($/cap)	4.81	4.63	4.63	10.00	8.24

11. Total annual and present value costs including both construction and O&M for both water supply and sanitation are shown below. The annual costs are based on a 20-year period and 10% interest rate for which the capital recovery factor is 0.12.

	I	II	III	IV	V
Annual Water, ($/yr/cap)	2	4	7	7	11
P.V. Water, ($/cap)	14	34	55	55	91
Annual Sanitation, ($/yr/cap)	2	4	7	10	12
P.V. Sanitation, ($/cap)	17	30	55	87	96
Total Annual Cost, ($/yr/cap)	4	8	14	17	23
Total P.V. Cost, ($/cap)	31	64	110	142	187

12. From para. 8, it is seen that water system construction costs range from US$12/capita for standposts to US$74/capita for house connections, and sanitation costs increase from US$12/capita to US$88/capita. The per capita costs appear to be low, which seems due primarily to the rigorous design of water and sewerage networks that resulted in more efficient and less costly systems than those found in practice.

13. Para. 8 shows that house connections (Level V) are 6 times more expensive than standposts (Level I), 2.5 times more expensive than yard taps (Level II), and 1.6 times more expensive than the sanitary core (Level III). The per capita cost of yard taps is more than twice that of standposts. This paragraph also shows that conventional sewers are 7 times more expensive than pit latrines, 3.5 times more expensive than pour flush toilets with soakaways, and 1.8 times more expensive than septic tanks with drainfields.

14. Para. 8 indicates that the small bore sewer system of Level IV is significantly more expensive than the septic tank/drainfield system of Level III; yet they probably render comparable service. Actually, the conventional sewer design of Level V is not much more expensive than small bore sewers. The relative difference in total present value sanitation costs between Levels III and IV after taking acount of operation and maintenance (as shown in para. 11) is even smaller. One concludes, at least for this example where construction is not staged and systems are not upgraded over time, that small bore sewers should be avoided unless soil conditions preclude on-site sanitation.

15. Para. 9 indicates that at every level of service, the construction cost of sanitation facilities is about one-half total system cost (actually, slightly more than half). These figures also show that except for Level I,

water treatment represents about 20% of total water system cost, the distribution network is about 25%, and on-site facilities represent nearly 50%. Para. 9 also shows that wastewater collection networks for Levels IV and V are about twice as costly as water distribution networks. On-site sanitation facilities are seen to represent a very large proportion of total system cost.

16. Para. 10 shows that the present value O&M sanitation cost for Level IV (small bore sewers) is about twice that of Level III (septic tanks with drainfields). This is because the expensive collection network of Level IV must be maintained, sewage lagoons must be operated, and individual on-site vaults must be desludged.

17. Although they cannot be quantified, speculation can be made about the benefits for this study; they are probably of two types: convenience (i.e., accessibility) and health. Upgrading from Level I to II, convenience benefits probably increase sharply, but thereafter they are subject to diminishing marginal returns. Health benefits, however, probably do not change much at lower levels of service until Level V is achieved, at which point they increase sharply. The resulting total benefit function, which is the sum of the health and convenience benefits, probably has an inflection point between Levels III and V. Maximum net benefits presumably occur at Level V. Among the three lower levels of service, however, maximum net benefits may occur at Level II, which employs yard taps for water supply and pour flush toilets for sanitation. This level provides a high degree of convenience and is probably not much worse in health benefits than Level III. Hence, where affordability is at issue, yard taps may be optimal.

Costs of Alternative Water Suply and Sanitation

Services in Brazil

by

Keith A. Demke
Donald T. Lauria

INTRODUCTION

1. The goal of the International Drinking Water and Sanitation Decade is to provide adequate water supply and sanitation for everyone by 1990. It is clear that in many parts of the world, it will not be possible to use the conventional water supply and wastewater systems of the economically advanced countries because of their high cost. Instead, widespread use will have to be made of more rudimentary facilities such as public standposts and yard taps for water supply, and pit latrines and septic tanks for wastewater disposal.

2. Although such facilities are already in use in many developing countries, it is necessary to obtain better information about their costs. At present, little is known about the savings that can be obtained from using, say, yard taps instead of house connections, or public standposts instead of yard taps. Clearly, if the savings from employing a lower level of service are small, little justification may exist for reducing design standards. On the other hand, large savings will argue strongly in favor of simpler systems. Cost data are therefore seen to play an important role in selecting the type of facilities and levels of service to be employed, especially for the poor.

3. In order to obtain information on the costs of different water and sanitation service levels, a case study was made for the town of Rio Casca in the State of Minas Gerais, Brazil. A new water supply system was recently provided for this town through the efforts of COPASA, the state water supply planning agency, and additional facilities are not actually needed. The maps and data from Rio Casca, however, constitute a valuable source of information for preparing other designs using different standards. It was for this reason together with the interest and cooperation of COPASA that Rio Casca was chosen as a case study. While the results of this investigation are site specific, it is likely that they apply on a general basis to other parts of the world.

4. Before starting the work in Rio Casca, it was necessary to obtain information on the costs of water supply and sanitation system components in Brazil. This was done from a study of recently completed projects by COPASA. The results of this preliminary work are described in the following section.

COST FUNCTIONS

5. During a field visit to the offices of COPASA in Belo Horizonte, Brazil, in August 1978, data were obtained on the characteristics and costs of 64 new water systems for towns ranging in size from 500 to 260,000 persons; most places, however, had design populations between 5000 and 10,000.

Mathematical models were fitted to the data for the components of water and sewerage systems using linear regression. Both additive equations of the form in eq. (1) and multiplicative expressions like eq. (2) were used, and the ones with the best fits are reported herein.

$$C = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n \qquad (1)$$

$$C = B_0X_1^{B_1} X_2^{B_2} \ldots X_n^{B_n} \qquad (2)$$

The task of regression analysis was to obtain numerical values for the parameters (B's) given observations for cost (C), the dependent variable, and the set of independent variables (X's).

6. In some cases, the data sample was small or incomplete which required various assumptions for determining costs; these are described below. In all of the functions herein, the raw data on cost were in units of UPC's which have been changed to 1978 US dollars using the relationship US$ = 15.5 UPC.

7. Water Pumping Station A model was fitted to construction cost data for 29 water pumping stations. The resulting equation is:

$$WPSC = 1548\ (MDQ)^{0.64}(TDH)^{0.23} \qquad (3)$$

where WPSC = water pumping station cost in US$, MDQ = maximum daily design flow in lps, and TDH = total dynamic head in m. The square of the correlation coefficient (R^2) for this model is about 0.80. An alternative equation with R^2 = 0.78 that gives similar results but is easier to use is:

$$WPSC = 3936(MDQ)^{0.63} \qquad (4)$$

8. Water Treatment Plant Of the communities for which cost data were available, 37 have water treatment facilities (in addition to simple chlorination), including 12 package plants, 10 contact clarifiers, 9 conventional plants and 6 super filters (these designations are used by COPASA). Separate cost equations were developed for each type of plant, but in some

cases, goodness of fit was poor. By pooling the data for all 37 plants, the following equation was obtained:

$$WTPC = 730\ (ADQ)^{0.694} \qquad (5)$$

where WTPC = water treatment plant construction cost in US$, and ADQ = average daily design flow in m^3/day (cmd); $R^2 = 0.87$.

9. <u>Storage Reservoir</u> Analysis of cost data for ground-level water storage tanks resulted in the equation:

$$GSTC = 688\ (VOL)^{0.67} \qquad (6)$$

where GSTC = ground storage tank cost in US$ and VOL = volume in m^3; $R^2 = 0.85$. A sample of only 7 elevated storage tanks failed to produce an equation with reasonable goodness of fit.

10. <u>Water Pipelines</u> Cost data were analyzed for PVC water pipelines with diameters in the range of 60 to 160 mm. The equation with best fit is:

$$WPLC/L = 4.27 - 0.16\ D + 0.025\ D^{1.5} \qquad (7)$$

where WPLC = water pipeline cost in US$, L = length in m, and D = diameter in mm. Two other equations which give nearly identical results are:

$$WPLC/L = 0.0092D^{1.58} \qquad (8)$$

$$WPLC/L = -8.9 + 0.23\ D \qquad (9)$$

For all three equations, R^2 is about 0.99.

11. Other Water Facilities Assumptions and limited field data yielded the following estimates for other water supply facilities:

Item	Cost (US $)
Public Standpost	500
Yard Connection w/meter	50
House Connection w/meter	75
Yard Hydrant	25
Single House Tap	50
Full House Plumbing	150

12. Sanitary Sewers Relatively little bid data are available for sanitary sewers. However, COPASA estimated the work, materials, and labor required to construct vitrified clay (VC) sewers with diameters in the range of 100 to 500 mm and excavation depths from 1.5 to 4.5 m. Fitting an equation to the resulting cost data resulted in the following expression:

$$SSC/L = 9.81 + 173\ D^2 + 0.51\ X^3 \qquad (10)$$

where SSC = sanitary sewer cost in US $, L = sewer length in m, D = diameter in m, and X = average excavation depth in m. R^2 = 0.98.

13. Sewage Pumping Station Bid data are unavailable for sewage pumping stations in Minas Gerais. It was assumed that their cost can be estimated, however, using a function from the U.S. after adjusting for the relative costs of construction in the two countries; the expression is:

$$SPSC = 1119\ (MDQ)^{1.08} \qquad (11)$$

where SPSC = sewage pumping station cost in US $ and MDQ = maximum daily sewage flow in lps.

14. Other Sewerage Facilities Assumptions about the costs of other sewerage facilities include the following:

Item	Cost (US $)
Sewage Lagoons	2 to $3/m^3$
Ventilated Pit Privy	75
Pour Flush Toilet w/Soakaway	150
Septic Tank w/Dranfield	300
Septic Tank	150
Lateral from House to Street	133

15. Operation and Maintenance

Item	Cost (US $)
Electric Energy	0.05/KW-HR
Alum	0.11/kg
Lime	0.15/kg
Chlorine	0.15/kg
Hardware Operation & Maintenance	1% of construction cost/yr
Replace Pit Privy	75/every 10 yr
Desludge Septic Tank	15/every 4 yr

STUDY COMMUNITY

16. The town of Rio Casca has a present population of about 6,000 residing in an area of about 80 ha, although most of the people are concentrated in about half this space. The average number of persons per dwelling is six. The population is expected to increase at an annual rate of about 3% so that in 20 years, the number of inhabitants will be about 10,800. With an expected future average density of 130 persons/ha, the area of the town at the end of the planning period will be about 83 ha. Hence, it appears that town boundaries will not expand much in coming years; rather, the density will increase.

17. The town is divided by a river which serves as the present source of water supply. After the construction of sewers, community wastewaters will be discharged downstream of the town. For the most part, the town is flat. However, a point of high elevation is about 70 m above the river.

LEVELS OF SERVICE

18. The work of this study began by selecting a target level of water supply service and an associated level of sanitation service for Rio Casca. It was initially assumed that the entire community would be served with water through public standposts and that pit privies would be used for waste disposal. It was further assumed that none of the existing water and sanitation facilities would be incorporated into the new design; rather it would consist entirely of new piping and facilities.

19. Once the initial level of service was selected, water and sanitation systems were designed to meet it. The design population and conditions were for 20 years in the future. Then the level of service was upgraded to yard taps for water supply and pour flush toilets for sanitation, and entirely new systems were designed. This process of selecting a service level and designing facilities was repeated five times, with each level providing greater convenience and health benefits than before. Each design was treated as entirely separate, and no attempt was made in any one design to upgrade from one level of service to another.

20. The five levels of water supply and sanitation service were as follows:

	I	II	III	IV	V
Average Demand, lcd	25	50	100	100	200
Max. Daily Demand, cmd	405	810	1620	1620	3240
Water Distribution	Standposts	Yard Taps	Sanitary Cores	Sanitary Cores	Full Plumbing
Sanitation Facilities	VIP Latrines	P.F.w/ Soakaway	P.F.w/ Septic Tank	P.F.w/ Sewers	Water Borne Sewerage

21. Under Level I, public standposts with a service radius of about 100 m each were assumed for water supply. Hence, for each standpost, the area served was about 3.1 ha and the number of persons was about 400. A total of 27 standposts was required, and the average design flow was 25 lcd which, with a ratio of maximum daily to average demand of 1.5, resulted in a total maximum daily flow of 405 cmd (this same peaking factor was used for all service levels). For waste disposal, ventilated improved pit (VIP) latrines were assumed. These facilities, which must be moved to a new site about every 10 years, handle human wastes only; it was assumed that the small quantities of sullage could be disposed of in yards, gardens and roadside ditches.

22. The facilities for water supply under Level II were yard taps; with a design population of 10,800 and 6 persons per house, about 1800 were needed. Water pipes were required on nearly every street to serve the houses, and the distribution system had closed loops instead of open branches. With average per capita use of 50 lcd, sanitation facilities had to be able to handle some sullage as well as human wastes; a pour flush (PF) toilet with soakaway was assumed. The pit life of these facilities is about four years.

23. Under Level III, a kitchen tap and shower (sanitary core) was assumed for water supply, and a pour flush toilet was used for sanitation. Because of relatively high water use (100 lcd on average), a multi-compartment septic tank with drainfield was provided for both sanitary wastes and sullage. Desludging of the septic tank was assumed to be required about once every four years.

24. Level IV employed a sanitary core for water supply and a septic tank for sanitation,as with Level III. However, instead of using a drainfield and soil absorption for wastewater disposal, a system of small bore street sewers was assumed, with minimum diameter of 100 mm and minimum design velocity of 0.3 m/sec. The small size and velocity were made possible because of solids retention in the tanks, thus making it necessary for the sewers to handle liquid only. Desludging was assumed to be required every four years, and a sewage lagoon with 20 days detention was provided for treatment.

25. Level V Assumed multiple in-house taps and appliances for water supply and conventional water-borne sewerage for sanitation. Since sewers must carry solids, minimum size and velocity of 150 mm and 0.6 m/sec, respectively, were asumed. A sewage lagoon with 20 days detention was provided for treatment.

ALTERNATIVE DESIGNS

26. Required design work for this study had to be sufficiently detailed to enable using the cost equations in pars. 5-15. For treatment plants, this required estimating maximum daily flows; water storage tanks similarly depend on flow (required volume was assumed to be 30% of maximum daily flow). Water transmission lines and sewage force mains depend on length and diameter which required hydraulic analysis. Similarly, pumping stations involved computations to determine total dynamic head (TDH). Finally, water networks which depend on pipe length and diameter, and sewage networks which depend on pipe length, diameter and depth, required use of the computer.

27. In the case of the water networks for public standposts (Level I), pipes were laid along streets in the shortest path between source of supply and points of demand. This resulted in a branched system with open circuits.

The network was designed to deliver peak hourly demands (3 times average flow) at a minimum residual pressure of 10 m. Linear programming and the computer were used to determine pipe sizes that minimized total construction costs. The smallest allowable pipe diameter was 25 mm.

28. The water distribution networks for Levels II - V were looped systems which had to be designed on the computer; the minimum allowable pressure was 10 m. The sewage networks for Levels IV and V (small bore and conventional sewers) similarly required the computer for design. The standards for minimum velocities and pipe sizes are in pars. 24 and 25.

29. The main characteristics of the facilities for the five service levels are summarized in Table 1. In general, the symbols refer to the variables in the cost equations of pars. 5-15 and have the same units. New symbols in Table I not previously introduced include average pipe diameter ($\overline{D}$) in water and sewage networks and average excavation depth ($\overline{X}$) in sewage networks. Average diameter is the sum of length times diameter for each link divided by total length, and average excavation depth in the sum of length times excavation for each link divided by total length. The wastewater collection networks for Levels IV and V each require four pumping stations.

30. Pipe size distributions for the water works are shown in Table 2. Note the large proportions of length in each network with diameters smaller than 50 mm.

31. Differences in system characteristics can be seen from Table 1. Some important observations are as follows. The total length of pipe in the water distribution network approximately doubles by designing for some kind of house connection (i.e. Level II-V) instead of using public standposts (Level I). The mean diameter of pipe in the standpost network, however, is larger than that in the yard tap system (Level II) and about the same as in the sanitary core system (Levels III and IV). This is because with relatively few pipes in the standpost system, each must carry a fairly high proportion of total flow. The total length of street sewers is the same for Levels IV and V, as expected, but mean pipe diameters and mean excavation depths are greater for the higher level of service (V). This is primarily due to the minimum pipe size and velocity restrictions imposed on network design.

COSTS

32. Construction costs of water and sanitation facilities for the five service levels are shown in Table 3. They are based on system characteristics in Table 1 and the cost functions in pars. 5-15. For each design,

Table 1 - Water and Sanitation Facilities

Water	I	II	III	IV	V
Raw Pumping	MDQ = 4.69 lps TDH = 11 m	MDQ = 9.38 lps TDH = 13 m	MDQ = 18.8 lps TDH = 11 m	MDQ = 18.8 lps TDH = 11 m	MDQ = 37.5 lps TDH = 11 m
Raw Transmission	L = 100 m D = 100 mm	L = 100 m D = 100 mm	L = 100 m D = 150 mm	L = 100 m D = 150 mm	L = 100 m D = 200 mm
Treatment	ADQ = 270 cmd	ADQ = 540 cmd	ADQ = 1080 cmd	ADQ = 1080 cmd	ADQ = 2160 cmd
Finished Pumping	MDQ = 4.69 lps TDH = 68 m	MDQ = 9.38 lps TDH = 66 m	MDQ = 18.8 lps TDH = 61 m	MDQ = 18.8 lps TDH = 61 m	MDQ = 37.5 lps TDH = 61 m
Finished Transmission	L = 350 m D = 100 mm	L = 350 m D = 100 mm	L = 350 m D = 150 mm	L = 350 m D = 150 mm	L = 350 m D = 200 mm
Storage	VOL = 120m^3	VOL = 240m^3	VOL = 490m^3	VOL = 490m^3	VOL = 970m^3
Distribution Network	L = 5159 m $\bar{D}$ = 42.8 mm	L = 10,765 m $\bar{D}$ = 36.9 mm	L = 10,765 m $\bar{D}$ = 45.2 mm	L = 10,765 m $\bar{D}$ = 45.2 mm	L = 10,765 m $\bar{D}$ = 56.9 mm
Devices	27 Standposts	1800 Yard Hydrants	1800 Sanitary Core	1800 Sanitary Core	1800 Full Plumbing
Sanitation					
Collection Network	-	-	-	L = 9965 m $\bar{D}$ = 119.7 mm $\bar{Y}$ = 1.78 m	L = 9965 m $\bar{D}$ = 165.1 mm $\bar{Y}$ = 2.35 m
Raw Pumping	-	-	-	MDQ = 18.8 lps	MDQ = 37.5 lps
Force Main	-	-	-	L = 400 m D = 150 mm	L = 400 m D = 200 mm
Treatment	-	-	-	VOL = 21,600m^3	VOL = 43,200m^3
On-Site Devices	1800 VIP Latrines	1800 P.F. w/Soakaway	1800 P.F. w/Septic Tank & Drainfield	1800 P.F. w/Septic Tank & Sewer	1800 Sewers

Table 2 - Distribution of Pipe Sizes

Diameter (mm)	Per Cent of Total Length I	II	III and IV	V
25	25	55	40	18
30	27	10	14	19
38	13	13	11	14
50	18	9	14	18
75	10	9	8	15
100	7	4	10	7
150	-	-	3	6
200	-	-	-	3

the cost of developing the water supply source was assumed to remain constant at US$8,000, which is roughly the average value obtained from COPASA. The unit cost of sewage lagoon construction was decreased from about 2.6 to 2.0 US$/$m^3$ for Levels IV and V, respectively, to reflect economies of scale in construction; the accuracy of these values is uncertain. Per capita construction costs are given for both the present population of 6000 and the design population of 10,800. The data in Table 3 cover both the public facilities that are normally provided by the municipality and the private facilities that are installed by individual owners. Replacement costs are not shown.

33. Table 4 indicates the cost of water and sanitation components as a percentage of total construction cost. Two columns of values are shown for each level of service. In the column labeled "Water", the cost of water components is given as a percentage of total water system cost. In the "Total" column, the cost of both water and sanitation components is given as a percentage of total (i.e. water plus sanitation) system cost. The individual components included in each category of Table 4 are indicated in the notes following the table.

34. Operating and maintenance (O+M) costs are given in Table 5; unit costs are taken from par. 15 herein. Pumping costs are based on power requirements. Annual maintenance costs of public facilities (e.g. networks, pump stations, sewage lagoons, etc.) are based on 1% of their construction costs; on-site water distribution devices and sanitation facilities were excluded in determining maintenance charges. The annual (equivalent) costs shown in Table 5 of replacing latrines and desludging vaults are based on values in par. 15 but are aproximate because of their lumpiness; the present value costs of these operations, however, are accurate. The annual interest rate for obtaining present values is 10%.

Table 3 - Construction Costs, US$

	Service Level				
	I	II	III	IV	V
WATER FACILITIES					
Source Development	8,000	8,000	8,000	8,000	8,000
Raw Pumping	7,200	11,700	17,500	17,500	27,500
Raw Transmission	1,300	1,300	2,600	2,600	4,300
Treatment	36,000	57,500	93,000	93,000	150,000
Finished Pumping	11,000	17,000	26,000	26,000	40,500
Finished Transmission	4,700	4,700	9,200	9,200	15,200
Storage	17,200	27,300	43,400	43,400	69,100
Distribution Network	26,900	50,800	63,200	63,200	84,200
Service Connections	--	90,000	135,000	135,000	135,000
Distribution Devices	13,500	45,000	90,000	90,000	270,000
Total Water Cost	125,800	313,300	487,900	487,900	803,800
Cost/Capita					
- Design Population	12	29	45	45	74
- Present Population	21	52	81	81	134
SANITATION FACILITIES					
On-Site Sanitation	135,000	270,000	540,000	270,000	180,000
House Laterals	--	--	--	239,400	239,400
Collection Network	--	--	--	191,600	284,000
Network Pump Stations	--	--	--	33,800	89,700
Raw Pumping	--	--	--	26,700	56,500
Force Main	--	--	--	10,600	17,300
Treatment	--	--	--	56,500	86,000
Total Sewerage Cost	135,000	270,000	540,000	828,600	952,900
Cost/Capita					
- Design Population	12	25	50	77	88
- Present Population	23	45	90	138	159
WATER AND SANITATION FACILITIES					
Total Construction Cost	260,800	583,300	1,027,900	1,316,500	1,756,700
Total Cost/Capita					
- Design Population	24	54	95	122	162
- Present Population	44	97	171	219	292

Table 4 - Per Cent of Total Construction Cost

	I		II		III		IV		V	
	Water	Total	Water	Total	Water	Total	Water	Total	Water	Total
WATER FACILITIES										
Source[1]	13	6	7	4	6	3	6	2	5	2
Treatment[2]	29	14	18	10	19	9	19	7	19	9
Transmission[3]	12	6	7	4	7	3	7	3	7	3
Distribution[4]	35	17	25	13	22	10	22	8	19	9
On-Site[5]	11	5	43	23	46	22	46	17	50	23
Total	100	48	100	54	100	47	100	37	100	46
SANITATION FACILITIES										
On-Site[6]		52		46		53		39		24
Collection[7]		0		0		0		17		21
Treatment[8]		0		0		0		7		9
Total		52		46		53		63		54

Notes

1. Includes Source Development, Raw Pumping and Raw Transmission from Table 3.
2. Includes Treatment from Table 3.
3. Includes Finished Pumping and Finished Transmission from Table 3.
4. Includes Storage and Distribution Network from Table 3.
5. Includes Service Connections and Distribution Devices from Table 3.
6. Includes On-Site Sanitation and House Laterals from Table 3.
7. Includes Collection Network and Network Pump Stations from Table 3.
8. Includes Raw Pumping, Force Main and Treatment from Table 3.

Table 5 - Operation and Maintenance (O+M) Costs

	I	II	III	IV	V
			WATER FACILITIES		
Raw Pumping, US$/yr	180	430	730	730	1510
Finished Pumping, US$/yr	1140	2210	4080	4080	8090
Maintenance, $/yr (2)	1260	2680	3980	3980	5340
Chemicals, $/yr	760	1520	3040	3040	6080
Total Water O+M Cost					
Annual, US$/yr	3340	6840	11,830	11,830	21,020
Present Value, US$ (5)	28,000	58,000	101,000	101,000	179,000
Water Construction Cost, US$	126,000	313,000	488,000	488,000	804,000
Total P.V. Water Cost, US$	154,000	371,000	589,000	589,000	983,000
			SANITATION FACILITIES		
Wastewater Pumping, US$/yr	0	0	0	1280	2730
Maintenance, $/yr (2)	0	0	0	5590	7730
Private On Site					
Annual, $/yr (3)	13,500±	6,750±	6,750±	6,750±	0
Present Value, $ (4)	52,000	50,000	50,000	50,000	0
Total Sanitation O+M Cost					
Annual, US$/yr	13,500±	6,750±	6,750±	13,620±	10,460
Present Value, US$ (5)	52,000	50,000	50,000	108,000	89,000
Sanitation Construction Cost, US$	135,000	270,000	540,000	829,000	953,000
Total P.V. Sanitation Cost, US$	187,000	320,000	590,000	937,000	1,042,000

Notes

1. Annual O+M unit costs are from para. 15.
2. Maintenance costs = 1% per year of (Total Construction Cost - On-Site Construction Cost)
3. For Level I, the approximate annual cost of replacing latrines is $75/10 yrs x 1800 dwellings = $13,500/yr. For Levels II-IV, the approximate annual cost of desludging vaults is $15/4 yrs x 1800 dwellings = $6,750/yr. (Cf. par. 15)
4. For Level I, a cost of $75/dwelling is incurred in year 10 for replacing latrines; for Levels II-IV, a cost of $15/dwelling is incurred every 4 years for desludging (Cf. par. 15). The annual interest rate is 10%.
5. The annual interest rate is 10%.

35. Total present value construction plus O+M costs are shown in Table 6. Costs are broken down into those normally borne by the municipality (Public) and those borne by individual users (Private). For water facilities, private costs include service connections and on-site water appliances. For sanitation, private costs likewise include connections and on-site facilities but also include the present value cost of replacing latrines (for Level I) and desludging vaults (for Levels II-IV). Per capita costs are shown on both an annual and total cost basis; the annual costs assume a 10% interest rate and a 20-year period. Per cpaita costs are shown for both the design and present populations.

OBSERVATIONS

36. From Table 3, it is seen that water system construction costs range from US$12/capita for standposts to US$74/capita for house connections with "full" service. Corresponding sanitation costs increase from US$12/capita to US$88/capita. These values and references to per capita costs throughout this section are based on the design rather than the present population (present population per capita costs are 80% higher).

37. The per capita costs appear to be low, especially for a community the size of Rio Casca. This may be due in part to the fact that contingencies, land, engineering, legal and administration costs have been ignored. Perhaps more important, the design of both water and sewerage networks was rigorously made using the computer which resulted in more efficient and less costly systems than those likely to be found in practice.

38. By using yard taps for water supply instead of standposts, construction costs more than double (US$29/capita vs. US$12/capita). Upgrading from yard taps to sanitary core (single house taps) increases construction cost about 50% (from US$29/capita to US$45/capita). The "full" plumbing system is about 2/3 more expensive than the sanitary core (US$74/capita vs. US$45/capita). Alternatively stated, the highest level of water supply service is 6 times more expensive than standposts, 2.5 times more expensive than yard taps, and 1.6 times more expensive than the sanitary core.

39. By using pour flush toilets with soakaways for sanitation instead of pit latrines, construction costs approximately double (US$25/capita vs. US$12/capita). Upgrading to septic tanks with drainfields again doubles the cost (from US$25/capita to US$50/capita). Septic tanks with small bore street sewers are about 50% more expensive than septic tanks with drainfields (US$77/capita vs. US$50/capita). Finally, a conventional water borne sewerage system is only 15% more expensive in construction costs than small bore sewers (US$88/capita vs. US$77/capita). Alternatively stated, conventional sewers are 7 times more expensive than pit latrines, 3.5 times more expensive than pour flush toilets with soakaways, and 1.8 times more expensive than septic tanks with drainfields.

Table 6 - Total Present Value Construction, Operation and Maintenance Cost, US$

	I	II	III	IV	V
Water Supply	154,000	371,000	589,000	589,000	983,000
Public	154,000	236,000	364,000	364,000	578,000
Private (1)	0	135,000	225,000	225,000	405,000
Sanitation	187,000	320,000	590,000	937,000	1,042,000
Public	0	0	0	378,000	623,000
Private (2)	187,000	320,000	590,000	559,000	419,000
Total Public	154,000	236,000	364,000	742,000	1,201,000
Total Private	187,000	455,000	815,000	784,000	824,000
Total P.V. Cost	341,000	691,000	1,179,000	1,526,000	2,025,000
Design Population, $/cap.(3)	32	64	109	141	188
Present Population, $/cap.(3)	57	115	197	254	338
Annual Cost, $/yr (4)	41,000	83,000	141,000	183,000	243,000
Design Population, $/cap/yr. (3)	4	8	13	17	23
Present Population, $/cap/yr. (3)	7	14	24	31	41
Public/Total, %	45	34	31	49	59

Notes

1. Covers service connections and on-site distribution devices.
2. Covers house laterals, on-site sanitation, plus the present value of replacing/desludging on-site facilities.
3. Design Population = 10,800; Present Population = 6,000.
4. With 10% annual interest and 20-yr. period, the capital recovery factor is 0.12.

40. The increase in water supply and sanitation construction costs with level of service is shown graphically in Fig. 1, where level of service is denoted by average per capita design flow. The almost linear shape of these curves is noteworthy. Had level-of-service been denoted by, say, water carrying distance instead of average design flow, the curves would be convex, indicating a sharp increase in per capita cost with level. From the slopes of the curves in Fig. 1, it is seen that the marginal construction cost of changing the service level of either water or sanitation is about US$0.40/capita per lcd.

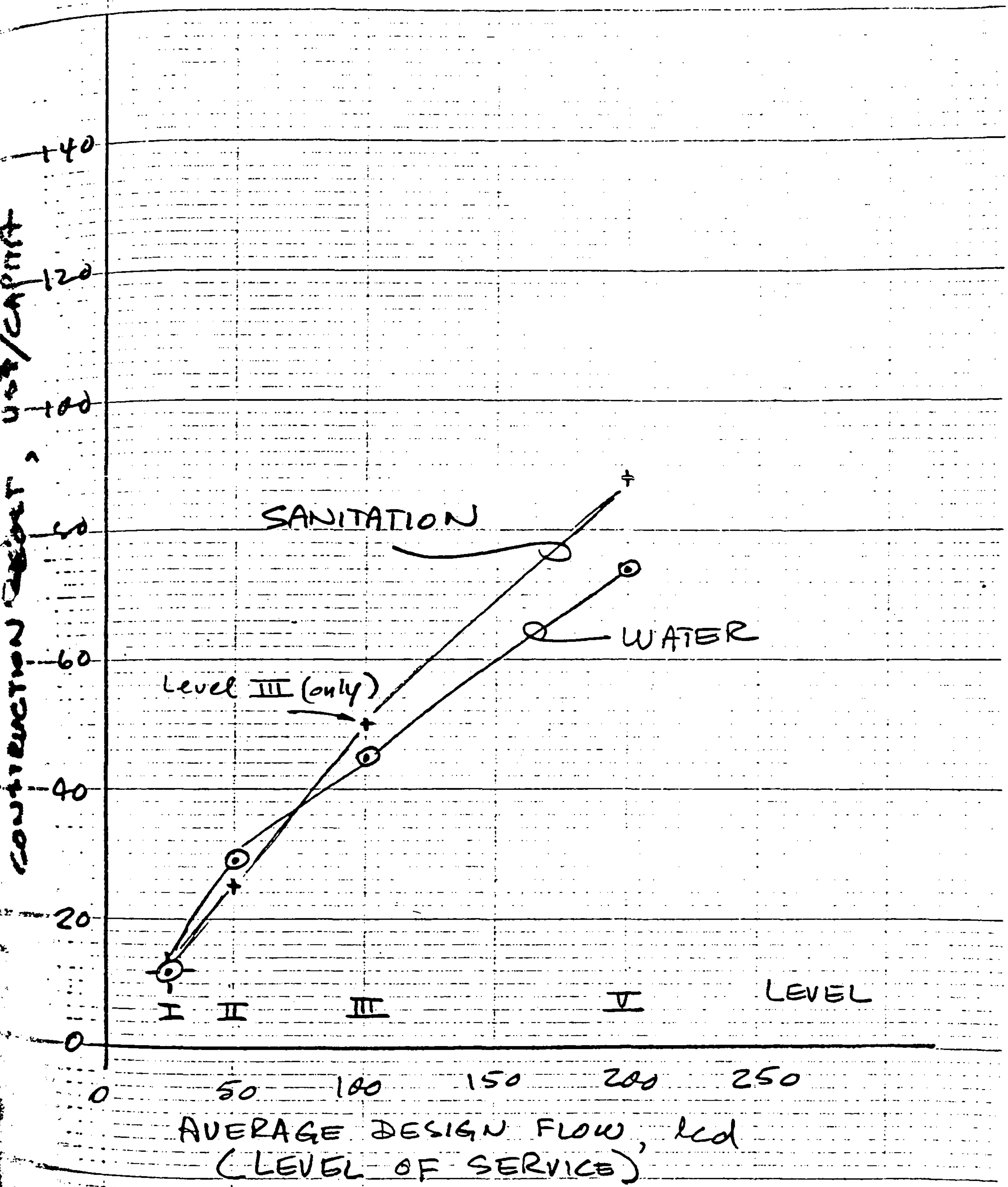
41. Table 3 indicates that the small bore sewer system of Level IV is significantly more expensive than the septic tank/drainfield system of Level III; yet they probably render comparable service unless soil absorption properties are poor. Indeed, the conventional sewer design of Level V is not much more expensive than small bore sewers. The relative difference in total present value sanitation costs betwen Levels III and IV after taking account of operation and maintenance is even smaller. One concludes, at least for this example where construction is not staged and systems are not upgraded over time, that small bore sewers should be avoided unless soil conditions preclude on-site sanitation.

42. Table 4 indicates that at every level of service, the construction costs of sanitation facilities is about one-half total system cost (actually, slightly more than half). A possible exception is Level IV where the sanitation system represents about 63% of total cost.

43. The figures for water components in Table 4 indicate that except for the standpost system (Level I), treatment represents about 20% of total water facilities cost, the distribution network is about 25%, and on-site facilities represent nearly 50%. As previously mentioned, network costs are probably low because of the efforts to optimize design. One concludes that on-site facilities merit careful consideration in the design of water systems. For example, examination might be made of (1) serving multiple dwellings from a single connection and (2) including connection costs in the package of facilities for financing.

44. The figures in Table 4 for Levels IV and V show that the percentages of total system construction cost represented by water and wastewater treatment plants are about equal. It can also be seen that wastewater collection networks for these same levels of service are about twice as costly as water distribution networks. Finaly, on-site sanitation facilities are seen to represent the largest proportion of total system cost for all levels of service, but especially so for Levels I-IV. As in the case of water facilities, on-site sanitation hardware merits careful consideration in system design.

45. Table 5 shows that slightly more than 80% of total present value water system cost is due to construction, while nearly 90% of sanitation cost is tied up in capital. The difference is partly due to the fact that sewerage facilities are slightly more costly than water, but more important, operating costs of wastewater treatment facilities are low due to the use of sewage lagoons.



1- CONSTRUCTION COST VS LEVEL OF SERVICE

46. Note in Table 5 that the present value O+M sanitation cost for Level IV (small bore sewers) is about twice that of Level III (septic tanks with drainfields). This is because the expensive collection network of Level IV must be maintained, the sewage lagoons must be operated, and individual on-site vaults must be desludged. Note that the O+M sanitation cost for Level V is lower than that of Level IV, largely because no need exists to desludge on-site vaults. It is seen in Table 5 that a trade-off exists for sanitation between Levels III and IV. Both levels provide essentially equal service, but Level III with septic tanks is less capital intensive than Level IV with small bore sewers. However, this difference is not offset by operating cost savings. In fact, both capital and other costs are higher for Level IV than for Level III. The net result is that small bore sewers appear to be uneconomical. With staged construction whereby septic tanks provided for an initially low level of service are retained and incorporated into an upgraded system, small bore sewers would be more economically advantageous.

47. Table 6 shows a breakdown of total present value water and sanitation costs between public and private; private costs in general cover on-site facilities. The ratio of public to total cost is shown in the last row where it is seen that in Level III, the lowest ratio (only 31%) of total present value cost is in public facilities, the remainder being associated with on-site facilities. This level, then, renders relatively high service and has low external financing requirements. Assuming an average family size of 6, the total annual costs per dwelling in US$ for both water and sanitation facilities for Levels I through V, respectively, are 23, 46, 78, 102 and 135. For water facilities only, the costs are 10, 25, 39, 39 and 66.

48. With the cost information in Table 6, the optimal service level could be identified if similar data were available for benefits. Unfortunately they are not, but it is possible to speculate on the benefit function. Let us assume that benefits are of two types: convenience (i.e. accessibility) and health. Addressing convenience benefits first, it is probably safe to assume that at Level I, they are somewhat larger than costs. Upgrading from Level I to II, convenience benefits increase sharply, but thereafter they are subject to diminishing marginal returns which results in the assumed concave function shown in Fig. 2.

Health benefits on the other hand probably do not change much at lower levels of service until Level V is achieved at which point they increase sharply. The resulting function is mostlikely convex, as shown in Fig. 2. At Level I, health and convenience benefits might be roughly of the same magnitude, but at Level V, health benefits probably outweigh convenience benefits by a substantial margin. The resulting total benefit function, which is the sum of the health and convenience functions, is shown in Fig. 2; it has an inflection point between Levels III and V.

Maximum net benefits presumably occur at Level V as shown; certainly this is the implication in economically advanced countries where budgetary constraints and affordability are not serious issues. Among the three lower levels of service, however, it is suspected that maximum net benefits may

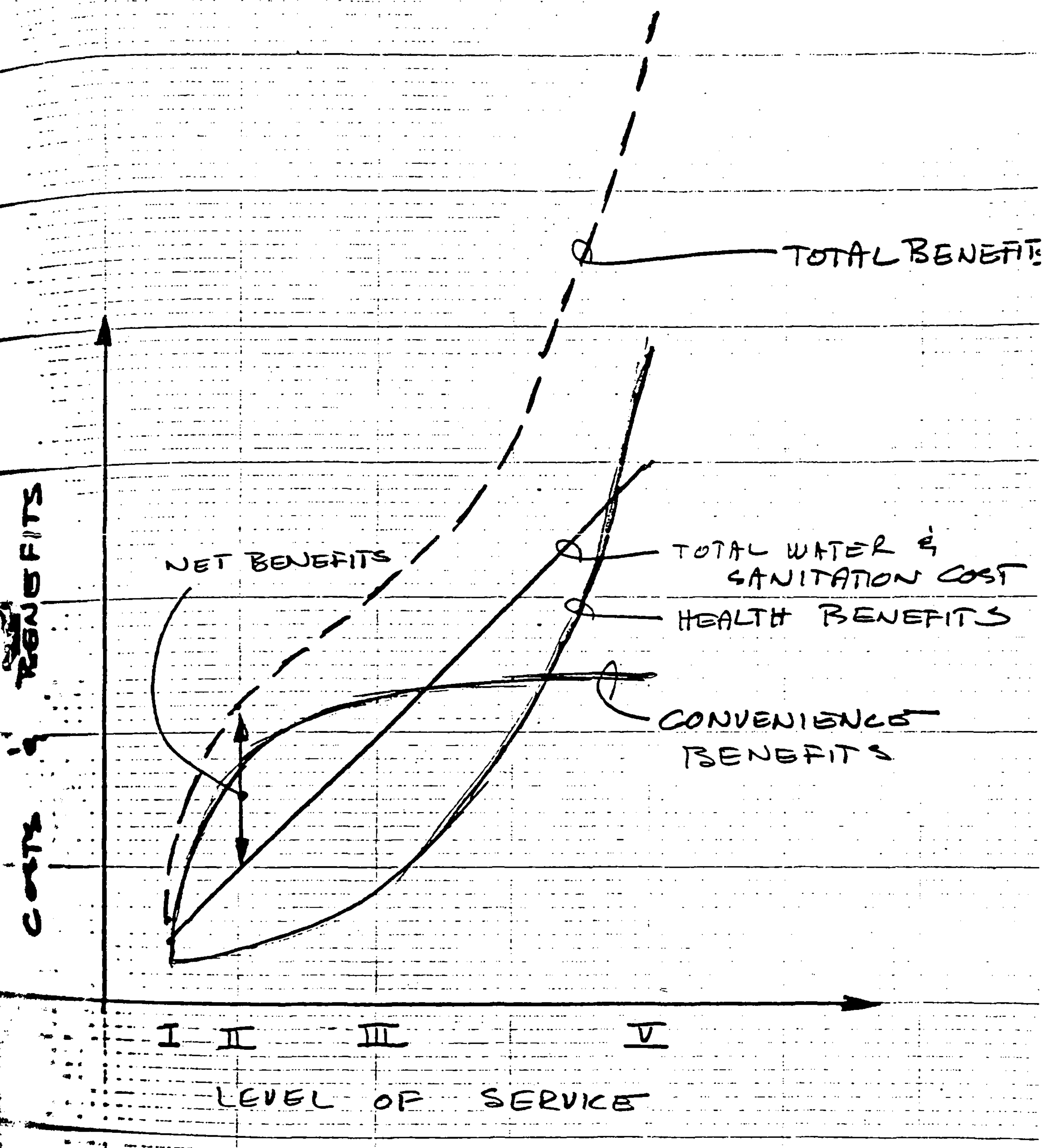


Fig 2 - SCHEMATIC DIAGRAM OF COSTS & BENEFITS VS LEVEL OF SERVICE occur at Level II, which employs yard taps for water supply and pour flush toilets for sanitation. This level provides a high degree of convenience benefits and is probably not much worse in health benefits than Level III. Hence, where affordability is at issue, yard taps may be optimal. The annual cost per dwelling for both water and sanitation at Level II is US$46. Assuming users are able to spend up to 5% of their income on these facilities, the minimum required annual income per dwelling is about US$900.

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