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iversity of Technology

N:o B 31

Department of Civil Engineering
Institute of Water and Environmental Engineering
Postgraduate Course in Water Supply and Sanitation 1986-88
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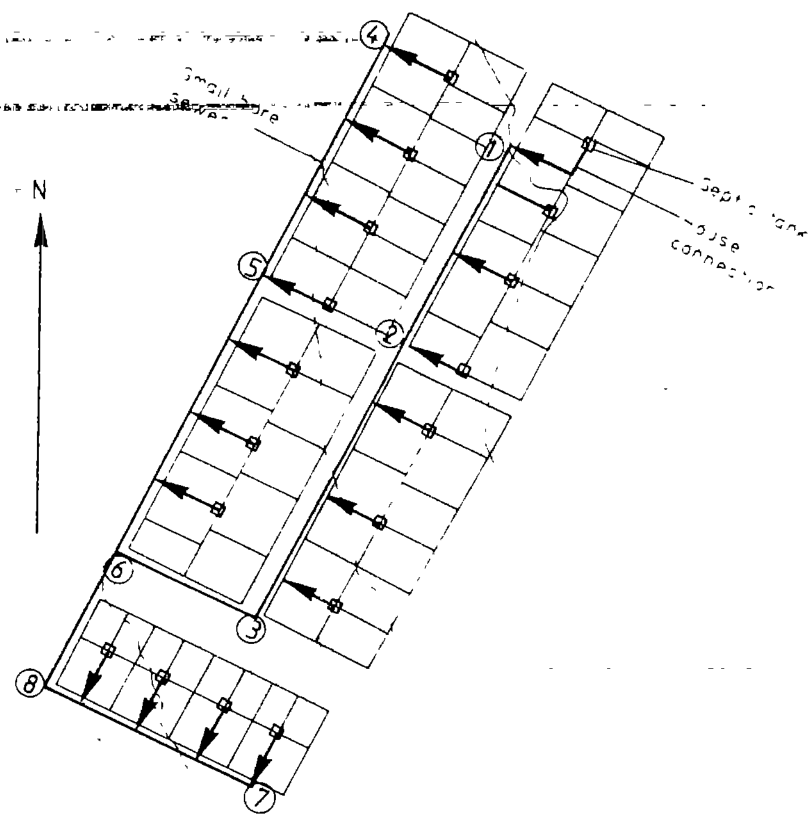

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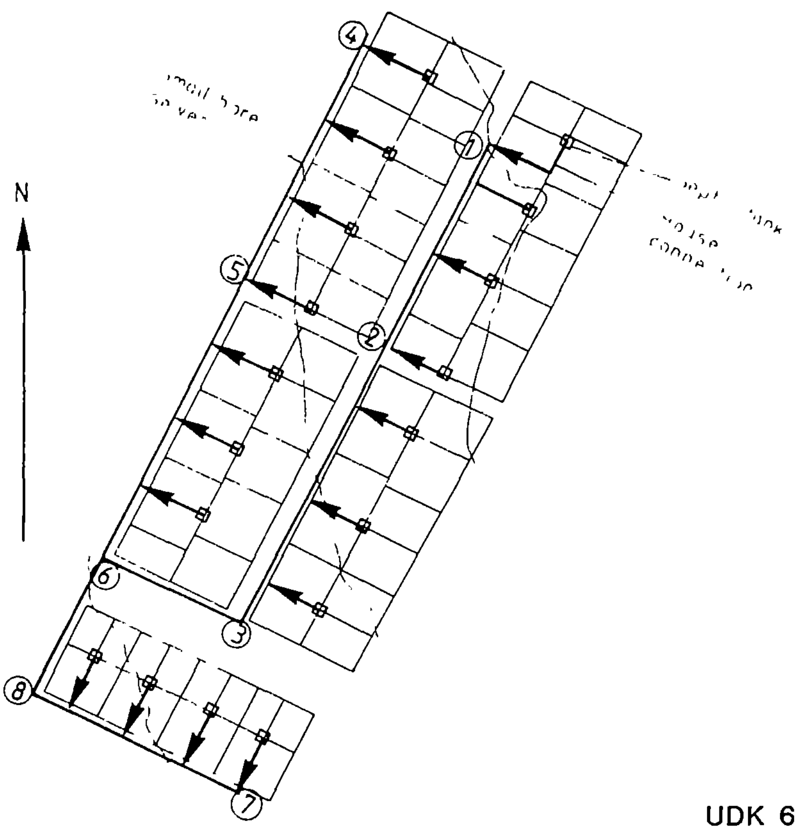

Tampere 1988

UDK 628.21-22
ISBN 951-721-252-6
ISSN 0784-655X

APPLICABILITY OF SMALL BORE GRAVITY SEWER SYSTEM TO THE CONDITIONS OF ADDIS ABABA

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ABSTRACT

The city of Addis Ababa has a small percentage of septic tanks (about 12 %), which have only minimal success in the leaching of the effluent because of poor design and construction practices and the impervious nature of the soil.

The vast majority of the pit latrines found in the city cannot be considered as meeting even minimal standards regarding their sanitary conditions and accessibility for desludging. In most parts of the city particularly in the densely populated areas free space is not available for the construction of new pit latrines. Therefore, even a pit latrine is in a poor condition, emptying the same old pit latrine has been a common practice and permanent solution for many years.

The conventional sewerage system, which is partly under construction is totally inadequate for the city of Addis Ababa. The inadequate conventional sewerage services together with the small percentage of septic tanks and their failures as a result of impervious soil condition for waste water disposal are contrary to the considerable expansion of the water supply sector in Addis Ababa.

Alternative off-site waste water disposal systems such as small bore sewer system could be a remedy for the sanitary problems in some parts of the city especially in areas, where the existing on-site disposal facilities and unit water consumption are within the acceptable limit for the application of the system.

1 INTRODUCTION

Domestic waste water disposal has been one of the biggest problems in urban areas of the developing countries and in smaller communities of the industrialized countries. This is mainly because of the limited financial resources to provide them with the conventional sewer system, which is the most effective and expensive off-site waste water disposal system.

Alternative off-site waste water disposal technologies have been devised and developed with minimum cost having approximately similar service level as the conventional sewer system. Small bore sewer system is one of the newly developed off-site alternative technologies. It has been practiced in the United States, Australia, Nigeria and Zambia since the beginning of 1970's.

Small bore sewer system requires mainly facilities to settle solids such as interceptor tanks and small diameter plastic pipes to transport the partially treated waste water to a disposal site for further treatment. From previous experiences it has been proved that there is economic gains in the use of small bore sewer system if existing septic tanks are utilized for solid settlement. The design of small bore sewer system is dependent on the quantity and quality of waste water from households.

The quantity of waste water generated by individuals, estimated from the unit water consumption data currently available in Addis Ababa could help in the design of off-site waste water system, especially when there is not enough time for data collection and detailed analysis of the waste water flow in Addis Ababa.

The waste water quality analysis made at Kaliti waste water laboratory from septic tanks in the beginning of September and at the end of October together with the waste water quality parameters in August 1987 at the different stages of the treatment plant, could help to understand the seasonal quality variation of the waste water and the strength of sewage in Addis Ababa.

The data collected regarding the distribution of the on-site disposal facilities and the service level of the newly constructed conventional sewer system could give a general impression about the sanitary situation in Addis Ababa. The design example made at a selected site in Addis Ababa could also help to consider the possible technical applicability of small bore sewer system in some parts of the city.

This paper is intended to give a background information on the sanitary situation and the possible technical applicability of small bore sewer system as alternative off-site sanitary technology in Addis Ababa, considering existing on-site disposal facilities, specific water consumption and topographical situation.

2 DOMESTIC WASTE WATER CHARACTERISTICS

2.1 Quantity

Estimating how much sewage or wash water flows from homes, public buildings or different establishments is the essential parameter in designing of waste water disposal system. The quantity of domestic waste water is very much dependent on the volume of excrement and sullage. The various specific factors, such as food type and climatic conditions also play an important role in the determination of the quantity of domestic waste water.

Santala (1984) listed the following points as the major factors in determining the quantity of domestic waste water for different establishments:

- amount of water supplied
- means of water supply
- price of supplied water
- amount and type of plumbing fixtures
- family size
- age level, health condition and mobility of family members
- water use habits of family members.

Based on the above mentioned factors many authors recommend different amounts of domestic waste water flow in litres per capita per day (lcd). For example, Laak (1980) and Santala (1984) reported waste water flow to be approximately equal to water use with the exception in arid regions where water is used for irrigation and high ground water table areas where groundwater infiltrates the waste water collection system.

Tchobanoglous (1985) also recommended a wider range of waste water flow, as from 60 % - 80 % of individual daily water use. In most cases, where a septic tank receives all the domestic waste water, the quantity is taken to be about 90 % of the water consumption (ENSIC 1982).

The total amount of water used per person per day depends on the economic level and water use habits of the individual. According to ENSIC (1982), in rural areas the range is between 10 - 40 lcd, whereas in urban areas, water consumption rate may go up to 300 lcd.

Singh (1980) reported that in India water required for domestic purposes for average Indian condition to be about 135 lcd. In Kenya for the city of Nairobi the average domestic water consumption between the year 1975 to 1984 was 80 lcd (Ngari 1986). Whereas in Finland, according to Santala (1984) the mean values for water consumption in urban areas are usually in the range of 100 to 250 lcd. Water supply service levels also have a great impact on the variation of average domestic water consumption. The following table may give a rough idea of the situation in the different types of water supply systems.

Table 1. Typical domestic water usage (Hofkes 1986).

Type of Water Supply	Typical Water Consumption (lcd)	Range (lcd)
Communal water point (e.g. village well, public standpost)		
- at considerable distance (> 1000 m)	7	5 - 10
- at medium distance (500 - 1000 m)	12	10 - 15
Village well walking distance < 250 m	20	15 - 25
Communal standpipe Walking distance < 250 m	30	20 - 50
Yard connection (tap placed in house-yard)	40	20 - 80
House connection		
- single tap	50	30 - 60
- multiple tap	150	70 -250

2.2 Quality

The characteristics of domestic waste water vary for different establishments such as homes, restaurants, hospitals, schools etc. depending on specific water consumptions and other major factors mentioned in Chapter 2.1.

Basically domestic waste water originates from two sources: excrements and sullage, (Laak, 1980). The excrement includes faeces and urine and it varies from person to person in volume, composition and concistency. As reported by Feachem et al (1980), this variation mainly depends on type of food adopted and climatic condition in a given area. The variation also depends on age group of inhabitants, state of health of individuals and level of per capita consumption of water in that particular area.

Sullage as defined by Feachem et al (1980), is the domestic waste water from baths, sinks and the like, excluding the waste water containing exreta.

The concentration of the different kinds of pollutant loads in domestic waste water therefore depends on the amount and composition of excrement and sullage. For example, the total nitrogen in the form of organic and ammonia nitrogen and phosphate originate mostly from the large volumes of urine. Waste materials such as toilet paper causes additional pollutant load especially of COD, BOD and solids to the toilet waste water (Laak 1980).

According to a report by Feachem et al (1980) experiments made in U.S.A. showed that sullage contributes about 52 %

of the BOD, 43 % of the COD, 15 % of the nitrogen and 45 % of the phosphate.

These values should not be taken as standard values, since the quality of the sullage varies depending mainly on the per capita consumption of water, types of sanitary fixtures, water use habits of individuals and quantity and quality of detergents used for washing purposes.

Table 2 shows the average concentration of pollutant loads discharged from sanitary fixtures.

Table 2. Average concentration (mg/l) of pollutants from plumbing fixtures (Laak 1980).

	Fixture				
Pollutant	Water Closet	Laundry	Sink	Bath	Kitchen
COD	900	700	400	300	1 400
BOD_5	300	300	200	200	700
TN	200	10	2	2	5
PO_4	100	200	50	1	10
SS	300				500
Grease				750	
Bacteria (Coliforms), colonies/100 ml	10^6 [a]		10^6 [b]		

[a] Faecal
[b] E. coli, faecal and other.

As reported by ENSIC (1982) the quality characteristics of domestic waste water may be classified as strong medium or weak, depending on the concentration of its various components. The Table 3 gives a typical approximate composition of medium strength domestic waste water.

Table 3. Approximate composition of medium strength domestic waste water, modified from ENSIC (1982).

Parameter	Values mg/l, except as noted
pH units	6,5 to 7
Dissolved oxygen	0 to 3
Biological oxygen demand	200
Chemical oxygen demand	610
Total phosphorus	30
Total solids	700
Total suspended solids	300
Total dissolved solids	400
Total nitrogen	35
Nitrate	0
Nitrite	0
Sulphate	45
Alkalinity as $CaCo_3$	120

Table 3 may help as a guide for comparison other than a basis for design, because the composition of domestic waste water fluctuates with time and place as individual water use activities occur intermittently and contribute varying quantities of pollutants.

3 SMALL BORE SEWER SYSTEM

3.1 Principles of the System

According to Otis (1986) small bore sewers are designed to handle only the liquid portion of the waste water. Grit, grease and other troublesome solids that may obstruct the sewer are separated from the flow in interceptor tanks upstream of each connection. For proper functioning, the system requires facilities to settle solids, usually at each household or for groups of households. Septic tanks and aqua-privies are the common types of interceptor tanks.

Simmons and Newman (1985) reported that the operation of the system, in principle, is similar to a series of sink traps stretched out over a long distance. If there is positive net fall from inlet to outlet any number of litres put in the upper end will eventually reach the lower end. The small diameter pipe, which is laid at a relatively constant depth regardless of grade, has a profile showing many uphill and downhill sections. The outlet is lower than the inlet on any house served by the sewer. The draining process involves delays, surcharging and many transitions from fullpipe flow to partial pipe flow. However after the lower sections are filled, all the liquid in the inlet will reach the outlet. The figure below shows the arrangement of small bore sewer system.

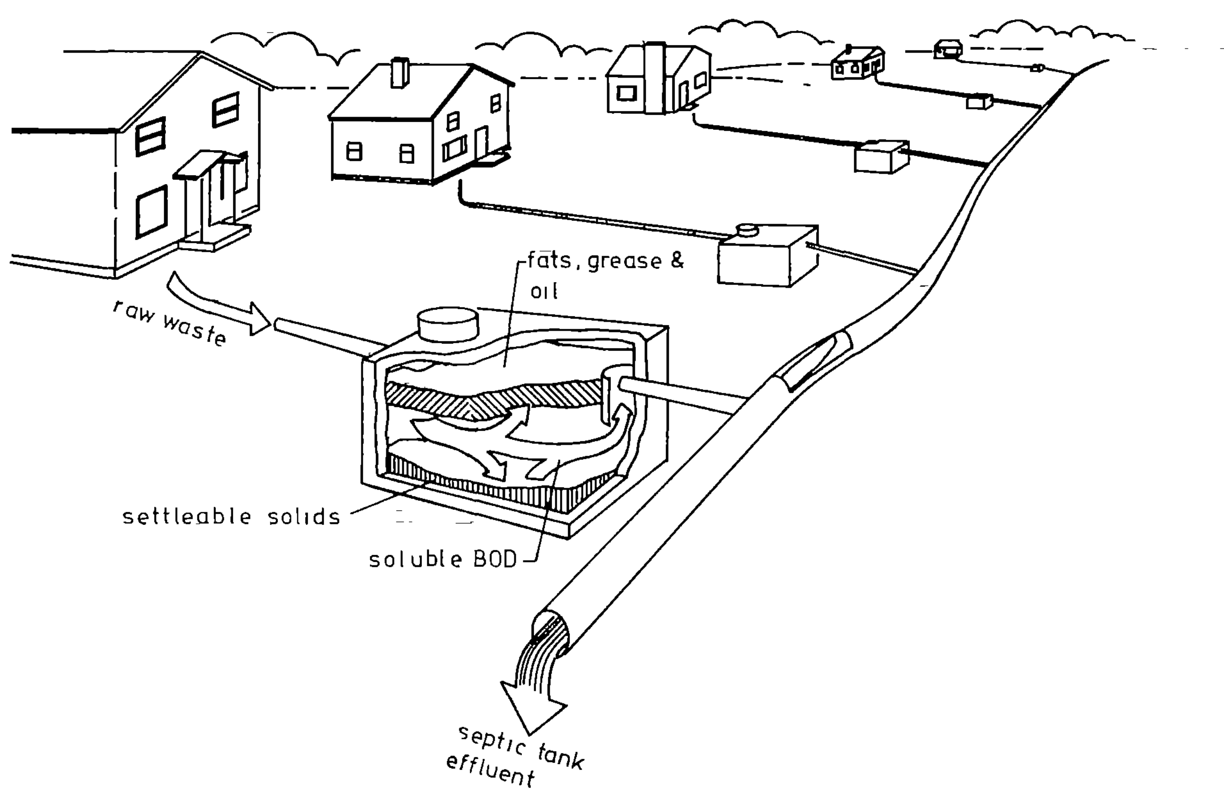

Figure 1. Schematic diagram of small diameter gravity system (Otis 1981) cited by Kreissl (1984).

3.2 Components of the System

Small bore sewer system consists of house connections, interceptor tanks, the sewer and their appurtenances and a sewage treatment facility. Occasionally, individual pumping stations may be required to lift the effluent from the interceptor tank into the sewer to overcome adverse elevation differences. Pumping stations may be also required in the sewer system in very flat areas (Otis and Mara 1985). The house connection is made at the inlet to the interceptor tank. All household waste water enters the system at this point.

The inteceptor tank is a rectangular or cylindrical watertight chamber, usually located just below ground level, with baffled inlet and outlet, to receive both excreta and flush water from toilets as well as other household waste water. It is usually designed to detain the liquid flow for at least 24 hours. Settleable solids settle to the tank bottom, and will be digested anaerobically. A scum of light materials (including fats and greases) rise to the top. The clarified liquid flows through an outlet structure below the floating scum layer. The accumulated solids periodically will be removed through an access port. Typically a single-chamber septic tank may be used as interceptor tank (World Bank 1985 a).

According to Otis and Mara (1985) sewers or conduits are small bore plastic pipes (mimimum diameter of 100 mm) which are trenched into the ground at depth sufficient to collect the settled waste water from most connections by gravity. They are not necessarily laid on a uniform gradient with straight alignment between manholes or clean-outs. Clean-outs and manholes provide access to the sewers for inspection and maintenance. The sewers must also be ventilated to maintain free flowing condition. For uniform gradient sewers vent within the household plumbing are sufficient. If inflective gradient sewers are installed, the high points of the sewer should be ventilated either by locating the high points at connections or by installing a clean-out with a ventilated cap.

Liftstations are also necessary where elevation differences do not permit gravity flow along the sewer or from interceptor tanks to the sewer.

Since the effluent from the interceptor tank contains high concentration of organic matter, nutrients and micro-organisms, it should not be discharged without treatment to the surface drains, streams or lakes. It can be normally treated through subsurface soil absorption system or pond system. Figure 2 shows the major components of small bore sewer system.

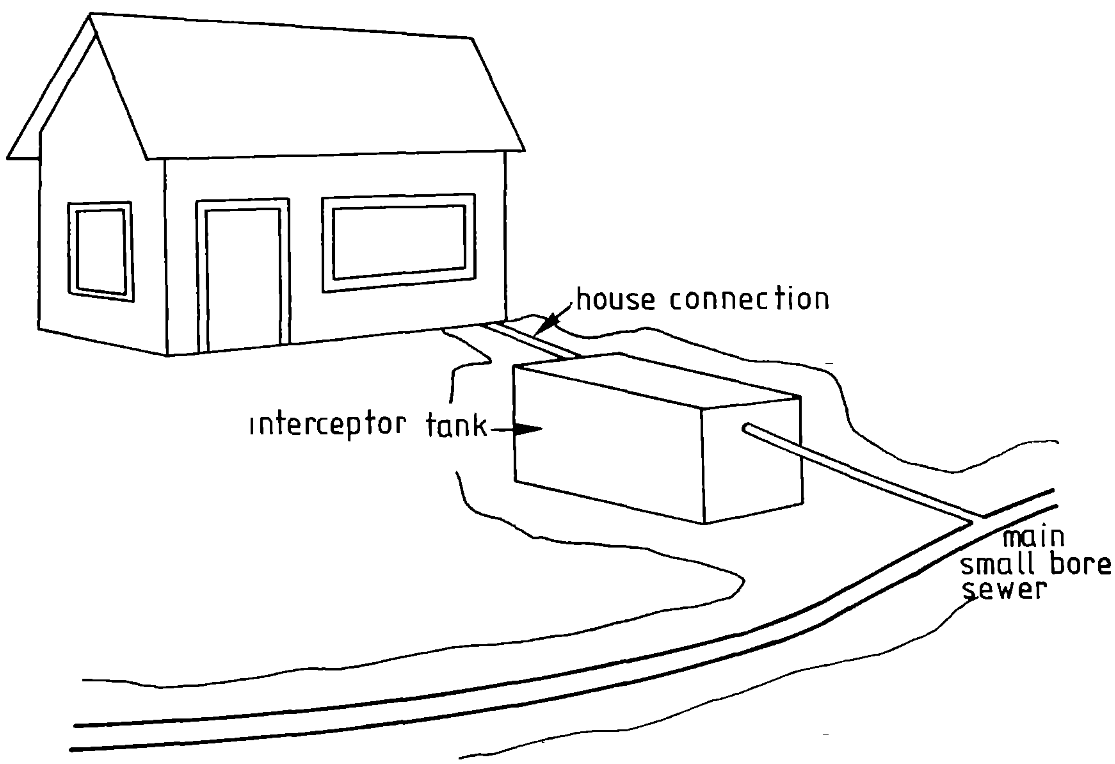

Figure 2. Components of a small bore sewer system (World Bank 1985).

3.3 Experiences of the System in Different Countries

3.3.1 Zambia

According to Otis and Mara (1985) the small bore sewer system was originated in the late 1950's in Zambia to remove settled waste water from failing aqua-privy tanks, to avoid surface seepage of waste waters. They were originally designed for a minimum daily peak velocity of 0.3 m/s for partially full flow and the pipes were 100 mm minimum bore and laid at a minimum gradient of 1 in 200. Since then the system has been developed in many parts of Zambia. In 1978 there were 532 one- or two bedroom houses served by the sewered aqua-privy system in the Chipanda low-income housing area, which was constructed in 1960.

3.3.2 Nigeria

In Nigeria the first sewer system was constructed in 1964 in Kwara state. This system serves 256 enclosed family group, each having 15 to 40 people. Each group is provided with a sanitation block comprising a laundry, shower room and an aqua-privy compartment. Otis and Mara (1985) reported that exposed connector pipes liable to damage and blockage of junction boxes due to negligence in regular desludging to be the major operational problems in the system. These problems had also been aggravated further by poor tank outlet design. Many outlets were broken permitting the escape of floating solids.

3.3.3 Australia

The small bore sewer system has been applied successfully since 1962 in southern Australia (Otis and Mara 1985). World Bank (1985) also reported that the state of southern Australia has the largest number of small bore sewer systems receiving septic tank effluent. By mid 1982 in southern Australia over 65 townships were served by small bore sewers. There were also plans for extensions and new schemes in different parts of Australia rising the total length of small bore sewer system to 750 km. The systems were designed at a minimum flow velocity of 0.46 m/s at half-fullpipe and average waste water flow of 136 lcd. Pipe diameters of 100, 150 and 200 mm were used (Otis and Mara 1985). World Bank (1985) also reported that the south Australian 20 years experience with small bore sewers has been excellent and systems installed in the early 1960's are working very well today.

3.3.4 U.S.A.

Otis and Mara (1985) reported that, in the United States the first small bore sewer system was constructed in 1975. It was a small research or demonstration system serving of self help-housing project for low-income families in Mt. Andrew Alabama. In 1977 another small bore sewer system was constructed in Westboro Wisconsin, a small rural community of approximately 200 persons. Field and laboratory experiments made in Mt. Andrew Alabama and Westboro Wisconsin showed that the small bore sewers have been performing well. The only regular maintenance has been pumping of the interceptor tanks. Observation of the sewers indicate that they rarely flow more than one-eight to one-quarter full. Solids accumulation in the sewers is primarily due to slime growth which commonly slough from the pipe wall (Otis and Mara 1985).

3.4 Technical Advantages and Disadvantages of the System

According to Otis and Mara (1985) collecting the settled domestic waste has the following principal advantages:

- Since the sewers are not required to carry solids, large quantities of water are not required for solid transportation. Therefore the system can be used reliably at places where domestic waste water consumption and where long flat runs with few connection are necessary.

- The sewers need not be designed to maintain a minimum flow velocity for self cleaning due to the removed settleable solids. Rather than being installed in a straight path with curvelinear alignment with a variable or inflective gradient, reducing excavation costs by following the natural topography more closely avoiding obstruction within its intended depth.

- The sewer and any pumping equipment are smaller in size as compared to the conventional sewerage system, because peak flows can be attentuated by the interceptor tank. Expensive manholes can also be replaced with less costly cleanouts or flushing points since mechanical cleaning equipment is not necessary to maintain the sewers in a free flowing condition. Treatment costs can be reduced since screening, grit removal and primary sedimentation are taken care of by the interceptor tank.

The disadvantages of the system are the continued need to maintain and pump the interceptor tanks and the special design problems relative to odour and corrosion inherent with interceptor tank (Kreissl 1984). Illegal connections may also create operational problems, since these connections are not likely to have interceptor tanks thereby introducing solids into a system, which is not designed to handle solids (Otis and Mara 1985).

3.5. Planning of the System

The planning of the waste water collection system may result both from sanitary conditions created by the lack of facilities or their poor conditions and from increase in population density that seriously threaten the health of the people and prevent sound social and economic development (Okun and Ponghis 1975).

On-site sanitation, which in most cases is believed to be less expensive than off-site sanitation may not be used due to a variety of factors such as population density and soil condition. Sewerage system therefore will be the best possible sanitation technology for serving these areas; because the users will be able to dispose of both exreta and household waste water with a negligible magnitude of health risk to the users as well as to the community. Water supply service levels also limits the use of on-site sanitation facilities. Pipes usually supply 20 to 25 liters per capita daily. When a yard tap is provided water use increases to 50 liters per capita daily, and when water is supplied through 50 to 100 liters per capita daily; which is about the limit for on-site disposal of sullage (Kalbermatten, et al 1980).

Otis (1986) reported that many unserved communities are facing severe financial hardships in providing proper waste water facilities for their citizens because of the high cost of conventional sewerage. The most costly components being the installation of the waste water collection system, which can represent as much as 90 % of the total capital cost of the facilities. Small bore sewers have been found practically suitable for communities where on-site disposal was practiced and could not be continued without modification because of inadequate infiltration beds and clogged soakage pits or increased sullage water has been the extent that on-site disposal is no longer possible. In such situations the septic tank effluent is best discharged into small bore sewers; this is almost always less expensive than abandoning the septic tanks and installing a conventional sewer network. According to Otis and Kreissl

(1983) cost comparison made between the conventional sewerage system and small bore sewer system at different project in the U.S.A. The small bore sewer system has been found more costly when the costs of interceptor tank replacement and service laterals were included. With the construction of new interceptor tanks and service laterals could not be cheaper than the conventional sewerage system (Kalbermatten et al 1980). On flat terrain it may be economically advatageous to install sewered septic tank systems (Kalbermatten et al 1980).

According to Otis and Mara (1985) the most economical application for small bore sewer system in developing countries is likely to be for the upgrading of areas where existing installations such as septic tanks or pour-flush latrines with leach pits are failing or are not functioning properly because of increased water use or urban expansion, rendering inadequate the area available for septic tank drain fields or on-site disposal of pour-flush effluents and sullage. In these circumstances, the septic tanks can be used as interceptor tanks to reduce the cost of installing the small bore sewers. Upgrading existing sanitation facilities in this matter is far more economical than constructing conventional sewers, not only because of the reduced construction costs but also because small bore sewers are not dependent on a good and reliable water supply to function properly.

3.6 Design of the System

3.6.1 Interceptor Tank Design

The primary purpose of the interceptor tank is to receive the raw household water and retain solids in order to provide a satisfactory effluent for disposal into the ground or by other means.

When the household waste water containing solids in suspension reaches a relatively quiescent state in the tank, those solids having a higher specific gravity than the liquid will tend to settle and those with a lower specific gravity will tend to rise. The tank provides for the separation, storage and digestion of suspended solids as well as for the growth, reproduction and death of a large number of anaerobic organisms (Seabloom et al 1984).

According to ENSIC (1982) to fulfill the above-mentioned conditions, the tank must be designed to provide the following conditions:

1. Liquid volume sufficient for a 24-hr fluid retention time.
2. Proper placement of inlet and outlet devices and adequate sludge and scum storage space to prevent the discharge of sludge or scum in the effluent.
3. Since the digestion process in anaerobic/direct ventilation is not necessary. However, provision should be made for the escape of the gases produced in the tank.

There are various formulas and standards to determine the effective capacity of the tank to fulfill the above mentioned conditions. Watt (1984) recommend the following general expression:

Tank design capacity (C) = capacity needed for sludge and scum storage between desludging (A) + capacity needed for sewage retention and settling in the supernatant layer just before desludging (B)

or C = A + B
= pnfs + prq

Where
C = tank capacity in litres
p = number of years between desludging
n = number of people using the system
f = factor relating rate of sludge digestion to temperature, given on Table 4
s = rate of sludge and scum accumulation in litres per year given on Table 5
r = minimum retention time required in tank for solids settlement, often taken to be 24 hours
q = sewage flow generated for each person using the tank (litres/person/day)

Table 4. Values of sizing factor "f" for stated desludging intervals and temperatures (ENSIC 1982).

Number of years between desludging	more than 20 ^oC throughout year	more than 10 ^oC throughout year	less than 10 ^oC during winter time
1	1.3	1.5	2.5
2	1.0	1.15	1.5
3	1.0	1.0	1.27
4	1.0	1.0	1.15
5	1.0	1.0	1.06
6 or more	1.0	1.0	1.0

Table 5. Rate of sludge accumulation 'S' in litres (ENSIC 1982).

Material used for anal cleansing	Water closet or latrine wastes only	Household sullage in addition to waste
Water, soft paper	25	40
Leaves, hard paper	40	55
Sand, stone, earth	55	70

The shape of the tank may be circular, rectangular or square. A rectangular shape for a single compartment tank is most favoured with a length three times its width, the depth being 1.22 m to 1.83 m (ENSIC 1982).

The design and location of inlet and outlet devices have considerable influence on tank operation. Inlet and outlet pipes must allow the tank influent and effluent to flow freely without becoming blocked by the developing scum layer or disturbing the settled sludge. According to World Bank (1985 a) recommendation, the inlet to the tank can be a sanitary T-fitting or an elbow with a diameter greater than 10 cm, its vertical leg extending 20 % of the liquid depth. ENSIC (1982) also recommended that the gradient of the inlet pipe should not be steeper than 1.5 % for the last 10 meters; the top limb should also rise 15 cm above the water level. The outlet of the tank can also be a sanitary T-fitting or a baffle placed in such a way that its vertical leg must extend to about 40 % of the liquid depth (World Bank 1985 a).

In addition to inlet and outlet arrangements manholes should also be properly provided to serve as means of inspecting the tank and emptying the settled sludge. The manhole should be airtight to prevent odour from escaping. Waterlines (1987) also recommends a slight slope on the bare of the tank to make desludging easier. Digestion of sludge and also to a lesser extend the scum, produce gases, and hence some form of ventilation is necessary for the tank. Figure 3 shows the components of interceptor tank.

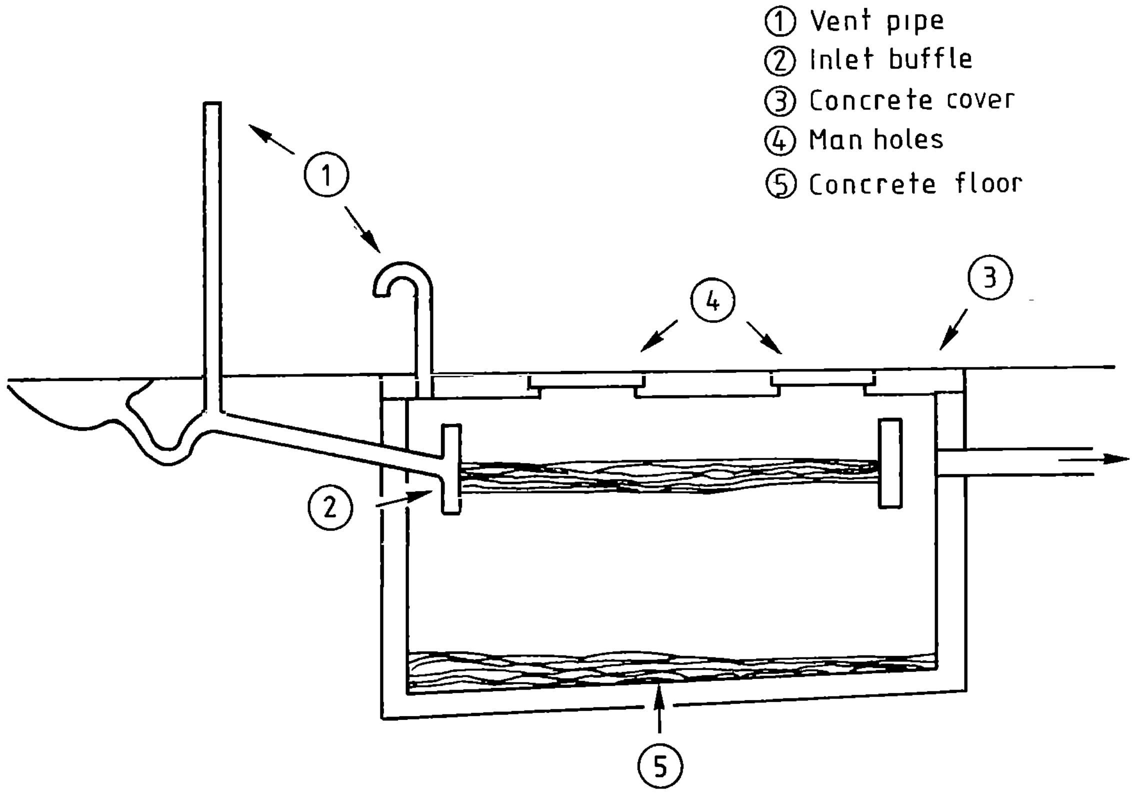

Figure 3. Arrangement of single compartment tank modified from Waterlines (1987).

3.6.2 Sewer design

As small bore sewer system is a method which carries clarified waste water from users to a selected outlet using the energy resulting from the difference in elevation of its upstream and downstream ends. The conduit must be set deep enough to receive flows from each user and it must have sufficient size and gradient to carry these flows. Therefore design decisions regarding its location, depth, size and gradient must be carefully made to hold hydraulic losses within the limits of available energy. When the difference in elevation are insufficient to permit gravity flow, energy must be added to the system by lift pump (Otis and Mara 1985). Simmons and Newman (1985) recommended the following procedures in the design of the sewers:

1. To plot the ground profile along the proposed sewer.
2. To note on the profile the anticipated discharge and elevation of the interceptor tank.
3. To make a careful estimation of maximum number of houses to be served by the proposed sewer.
4. To determine the design period of the system.
5. To calculate the flow rate to be expected in the sewer.

When designing the layout, the pipes can be laid to a rolling grade, following the slope of the land. Some sections can even have a negative or uphill gradient, provided that there is enough overall slope to carry the maximum flow. The waste water remaining in the dips when provided that there is enough overall slope to carry the maximum flow. The waste water remaining in the dips when there is no flow does not cause problem in the pipe, due to the absence of solids to settle out and block the pipe. The flow in the small bore sewer system can be partially full or under pressure. The only limit to the pressure head is that it must not rise above the interceptor tanks. If this occurs there would be a backflow of sewage into the tanks (World Bank 1985 b).

Some allowance also must be given for peakflow conditions in the system, even the interceptor tanks provide some attenuation. The peak flow factors are generally taken as 1.5 or 2 (World Bank 1985 b). Having decided on the design values for the number of people to be served and the amount of waste water each person will produce, the design flow for individual households and each part of the sewer network can be calculated by using the equation

$$Q = N \times q$$

Where
- Q = design flow, m3/s
- N = number of connections to the sewer
- q = design flow for each connection m3/connection/s

The detailed hydraulic design can be done by using Manning's equation

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Where
- V = velocity of flow, m/s
- n = pipe roughness coefficient
- R = hydraulic radius, m
- S = slope of the hydraulic grade line, m/m

When designing the system the following recommendation given by Kalbermatten et al (1980) are very helpful:

- A minimum velocity of 0.3 m/s may be used at peak daily flows for flushing mains until sufficient connections are made.
- A minimum diameter of 75 mm for connecting mains and interceptor tanks and 100 mm for mains can be used.
- A roughness coefficient n = 0.013 for vitrified clay pipe and n = 0.011 for PVC can be applied. Minimum grades for 75 mm and 100 mm diameter pipe may be taken as 1 in 150; whereas for 150 mm and 250 mm diameters grades of 1 in 250 and 1 in 300 respectively can be used. These grades should not be taken as standard values, even greater slopes can be used whereever possible.
- A minimum pipe cover on all pipes under roads or areas subjected to wheel loads should be 1 m above the collar of the pipe. In other situations a general minimum of 0.5 m may be taken depending on the nature of the

terrain. The Figure 4 shows a typical arrangement of sewer profile.

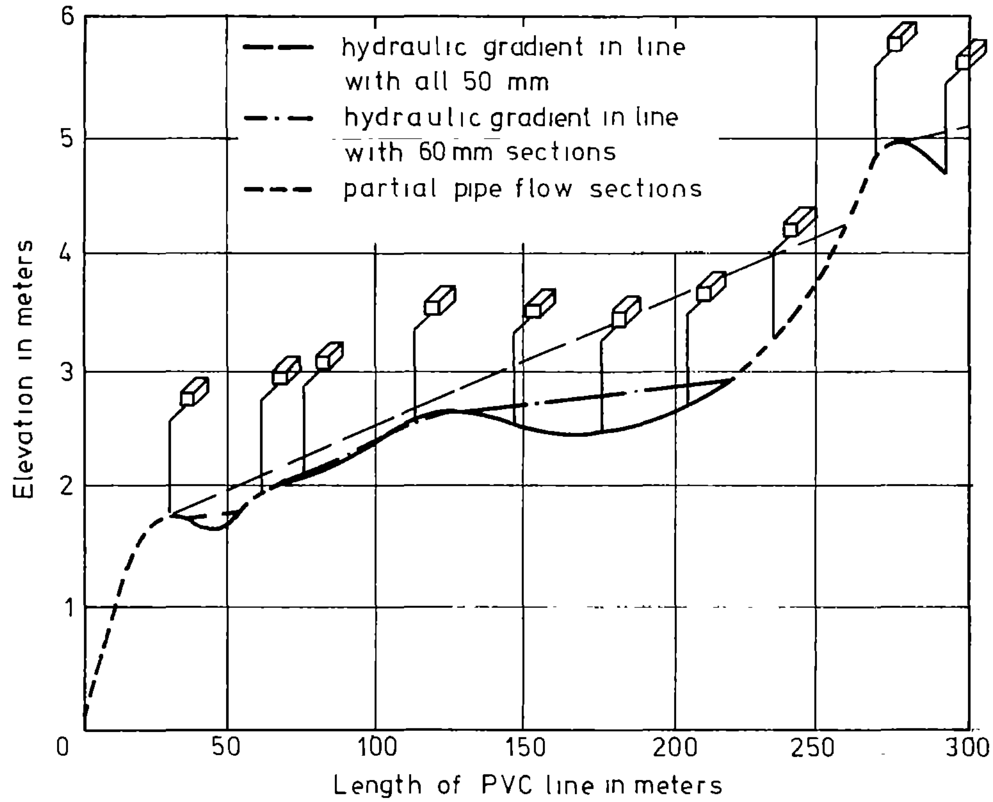

Figure 4. Sewer profile showing hydraulic cradient resulting from increased flow (Simmons et al 1982).

3.6.3 Sewer Appurtenances

A satisfactory performance can not be achieved in the sewer system without a proper consideration of its appurtenances, such as cleanouts, manholes, lift stations and ventilation. Cleanouts and manholes provide points access for cleaning and maintaining the sewers. Cleanouts or manholes should be located at all upstream terminals, intersection of sewer lines, major changes in direction, high points and at intervals of 150 m to 200 m in long flat sections (Otis and Mara 1985).

Lift stations are used to overcome adverse elevation conditions either at individual service connections or to raise collected waste water from one drainage basin to another. Lift stations at individual connections are simple in design with low-head, low-capacity corrosion resistant pumps to handle water rather than sewage. The major lift stations serving a drainage basin are conventional in design, except when large capacity solid handling pumps are necessary. Therefore small capacity pumps typically used for clean water can be used since large solids and debris do not enter to the sewers and peak flows are attenuated significantly. However because of the septic nature of the waste water in small bore sewers, corrosion and odours are major problems, therefore all equipment should be of non ferrous material to prevent the corrosion problem (Otis and Mara 1985). Ventilation is not necessary for satisfactory operation of the small bore sewers if the sewers are laid on a uniform negative slope. However, if positive slopes are allowed in some sections, portions of the pipe will remain full and gases may accumulate at the high point to create an air lock. To prevent this from occuring, the gases must be ventilated. A house connection or a cleanout at the high point could serve as a ventilation (Otis 1986).

3.7 Construction of the System

The interceptor tank may be constructed of reinforced concrete. It must be watertight to prevent infiltration which adds the volume of liquid the sewers must carry and reduces the solid retention capacity of the interceptor tank (Otis and Mara 1985). It must also be structurally durable and stable. The walls of the tank must be coated with bituminous after installation for water tightness. Other materials such as polyethylene and fiber glass also may be used for the construction of the tank. The most important installation is that the tank should be placed on a level grade and at a depth that provides adequate gravity flow from the home and matches the invert elevation of the house sewer. The tank should be placed on undesturbed soil so that settling does not occur. If the excavation is dug too deep, it should be backfilled to the proper elevation with sand to provide an adequate bedding for the tank. The tank should be placed in an area with easy access to avoid pumpout problems. Baffles, tees and elbows should also be made of durable and corrosion-proof materials. If existing septic tanks are used as interceptor tanks in the system, they should be carefully inspected for structural integrity, cracks, open joints and baffles (ENSIC 1982).

The most common material for small bore sewers is PVC which is durable, has a simple and leak proof jointing and is light and easy to lay (World Bank 1985 b). Since uniform gradients with straight alignments are not necessary the pipe can be assembled at the ground surface and laid in the excavation. Since the gases produced in small bore sewer system are very corrosive, all component parts should be made from corrosion resistant material. Odour may be a problem, where the waste water is agitated such as at lift stations, submerging the inlet has been found the best solution to overcome odour problems (Otis 1986).

3.8 Operation and Maintenance of the System

Operation and maintenance of the system must be performed on regular basis. It includes removal of sludge from each of the interceptor tanks and cleaning of the sewer mains. The interceptor tanks should be regularly inspected, usually once in a year and they should be emptied when necessary usually every 5 years. Desludging must be carried out if the scum layer is within 75 mm from the bottom of the outlet T-fitting or if the sludge layer is within 300 mm below the bottom of the inlet or outlet T-fitting. The interceptor tanks can be cleaned by pumping the contents to a tank mounted truck for hauling to a suitable disposal works (World Bank 1985 a). Any blockages to the sewer can usually be cleaned by a combination of rodding from the nearest cleanout or manhole and flushing. If this is unsuccessful, the blocked section of pipe can be broken into and flush out should be installed when the sewer is reinstated (World Bank 1985 b).

According to Otis and Mara (1985) routine flushing of the sewer mains has not been found necessary in any of the systems currently in use. However periodic hydraulic flushing is recommended to prevent blockage. This is usually sufficient to remove most solid accumulation. Flushing should begin at the upstream terminal end of the sewers, and each section between cleanouts or manholes should be flushed successively downstream. Each cleanout or manhole is flooded with water toa depth sufficient to create a flow velocity of at least 0.5 m/s in the section. Care must be taken not to surcharge the system excessively during the flushing because this creates sewage backups at individual connections.

3.9 Cost Aspects of the System

As reported by Otis and Kreissl (1983) small bore sewer systems have been a viable alternative to conventional gravity sewers in small communities. According to surveys in the U.S.A. they have performed reliably with little routine maintenance and in general have been less costly to construct. Estimated cost savings over conventional gravity range from 0 to 50 % with 20 to 30 % being typical. The most costly component of conventional sewage system is the collection system. Sewer construction accounts for 80 to 90 % of the total capital costs of the collection and treatment facility and more than 65 % of the total annual costs (Otis and Kreissl 1983). The cost of small bore sewer construction were found to be significantly less than the conventional sewers. In Australia savings of 25 to 35 % in the cost of construction have been reported, but this estimate does not include the construction costs of interceptor tanks, house connections and tank pumping. If the cost of pumping the interceptor tank is included the estimated operation and maintenance costs of small bore sewer systems were similar to the conventional sewer system (Otis 1986).

As stated by Kalbermatten et al (1980) the reduction in cost of small bore sewer system is possible because such a system requires small pipe diameter, because of minimum scouring velocities and less number of appurtenance. Since the hydraulic design is based on the hydraulic grade line rather than the pipe invert as in the case of conventional sewerage system, the construction costs can also be reduced significantly by avoiding horizontal and vertical controls. The horizontal and vertical controls may lead to deeper excavation.

4 MUNICIPAL WASTE WATER DISPOSAL PRACTICES IN ADDIS ABABA

4.1 General Features of the City

The city of Addis Ababa was founded 100 years ago. It is the capital, administrative and commercial centre of Ethiopia and the seat of many international agencies.

The city is located on a huge plateau near the geographic centre of Ethiopia. The present area of the city is approximately 218 km^2. The altitude of the city varies from 2 800 m in the north to 2 200 m in the south above sea level, ensuring quite favourable climatic conditions. The major portion of the city's topography is made up of hills, valleys, rivers and dry streams. Rain comes twice a year. Heavy tropical rain has been experienced from mid June to September. The second rainy season occurs from mid February through April. The remaining months of the year are practically free of rain. The average temperature is approximately 17 ^oC, the normal daily temperature varying between 28 ^oC and 5 ^oC.

According to Office of the Population Cencus (1984) the population in the city was found to be about 1.5 million. The population growth rate has been estimated to be 2.75 %. The growth rate is a combination of birth rate and immigration from the rural areas.

The city council of Addis Ababa is the highest administrative body of urban Dwellers association. It comprises of 25 kefetegnas (highers) consisting 284 kebeles within them. The kebele being the lowest level of urban Dwellers association in the city council.

As a general trend, in the southern part of the city new industries, warehouses and garages are expanding. East and westward residential buildings are developing. The city of Addis Ababa, as any other cities of the developing countries, is also the victim of economic, social and cultural problems, which impose an ever-increasing strain on the existing infrastructures. Among the sectors seriously affected is sanitation, especially the management of household waste water.

4.2 Estimation of Waste Water Quantity in Addis Ababa

In Addis Ababa it is hard to get detailed information or statistical data on the average amount of domestic waste water generated per capita per day. The individual waste water consumption is usually related to the specific water consumption. Therefore if documented studies and design practices are available for specific water consumption, one can estimate the amount of waste water per capita per day. Different consulting companies have studied the specific consumption of water in Addis Ababa.

B.C.E.O.M. (1980) studied and classified the water demand trend in Addis Ababa into three consumption groups:

- traditional housing units served by standpipes 10 lcd
- traditional housing units with yard connection 30 lcd
- modern housing units provided with sanitary facilities 80 lcd.

Addis Ababa Water Supply and Sewerage Authority improved these recommendations and adopted the following three traditional design values:

a) The first group consists of the city residents with lower income having traditional housing unit type with one or two rooms for a family and shared pit latrines for waste disposal between two or more families. This group is usually dependent on public taps and neighbourhood yard connection, the per capita water consumption being roughly from 20 to 30 l.

b) The second category comprises of city residents with a better income, having traditional housing type with two or more shared rooms between a family. This group is likely to have yard connection. The per capita consumption of water is as high as 50 l. They usually have one pit latrine for the family.

c) The third category consists of the higher income group with modern inhouse sanitary facilities. The per capita consumption of water is taken as high as 100 l. The waste water generated by this group is usually taken care by septic tanks or similar type of structures, but not water tight with leaching fields as the actual septic tank is. Very few houses from this group are also discharging their domestic waste water to the newly constructed sewerage system.

The reasons for these improvements are:

- the fast cultural changes towards the use of water because of mass education in the past 13 years
- the unchanged price of water for 40 years, increased the demand for water; water being cheapest thing as compared to the rest of service giving infrastructures
- increased production of water because of newly developed water supply projects.

From the above information one may arrive at an average specific consumption of water in Addis Ababa to be approximately 80 lcd. When detailed specific datas are lacking to estimate the unit water consumption in a given area this amount is taken as a design value.

The latest study made regarding the overall average per capita consumption of water in Addis Ababa for the coming 60 years is the one made by a Canadian Consulting Company AESL (1984). The results of the study shown in Table 6 may help to visualize the situation in Addis Ababa regarding the waste water disposal problems based on the water consumption figures as studied by the consulting company.

Table 6. Projected per capita demand modified from (AESL 1984).

Year	Average demand in lcd
1990	85
2000	110
2010	135
2030	185
2040	215
2050	240

The consulting company adopted a constant consumption growth of 2.6 liters per capita per year, expecting some social, cultural and economic improvements in the city.

The quantity of domestic waste water in Addis Ababa may be taken from 70 to 90 % of the specific water consumption. The other 10 to 30 % of the specific water consumption may be used for gardening and other related purposes, especially during the dry seasons.

4.3 Estimation of Waste Water Quality in Addis Ababa

Addis Ababa Water and Sewerage Authority has been responsible for the disposal and treatment of liquid waste since the 1970's. To fulfil these objectives efforts have been made to organize modern sanitary facilities and rehabilitate existing waste disposal systems. As a result of organizing a modern sanitary system the waste water laboratory has been established as part of the waste water treatment plant.

The laboratory is located at Kaliti Waste Water Treatment Plant and it is responsible for the collection and analysis of samples from the different stages of the sewerage system, such as from the treatment plant, primary and secondary sewer lines, night soil digestion tanks etc. It is also responsible for the routine follow up of waste water quality from the on-site disposal facilities in the city, such as pit latrines and septic tanks. Collection of samples for on-site disposal systems is usually carried out by taking the samples from vacuum trucks, which is transporting waste water from the different on-site facilities to the central treatment plant.

The quality of the waste water from the on-site disposal varies very much depending on whether the waste water is from pit latrines, septic tanks, public toilet facilities or a combination of two or more on-site disposal systems. Therefore one should be very careful to identify the source of the waste water from vacuum trucks, especially when studying specific characteristics of waste water from a given on-site disposal system.

In this particular situation emphases has been given to analyse the quality characteristics of the waste water from septic tanks. To fulfil this objective, 10 samples were collected and analysed for different parameters as shown in the Table 7.

Samples 1 to 4 were collected and analysed in the first week of September 1987. The other six samples 5 to 10 were collected and analysed from mid October to end of October 1987. This time variation was because of lack of manpower in September for sample collection and laboratory analysis.Laboratory procedures and method of analysis for each parameter were done according to Standard Methods for the Examination of Water and Waste Water.

The values shown in Table 7 should not be taken as the average waste water characteristics from septic tanks in Addis Ababa, because of the smaller number of samples as compared to the size of the city and the rough situations of the sanitary facilities in the city. In addition to these, the shorter duration of sampling and uneven distribution of samples within the whole city were not favourable conditions to get representative average values. The variation in quality characteristics as a result of time difference can be easily visualized by comparing the results of samples 1 to 4 with samples 5 to 10. Samples 1 to 4 were collected and analyzed in the rainy season (beginning of September) and therefore dilution of waste water was significant because of underground and surface infiltration. They affected the actual concentration of the different parameters especially the total suspended solids. Therefore, for the design of a waste water disposal system, regarding quality characteristics, it is advisable to run extensive laboratory test at different seasons of the year on different sites.

The results may help to compare the particular situation with the average theoretical domestic waste water characteristics. The waste water analysed in Addis Ababa is much stronger than the approximate strength of domestic waste water given on Table 2. The cause of a variation in strength may be taken as a result of the variation in specific conditions discussed in chapter 2 of this paper. Especially the higher values of total suspended solids, biological oxygen demand and chemical oxygen demand could be because of the type and amount of toilet paper and other external solid waste materials usually discharged into the tank directly through the manholes or house connection boxes.

Table 7. Quality characteristics of waste water from septic tanks in Addis Ababa.

Sample identification No	BOD_5 mg/l	COD mg/l	TSS mg/l	VS mg/l	Mineral matter mg/l	TN mg/l	TP mg/l	SO_4^{2-} mg/l	pH
1	150	785	400	280	120	280	5.6	24	7.5
2	250	1 020	465	280	185	365	6.2	25	7.6
3	245	900	415	300	115	310	5.7	25	7.4
4	320	1 035	515	375	140	345	6.3	27	7.5
5	190	635	890	640	250	105	17.5	30	7.8
6	280	1 515	1 265	885	380	140	15.2	1 125	4.5
7	230	1 535	1 400	950	450	165	82	16	7.5
8	515	1 985	1 430	1 045	385	135	65	10	6.8
9	240	1 435	1 280	965	315	165	75.5	23	7.8
10	355	2 255	1 530	935	595	200	125	0	7.5

The NO_3^-, NO_2^- and DO were also checked and found out to be nil.

4.4 On-site Waste Disposal Practices

4.4.1 Private Practices

According to a study made by American Consulting Company (P.A.S. 1982) 83 % of the city or one million urban residents in 1981 were dependent on exreta disposal without water carriage. According to statistical information in 1985/86 from Addis Ababa water and sewerage authority, 43.2 % of the housing units in Addis Ababa have pit latrine in common. The other 13.1 % have private dry pit latrine in their compound. 12.3 % of the housing units are provided with modern sanitary facilities and a septic tanks in their compound. The remaining 31.4 % of the housing units do not have any kind of exreta disposal system. They are more or less dependent on public toilet facilities, nearby bushes, small streams and ditches, and open fields for their exreta disposal. The Table 8 gives the detailed statistical information regarding the distribution of housing units with respect to on-site disposal practices.

Table 8. Distribution of housing by type of toilet facilities in Addis Ababa.

Zone	Flushed toilet private	Flushed toilet shared	Pit latrine private	Pit latrine shared	Without excreta disposal practices	Wore specified	Total
1	3 420	430	1 240	23 260	14 860	610	43 820
2	5 140	590	6 300	22 930	14 450	610	50 020
3	8 580	410	8 560	13 250	13 730	620	45 150
4	4 760	510	6 920	20 250	12 840	920	46 200
5	4 300	370	7 400	20 480	13 640	570	46 760
Addis Ababa Total	26 200	2 310	30 420	100 170	69 520	3 330	231 950
%	11.3	1	13.1	43.2	30	1.4	100

The above mentioned figures clearly show the wide application of private and shared pit latrines and the sanitation problems in Addis Ababa. There is no reliable information how and when traditionally the on-site waste disposal systems have been introduced and developed in the city. But it is believed that septic tanks and dry pit latrines have been taken as permanent and reliable disposal systems since the beginning of the 1940's. Despite their wide application, there has not been extensive studies regarding suitability of soil condition, depth of ground water table, extent of ground water pollution, adequacy of space with respect to the development of the city and their influence on social, cultural and economic aspects on the community.

Practically, there are no construction and design standards regarding the on-site disposal systems in Addis Ababa. Septic tanks constructed of reinforced concrete or any other watertight construction material are very rare. The walls of the tanks are usually constructed of stone without mortar or sometimes with very few mortar. The cover may be constructed of reinforced concrete or wood and cement mortar. Most of the septic tanks are rectangular with a volume of 8 m^3. Septic tanks of properly designed and constructed with drain fields are not common in Addis Ababa. During the dry seasons the liquid waste discharged to the tank usually percolates into the soil through the joints of the masonry wall. The following figure shows ventilated and unventilated pit latrines in Addis Ababa.

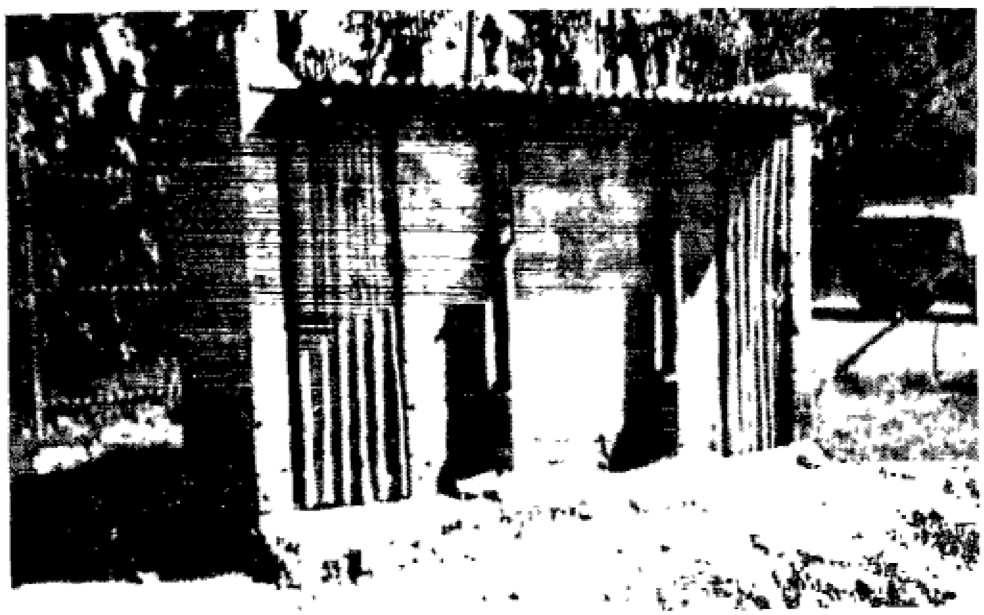

Figure 5. Typical ventilated and unventilated pit latrine in Addis Ababa.

4.4.2 Communal Practices

The city council of Addis Ababa is responsible for the construction, operation and maintenance of public toilet facilities. Efforts have been made by the city council to construct new toilet facilities in different parts of the city and to keep the old ones in good service level.

According to mutual information from the city council, there are about 59 public toilet facilities each of which serving approximately 50 to 60 people per hour. They are mostly located near places where people concentrate such as marketplaces, bus terminals, churches etc.

Some of the public toilets visited during the data collection period had wash basins for laundry purposes. During the visit, it had been also observed that some of the septic tanks of the toilets are filled with sludge, leaving no space for the supernatant water to accumulate for underground disposal. It is also difficult to know weather the leaching fields and outlet structures of some of the tanks were working properly. The public toilets located nearby small streams and rivers discharge the effluent directly in small streams and rivers. Due to shortage of water from the main supply line or failure in the plumbing system some of the visited toilets were not operational. The Figure 6 shows a public toilet facility in Addis Ababa.

Figure 6. One of the public toilet facilities in Addis Ababa.

4.5 Off-site Waste Water Disposal Practices

4.5.1 Conventional Sewerage Practices

The overall sanitary situation and the growth of capital in Addis Ababa brought the idea of conventional sewerage system as an alternate waste disposal system at the beginning of the 1970's. In 1972 a feasibility study report regarding conventional sanitary sewerage system was produced by a French Consulting Company (BCEOM). Because of the financial constraints and the poor construction of traditional housing units for modern sanitary facilities, the study had been limited to a population equivalent of 200 000, essentially to serve only the commercial or public buildings and few modern housing units.

The feasibility study has been later developed as design and construction project in two phases. The first phase of the project, its construction has already been completed, comprised of waste water treatment plant construction (stabilization pond) and some sewer line construction. The sewer line construction in this phase, known as Lideta and western interceptor was covering as far north as Jimma road and has a total length of approximately 50 km of pipe laying.

The treatment plant is located at about 18 km from the center of the city, a place called Kaliti. The treatment of the water born-sewage is carried out by recirculation in a series of oxidation ponds, proceeded by screens and grit chambers. In addition to the oxidation ponds, digestion tanks and drying beds have been constructed for night soil treatment from pit latrines and septic tanks. Figure 7 shows the Kaliti Waste Water Treatment Plant layout plan.

According to P.A.S. (1982) the initial design of the treatment plant was to serve only a population equivalent of 50 000 and produce an effluent of moderate quality with a filtered BOD_5 in the range of 50 - 90 mg/l and suspended solids less than 50 mg/l.

In the future the stabilization ponds will be converted to aerated lagoons, and then the plant will be adequate to provide the same degree of treatment for a population equivalent of 200 000. Population equivalent takes into account the effect of industrial wastes as well as domestic sewage. Physical and chemical analysis are made daily to determine the quality characteristics of the waste water at the different stages of the treatment process. Table 9 gives some impression on the treatment efficiency of the plant.

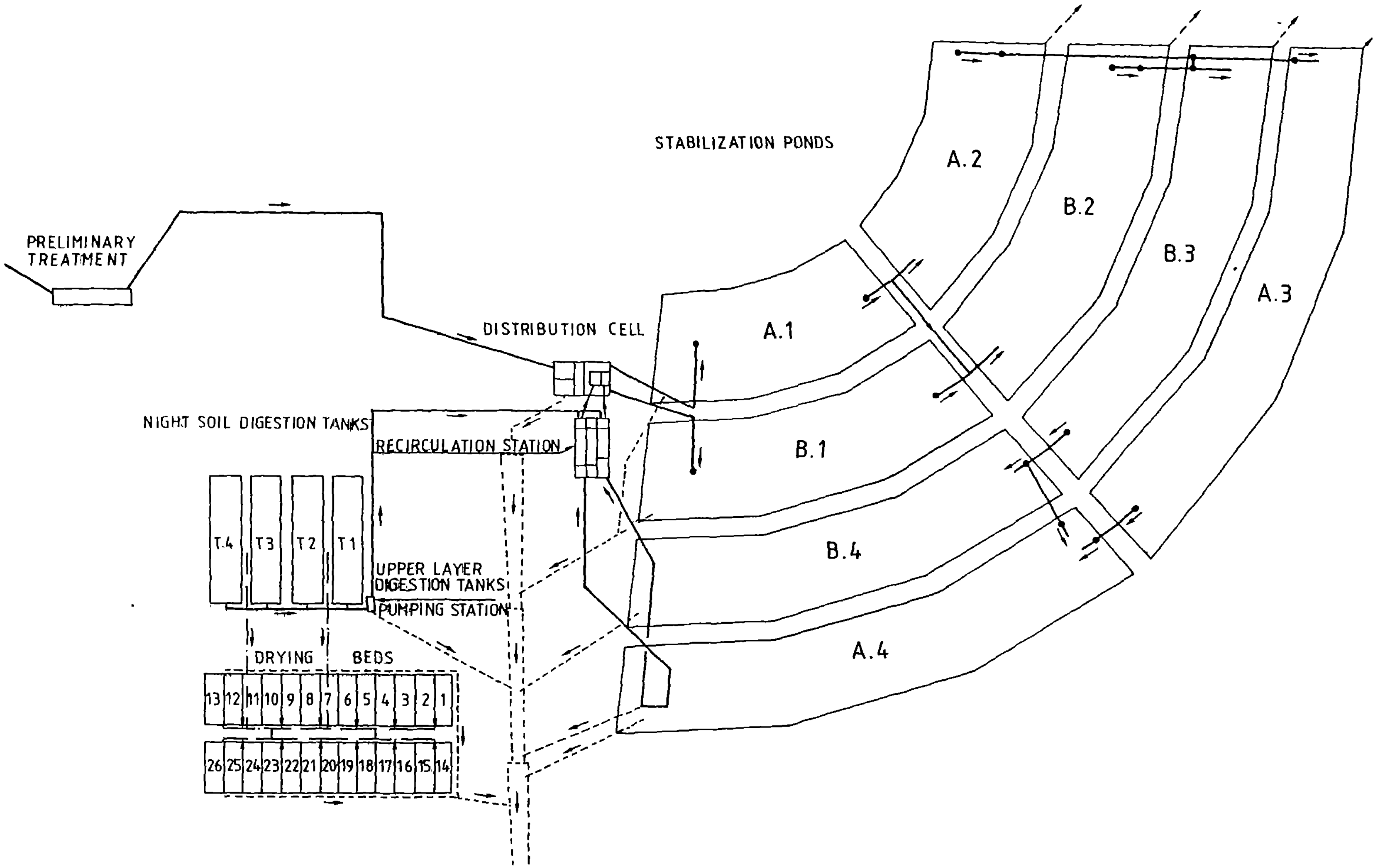

Figure 7. The Kaliti Waste Water Treatment Plant layout (Addis Ababa Water and Sewerage Authority).

Table 9. Average quality characteristics of waste water in August 1987 at different stages of treatment process at Kaliti Waste Water Treatment Plant.

	Influent			A1			A2			B1			B2		
Parameter	min	max	average	min	max	average	min	max	average	min	max	average	min	max	average
BOD_5	40	170	80	30	80	50	40	60	50	25	30	30	25	60	40
COD	85	310	145	115	560	280	110	185	155	95	170	135	120	205	160
TSS	160	410	520	150	870	410	150	240	200	155	200	175	110	325	200
NH_4^+	9.40	19.40	14.3	5.09	12.90	7.75	0.52	0.85	0.68	5.81	5.81	5.81	0.69	0.69	0.69
NO_3^-	0	0	0	7.92	8.8	8.44	3.52	4.4	4.12	3.52	12.32	7.81	2.20	4.40	3.23
NO_2^-	0	0	0	1.32	1.98	1.76	0.01	0.018	0.015	0.99	4.54	2.17	0.016	0.495	0.070
TP	2.6	3.5	3.05	4.5	4.8	4.6	2.0	3.2	2.43	3.10	3.50	3.27	2.2	3.2	2.83
DO	nil	nil	nil	3.4	6.2	4.8	10.1	17.2	13.65	3.8	6.2	5.0	17	21.9	19.45
pH	7.3	7.6	7.4	7.8	7.9	7.8	9.8	10	9.9	8.2	9.0	8.6	9.0	9.2	9.1

Table 9. Cont'd.

Parameter	A3 min	A3 max	A3 average	B3 min	B3 max	B3 average	A4 min	A4 max	A4 average	Filtered A4 min	Filtered A4 max	Filtered A4 average
BOD_5	30	50	40	20	50	30	40	50	60	5	30	15
COD	90	180	140	110	170	140	85	180	120	50	50	50
TSS	135	235	180	85	205	155	130	230	175	-	-	-
NH_4^+	0.21	0.67	0.45	-	-	-	0.26	0.45	0.32	0.25	0.26	0.26
NO_3^-	2.60	3.08	2.77	2.20	3.08	2.64	2.20	3.08	2.78	3.06	3.08	3.07
NO_2^-	0.01	0.02	0.008	0	0.015	0.0075	0.006	0.009	0.007	0.006	0.007	0.007
TP	1.90	2.00	1.97	2.40	3.00	2.70	1.80	2.20	2.00	2.00	2.20	2.10
DO	14.2	15.8	15.0	13.9	15.9	14.8	13.8	15	14.4	-	-	-
pH	10	10	10	10	10.4	10.2	10	10	10	10	10	10

The second phase of the project, whose construction is near completion, consists of sewer line construction (eastern interceptor) and misellaneous house connections. This phase has covered the construction of approximately 44 km of primary mains and 31.5 km of secondary lines. According to mutual information from Addis Ababa Water and Sewerage Authority 15 km of additional secondary line construction has been added to the contract later bringing up the total length of the secondary line to 46.5 km. In this phase the main line is extended to serve the ECA/UN complex, Hilton hotel and as far north as Art Kilo and Churchill avenue.

The sewerage system in general has not yet started functioning fully awaiting for the construction of private connections and waste water tarrifs.

According to P.A.S. (1982) the conventional sewerage system at its optimum capacity could serve only 1/6 (17 %) the total population of Addis Ababa. Based on the 1982 population estimate this percentage will decrease every year because of the annual population growth showing the magnitude of the sanitary problem in Addis Ababa. Therefore alternative solutions must be defined and developed to withstand this situation.

4.5.2 Vacuum Truck Collection Practices

Vacuum truck collection refers to the collection of liquid wastes (night soil) that are accumulated in private or public toilets and septic tanks. The Addis Ababa Water and Sewerage Authority and the city council have their own vacuum trucks to fulfil this objective. Addis Ababa Water and Sewerage Authority is responsible for the collection of wastes from shared or privatly owned pit latrines and septic tanks, whereas the city council is responsible for public toilets.

According to mutual information from Addis Ababa Water and Sewerage Authority, the present total number of vacuum trucks owned by both bodies is 25. The number of vacuum trucks on duty daily being less than 20 because of lack of spare parts . Each truck on duty makes 6 to 8 trips daily emptying 6 to 10 m^3 of liquid waste per trip. Each picking up is invoiced about 30 ETB (USD 14). The Figure 8 shows a vacuum truck collecting waste water from pit latrines.

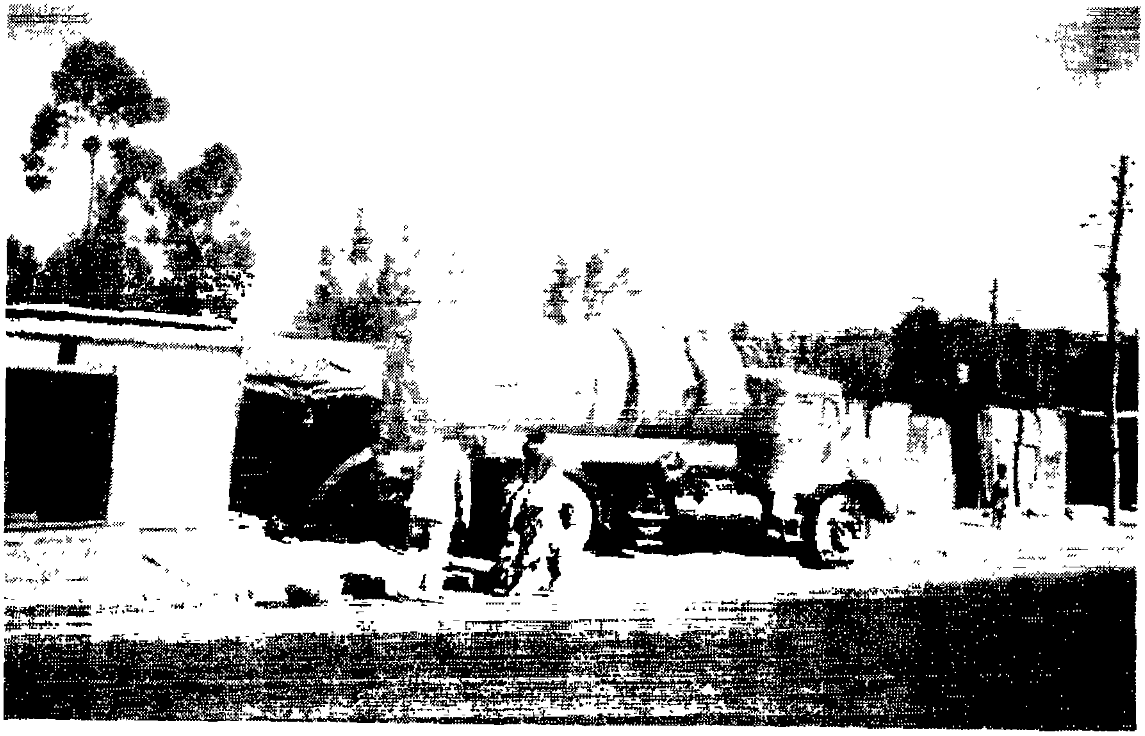

Figure 8. A vacuum truck picking up liquid waste in Addis Ababa at one of the pit latrines.

The liquid waste carried by these vacuum trucks is poured off at Kaliti Treatment Plant in a specially prepared night soil digestion tanks. According to a report on the first phase of the sewage treatment plant construction, the night soil digestion tanks have a capacity of treating 250 m^3 of night soil per day. Taking into account the average temperature in Addis Ababa (17^oC) and the partially digested nature of the night soil in the pit latrines and septic tanks, the digestion time of sludge was recommended to be 75 days. The overall efficiency of the digestion tank is still on experimentation. From the above information, it is obvious that all the collected liquid waste by vacuum trucks could not be handled by the digestion tanks. The liquid waste in excess of the digestion tank capacity poured off in ditch at the treatment plant compound. In the dry seasons, the liquid part of the poured sewage goes to a nearby stream by gravity and the solid part remains in the treatment plant compound. But the freshly poured sewage during the rainy season and the accumulated solid sewage during the dry seasons will be transported together to the same stream by the rain water. Figure 9 shows a vacuum truck discharging waste water in the Kaliti treatment plant compound.

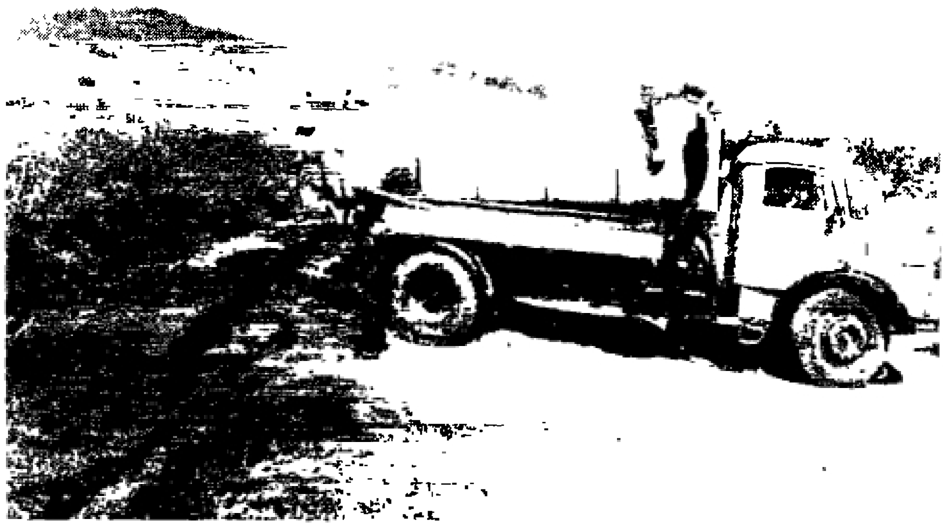

Figure 9. A vacuum truck pouring excess liquid waste in a ditch at the treatment plant compound.

The efficiency of vacuum truck liquid waste collection is always at a risk, because of inaccessible location of pit latrines and septic tanks, requiring careful and time consuming operation of the truck and the use of numerous length of suction pipes to reach the point. This is especially true in the central part of the city, where densily packed traditional housing units are dominant.

5 DESIGN EXAMPLE

5.1 Description of the Problem

The site had been selected during the data collection period from the beginning of September to the end of October. The selected site is found in the eastern part of the city at Kefetegna 17 Kebele 24. As shown on the layout plan Figure 10 only 65 houses are taken for the calculation of the design example. These are one of the many groups of houses constructed by housing cooperatives in Addis Ababa since 1975. The particular reasons for the selection of this site are:

1) The presence of a kind of septic tank for all the houses, which can be modified and used if required later for waste water disposal into small bore sewers.

2) The uniformity of houses and living condition regarding water consumption as well as waste water discharge.

3) The presence of in-house modern sanitary facilities for all the houses.

4) The suitability of the site with respect to terrain for the application of small bore sewer.

Even though the septic tanks found in the area have not been designed and constructed according to standard design formulas such as the one shown in Chapter 3.6.1, it is assumed that with a slight modification on the inlet and outlet structures, the tank will perform well both for the physical and biological treatment.

According to the estimation in Chapter 4.2, the average waste water consumption for this area could be taken as 70 lcd. This value does not take into account the fluctuation of waste water in the tank because of infiltration and percolation at different seasons of the year. There is also no reliable information as to the amount of fluctuation of waste water discharge by individuals through the day to assume a reasonable peak factor based on numerical data. But the assumption of a minimum peak factor of 1.5 as recommended by World Bank (1985 b) could help for the flushing of accumulated solid in the sewer.

Accumulation of solid in the sewer could occur because of the strong nature of the sewerage and the poor construction practices of the septic tank for efficient solid settlement. It could also help to take care of increased flow conditions in the sewer because of infiltration into the septic tank during the rainy seasons.

The design per capita consumption of waste water per day based on the above mentioned peaking factor will be 105 l. If the average number of people per household is taken as 5, the design waste water discharge per household will be 525 l/d (0.006 l/s). As shown on the layout plan Figure 10 septic tanks in this particular site are shared between 4 or 2 houses. The use of shared septic tanks instead of one septic tank for one house could have economic advantage as to the reduction of construction material.

5.2 Results and Procedures

The hydraulic calculation is made according to Manning's equation given in Chapter 3.6.2 and it is shown on the Table 10.

able 10. Hydraulic calculation for the design example (According to Manning equation).

1 tation umber	2 Station elevat m	3 Distance m	4 Difference in elevation over the section	5 Length of the ref. m	6 Average slope of section	7 Number of houses served in the section	8 Number of connection	9 Design flow l/s	10 Pipe diameter mm	11 Flow at full pipe l/s
1	2 340	0								
			3.0	86	0.035	11	3	0.066	50	1.77
2	2 337	86								
			4.5	118	0.038	25	7	0.150	50	1.17
3	2 332.5	204								
			2.2	58	0.038	27	8	0.162	50	1.17
6	2 330.3	262								
4	2 337.7									
		0								
			4.0	98	0.041	12	3	0.072	50	1.21
5	2 333.7	98								
			3.4	116	0.029	22	7	0.132	50	1.02
6	2 330.3	232								
			1.6	56	0.029	49	15	0.294	50	1.02
8	2 328.7	290								
7	2 330.7	0								
			2.0	84	0.023	16	4	0.096	50	0.287
8	2 328.7	84								

The following descriptions also help to understand the design procedures and arrangement of the tables.

The values in Columns 1, 2, 3, 5, 7 and 8 can be directly obtained from Figure 10.

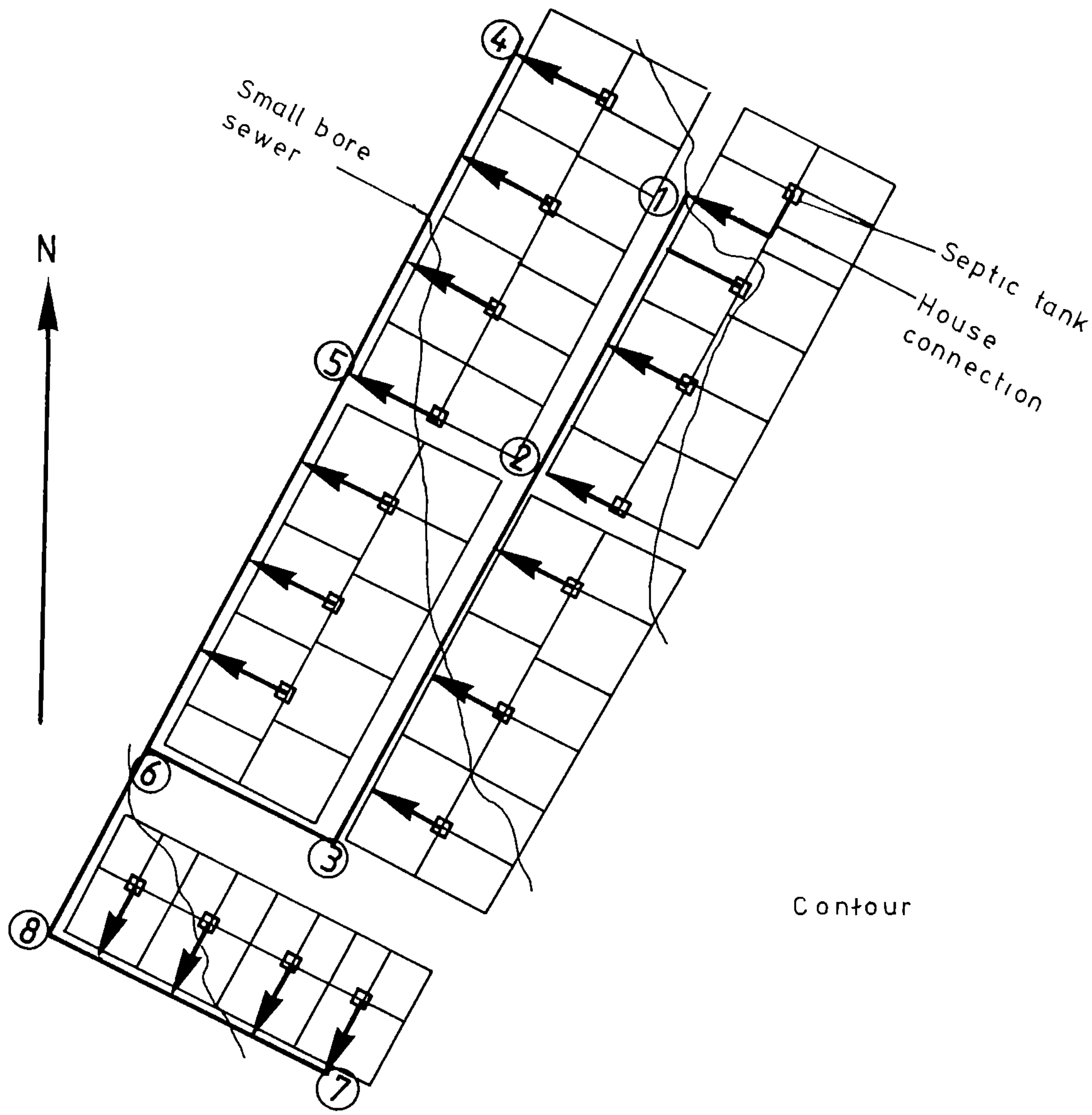

Figure 10. Site plan showing the arrangement of houses, septic tanks and proposed sewer line (Addis Ababa Masterplan Office 1986).

Elevation difference over the section given in Column 4 can be determined as the difference of elevation between adjacent stations.

The average slope of the section found out by dividing Column 4 by Column 5 is shown in Column 6.

Design flow, given in Column 9, is obtained by multiplying 0.006 l/s/household with the number of houses given in Column 7.

Column 10 represents the pipe diameter in millimetres computed by Manning's equation using values from Column 6, 9 with a roughness coefficient of 0.011 and approximated to the next largest commercially available pipe size. This is the minimum allowable pipe size in small bore sewer system.

Column 11 represents flow at full pipe flow condition computed by Manning's equations using values from Column 6, 10 and roughness coefficient of 0.011.

The full pipe flow condition (Column 11) is greater than the design flow (Column 9) in every section. This implies that there is no section excessively surcharged or there is no pipe to carry waste water flow under pressure during peak flow periods. This avoids backflow condition in any connection as far as all the outlets of the septic tanks are higher in elevation than the sewer network. But if the full pipe flow condition in anyone of the sections was less than the corresponding design flow, a larger pipe size could have been selected or the slope could have been changed till the full pipe flow condition in the given section is greater than the design flow.

5.3 Cost Calculation Utilizing the Existing On-site Facilities

The major capital cost items for the implementation of small bore sewer system are the material and labour costs of tank modification and pipe laying.

In this particular example, the major tank modification costs may be the construction and arrangement of inlet and outlet structures. Because the rehabilitation of the inlet and outlet structures at least guarantee the entrance of sewage without causing much disturbance to the sedimentation process and the outflow of only minimal concentration of settleable solids. Diameter 100 mm pvc sanitary T-fitting may be used for this purpose as recommended by ENSIC (1987) for both inlet and outlet pipes, so that the total number of the sanitary T-fitting required will be 84.

If 32 ETB/person as given by UPONOR (Feb 1988) is used as the bases for cost calculation, excluding transportation from the factory and material sales tax, the total cost of the sanitary T-fitting will be 2 688 ETB. If the cost of 50 mm diameter pvc pipe together with sockets and gaskets as given by UPONOR (Feb 1988) is 11 ETB/m, the total material cost excluding transportation and material sales tax for a total length of 616m pipe will be 6776ETB. Tank modification together with pipe material excluding transportation and material sales tax will be 9 464 ETB. If this is computed on the bases of cost per household it will come 145 ETB/household.

Addis Ababa Water and Sewerage Authority adopted a minimum diameter of 200 mm pvc pipe for the secondary mains in the conventional sewer system to receive waste water from individual housing units. If this minimum diameter adopted in the conventional sewer system and the 40 ETB/m price given by UPONOR (Feb 1988) for 200 mm diameter pvc pipe are used in the place of 50 mm diameter pvc pipe, the total cost of pipe excluding transport and material sales tax will be 24 794 ETB. This is 381.5 ETB/household.

From this discussion it can be seen how much the material costs for small bore sewer system is lower than the material costs of the conventional sewer system of existing on-site disposal facilities. It is also obvious that, the construction, transportation and material sales tax for the conventional sewer system will be higher than the small bore sewer system; because these cost items are directly proportional to the size of the pipe.

5.4 Cost Calculation for Small Bore Sewer System as a New Scheme

One of the major cost savings in small bore sewer system is the utilization of existing on-site water carriage disposal facilities. If there are no water carriage on-site disposal facilities or if they are in poor condition to serve for the purpose, it is necessary to include the construction cost of septic tanks (interceptor tanks).

In this particular example, as it has been discussed earlier all the houses are provided with septic tanks, but assumption is made as if there are no on-site disposal facilities to be modified requiring the construction of new interceptor tanks. The existing location of the tank shown on the layout plan serving 4 or 2 houses at a time is taken as the location of the new septic tanks serving the same number of houses.

6 APPLICATION OF SMALL BORE SEWER SYSTEM TO BIGGER CITIES

6.1 Experiences in the Application

The experiences in the application of small bore sewer system is limited to small rural communities and townships in the United States, Australia, Zambia and Nigeria. It has been considered as an affordable and alternate off-site waste water disposal technology since the beginning of 1970's for rural communities having 400 to 4000 people (World Bank 1985 b).

The favourable condition for its application in all the above mentioned countries has been the presence of failing on-site, water-carriage waste water disposal facilities. As it has been stated by Otis and Kreissl (1983), the costs of conventional sewer system has been unaffordable by small rural communities in the United States to replace failing on-site waste water disposal system.

The use of existing septic tanks with a slight maintenance and modification for solid settlement and small diameter PVC pipes for effluent transportation results capital cost savings over the conventional sewer system.

The application of the system to smaller rural communities in the developing countries has no practical meaning at the moment, because most of the rural communities do not have even dry pit latrines let alone water carriage on-site disposal systems. Its application as a new scheme in the rural communities of the developing countries is also limited due to the lack of financial resources and the low level of the per capita water consumption to have a water carriage disposal system.

According to Otis and Mara (1985), the system could be applied in urban areas of the developing countries if the existing on-site disposal systems are in favourable condition for the application of the system.

In some of the developing countries the experiences of on-site water carriage disposal systems as the only alternative have been limited due to the higher construction costs of such a system and scarcity of water. Therefore careful observation should be made for a given town or city regarding the type, homogenity and the conveniency of small bore sewer system. When there is no homogeneity in the type of on-site disposal systems for a given city like Addis Ababa, it will be helpful to divide the city into small sections or zones depending on similarities in existing on-site disposal facilities and topographical conditions. Sections having the right type of on-site waste water disposal facilities can be further studied independently regarding the conditions of the on-site disposal facilities and the economic benefits over the conventional sewer system.

The design example shown in Chapter 5 shows the possible technical applicability of the system in some parts of the city. The cost effectiveness and service reliability of such a system if applied at wider scale in the city of Addis Ababa could not be determined with in such a short study period based on individual efforts. It needs quite a lot of time and manpower with different professional discipline for technical and economic analysis.

The following chapter discusses the general situation for the applicability of the system by dividing the city into sections such as northern, central, eastern and western sections. Each section within the boundary has common characteristics with respect to on-site disposal facilities, topographical conditions and unit water consumption.

6.2 Applicability of Small Bore Sewer System to Addis Ababa

6.2.1 Northern Section

The northern section takes into account 7 Kefetegnas (higher) namely Kefetegna 9, 10, 11, 12, 13, 14 and partly 8, all having roughly similar topographic situation and waste water disposal facilities. According to population census in 1984 there are about 295 000 people in this part of the city. The major part of this section is utilized for residential buildings. There are only few industrial and commercial activities as compared to the other sections. Most of the houses in this area are old and traditional type. Expansion towards the north is limited because of the Entoto mountain range. New house construction is becoming limited due to scarcity of open space. Since this area is at a higher altitude as compared to the source of the city's water supply and main distribution reservoirs, scarcity of water is more pronounced here than in any of the other sections. This is because of failures of pumps and electricity to take the water up to the hillside for gravity distribution. There are some springs owned by Addis Ababa Water Supply and Sewerage Authority and some hand dug wells owned by individuals to assist the main water supply system.

The ragged and steep slope nature of the terrain in this section has created a very big elevation variation between the location of individual houses as well as on their on-site disposal facilities. This may affect the expected gravity flow conditions from almost all the individual on-site disposal facilities to a sewer system and limit the flexibility of economical pipe laying. Therefore economic design and construction of sewers will be at risk, limiting the optimum horizontal and vertical flexibility of pipe laying, which is one of the basic principles of small bore sewer system for cost saving.

The other basic problem to the application of small bore sewer system in the northern section is the type and condition of the existing on-site disposal facilities. Most of the on-site disposal facilities in this part of the city are dry pit latrines. They are constructed of masonry wall below ground level. In some places, especially during the rainy seasons due to infiltration of ground water, the waste water from the tank flows over on the ground surfaces and causes the attention of desludging the pit latrine before it is utilized to its maximum capacity. The number of septic tanks in this part of the city is not more than 4 % from the total number of septic tanks shown on Table 8 Chapter 4. They are not also concentrated in one area within the section to handle them together. The septic tanks are also constructed from similar materials in a similar way as the pit latrines. The only difference between the septic tanks and pit latrines is that the septic tanks are connected to the internal sanitary system to take care of the sullage.

Ground water infiltration during the rainy season causes similar problem as in the case of dry pit latrines. During the dry season tanks are almost free from the supernatant liquid.

The small number of septic tanks and their scattered distribution within the section together with the ragged nature of the terrain limit the application of small bore sewer system in this part of the city.

6.2.2 Central Section

The central section of the city consist of 11 Kefetegna urban Dweller associations namely Kefetegna 1, 2, 3, 4, 5, 6, 7, 15, 21, 22 and partly Kefetegna 8, having roughly similar topographic conditions and on-site disposal facilities. Most of the commercial and business activities in Addis Ababa belong to this part of the city. The construction of new residential buildings is very limited because of lack of open space. Most of the existing residential buildings are old and densly packed traditional type. According to population census in 1984, there are about 463 000 people in this section. A study conducted by P.A.S. (1980) on one sample area with in this periphery showed that the population density per hectar to be 645. This study also reported that the need for water and sanitation is very high in this part of city. There are only a small percentage of private water taps and about 70 % the residents are dependent on neighborhood taps. The per capita water consumption is also reported to be as low as 21 l.

The central section also has almost similar topographical situation as the northern section resulting in a significant elevation differences between the location of houses. Further subdivision into smallest section could reduce the elevation variation between the houses with a reasonable areal coverage resulting gentle slopes within the smaller divisions. The application of small bore sewer system regarding topographical situation could be possible in some of the smaller divisions.

The dry pit latrines are the overwhelming excreta disposal in this part of the city. Sullage is usually discharged into nearby ditches and open fields. The highest part of the pollution load in the small rivers and streams may be contributed by the central section. The major operational problems in desludging is encountered in this part of the city because of inaccessible location of pit latrines and clogging of suction pipes by solid materials thrown into the pit latrine. Outflowing pit latrines even during the dry season is very common because of the inaccessibility of the pit latrines and the inadequate number of vacuum trucks for desludging. Practically there is no open space for the construction of new pit latrines to replace the old ones. The application of small bore sewer system as to the existing on-site disposal facilities and lower per capita consumption of water is practically impossible.

6.2.3 Eastern, Western and Southern Section

The eastern, western and southern sections all together include 8 Kefetegna urban Dweller associations namely 16, 17, 18, 19, 20, 23, 24 and 25. According to population statistics (1984) there are about 406 000 people in all these sections. They are less densly populated than the northern and central sections. All these Kefetegnas are also represented by similar topographic condition and waste water disposal facilities. They are newly developed residential areas, with modern villas and apartments, built by individuals, housing co-operative and the Ministry of Urban Development and Housing. Most of the city's industries, garages and warehouses are found in the southern section especially in Kefetegna 19 and 20. These sections have got the highest expansion rate towards the east, west and south since 1975. The future expansion of the whole city is also dependent on these sections due to the convenient topographical situation for house construction.

Generally they have got a gently sloping terrain towards the south. Most of the houses in these sections have got a kind of septic tank constructed of masonry wall without mortar below ground level. Covers are constructed of reinforced concrete. The wall of the tanks is not usually constructed to be water tight and has no leaching field being contrary to the actual septic tank discussed in Chapter 3 of this paper. But the impervious nature of the black cotton soil, which is the dominant soil type in these sections could provide a natural water tightness to a certain extent. Because of lack of leaching fields and the impervious nature of the soil, percolation of waste water into the ground is very minimal. As a result of these phenomenon overflow of waste water on the ground occurs especially during the rainy seasons.

The use of septic tanks as permanent on-site disposal system for this part of the city could be limited in the near future because of the impervious nature of the soil. The conventional sewer system which is under construction in some parts of these sections could cover only a very few portion of the sections. Therefore the application of small bore sewer system utilizing the existing on-site disposal facilities could be technically justifiable in these sections.

7 CONCLUSION

Small bore sewer system is a relatively new sanitary technology, whose principle of operation and cost effectiveness over the conventional sewer system have not yet been known by many countries.

Small bore sewer system is particularly suitable, where water carriage on-site disposal system has been practiced, but cannot be continued without modification, maybe because of inadequate infiltration beds and clogged soakage pits or increased sullage water to the extent that the on-site disposal is no longer possible.

If existing on-site systems are utilized for solid settlement, small bore sewer system has economic savings of 20 % to 30 % on capital cost over the conventional sewer system. This is because of less material and labour requirements to install small bore sewer than the conventional sewer system.

The technical applicability of small bore sewer system in Addis Ababa is appreciable in the less densely populated areas, where overflow of waste water from septic tanks is a problem due to the poor construction practices of septic tanks and the impervious nature of the soil for the leaching of septic tank effluent.

The technical applicability of small bore sewer system in the densely populated areas of Addis Ababa could be very limited due to lack of water carriage on-site disposal systems and the smaller amount of specific water consumption (about 21 lcd) for off-site waste water disposal which must be at least 50 lcd.

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