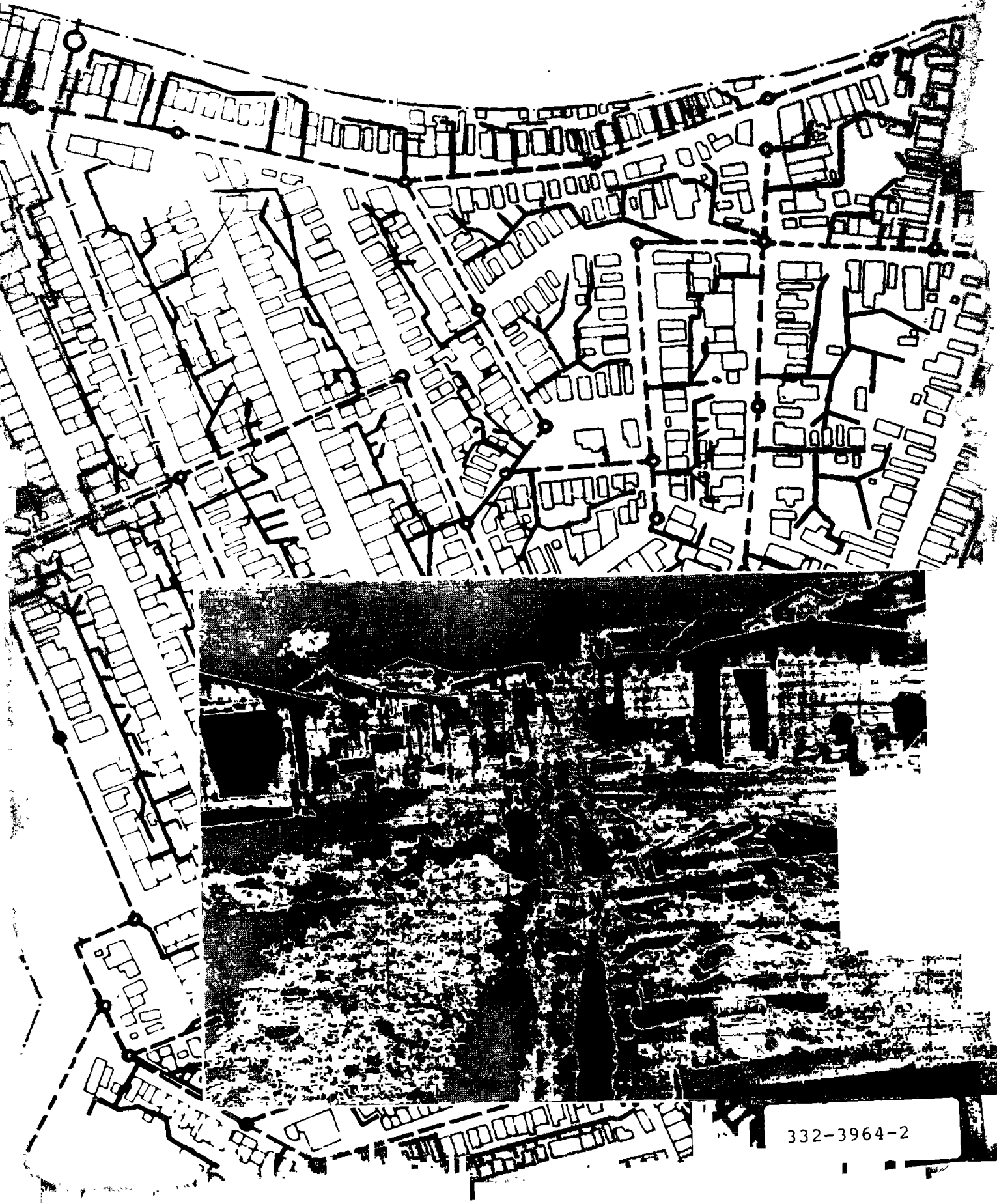




**UNCHS
HABITAT**

THE DESIGN OF SHALLOW SEWER SYSTEMS



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THE DESIGN OF SHALLOW SEWER SYSTEMS

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FOREWORD

The importance of providing safe and adequate water supply and sanitation has gained increasing international attention over the last two decades. The concern of national and international organizations with the gross shortfall in the delivery of basic services, especially to the low-income urban and rural poor, was expressed at Habitat: United Nations Conference on Human Settlements, held at Vancouver, Canada, in 1976. Subsequently, the United Nations Water Conference, held at Mar del Plata, Argentina, in 1977, recommended that the period 1981-1990 be designated International Drinking Water Supply and Sanitation Decade. The Decade was launched by the General Assembly on 10 November 1980 at a one-day special meeting during its thirty-fifth session. In its resolution 35/18 of 10 November 1980, the General Assembly stated that during the Decade, Member States would assume a commitment to bring about a substantial improvement in the standards and levels of services in drinking water supply and sanitation by the year 1990. The United Nations Centre for Human Settlements (Habitat) is actively collaborating with other United Nations agencies in assisting national governments to achieve the objectives of the decade. UNCHS (Habitat) was directed by the Commission on Human Settlements, in its resolution 4/16 of 6 May 1986, to embark on a work programme to assist developing countries in the provision of adequate infrastructure in low-income communities. The work programme defines a role for UNCHS (Habitat) which would complement the activities of other United Nations agencies and take advantage of the particular strengths of UNCHS (Habitat) in information transfer, training and demonstration projects.

The effects and initiatives of many international agencies, in particular the World Bank, has led to the identification of a number of technologies for sanitation which are less costly than waterborne sewerage, yet able to provide the same health benefits and be both socially and environmentally acceptable to the users. A majority of these technologies rely on the on-site disposal of human wastes. Space for such disposal facilities is usually available in rural and low-density to middle-density urban areas. Their use in high-density urban areas, which are being increasingly supplied with water-distribution services, is limited. Unfortunately, the bulk of slum and squatter-settlement housing in the cities of developing countries is high-density and very few options are available for providing low-cost waste disposal facilities to these communities. Recently, however, the shallow sewer system of sanitation has emerged as a result of adapting design standards to suit the physical conditions of a majority of these low-income settlements and taking advantage of advances in knowledge on the mode of operation of sewer systems.

This technical manual sets out criteria, standards and procedures for designing and constructing shallow sewer systems. They are compared with other sanitation technologies, and the conditions under which they are considered to be particularly advantageous to low-income communities are established. Strategies for implementing shallow sewer systems, so as to promote the technology and provide a basis for comparing the cost of different sanitation technologies, are presented, together with methods of determining community affordability. Case studies of successfully implemented shallow sewer systems, including one executed by UNCHS (Habitat), are also considered. Finally, the manual presents a shallow sewer design example.

The manual is specifically designed to demonstrate technology that lends itself to application in low-income settlements and presents some novel approaches and institutional changes which have yielded positive results in the continued bid to narrow the deficit in the provision of urban services to poor communities. For these reasons, the manual has a special significance for the efforts of the International Year of Shelter for the Homeless (IYSH) which, amongst its various objectives, seeks to provide basic services to deprived communities. The programme, scheduled for 1987, recognizes the importance of the role that basic infrastructure can play in assisting the millions of poor all over the world to build and improve their shelter and neighbourhoods and, by so doing, to integrate them in the process of economic development.

Arcot Ramachandran

Dr. Arcot Ramachandran
Under-Secretary-General
Executive Director

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INTRODUCTION

A. Background

The Commission on Human Settlements at its fourth session in 1981 requested the United Nations Centre for Human Settlements (Habitat) to implement the following activities for the provision of infrastructure in slums and squatter-settlement areas and in rural settlements:

(a) To continue the Centre's work on research and development in the field of human settlements infrastructure;

(b) To co-operate with other United Nations agencies and thereby make a significant contribution to the International Drinking Water Supply and Sanitation Decade;

(c) To execute demonstration projects integrating the provision of infrastructure with other aspects of community development;

(d) To promote the development, and the evaluation of appropriate materials, equipment, techniques, standards and training manuals related to the provision of infrastructure affordable for low-income groups, with special emphasis on alternative sanitation solutions;

(e) To communicate the experience acquired to developing countries and to make use of the Centre's considerable expertise in the collection and transfer of information and in the provision of training assistance.

UNCHS (Habitat) has, since 1981, been engaged in executing the above mandate. Through reports, such as the present document, it communicates the experience gained through these activities. This document presents an example of its work in identifying and promoting an innovative sanitation technology especially suited to the requirements of high-density, low-income settlements in developing countries.

B. The problem of sanitation as it relates to human settlements in developing regions

In 1983, the World Health Organization ^{1/} estimated that, of the 2,552 million people who live in the four developing regions of Africa, Asia and the Pacific (excluding China), Latin America and Western Asia, less than a third had access to adequate sanitation. Urban areas are usually better endowed with sanitation than rural areas. An estimated 59 per cent of the total urban population in developing countries has adequate sanitation services while only 12 per cent of the rural people are so served. Where deficiencies have occurred in urban areas, these have traditionally been in low-income communities. Approximately 60 per cent of the population of Latin America is now urbanized, yet urban growth rates are expected to remain high until the end of the century. Slums and squatter settlements which house a majority of low-income urban people, form 30 per cent of Rio de Janeiro, 50 per cent of Recife, 60 per cent of Bogota, 72 per cent of Santo Domingo and 46 per cent of Mexico City. Sanitation coverage in these deprived urban areas is often no better than in the rural areas.

With only about a quarter of Africa's population living in urban areas, the continent is now experiencing the highest urban growth rate in the world - some 5 per cent per annum. Slums and squatter settlements accommodate 90 per cent of the population of Addis Ababa, 61 per cent of Accra, 33 per cent of Nairobi and 50 per cent of Monrovia.

East Asia, now nearly 30 per cent urbanized, can expect an urban growth rate of 3.7 per cent per annum in the present decade. South Asia, with more than three quarters of its population still in rural areas, has yet to experience the peak of its urban growth which is expected to be around 4.3 per cent annually during the next 15 years. Slums and squatter settlements account for 29 per cent of Seoul, 31 per cent of Pusan, 67 per cent of Calcutta, 45 per cent of Bombay, 40 per cent of Karachi and 60 per cent of Ankara. 2/

Within each of these regions, there are countries that experience annual urban growth rates of more than 6 per cent. If such growth continues a doubling of urban populations every 12 years or sooner will be experienced. Although urban areas are growing very quickly in nearly all developing countries, the slums and squatter settlements, which will accommodate the greatest proportion of the additional population are growing even faster. Estimates range from 6 to 12 per cent annually. Effective and affordable means of providing sanitation to these areas require urgent consideration.

In most developing regions of the world, rural people traditionally use the field or the bush for defecation. Rural settlements especially scattered communities, do not have the aesthetic incentive to demand sanitation and rely instead on the natural assimilative capacity of the surrounding countryside to serve their needs. While this practice is not recommended from the viewpoint of public health, it has less serious implications in these rural areas than in urban areas where large numbers of people are settled in a small space. Inadequate disposal of excreta is perhaps the single most important factor in the transmission of serious diseases causing both disability and death in these areas. It is in urban slums and squatter settlements that the lack of sanitation coupled with very high population densities, poses the severest problems of intra-community contamination and disease.

Urban slums are usually old, well established areas located near the centres of large cities, although recently, slum areas can also be found on the urban periphery where settlements have been developed for low-income workers. Slums are characterized by very high population densities: for example, in Delhi the average density of population for the old sections of the city is between 988 and 1480 persons per hectare; and in Casablanca, Morocco, the average density of slum areas is 770 persons per hectare as opposed to 70 persons per hectare in high-income residential areas. Over 20 developing countries have urban areas where the population density exceeds 700 persons per hectare. Slum properties are usually served by municipal utility networks. However, because of the age of many slums and the problem of overcrowding, these services are usually totally inadequate and deteriorating rapidly.

Squatter settlements, usually grow on sites unsuitable for conventional development, as a result of the great pressure to house low-income groups. Unlike slums, they are not legitimate settlements, and the occupants do not have title to the land on which they have

built their houses. Population densities in these settlements show wide variations between sparsely built peripheral settlements, with densities around 20 persons per hectare, to urban types of shantytowns exceeding 2,000 persons per hectare. The standard of squatter-settlement housing is much lower than that of slums, services are rarely available and opportunities for connecting into municipal utility networks are poor. Sanitation in squatter settlements, where it exists at all, is generally very primitive.

One of the fundamental problems in increasing sanitation coverage in urban areas is the high cost of conventional sanitation services. General estimates based on 1978 prices indicate that \$300 billion to \$600 billion would be needed to provide sewerage in a conventional manner to all urban settlements. Even assuming that sewerage is only provided to an average of 60 per cent of the urban population and that medium-cost and low-cost sanitation systems are provided to the remaining populations in equal proportions, an estimated total investment cost of \$218 billion would still be necessary to achieve blanket coverage in urban sanitation by the year 2000. Since the annual level of investment required to achieve such coverage in most developing countries is somewhere between 3 and 6 per cent of the gross domestic product of those countries, governments wishing to address the problem of sanitation would have to forgo opportunities to invest in other unsatisfied basic needs, such as food, housing, health and education, and in the industrial, energy and transport sectors. Few countries are likely to make this priority decision. One of the most effective means of overcoming this problem is to reduce the cost of providing sanitation, while maintaining, if possible, the convenience offered by conventional sewerage.

In a bid to address the problem, a study undertaken by the World Bank ^{3/} identified over 20 different sanitation technologies. Unfortunately, however, most of the technologies, while having the capacity to provide a comprehensive solution to sanitation in both rural and low-density to medium-density urban areas, are inappropriate in areas where the density of settlement is high, incomes are low and the need for wastewater disposal is most urgent. The principal reason for this is that a majority of low-cost technologies are on-site systems, such as the ventilated improved pit latrine and pour-flush toilet, which dispose of excreta but cannot cope with wastewater. Unfortunately, the soil has limited capacity to absorb this wastewater as population densities increase, crowded housing conditions worsen, and water use rises. Therefore, the problem of excess wastewater intensifies. Past efforts to build open drains for wastewater drainage have mainly been unsuccessful because, besides being expensive, they rapidly become clogged with sand and blocked with refuse. Moreover, because a majority of the slum and squatter areas demonstrate little intentional planning, even the implementation of high-cost waterborne systems, such as conventional sewerage, present problems. Few, if any, sanitation technologies are currently available which can be considered well suited to the physical peculiarities of these deprived areas.

C. Purpose and scope of the manual

The specific objective of this publication is to introduce an innovative low-cost sanitation technology, known as shallow sewerage, and to present a methodology and criteria for its planning, design and implementation. The technology has emerged through research conducted over the past five years, and it has been successfully applied in Brazil and Pakistan. Shallow sewerage eliminates the public health

risks usually associated with inadequate excreta and wastewater disposal in areas of high population densities and inadequate water supply, and it achieves this at only a fraction of the cost of conventional sewerage. The technology is eminently suited to the requirements of a majority of urban slums and squatter settlements of developing countries. This manual has been prepared as a design tool for national planners and engineers engaged in the provision of infra-structural services to these settlements.

Shallow sewerage offers the same level of user convenience as conventional sewerage. Relaxations in technical standards adopted in its planning and design achieve considerable reductions in cost, and the methods employed in implementing shallow sewerage systems, which promote the active participation of the community at all stages, guarantee that a very high level of service is provided to the community in the short term. These and other characteristics of shallow sewerage which make it a cheap and effective means of sanitation are discussed in chapter I. The factors which distinguish shallow sewerage from other sanitation technologies, the prerequisites for the satisfactory functioning of this system and the conditions under which it is particularly effective are also discussed in detail in chapter I. Criteria for the design of shallow sewers and specifications for their construction are presented in chapter II. Project implementation strategies, which will ensure the successful introduction of the technology in low-income settlements, are discussed in chapter III. Details of construction and maintenance procedures are presented in chapter IV, and economic and financial aspects are considered in chapter V. Finally, studies of examples where the technology has been successfully introduced and observed to perform satisfactorily are presented in chapter VI.

D. Acknowledgements

This publication draws heavily upon the work and experience of the Rio Grande do Norte State Water and Sanitation Company (CAERN) in northeast Brazil, in identifying and developing the concept of shallow sewerage. A special word of thanks is due to CAERN's Low-Cost Sanitation Technical Unit and to its principal technical consultant, Mr. Jose Carlos de Melo, whose ideas inspired much of the initial conception of the system. Thanks are also due to the Bank of Credit and Commerce International (BCCI) Foundation with whose collaboration UNCHS (Habitat) has also successfully demonstrated the use of the technology in Orangi, a large squatter settlement on the periphery of Karachi, Pakistan.

I. CHARACTERISTICS OF SHALLOW SEWERAGE

A. System description

Shallow sewers are designed to accept all household wastewaters - excreta, toilet flushwater, and sullage - in their fresh state for off-site treatment and disposal. They consist of a network of small-diameter pipes laid at flat gradients in locations away from heavy imposed loads, such as vehicular loads, usually in the backyards and narrow back alleys of both planned and unplanned settlements. This allows short overall lengths of pipework to be laid in shallow trenches (hence the name) with small inspection chambers provided along their lengths to facilitate access for maintenance. Most high density low-income housing areas have few motor-accessible roads within them and, hence, a majority of the sewers may be laid at shallow depths throughout most of their length. Typical layouts of shallow sewer systems are presented in figure 1.

Shallow sewers are designed to be flushed frequently: essentially, all households within a block are connected to the sewer that passes through it. This is required not only to ensure trouble-free operation but, more important, to interrupt intra-community contamination. Several houses are connected to the same sewer which, when it emerges from the block, has several options: (a) to be connected to a conventional street sewer; (b) to be discharged into a communal septic tank and, thence, by a small-bore sewer to waste-stabilization ponds or other treatment process; or (c) to be discharged straight into ponds. The choice is site-specific. The shallow depths of the emerging sewers can often be maintained by locating them in streets in places not subject to vehicular loadings, such as along footpaths immediately adjacent to property boundaries. Where it is unavoidable to cross streets subject to such loadings, suitably designed concrete collars are provided around the pipe to serve as protection.

B. Mode of operation

Shallow sewers do not rely on large quantities of flushwater for trouble-free operation; instead, they rely on the high frequency with which wastewaters pass through the system. Densely populated areas offer ample opportunities for such operation. At the head of the sewer network, wastewater solids are flushed along by successive waves of wastewater, and, if any solids settle out in the sewer invert, wastewater builds up behind the deposit until the pressure is great enough to set it moving again. Such back pressures are easily established when the diameter of the pipe is small, since leakages past the deposited solids are minimized and an effective back pressure can be built up. Solids progress along the top end of the sewer line in a sequence of deposition - transport - deposition - transport, and this continues until the sewer has drained a sufficiently large area for the flow to cease being intermittent. Shallow sewers are also laid out in such a manner that they are located adjacent to the wastewater generating points within households. Hence, peak discharges created during flushing assist solid transport even when water consumption and, hence, wastewater generation are limited.

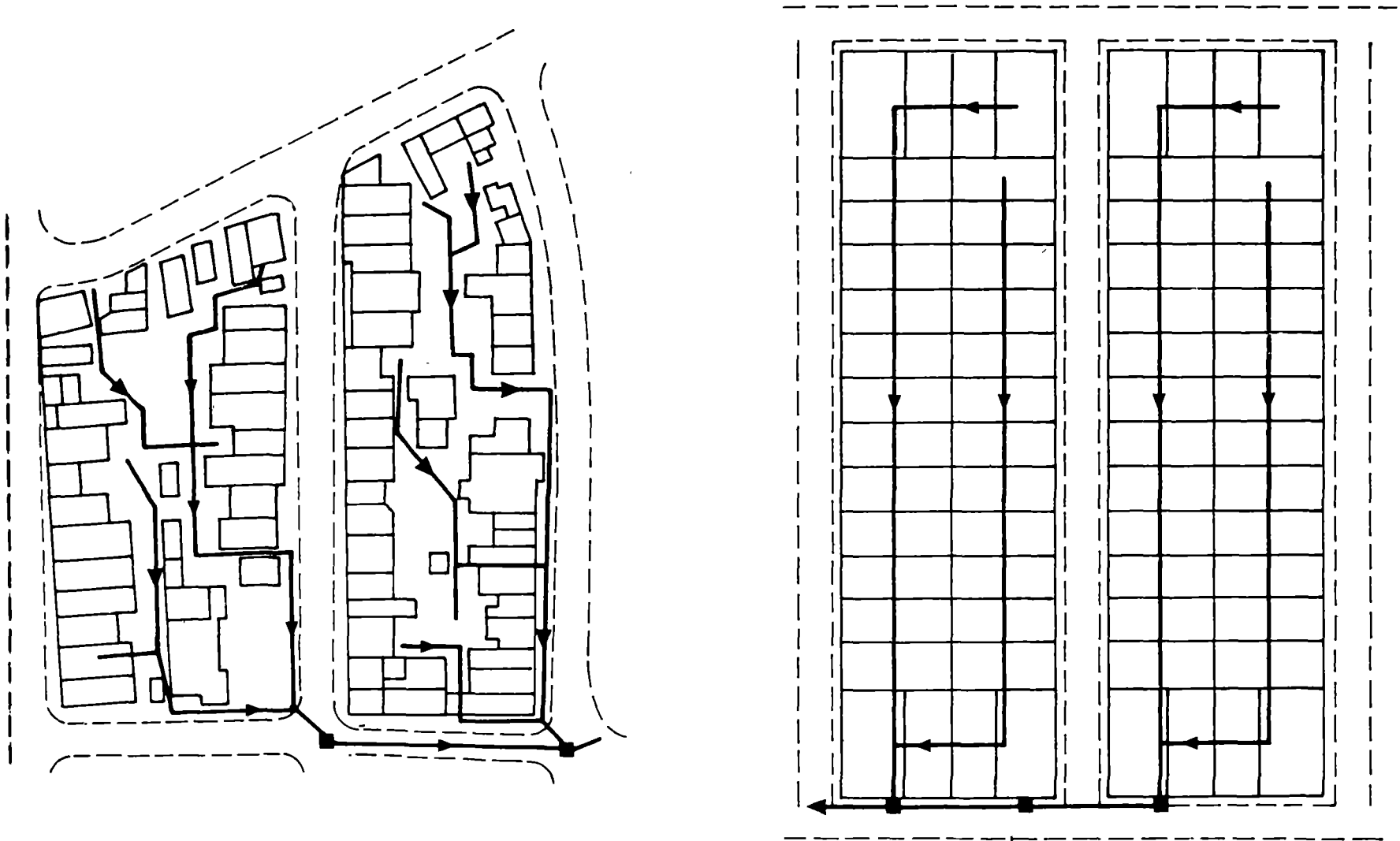


Figure 1. Shallow sewer layout for unplanned and planned human settlements

Source: G.S. Sinnatamby, D.D. Mara and M. McGarry. "Sewerage: shallow systems offer hope to slums", World Water, vol.9 No.1 (January-February 1986).

C. System advantages

Collecting all wastewaters from a settlement in the manner described above has seven principal advantages:

(a) Reduced water requirement. Since the sewers are designed for frequent flushing, in a manner that all wastewater generated by upstream households assists solid transport down-stream, large quantities of water are not needed for solid transport. Thus, unlike conventional sewers, shallow sewers can be employed without fear of blockage in areas where domestic water consumption is low and where water-saving plumbing fixtures and appliances are widely used. They have been successfully applied in areas where domestic water consumption does not exceed an average of 27 lcd. 4/

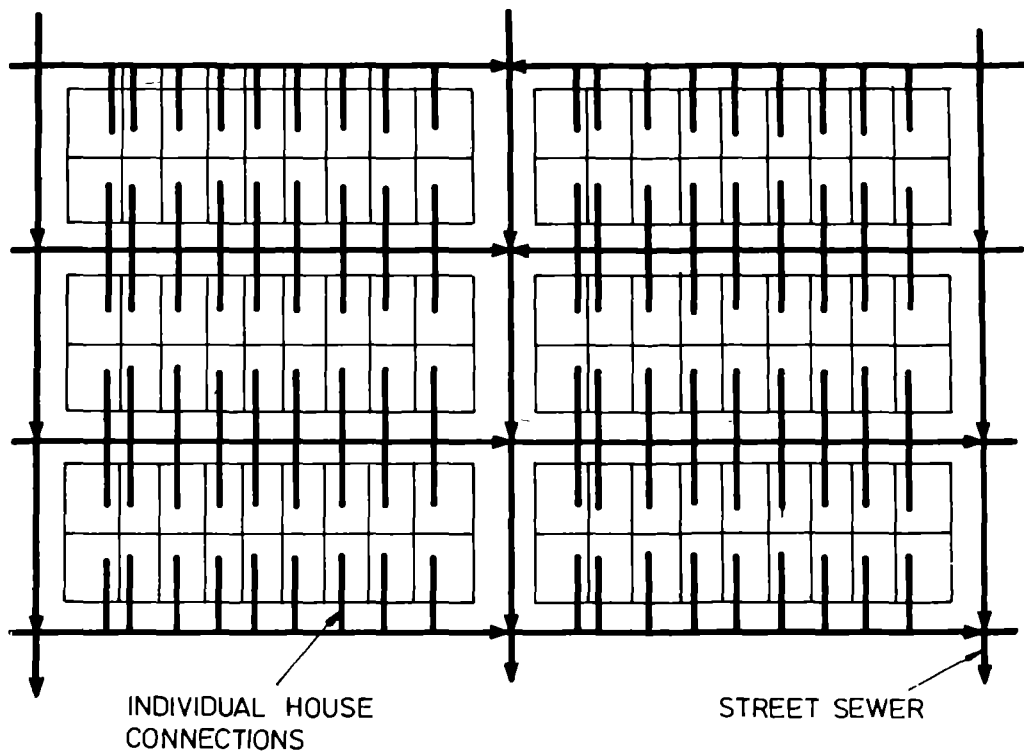
(b) Reduced length of pipework. Since short house connections are required and collector sewers are only necessary along some streets, a considerable reduction in the overall length of pipe network is achieved. This reduction may reach as much as 50 per cent in an efficient layout. Figure 2 illustrates the reduced length of pipework in shallow sewers when compared with conventional sewers.

(c) Reduced excavation costs. Since shallow depths are adopted for the bulk of the pipe network and since the overall length of the network is reduced, excavation costs are minimized. The reduced depth to which shallow sewers are laid also permits their implementation in high-density, unplanned areas where deep excavations could pose problems, especially in settlements containing precarious housing structures.

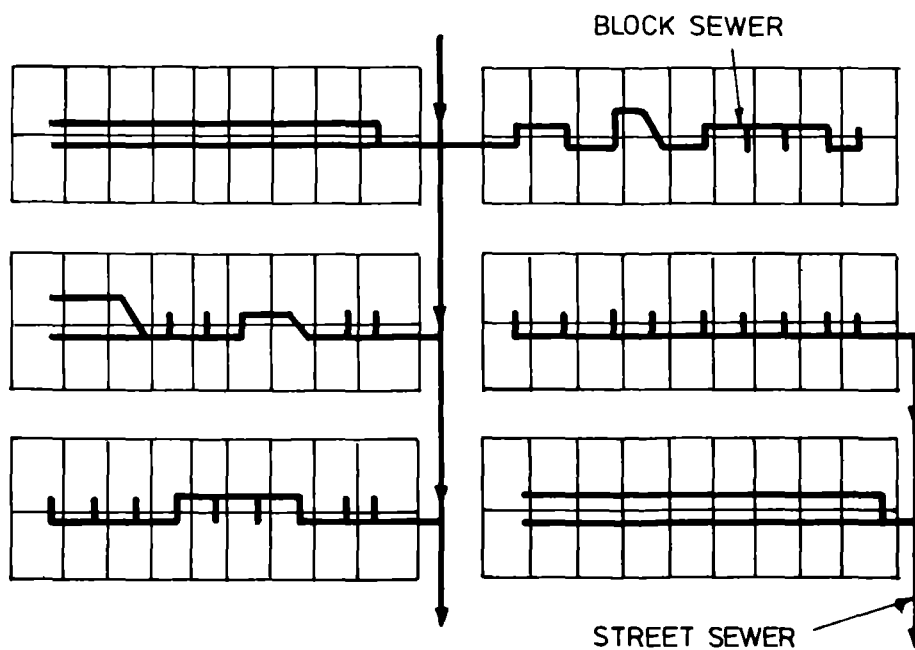
(d) Reduced material costs. Small-diameter pipes are used in the shallow sewer system in order to promote good solid transport. In addition, expensive, deep manholes, used to provide access for the maintenance of conventional sewers, can be replaced with much less costly shallow inspection chambers. This also obviates the need for mechanical cleaning equipment which is not readily available in developing countries.

(e) Reduced maintenance requirements. The increased frequency of sewer flushing, ensured through connecting large numbers of houses to a single sewer at the initial stage of commissioning the system, reduces the possibilities of blockages during the early life of the system. The reduced length of pipework and the shallow depths also facilitate maintenance and offer potential for community participation in maintaining the lengths of pipework passing through individual premises.

(f) High user connections. Because of the layout and mode of operation of shallow sewer systems, both the common house connections (sewers laid within the block) and street sewers are constructed concurrently. Hence, most, if not all, households are served immediately upon completion of construction: for example, in a squatter settlement in north-east Brazil, a connection rate of 97 per cent was obtained during the first year of construction. Such high rates of connection ensure that maximum benefits from the sanitation intervention are guaranteed from the outset. Urban community aspirations to have waterborne sanitation act to motivate community participation and acceptance.



CONVENTIONAL SEWER LAYOUT



SHALLOW SEWER LAYOUT

Figure 2. Schematic layout of conventional and shallow sewer systems

Source: J.C.R. de Melo, "Sistemas condominiais de esgotos" Engenharia Sanitaria (Rio de Janeiro), vol.24, No.2, (April-June 1985), pp 237-338.

(g) Potential for reduced treatment requirement. Where communal septic tanks are located at the points where the sewers emerge from blocks of houses and discharge their effluents to off-site treatment via small bore pipes, then screening, grit removal and primary sedimentation or treatment in anaerobic ponds are not needed at the treatment works, because these processes are performed in the septic tank. Clearly, the decision to incorporate communal septic tanks in the system needs careful evaluation, to assess cost trade-offs and local capacity to maintain the tanks.

Thus, relaxations in technical standards, brought about by diligent location of sewers and careful incorporation of recent research findings in the design and operation of sewers, have resulted in the development of an acceptable means of providing sanitation facilities at a level of service comparable with conventional sewerage but at a much lower cost. Because of their low costs of construction and maintenance and their ability to function with little water, shallow sewers can be used where conventional sewerage would be inappropriate. Shallow sewers, therefore, offer an opportunity of improving sanitation in a majority of low-income urban settlements in developing countries. The principal disadvantages of the shallow sewer system are that it requires extensive promotion of community awareness, together with house-to-house and physical surveys, at the planning stage, and good quality control during construction. However, the efforts devoted to promoting the system amongst low-income communities will enable them to identify themselves with the system, which, in turn, will result in its improved operation and maintenance in the long run.

D. Component parts

Shallow sewer systems consist of the following components: (a) house connections; (b) inspection chambers; (c) common block sewer lines; (d) street collector sewers; (e) pumping stations (on occasions); and (f) a sewage treatment plant (see figure 3). Pumping stations are only necessary if the collected sewage cannot be treated and disposed of within the same drainage basin. They may, also, be required in the sewer system itself in extremely flat areas, but this is very rare.

(a) House connection. All household wastewaters are connected to the common block sewer line at an inspection chamber along its length (see figure 4). Low-volume pour-flush or cistern-flush waterseal toilets (either pedestal seat or squat pan units) are connected to the inspection chamber via a 75 mm diameter, PVC or asbestos cement pipe. A vertical ventilation column of the same diameter is provided somewhere along the length of the house connection. (Conventional flush toilets may also be connected, but because the system does not require large quantities of water for its operation, their use is not prudent. A variety of low-volume waterseal pedestal seat and squat pans are available, and these are more than adequate.) All sullage generated on the premises is also connected to the inspection chamber by a suitable pipe, usually a 50 mm diameter PVC pipe. Where water consumption is large (greater than 75 lcd), the sullage may be connected directly to the inspection chamber. However, where consumption is low (25-30 lcd), it is advisable to pass the sullage through a grit/grease trap which acts as a sullage collector and also serves as a preventive maintenance device. Low levels of water consumption are usually associated with settlements served with a communal-standpipe level of water supply.

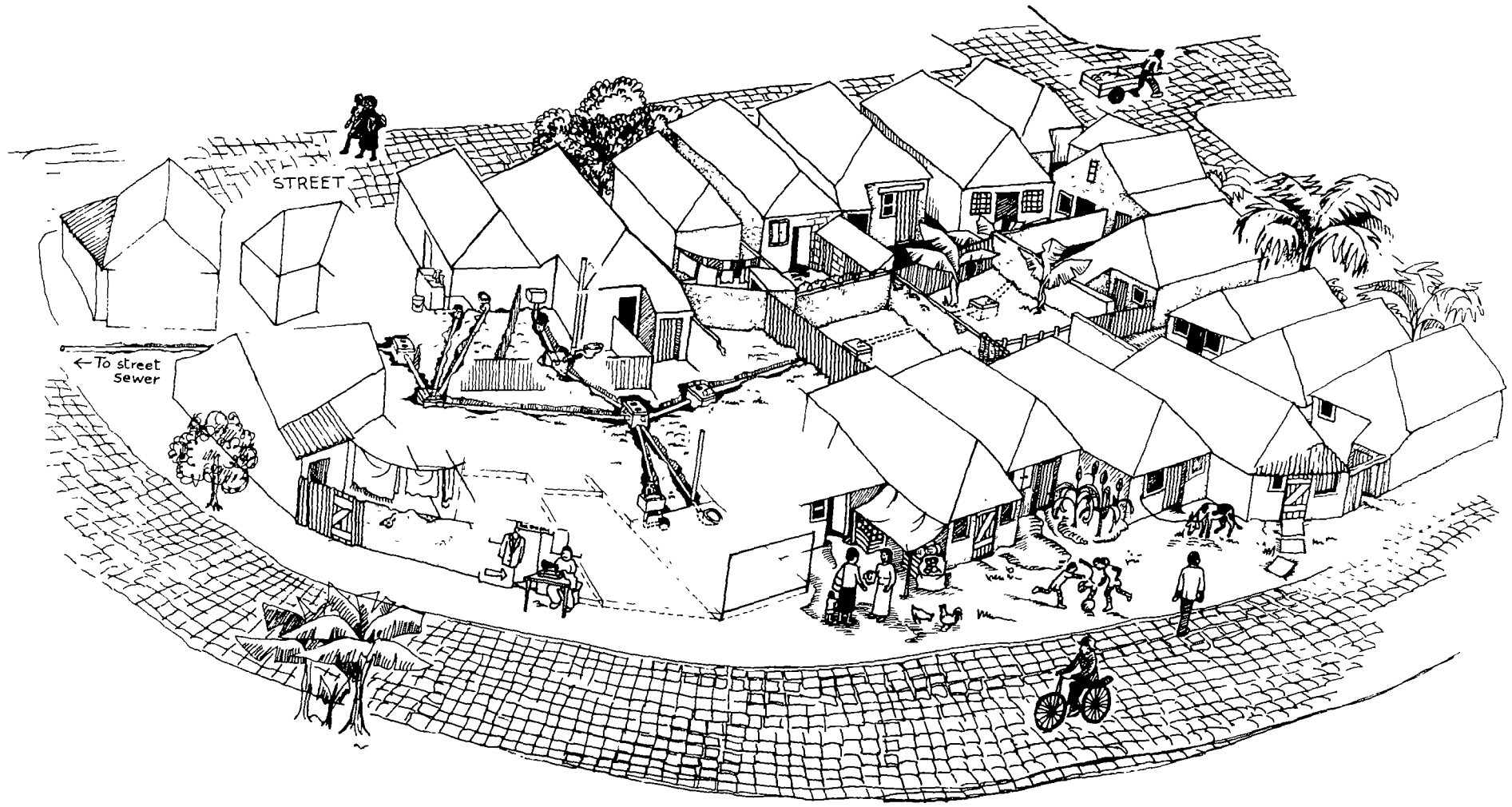


Figure 3. Illustration of shallow sewer system showing principal system components.

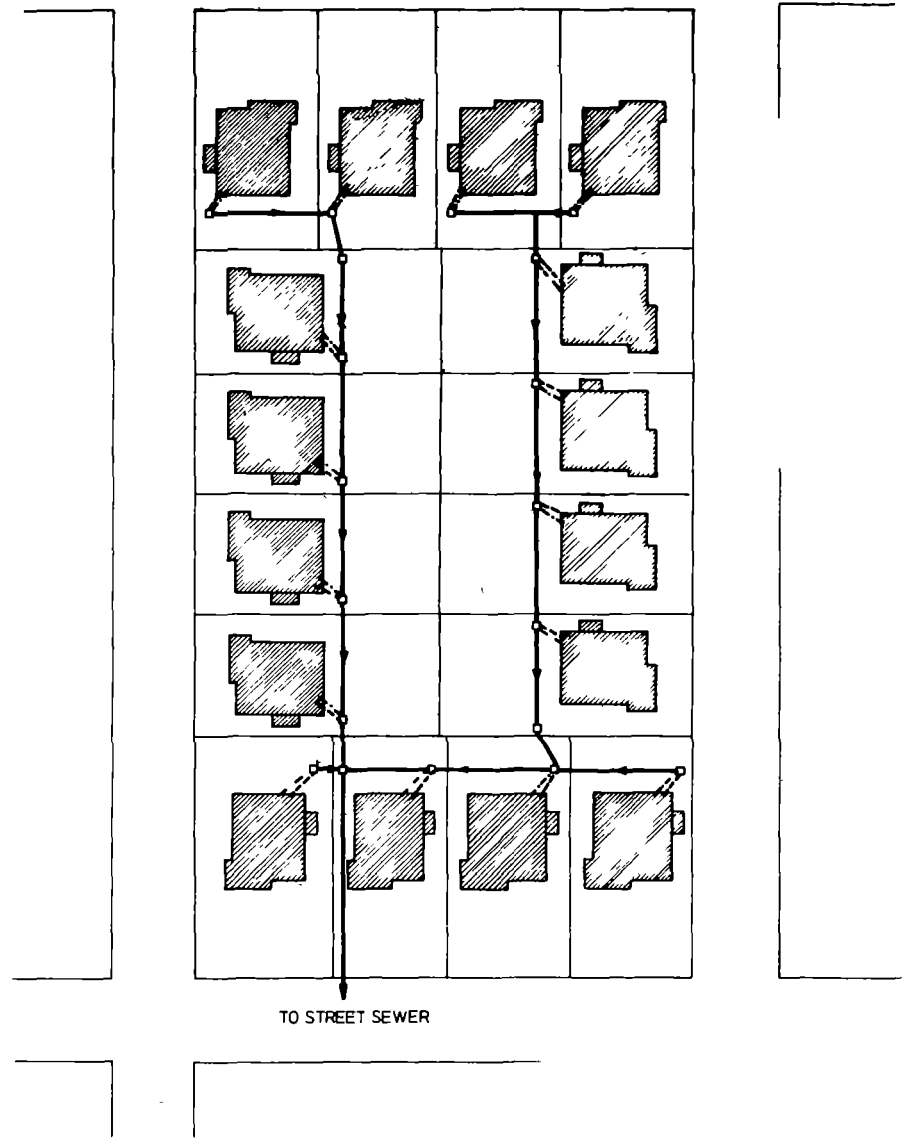
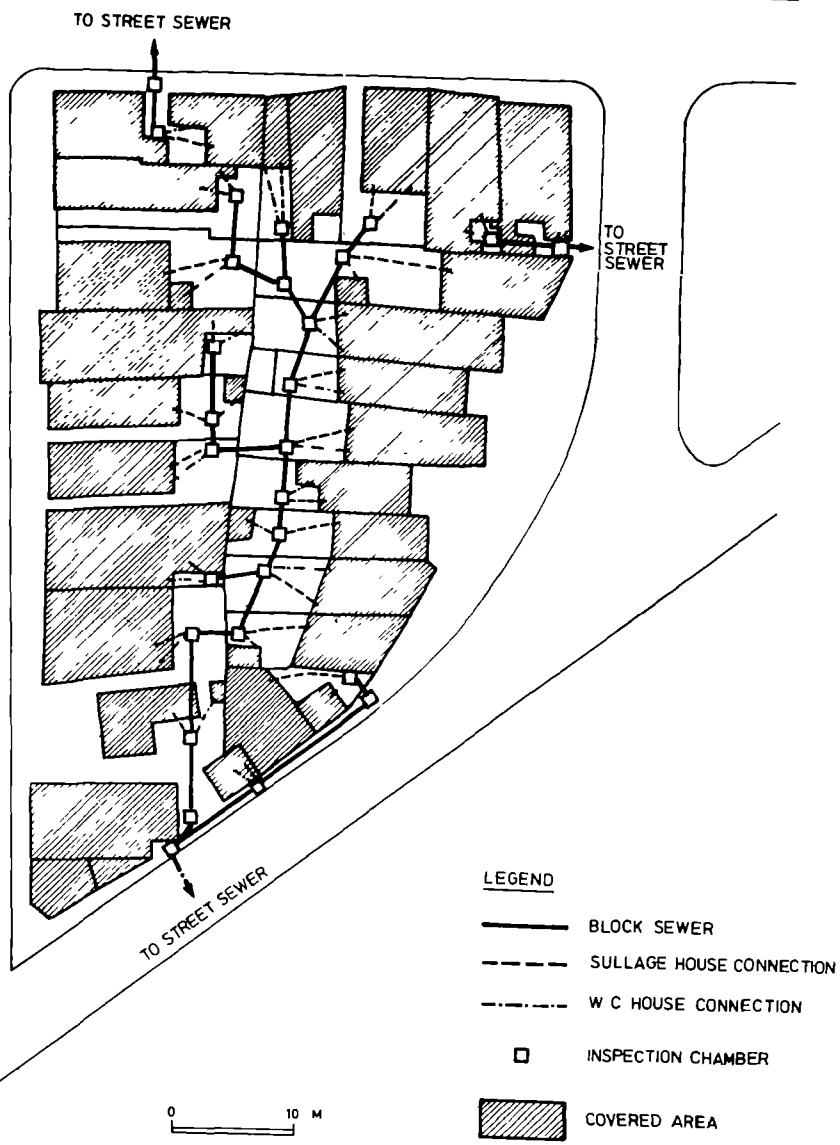


Figure 4. Shallow block sewer and house connection layout for unplanned and planned human settlements.

(b) Inspection chamber. Inspection chambers are provided at frequent intervals along the length of the common block sewer line. They serve both to provide access to the sewer line for the house connections and to facilitate sewer maintenance. Usually one inspection chamber is provided for each house, although, depending on the sewer layout, two or more houses may share a single inspection chamber. The dimensions of the chambers vary with depth. A tightly fitting reinforced concrete cover is provided to the chamber.

(c) Common block sewer line. The block sewers are small-diameter (minimum of 100 mm) clay or concrete pipes which are trenched into the ground at a depth sufficient to collect wastewaters discharged from the house connections by gravity and laid at a uniform gradient between adjacent inspection chambers along their length. Usually, a minimum depth to pipe invert of 0.4 m is provided to avoid accidental damage, although this may be reduced in special circumstances. The block sewers, while following a straight alignment between inspection chambers, rarely follow an overall linear alignment in unplanned settlements and are usually contoured around existing buildings. The objective in such a layout is to ensure that the block sewers are laid adjacent to all wastewater-generating points within the block: some straightening out of the sewer line will, however, be desirable. The sewer line will inevitably be required to pass under property boundary walls and, possibly, under future building extension areas: however, this does not usually pose any serious problem. Stone or brick arching of the wall or foundation will assist in avoiding the transmission of dead loads directly on to the pipe. The inspection chamber must, however, always be located in an open area.

(d) Street collector sewers. Street collector sewers are usually provided to a minimum diameter of 150 mm, although it is possible, where hydraulic capacities permit, to adopt 100 mm diameter pipes. They are laid at a depth compatible with their location. Wherever possible, they are laid under sidewalks away from vehicular traffic, at a depth which ensures the continuation of the flow within them and which is also adequate to receive the discharge from the block sewers. Where the depth to pipe invert exceeds 0.8 m, the sewers may be located, without protection, in streets subject to vehicular loadings. Where pipes are laid at depths less than 0.8 m, a concrete surround is provided at selected locations, for example where they pass under vehicular traffic, in order to protect the pipe. Inspection chambers are provided along the street collector sewers at intervals not exceeding 40 m, although, where mechanical sewer cleaning devices are available, this distance may be increased. Where communal septic tanks are provided at the point of emergence of the block sewers, the street sewers should be designed in accordance with the principles of small-bore sewers.^{5/}

(e) Pumping stations. Pumping stations may be necessary where the sewers become very deep or when it is required to transport the collected sewage to a different drainage basin for treatment and disposal. The use of pumping stations should, however, be eliminated, as far as possible, through careful sewer depth minimization and by treatment of all wastewaters within the same drainage basin.

(f) Treatment plants. In certain circumstances, it may be possible to discharge the wastewater into an existing conventional sewer system and, thus, be able to treat it at the works receiving the unsettled sewage. Where this is not possible, waste stabilization ponds are generally the wastewater treatment option of choice in

developing countries. If the number of houses served is small, treatment may also be provided by means of a communal septic tank and effluent infiltration trench.

Detailed criteria for the hydraulic design of shallow sewers and their appurtenances are discussed in chapter II. A design example is included in annex 1.

E.Applicability in developing countries

A recent study undertaken by the World Bank ^{3/} identified a variety of on-site and off-site excreta and sullage disposal systems (a descriptive comparison of a variety of relevant sanitation technologies is presented in table 1). On-site excreta and sullage disposal systems were found to be much less expensive in developing countries than off-site systems. However, shallow sewerage, which was developed after this study, is probably the only off-site system which, in certain conditions, is cheaper than on-site systems. There are also situations where on-site systems are technically unfeasible, and in such circumstances some form of off-site disposal is required. Shallow sewers are usually the most economical of all off-site disposal technologies and are therefore an obvious choice for consideration. Fortunately, it is precisely the same conditions which render on-site systems unfeasible or too expensive that make the shallow sewer system attractive in both technical and economic terms. These conditions include:

(a) High population densities. All on-site waste disposal options require adequate space within the lot for their installation. Such space is usually available in rural and low-density to medium-density urban areas. However, as the density of settlement increases, such space is not readily available, and, even when it is available, on-site systems are likely to meet with community opposition especially because they need desludging at some stage during their operation. All forms of pipe networks demonstrate marked reductions in unit household costs as the density of settlement increases, because the same length of pipework serves an increased number of houses. On-site systems, however, maintain a constant unit household cost irrespective of the density of settlement. At a given density of settlement, piped networks become more economical than on-site systems. Unfortunately, in the case of conventional sewerage this transition only takes place at extremely high population densities. Shallow sewers, being much cheaper than conventional sewers, become cost-effective at much lower densities. The population density at which this transition takes place varies with the physical conditions of the settlement (such as soil permeability, topography etc.), but in Natal, Brazil, this transition point occurred at a density of 160 persons per hectare (see figure 5). In areas with shallow rock, shallow sewers have even proved more cost-effective than on-site systems at population densities as low as 110 persons per hectare. ^{6/}

(b) Adverse ground conditions. All on-site excreta and sullage disposal systems rely on the ability of the soil to absorb all wastewaters generated on the premises. They also require some form of excavation for excreta storage. Under adverse ground conditions, such as shallow rock, high groundwater table and low soil permeability, on-site systems may become unfeasible. The shallow sewer system is one of the off-site options which may be adopted in such circumstances.

(c) High water consumption. Most low-cost, on-site waste disposal systems, such as pit latrines and pour-flush latrines, only

Table 1. Descriptive comparison of sanitation technologies

Sanitation technology	Rural application	Urban application	Construction cost	Operating cost	Ease of construction	Self-help potential	Water requirement	Required soil conditions	Complementary off-site investment ^a	Reuse potential	Health benefits	Institutional requirements
Ventilated improved pit (VIP) latrines and Reed Odorless Earth Closets (ROEC'S)	Suitable	Suitable in L/ M-density areas	L	L	Very easy except in wet or rocky ground	H	None	Stable permeable soil, groundwater at least 1 meter below surface ^b	None	L	Good	L
Pour-flush (PF) toilets	Suitable	Suitable in L/ M-density areas	L	L	Easy	H	Water near toilet	Stable permeable soil, groundwater at least 1 meter below surface ^b	None	L	Very good	L
Double vault composting (DVC) toilets	Suitable	Suitable in L/ M-density areas	M	L	Very easy except in wet or rocky ground	H	None	None (can be built above ground)	None	H	Good	L
Self-topping aquaprivy	Suitable	Suitable in L/ M-density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil, groundwater at least 1 meter below surface ^b	Treatment facilities for sludge	M	Very good	L
Septic tank	Suitable for rural institutions	Suitable in L/ M-density areas	H	H	Requires some skilled labor	L	Water piped to house and toilet	Permeable soil, groundwater at least 1 meter below surface ^b	Off-site treatment facilities for sludge	M	Very good	L
Three-stage septic tanks	Suitable	Suitable in L/ M-density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil, ground water at least 1 meter below surface ^b	Treatment facilities for sludge	M	Very good	L
Vault toilets and cartage	Not suitable	Suitable	M	H	Requires some skilled labor	H (for vault construction)	Water near toilet	None (can be built above ground)	Treatment facilities for night soil	H	Very good	VH
Sewered P1 toilets, septic tanks, aquaprivies	Not suitable	Suitable	H	M	Requires skilled engineer/ builder	L	Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H
Sewerage	Not suitable	Suitable	VH	H	Requires skilled engineer/ builder	L	Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H
Shallow sewerage	Not suitable	Suitable	L	L	Requires skilled engineer/ builder	M	Water near toilet	None	Sewers and treatment facilities	H	Very good	M

Source: J.M. Kalbermatten, and others, *Appropriate Sanitation Alternatives. A Planning and Design Manual* (Baltimore, Johns Hopkins University Press, 1982), p 160 (modified to include shallow sewerage)

Notes: L, Low; M, medium; H, high; VH, very high

a. On- or off-site sullage disposal facilities are required for nonsewered technologies with water service levels in excess of 50 to 100 lcd, depending on population density

b. If groundwater is less than 1 metre below the surface, a plinth can be built.

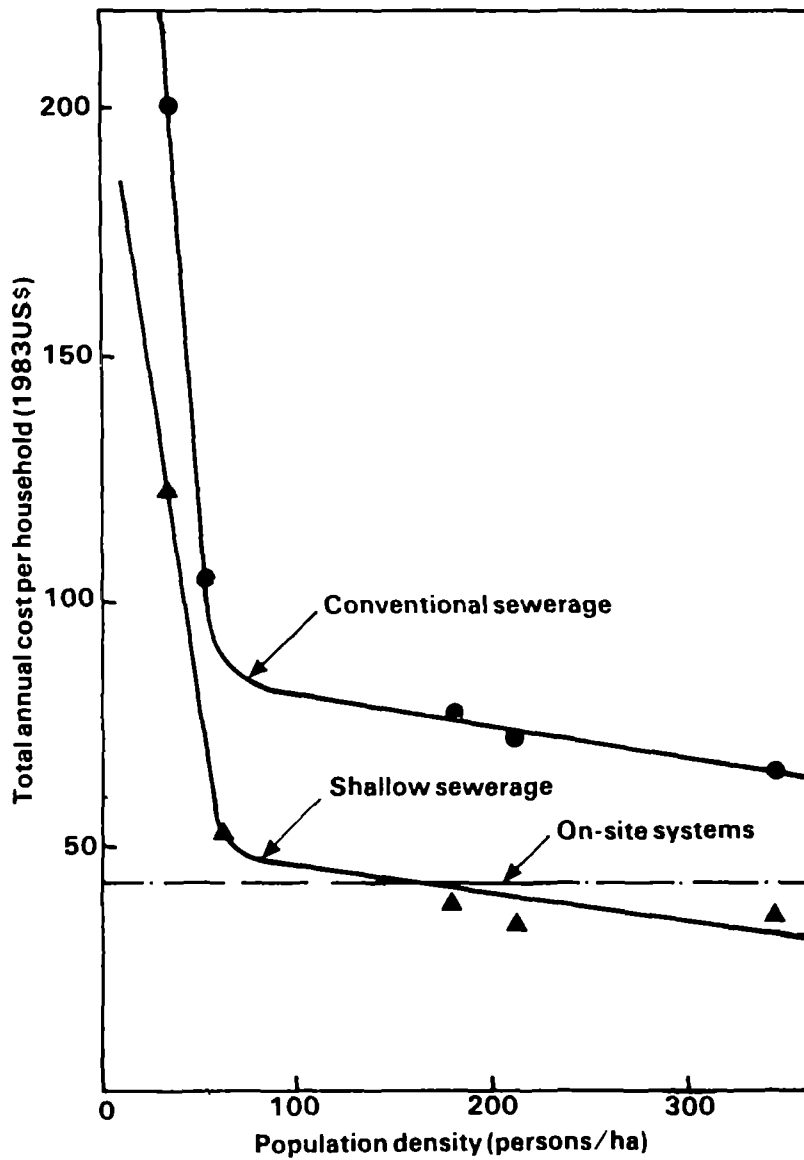


Figure 5. Variations in costs of conventional and shallow sewerage and on-site sanitation with population density in Natal, North-east Brazil.

Source: G.S. Sinnatamby, "Low-cost sanitation systems for urban peripheral areas in Northeast Brazil", Ph.D thesis, Department of Civil Engineering, The University of Leeds, Leeds, August 1983.

handle the disposal of excreta. Sullage is usually left to infiltrate into the ground at the surface or via some form of on-site sullage soakaway. As water consumption increases, the need for such soakaways increases. In areas of adverse soil conditions and high densities of population, the space for soakaways may not be readily available. Further, because low-income communities do not see the need for investing in soakaways for the disposal of sullage, it is not uncommon to see large quantities of sullage flowing in the streets. Such uncontrolled disposal of sullage can give rise to diseases such as filariasis, as well as erode the usually unsurfaced alleyways found in these settlements. Shallow sewers, because they dispose of both excreta and sullage, can be adopted in settlements where average levels of water consumption are high. A minimum average water consumption of at least 25 lcd is required, however, to be available for shallow sewers to operate without blockages.

(d) Varied socio-cultural settings. Shallow sewer systems may be applied under most socio-cultural settings. It is especially suited to cultures where anal cleaning by water or soft materials is used. No experience is available on which to assess their suitability in areas where bulky anal cleaning materials are used.

When on-site disposal technologies prove unfeasible or when density of settlement suggests that off-site systems may prove cost-effective, the full range of off-site disposal technologies has to be evaluated in technical, financial and economic terms. The available off-site disposal technologies are the following:

(a) Vault toilets and cartage systems. These require a high degree of organizational capability within the institution (usually a municipality) responsible for operating the system: the vault-emptying equipment (commonly a vacuum tanker) has to arrive at each vault very close to the chosen emptying frequency (two to four weeks), otherwise the system fails, and the emptying equipment must be properly maintained. In many developing countries, such a level of institutional competence is lacking, and very often the system cannot be considered feasible for this reason. Narrow access roads to most low-income settlements in developing countries would also suggest that the system may not always be appropriate.

(b) Conventional sewerage systems. These are so expensive that they are economically inappropriate in low-income communities. For example, studies undertaken by the World Bank ^{3/} showed that investment costs for conventional sewerage in eight capital cities in developing countries ranged from \$600 to \$4000 (at 1978 prices) per household, with corresponding annual costs ^{7/} between \$150 and \$650 per household. Such costs are clearly unaffordable when it is remembered that total annual household incomes are frequently less than \$500 and are often below \$200. Further, the unfeasibility of constructing deep sewers in high-density areas with precarious housing stock also precludes the use of conventional sewerage in low-income settlements.

(c) Small-bore sewers. These offer a feasible means of upgrading on-site systems, such as pour-flush toilet and septic tank systems, when improvements in the water-supply distribution system or increased housing densities have occurred. In new schemes, however, small-bore sewerage offers little advantage over conventional sewerage in terms of overall cost. Small-bore sewerage, as with the vault system, also necessitates frequent desludging. The equipment and organizational

capability for this task may not be readily available in developing countries, and access for purposes of desludging individual household septic tanks may not be adequate in most low-income, high-density settlements. In these circumstances, small-bore sewerage not only will prove to be only slightly cheaper than conventional sewerage but, more often than not, may prove technically inappropriate.

(d) Shallow sewer systems. These become increasingly economical as the density of settlement increases. In high density slums and squatter settlements, they are often cheaper than on-site systems: typical investment costs are in the range of \$125 to \$325, with corresponding annual economic costs 7/ between \$15 and \$35 per household. The very high rates of user connection, usually achieved through community involvement at the planning and implementation stages, ensure that a comprehensive sanitation solution is provided for the whole community and that maximum health impact is achieved immediately upon completion of the scheme. Besides being considerably cheaper than conventional sewerage, shallow sewers do not require excessive quantities of flush water for trouble-free operation.

II. SHALLOW SEWER DESIGN CRITERIA AND SPECIFICATIONS

A. Design considerations

A shallow sewer system is a separate sewer system which utilizes gravity for conveying raw sewage from all households to an outlet downstream. It must be set deep enough to receive flows from each user but must be located so that this depth is kept to a minimum. It must have sufficient size and gradient to carry these flows. In addition, maintenance operations, public safety and convenience must be evaluated in the light of water availability and the potential for user participation.

Suitable preventive maintenance devices, such as grit/grease traps, must be provided where water consumption is low and where sand and other inert materials are used, instead of detergents, for cleaning utensils. Shallow depths must be maintained not only for economy in construction but also for facilitation of user maintenance. Frequent sewer flushing, achieved through the connection to a single sewer line of a number of houses, must be ensured for good operation. Pipes with sufficient structural strength must be used, and suitable bedding materials must be selected to withstand backfilling, and impact and live loads where these are likely to occur. The type and number of appurtenances used must facilitate cleaning of the sewers with the kinds of cleaning equipment likely to be used. Public convenience and safety during construction are additional important factors.

B. House connections

All household wastewaters are drained to an inspection chamber located along the length of a common block sewer line, usually through two or more pipe connections. One of these is for the water closet connection and, depending on the distribution and number of sullage generating areas within each house, one or more sullage connections are also provided. Where a grit/grease trap is provided, it is usual to connect all the sullage to it and provide a single connecting pipe to the inspection chamber.

1. Water closet house connection

This connection is the short length of pipe that drains the water closet to the inspection chamber. A vertical ventilation column is usually provided somewhere along the length of the connection, often adjacent to the exterior wall of the house. The following specifications are recommended for the water closet house connection:

Pipe materials for house connection

and ventilation column: PVC or asbestos cement

Pipe diameter for house connection

and ventilation column: Minimum, 75 mm

Pipe gradient of house connection: Minimum, 1 in 50

Manually flushed squat pans, using 3 litres of water per flush, have been shown to be capable of transporting simulated waste materials an average distance of over 5 metres along 75 mm diameter

pipes laid at a gradient of 1 in 100. 8/ 9/ Since the layouts of shallow sewers are such that the common block sewer line is adjacent to the toilets, the water closet connections are usually short in length and rarely exceed 5 metres. Even so, a minimum gradient of 1 in 50 is recommended to take account of variations in site and sewer layout. Clearly, the shallowest gradients may be adopted where pedestal seats using large flush volumes are adopted. In any event, a gradient not flatter than 1 in 100 is recommended.

2. Sullage house connection

Where water consumption is low (25-30 lcd) and where sand, brick-bats and other abrasive materials are customarily used for cleansing utensils, all sullage house connections must be preceded by some form of grit/grease trap, especially for kitchen wastewaters. Even where water consumption is high and detergents are used for cleaning utensils, it is advisable to provide this preventive maintenance device. When the overflow pipe from these devices, i.e., the sullage house connection, is free from gross accumulation of solids, it may be laid at a very flat gradient. Direct connections to the common block sewer inspection chamber may also be made from laundry and bathing areas, including also kitchen wastewaters, in areas where the average water consumption is over 75 lcd. The following specifications are recommended for sullage house connections:

Pipe material:	PVC
Pipe diameter	Minimum, 38 mm but usually 50 mm
Pipe gradient	Minimum, 1 in 200

C. Common block and street collector sewer

Within a block, all water closet and sullage house connection pipes are connected to a single pipe known as the common block sewer. Where the natural drainage path within the block is unidirectional, only a single block sewer is necessary. Where this is not the case, in order to minimize excavation and follow the natural fall of the land, it may prove necessary to adopt more than one common block sewer.

The common block sewers are designed to be flushed frequently, and therefore as many houses as possible should be connected to them. They should be located adjacent to the toilets they serve and are, hence, usually located at the backs of houses. In certain housing layouts where the toilets are located at the front, block sewers are also provided at the fronts. When the block sewer emerges from the block, it is connected to a street collector sewer. Since block sewers and street collector sewers operate in a similar manner, criteria for their design are discussed together below.

Traditionally, the design of sewers has been based on the concept of ensuring that peak daily flows carry away any solids deposited during periods of low flow. These self-cleansing velocities occur at least once a day in the large downstream sewers but not usually in the small-diameter house connections and street collector sewers in the upper reaches of the network where the flow is intermittent. Recently, however, the concept of self-cleansing velocities in sewers as a basis for their design has been questioned by many researchers. It has been found that, although solids are deposited in pipes, they become re-suspended and transported on

subsequent flushing, as the pressure force caused by the difference in depth of water across the solids increases. 10/ 11/ Solids are therefore shifted along the pipes by the flushing action of sequential waves of wastewater, and, as solids deposit in the pipe invert, wastewater backs up until the pressure is sufficient to move the solids forward. Based on these findings, it has been suggested that there is no reason to attempt to design a totally deposit free house connection or sewer. 10/

A comprehensive study of the causes of blockage in house connections, conducted in the United Kingdom, 12/ concluded that most sewers experienced intermittent stoppages during normal operation and that these were removed by wave action rather than by the maintenance of a minimum scour velocity. Blockages were observed to be removed efficiently as the depth of flow increased and were primarily the result of poor workmanship and infrequent use of the system, rather than of limitations in pipe diameter or gradient. It would appear, therefore, that recent studies undertaken on the operation of sewers do not support the current design practice of restricting the use of flat gradients by working to a minimum mean velocity.

Unable to model the true mode of operation of sewers, especially at the upper reaches of a network, engineers have resorted to rules of thumb which have become increasingly conservative over the years, thus adding unnecessarily to the cost of sewerage. Current knowledge still offers no alternative to using the self-cleansing velocity design concept. It is on this principle that procedures have been developed for the design of shallow sewers, although recent research findings have enabled substantial changes to be made in design standards and criteria to promote cost reductions. These are discussed below.

1. Minimum and maximum velocities of flow

Minimum peak daily velocities in pipes have been said to lie between 0.76 m/sec 13/ and 1.0 m/sec. 14/ However, laboratory studies have shown that solids do not decelerate until they reach a threshold velocity below which no further motion is possible; this velocity, depending on solid shape, pipe size and slope, relative pipe roughness etc., was found to be between 0.2 and 0.4m/sec. 9/ 15/ Inert material will, however, be deposited at velocities below 0.3m/sec. Accepting these findings and assuming that sewers do not operate on the principle of self-cleansing velocities and that, when solids are deposited they become re-suspended and transported by subsequent flushes, a minimum flow velocity of 0.5m/sec is considered adequate. In Brazil, sewers have been designed for this value of self-cleansing velocity for over two decades. 16/ Maximum velocities of flow have, in the past, been specified, in order to reduce the possibility of pipe erosion. Such effects were said to occur at flow velocities in excess of 4.0m/sec, but studies have shown that erosion effects observed at velocities greater than this threshold value are only minimal, 17/ and hence no upper limit of flow velocity is recommended. Thus, the minimum and maximum sewage design velocities can be stated as follows.

Minimum (self-cleansing) velocity: 0.5 m/sec

Maximum velocity: No limit required

2. Minimum and maximum depth of flow

Minimum and maximum proportional depths of flow, at peak flow, are usually specified for pipes conveying sewage, in order to ensure that a sufficient sewage flow for solid transport and an adequate surplus capacity are provided in the pipe. A minimum proportional depth of 0.2 is generally considered necessary for solid transport, and a maximum proportional depth of 0.8 is usually recommended in order that approximately 8 per cent surplus capacity is available to provide a small margin of safety against underestimation of the sewage flow. Since it is now known that solids are deposited in sewers and transported on subsequent flushes, specifying a minimum depth of flow would appear to be unnecessary. However, in the absence of exact design methods, the maintenance of a minimum and a maximum proportional depth is recommended as follows:

Minimum depth of flow in pipe: 0.2 times pipe diameter.

Maximum depth of flow in pipe: 0.8 times pipe diameter.

3. Minimum sewer diameter

A minimum sewer diameter of 100mm is usually recommended. 16/ 18/ Although 75mm diameter pipes have been successfully utilized in Scandinavia 19/ it is unlikely, in most developing countries, that pipes made of suitable material are obtainable at a diameter of 75 mm and, even if available, that they are cheaper than a 100 mm diameter pipe made of commonly available materials, such as clay and concrete. Further, it is also difficult to ensure good workmanship in pipe-jointing at reduced pipe diameters. Hence, a minimum pipe diameter of 100 mm is recommended. Since small-diameter pipes have been shown to have better solid-transport properties than large-diameter pipes, because of their ability to build greater depths of water behind solids, 10/ 11/ there is no justification for using pipe diameters in excess of 100 mm, except when required by the magnitude of the flow. In fact, it is definitely not advisable to increase the pipe diameter under the reduced falls proposed for shallow sewers, since this decreases the depth of flow, and solids will thus tend to be deposited frequently in the pipeline. The following recommendation is, therefore, made regarding the minimum sewer diameter:

Minimum sewer diameter: 100 mm

4. Minimum sewer gradient

A wide range of minimum gradients has been recommended in the past. The study of the causes of sewer blockages in the United Kingdom 12/ found that sewer gradients, as with pipe diameters, were not determining factors in causing sewer blockages. House connections laid at gradients as flat as 1 in 1200 were found to operate satisfactorily for many years. In fact, the investigation discovered most blockages on the commonly recommended gradients of between 1 in 30 and 1 in 70. British practice 18/ recommends that a 100 mm diameter pipe be laid at a gradient not flatter than 1 in 70, provided it serves the equivalent of at least one water closet, and 1 in 80, when serving up to five houses. As pipe diameters increase, it is often common to see recommendations to adopt shallower sewer gradients: a minimum gradient of 1 in 150 is often recommended for 150 mm diameter sewer pipes. 20/ Minimum pipe gradients are, however, independent of pipe diameters. Using Manning's equation, it can be shown that the gradient required for a pipe is given by the following

equation:

$$I = \frac{Q^{-2/3} V^{8/3}}{1.49 n^2 (\theta - \sin \theta)^{5/3}}$$

- where I = gradient, m/m
Q = flow rate, l/sec
V = velocity of flow, m/sec
 θ = angle subtended at the centre of the pipe
by the wetted perimeter, radians
n = roughness coefficient

Taking the limiting conditions (in the upper reaches of a sewer network) of a minimum depth of flow of 0.2 times the diameter ($\theta=1.85459$) and a velocity of flow of 0.5 m/sec, and assuming Manning's roughness coefficient $n = 0.013$, the minimum pipe gradient is given by:

$$I = 0.01Q^{-2/3}$$

It follows that, for a given discharge the minimum permissible gradient is independent of the pipe diameter.

The above equation may be used to obtain minimum gradients for a range of flows. Brazilian practice recommends that the flow from a single cistern-flush unit of 2.2 l/sec be used to represent the minimum discharge at the head of any sewer system.^{16/} Clearly, such discharges are rapidly attenuated in the house connection as the solids move away from the water closet, and they are never obtained in practice in the sewers, but no problems have resulted from following this assumption. It is interesting to note that over 200 households with an average of five persons per household and an average flow of 100 lcd would be required to generate a flow equivalent to 2.2 l/sec. The minimum gradient corresponding to a discharge of 2.2 l/sec is 1 in 167 (0.6 per cent), and this attains a maximum self-cleansing velocity of 0.5 m/s. The recent success with minimum gradients of 1 in 167 in shallow sewer systems in Pakistan, in settlements where water consumption averaged only 27 lcd and where manually flushed squat pans were utilized for excreta deposition, ^{21/} ^{22/} ^{23/} coupled with the fact that sewers do experience intermittent formations of blockages, would suggest that very flat gradients may be safely adopted in areas of medium and high water consumption. However, in the absence of additional field data, a minimum sewer gradient of 1 in 167 is recommended.

Minimum sewer gradient = 1 in 167

5. Maximum number of houses to be connected to a single sewer line

British practice recommends that a maximum number of only 20 and 150 houses be connected to a single 100 mm and 150 mm diameter pipe, respectively. ^{18/} Yet, the same code suggests that, for water consumption levels less than 140 lcd, peak flows of 0.01 l/sec per person should be considered. On this basis, as many as 74 houses with

an average of five persons per house may be connected to a 100 mm diameter pipe laid at a gradient of 1 in 167. Although this number of houses and the corresponding gradients are both well in excess of the code recommendations, they are, in fact, almost exactly the same as recommended by the Institute of Plumbing, United Kingdom. 24/ On a similar basis, 219 houses may be connected to a 150 mm diameter pipe laid at the same gradient. Placing an arbitrary limit on the number of houses which may be connected to a pipe of a given diameter, even though it possesses sufficient hydraulic capacity to drain many more houses, is clearly irrational, especially in the light of recent findings that sewer blockages are often the result of infrequent usage.12/

Conventional British practice also recommends that each house be separately connected to the street lateral, and this sometimes necessitates very long house connections. Recently, up to four houses have been allowed to use a common connection, but private developers have emphasized that savings of up to a third could be achieved by connecting 20 houses by means of a common connection. 25/ In Brazil, up to 60 houses have been connected to a 100 mm diameter pipe laid at a gradient of 1 in 167, although hydraulically over 200 houses may be so connected. 26/ Given the possible economic and operational advantages of connecting a large number of houses to a single sewer line, there is little justification for limiting the number of houses that may be connected to a sewer, provided sufficient pipe capacity is available. Since water consumption and wastewater generation patterns are often different from country to country, the maximum number of houses to be connected to a sewer should be computed on the basis of the peak flow and the maximum flow capacity corresponding to the minimum gradient (see hydraulic design below). The flow-carrying capacities of downstream street sewers should be established to determine the number of houses that may be connected to these pipes.

6. Minimum depth of sewer

One of the most important features of shallow sewers, that has a marked influence both in reducing the overall cost of sewerage and in facilitating maintenance, is that the sewers are laid at a shallow depth. Usually, the minimum depth of block sewers is determined by the depth to invert of water closet and sullage house connections. Because the length of these connections is usually short, it is possible to lay pipes at a minimum depth to soffit of pipe of only 0.2m. However, in order that accidental damage to pipework may be avoided, it is prudent to adopt a minimum soffit cover of 0.3 m. This implies that a 100 mm diameter block sewer will be laid at a minimum trench depth only marginally greater than 0.4 m. While such depths are acceptable in areas not subject to vehicular loadings, continuation of the use of such depths, once the block sewer emerges into the street, necessitates careful location. Where it is inevitable that vehicular traffic pass over the line, pipes must be laid with a minimum cover to soffit of 0.8 m or, alternatively, the pipe must be protected with a concrete collar (see section D).

7. Peak sewage flow estimation

The peak flow at various stages of the pipe network may be calculated from the following equation:

$$Q = \frac{C.K1.K2.P.g}{86400} + Q1 + Q2$$

where Q = peak sewage flow at a point along the sewer in l/sec

C = fraction of consumed water which returns as sewage*

K1 = coefficient of flow variation above the average daily water consumption on the day of maximum water consumption**

K2 = co-efficient of flow variation above the average daily water consumption during the hour of maximum consumption***

P = total population along the stretch of sewer under consideration;

q = average water consumption in lcd

Q1 = groundwater infiltration in l/sec +

Q2 = point discharges to the stretch of sewer under consideration including upstream discharges in l/sec and

86400 = number of seconds per day.

*C (the percentage of water supplied to a house which does not return as sewage) is water used for such purposes as watering gardens and washing floors, cars and the like. However, such losses are likely to be minimal in low-income settlements. In the absence of more reliable field data, approximately 15 to 20 per cent of the total volume of water supplied to these settlements may be assumed not to return to the sewers. Thus, a value between 0.80 and 0.85 is recommended for the coefficient C.

** K1 (the ratio of the average daily flow on the day of maximum consumption to the weekly average daily flow) is usually of the order of 1.2.

K2 (the ratio of the average daily flow during the hour of maximum consumption to the weekly average daily flow) is usually within the range 1.5 to 2.0 . 16/

+Q1 Where sewers are laid below the groundwater level some ingress of groundwater into the pipe may be expected. Ideally, the addition of such water should be zero, but, in practice, some imperfectly sealed pipe joints will result in infiltration. If the prevention of groundwater ingress cannot be ensured, some allowance must be made for infiltration. This allowance is often quoted either as a volume of infiltration water per hectare per day (a typical conservative figure may be of the order of 20 m³/ha/day) or as a flow per kilometre length of sewer (a typical range of range of values may be 0.2 to 0.3 l/sec/km).

Although several equations are available in the literature for relating peak sewage flows to average sewage flows and contributing populations, ^{27/} most of these were derived from experience in industrialized countries. The above equation was, however, obtained from Brazilian practice, and it has been successfully applied in the design of a number of shallow sewerage schemes. Unless detailed local information is available, its use for shallow sewer design is recommended. In conventional sewer design, it is necessary to consider the initial and final populations to be served and their average rates of water consumption, because these are likely to change with time. However, the sewer design method presented here obviates the need for considering the initial sewage flow and requires that only the final peak flows be considered in order to establish the necessary pipe capacities. The fact that a minimum gradient is provided in the sewer designs, based on a minimum flow associated with the flushing of a water closet from a single household, ensures that the need to consider initial populations and water consumptions is eliminated. The minimum gradient recommended above has been established through successful practical application in areas of low water consumption where manually-flushed squat pans were provided for excreta deposition.

8. Hydraulic design

Shallow sewers, like conventional sewers, are designed for open-channel gravity flow. Any of the commonly known open-channel equations may be used for purposes of design in determining pipe capacities and flow velocities. Manning's equation is perhaps the most commonly used of all these equations and Macedo's modification of this (which effectively eliminates consideration of the hydraulic radius) is, for circular pipes, as follows: ^{28/ 29/}

$$v = 0.61 n^{-3/4} q^{1/4} i^{3/8}$$

where v = velocity of flow, m/s

n = Manning's pipe roughness coefficient

q = flow, m³/sec

i = slope of the hydraulic grade line, m/m

The value of n is usually taken as 0.013 for slimed sewers, so that the Macedo-Manning equation for circular pipes becomes:

$$v = 15.8 q^{1/4} i^{3/8}$$

An alternative approach to hydraulic design under gravity flow is available through the use of tables for hydraulic design of pipes published by the Hydraulics Research Station, United Kingdom.^{30/} The tables are derived from the Colebrook-White equation for turbulent transitional flow in determining discharge capacity and flow velocity. Such tables present pipe capacities and flow velocities under full-bore conditions for differing pipe diameters and gradients. Tables are also presented for relating velocity and flow under full-bore conditions to those under partly full conditions. Similar design tables using the Colebrook-White equation for the design of vitrified clay pipes are also available. ^{31/} The following pipe roughness (K) values are recommended for slimed sewers when using

either of the two Colebrook-White equations.

Concrete:	6.0 mm
Asbestos cement:	6.0 mm
Clayware:	1.5 mm
PVC:	1.5 mm

Having computed the flow of sewage along a pipe length, the sewer is designed to ensure that the following conditions are satisfied:

(a) Minimum self-cleansing velocities are attained. Ensuring that minimum gradients are provided automatically ensures that minimum self-cleansing velocities are attained.

(b) Depths to which pipes are laid are minimized within permissible limits.

(c) Adequate pipe flow capacity is available to carry the maximum peak future design flow.

(d) The depth of flow at peak flow is within the recommended limits. Once again, ensuring that minimum gradient requirement is satisfied will automatically ensure that the minimum depth of flow is provided. Since the maximum permissible depth of flow occurs at a flow equal to the full-bore flow (i.e, when $d/D = 0.8$, $q/Q = 1$) during full-bore condition, there is no need to verify that this condition is satisfied as long as condition (c) above is satisfied, i.e., provided that the sewer does not become surcharged.

(e) Minimum sewer diameters are provided.

An example of shallow sewer design using the above criteria is presented in annex I.

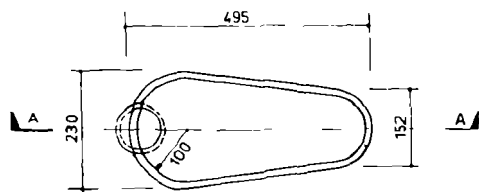
D. Appurtenances

1. Pour-flush water-seal units

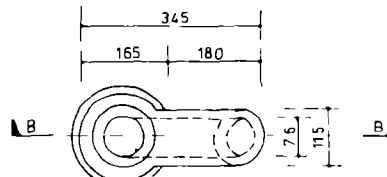
All forms of conventional pedestal toilet seats may be used in conjunction with the shallow sewer system. However, these use unnecessarily large quantities of water (9-19 litres per flush). Because shallow sewers do not need large quantities of flush water, manually flushed squat pans and pedestal seats which use approximately 3 litres of water per flush may also be utilized in conjunction with shallow sewers (see figure 6). Recently, low-volume cistern-flush units have been produced which use between 1.5 and 5 litres of water per flush. 32/33/34/

2. Grit/grease traps

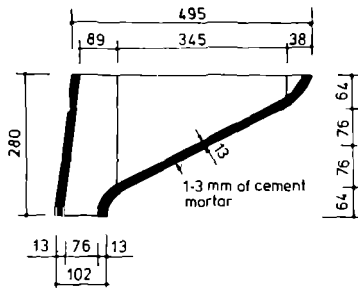
A variety of grit/grease traps is commercially available in most countries, and some examples of these are shown in figure 7. The device is provided to prevent the entrance to the block and street sewers of excessive quantities of grease and inert materials. Although it is advisable that they should be provided in the kitchen and wash areas of all shallow sewerage schemes, they are essential in areas where inert materials are used for cleaning utensils and where water consumption is low, otherwise grease could solidify in the



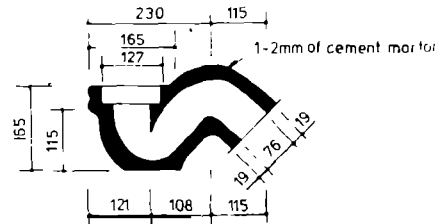
PLAN OF SQUATTING PLATE (PAN)



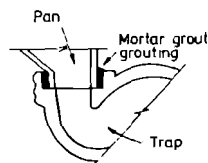
PLAN OF WATER SEAL UNIT (TRAP)



SECTION A - A



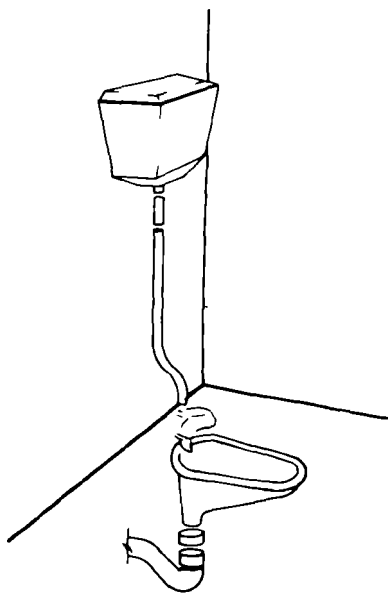
SECTION B - B



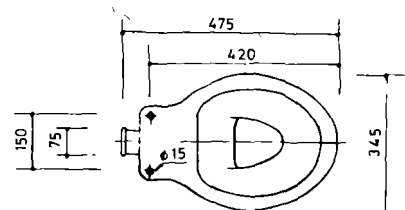
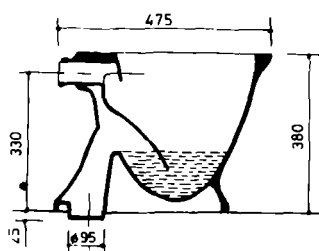
JUNCTION OF PAN TRAP

DETAILS OF MANUALLY FLUSHED SQUATTING PLATE (PAN)

Source: Kalbermatten, J.M., and others, *Appropriate Sanitation Alternatives - A Planning and Design Manual* (Baltimore, Johns Hopkins University Press, 1982).



UPGRADED SQUATTING PLATE WITH
LOW-VOLUME CISTERN FLUSH UNIT



LOW VOLUME FLUSH CERAMIC PEDESTAL UNIT

(Reproduced by courtesy CIDAMAR, Sao Paulo, Brazil)

Figure 6. Pour and cistern flush units for shallow sewerage.

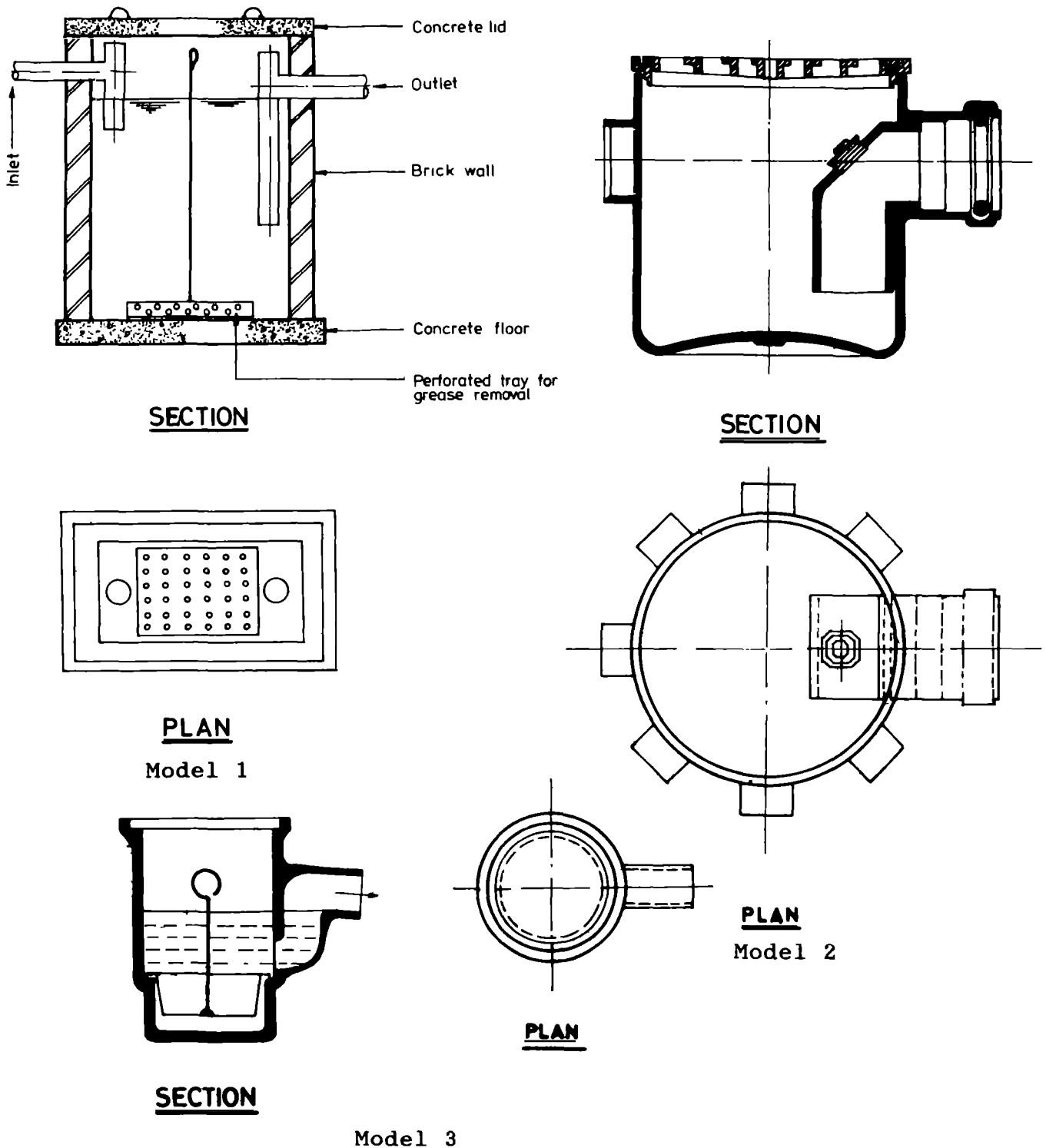


Figure 7. Examples of grit/grease traps for shallow sewerage

Source:

- (1) W.M. Malan, A Guide to the Use of Septic Tank Systems in South Africa, CSIR Research Report No.219, (Pretoria, CSIR, 1964).
- (2) Brasilit Inc., Nova Caixa Sifonada Brasilit, Sao Paulo - SP, Brazil, 1985
- (3) L. Woolley, Drainage Details in SI Metric, (London, Northwood Publications, 1978).

sewers and become the basic cause of a blockage. In low-income settlements, all washing and bathing activities are usually performed in a single room, and the provision of a grit/grease trap with a grated surface located at the lowest point in the room will ensure the surface drainage of all sullage generated in the room.

The design and construction of grit/grease traps should provide for conditions which are quiescent enough to allow the grease to rise and the grit to settle. In the past, grit/grease traps were made of glazed clayware, but plastic is commonly used today. An interesting design of grit/grease trap, shown as model 2 in figure 7, is a plastic one which has a number of multi-directional inflow connection ears. These ears are sealed initially but may be perforated to effect connections to the trap. This is especially useful in low-income housing areas, because the grit/grease trap may be used as the focus for sullage collection, and it facilitates future connections as users upgrade plumbing equipment by providing washing sinks etc., at some future date. Long connections to the block sewer inspection chamber, required each time a new plumbing installation is introduced, are thus eliminated.

The proper functioning of a grit/grease trap is very much dependent on the regularity with which it is cleaned. The frequency of cleansing will depend on local conditions, but a weekly inspection should be carried out. The grit/grease trap should be located as close as possible to the point of discharge from the kitchen.

3. Sewer ventilation

Ventilation to a shallow sewer network is provided through ventilation columns installed along individual water closet house connections. No ventilation columns are usually required along block and street sewers: only in cases of very long street sewer lengths (usually in excess of 5 km), without any block sewer connections along the length, would the provision of suitable ventilation columns become necessary in order to prevent the sewage sewer from becoming septic. Such situations rarely occur in shallow sewer layouts and the fact that a majority of the sewers are laid at very shallow depths in itself ensures facilitated ventilation.

4. Sewer pipes

Sanitary sewer pipe materials derive a substantial part of their basic load-carrying capacity from the structural strength inherent in the rigid circular pipe wall. Since individual water closet and sullage house connections are often laid within the premises they serve, they remain protected from heavy loads and, therefore, materials of lower quality and strength than those used for street sewers may be used for these and for the ventilation columns. Polyvinyl chloride (PVC), asbestos-cement and clayware pipes are commonly used for this purpose. Low-income squatter settlements and slums in many Asian and Latin American countries and some African countries have basic facilities for producing these pipes, often utilizing recycled materials and labour-intensive production processes.. With some guidance provided to entrepreneurs on controlling the quality of the product, it is possible to use materials which, being locally available, will present little problem for subsequent replacement and maintenance work. In some countries, 75 mm diameter vitrified clay pipes are also available and may be used for water closet house connections.

In order to reduce to a minimum the need for maintenance, all block and street sewers should be made of pipes of good quality and strength which are generally available in the formal markets. Although asbestos-cement pipes may be used for this purpose, their low resistance to acid attack, reduced beam strength and, often, high costs eliminate their consideration for use as block and street sewers. Vitrified clay pipes and reinforced and unreinforced concrete pipes are used for gravity sanitary sewers and are commonly adopted for block and street sewers. A number of mechanical processes, including centrifugation, vibration packing and tamping for consolidating concrete, enable non-reinforced concrete pipes to be manufactured up to diameters of 900 mm. Concrete pipes are, however, also subject to acid corrosion, and vitrified clay pipes, when available, are, perhaps, the most suitable for use in shallow sewer systems. Their extremely long service life and resistance to abrasion and chemical attack make them an ideal material for sewers.

Contemporary clay-firing techniques obviate the need to use vitrifying agents to ensure a high-density, strong and impervious pipe body. In some countries, where suitable clay materials are readily available, it is common to find a clay-pipe manufacturing capacity in the informal sector. Many of these establishments are located in and run by low-income communities, and it may, in certain circumstances, prove feasible to upgrade the capacity of these establishments to produce pipes of adequate quality and strength for use even for street sewers. Clearly, the availability of local materials, skills and production capacities and the overall scale of the sanitation programme envisaged will, to a large extent, determine the sewer-pipe material to be used. The income-generating potential for low-income communities in producing pipes and other appurtenances must be given due consideration in determining the nature of materials and products to be utilized in the implementation of shallow sewer systems.

While the strength and quality requirements of pipes used for house connections and block sewers may be relaxed somewhat, all street sewers should satisfy the following quality requirements:

Minimum crushing strength:	20 KN/m
Maximum moisture absorption:	9 per cent of original dry weight of pipe sample after soaking in water for 48 hours

5. Pipe joints

A common requirement which must be imposed on the design of all sanitary sewer systems, regardless of the type of sewer pipe specified, is the use of reliable, watertight, root-resistant and durable pipe joints. The requirement for the control of groundwater infiltration and wastewater exfiltration in sanitary sewer systems renders the specification of pipe joint design essential to proper block and street sewer design. A substantial variety of pipe joints is available for different pipe materials used in sanitary sewer construction.

Although there is a variety of gasket (elastomeric seal) pipe joints, which provide a desirable degree of flexibility and are readily fitted by unskilled labour, their use in most developing countries is very limited, especially for sewers in low-income communities. Rigid cement-mortar joints for dry-trench conditions

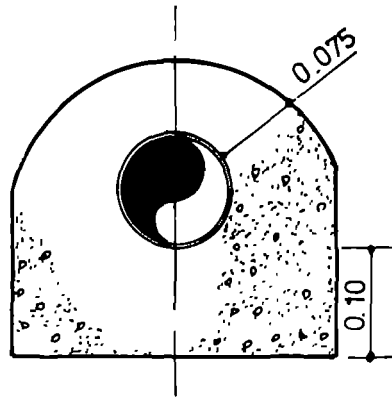
and bitumen-soaked coir-rope-gasket joints for pipework to be laid under the groundwater table are most commonly used in these areas. Water infiltration/exfiltration testing or air exfiltration testing is normally specified to ensure that pipe jointing is of adequate quality.

6. Pipe bedding

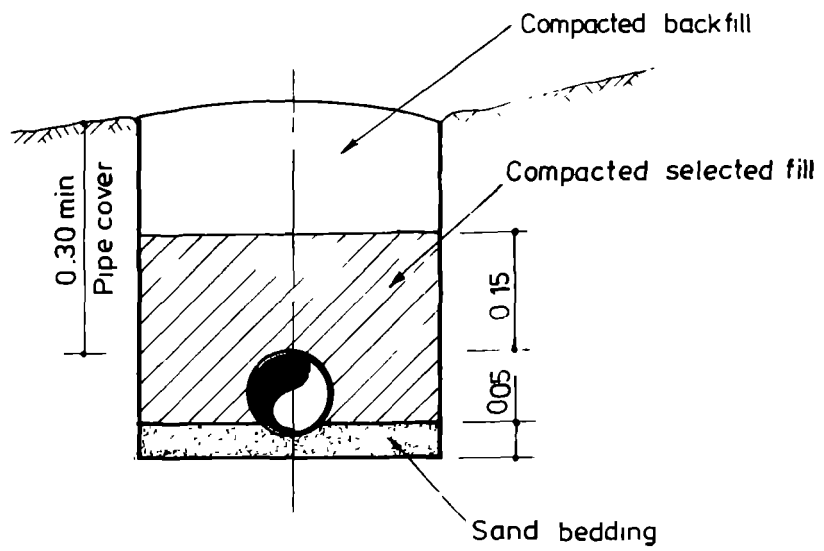
The contact between a pipe and the foundation on which it rests is the pipe bedding. The bedding has an important influence on the distribution of the reaction against the bottom of the sewer pipe and, therefore, influences the supporting strength of the pipe as installed. Loads on buried pipes are caused by the backfill above the pipes, additional wheel loads and distributed surcharge loads. The amount of total structural load that a pipeline can carry is dependent upon the combination of the strength of the pipe and of the bedding on which it is laid, so that high-strength bedding can be used with low-strength pipes or low-strength beddings used with high-strength pipes.

Rigid pipes, especially those of concrete and vitrified clay, are usually of sufficient intrinsic strength to withstand external loads with little or no additional support. At very shallow or very great depths, additional support, in the form of a granular bed, haunch or surround, is usually provided in conventional sewerage schemes which are almost always subject to both the load from the trench backfill material and loads from vehicles. In the case of shallow sewer schemes, however, vehicular loads are avoided for all block sewers and a majority of street sewers. In such cases, a 50 mm sand bedding has been found to be more than adequate to ensure the even distribution of loads along the length of the sewer and the prevention of pipe failure caused by overload fracture, beam fracture and bearing fracture. The pipe is usually laid in such a manner that approximately a quarter of the circumference of the pipe is embedded in the sand layer (see figure 8). Clean sand is normally used as the bedding material, and this has a minimum bedding factor of approximately 1.5, $\frac{35}{20}$ i.e., the composite strength of the pipe and the bedding is 50 per cent greater than the average intrinsic strength of the pipe. This form of pipe bedding is quite adequate for most requirements in a shallow sewer scheme. However, where the sewers pass directly under vehicular loads and are laid to a depth below 0.8 m to the invert of the pipe, they must receive additional support in the form of a granular bed, haunch or surround. A concrete surround, as shown in figure 8, is recommended. In a pipeline constructed with rigid pipes, flexibility is provided by the joints. This may be lost with a concrete surround, unless flexible joints are constructed in the concrete surround using compressible boards. These should coincide with a joint in the pipeline and should be not more than 5 m apart. In very poor site conditions, where significant movement is possible, these should be provided at each joint.

Flexibility is also usually required where a pipeline is connected to manholes or where it passes through a wall, i.e., at any point of construction where differential movement may subsequently be experienced. In the case of shallow sewers, the small inspection chambers and, on occasions, plot boundary walls may present occasions for such differential settlement. The settlement caused by these structures, will however, be too small to warrant any special provision to be made in the design. Arching of brickwork will in itself ensure that no loads are directly transmitted to the pipe. It



**CONCRETE PIPE
PROTECTION DETAILS**



PIPE BEDDING DETAILS

Figure 8. Shallow sewerage pipe bedding and protection

is, however, possible that, at some future date, an extension to an existing building may be required to pass over a shallow sewer line. In such a case and in all similar cases where load-bearing walls are required to pass above existing pipelines, special precautions in design are necessary. A joint should be provided in the pipeline within approximately 150 mm of the face of the structure, and, where the differential movement is likely to be appreciable, the length of the next pipe should be restricted to 600 mm and the structure around the pipe suitably arched to reduce the direct load on the pipe. It is however interesting to note that, in north-east Brazil, even where no such special provisions were made to protect the pipes as they passed under load-bearing walls, no adverse effects such as pipe fracture and failure were noted even after five years. Clearly, the nature of the will, to a large extent, determine the need for the provision of pipe flexibility.

7. Inspection chambers

In shallow sewer systems, inspection chambers are provided along block and street sewers for the following purposes:

- (a) Connecting water closet and sullage house connections to the block sewer;
- (b) Connecting block sewers to main street collector sewers;
- (c) Providing access for purposes of cleaning and maintenance;
- (d) Accommodating changes in direction in both block and street sewers.

The depth to invert of a sewer at the point where an inspection chamber is required will determine the dimensions of the chamber. Where the depths are shallow, usually up to 0.75 m, there is no necessity for the physical entry to the chamber for purposes of maintenance. However at, greater depths than this the chamber dimensions have to be such that the maintenance crew can physically enter the chamber. Since shallow sewer schemes rarely exceed 2.0 m in depth, three types of inspection chambers have been designed, depending on the depth of the sewer they serve. The dimensions of these chambers are presented in table 2 and are also illustrated in figure 9. In the rare event that the depth of sewer exceeds 2.5 m, a manhole of the type commonly used for conventional sewers, may be provided. A square form is usually adopted for the design of inspection chambers for shallow sewer systems; however, since, in most developing countries, split bamboo is the most common implement used to remove blockages, the use of a rectangular-shaped chamber (with the large dimension of the chamber being constructed along the length of the sewer line) will facilitate rodding through the formation of a gentle curvature on the rodding implement.

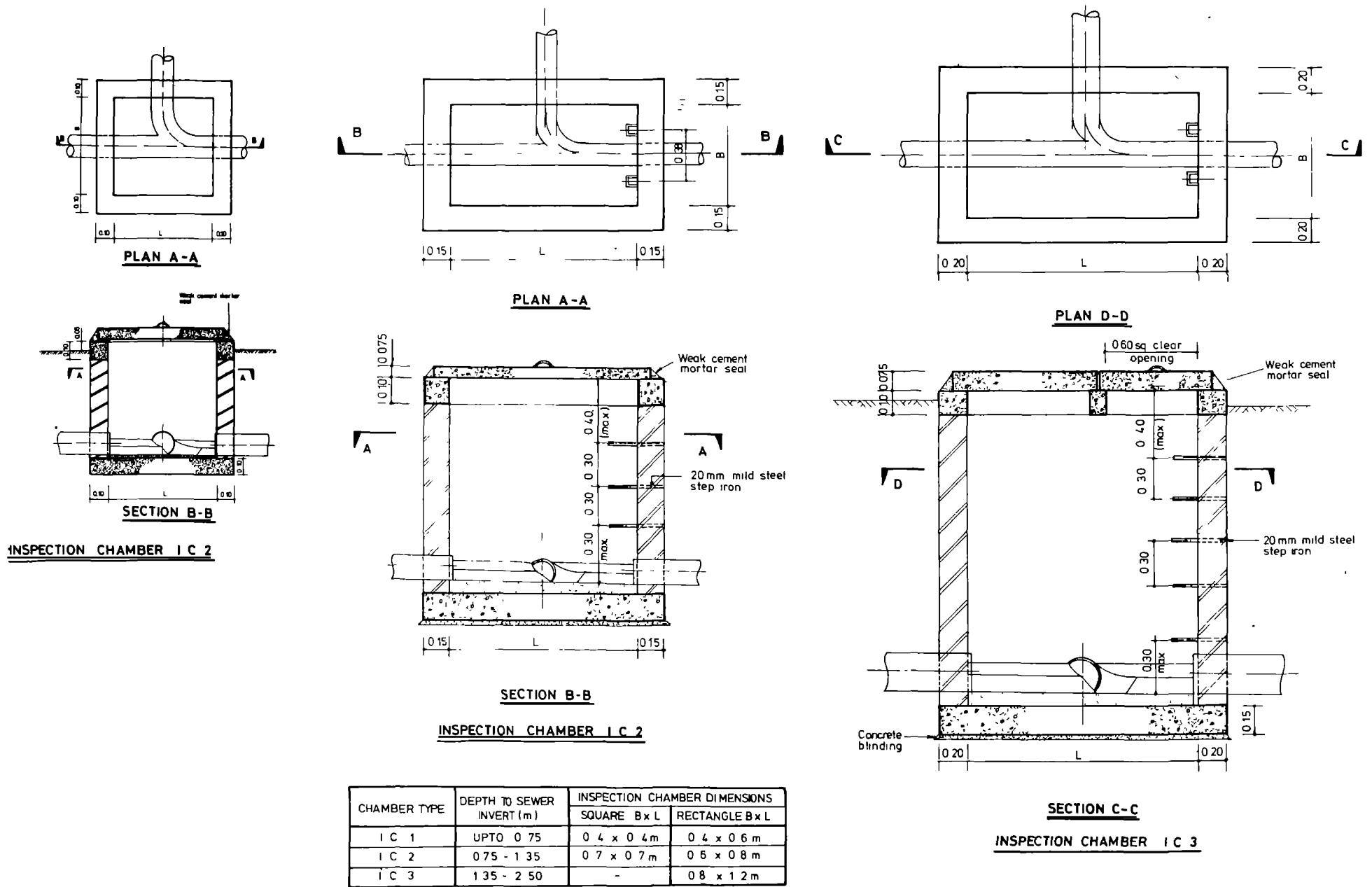


Figure 9. Shallow sewerage inspection chambers

Table 2. Inspection chamber dimensions

Chamber type	Depth of sewer (m)	Inspection chamber dimensions	
		Square (m)	Rectangle (m).
IC1	Up to 0.75	0.4 x 0.4	0.4 x 0.6
IC2	0.75 - 1.35	0.7 x 0.7	0.6 x 0.8
IC3	1.36 - 2.50	-	0.8 x 1.2

Inspection chambers are usually made with an unreinforced concrete base and brick or blockwork walls. Alternatively, the chamber walls may be cast in situ in concrete, with prefabricated moulds and shutters. In areas where stone is readily available, this may prove to be the most economical building material, provided that the stone is of adequate hardness and limited moisture absorbing capacity. Even though stone may be cheaper than brick or blockwork, this does not necessarily imply that it is the most economical material, since its use often requires greater quantities of cement mortar and higher constructional skills. The overall cost of finished chamber walls must be established prior to selecting the appropriate material.

All inspection chambers deeper than 1.0 m have to be provided with foot-rests inside them. These are made of 20 mm mild steel square or round bars, embedded 20 cm deep into the brickwork every fourth course. The foot-rests are staggered laterally in two vertical runs, which may be 38 cm apart horizontally, and must project 10 cm beyond the surface of the chamber wall. The top foot-rest should be 45 cm below the inspection chamber cover, and the lowest not more than 30 cm above the benching. The total length of step bar is 75 cm.

The finished top cover level of all inspection chambers should be 10 cm above surrounding ground level in order to prevent the ingress of surface waters to the chamber. Where it is necessary to maintain the cover flush with the surrounding ground level, as is usually the case with chambers constructed in the road, conventional steel manhole covers are necessary, especially where these covers are subject to heavy vehicular loading. The neck of the chamber would have to be suitably adapted to permit the use of these covers. Because shallow sewers are usually located along sidewalks, the use of simple reinforced concrete covers is usually adequate.

III. SHALLOW SEWER PLANNING AND IMPLEMENTATION STRATEGIES

The strategies to be adopted in planning and implementing shallow sewer systems will, to a large extent, depend on the nature and age of the settlement. Existing, unplanned, often illegal, low-income settlements necessitate far more effort at both the planning and implementation stages than newly-planned sites-and-services or low-income housing schemes, where shallow sewers may be introduced as one of the services provided. In both cases, however, the success of the sanitation system relies on involving and informing the beneficiary communities of the various aspects of the design and operation of the system.

A. Project area and drainage basin

The first step in planning a shallow sewer system is the establishment of the project area and associated natural drainage basins to which it conforms. This is usually done by delineating the boundaries on a 1:10,000 map with contours every 5 m. All planning of shallow sewer systems is undertaken according to natural drainage basins. Frequently, the entire settlement or project area conforms to the bounds of a single natural drainage basin, but where this is not the case parts of the project area conforming to different drainage basins can be considered in isolation for purposes of establishing sewer layouts and for organizing the community to participate in the programme.

Even for subsequent treatment of collected sewage, it is often advantageous to consider the use of separate treatment units for different drainage basins. However, the economics of adopting a single treatment unit, with suitably designed pumping stations to deliver the sewage from the different basins to a common point, must be assessed. Pumping may become inevitable in congested urban areas, in order to deliver sewage to a selected area for treatment, unless access to a nearby sewer exists. Although the project area may form only part of the total area of a natural drainage basin, perennial or non-perennial tributary water courses draining the basin may be used to dispose of treated effluents.

B. Physical surveys

In order to prepare detailed street sewer layouts, maps of the area to be served are required at a scale of 1:2000. The map should show elevations (by means of contours every metre), roads, buildings, property boundaries and other pertinent information. Information regarding the geology and hydrogeology of the area may also be required, in order to select suitable treatment sites and make accurate estimates of the cost of the scheme. While these preliminary surveys can be conducted without the assistance or co-operation of the community, a second survey which relies on such participation will have to be undertaken, in order to establish the layout of the block sewers. Because the block sewers invariably pass through individual properties, usually at the back of the house, community consent and co-operation are essential, initially to establish the location of the block sewers and inspection chambers and subsequently to obtain the elevations along the selected route.

Plans must be prepared for every block at a scale of 1:500, indicating each house, building and property boundary. When each house has been visited, and the householders' preferred location for

the inspection chamber within each plot has been established, a topographical survey is conducted to establish the elevations of inspection-chamber locations. The block sewer layouts can then be made on the block map. In highly congested unplanned areas, spot levels of the proposed inspection chamber locations can only be obtained by utilizing stilts to support the surveying equipment, in order to obtain the necessary line of vision above boundary walls for level readings.

C. Sample socio-economic survey

It is often the case in low-income housing settlements that very little information will be available regarding the types of services provided, plumbing equipment used, water availability and usage patterns, and household payment capacities - all essential information for planning and designing block sewers. In such cases, it is necessary to conduct a sample domestic survey to elicit such information and also provide some indication of the beneficiaries' preferences and priorities. Commonly, a minimum sample size of 7 per cent of the project population is used to obtain statistically valid information.

The nature and structure of the questionnaire will vary from one project site to the next, but basic information, usually obtained from formal questionnaires, includes the following:

- (a) Type of occupation of the house (rented, owned etc.);
- (b) Type of housing and its location within the compound;
- (c) Origin and size of family;
- (d) Income and occupation;
- (e) Levels of services and corresponding payments;
- (f) Nature of facilities, including plumbing and sanitary fixtures, and water usage patterns;
- (g) Present modes of excreta and sullage disposal;
- (h) Preferences for sanitation systems;
- (i) Deficiencies in the provision of services in the area and order of priority for resolving them.

The information obtained is usually structured in the form of a questionnaire that conforms with the general principles of "heuristic elicitation", i.e., each question is based on the answer of the previous question so that they are respondent-generated rather than investigator-generated and are, thus, minimally affected by interviewer bias. Additional information on the design and application of suitable socio-economic survey questionnaires together with sample formats are presented elsewhere. 26/36/37/

D. Institutional requirements

The nature of shallow sewerage demands that some local authority, usually the municipality or the water authority, be entrusted with the responsibility for designing and implementing the scheme. However, very few of these institutions have had any practical experience in

working with the communities they serve by involving them at the stages of technology selection design, construction and operation, as is required for shallow sewer schemes. It may prove necessary to create a special technical unit within existing institutions, in order that adequate training can be provided to the staff to ensure the successful delivery of this community-based sanitation system.

An alternative approach, which has had some success, is to entrust the tasks of mobilizing local communities and of executing the block sewers to non-governmental organizations (NGOs), while co-ordinating the overall scheme under the local authority which also remains responsible for executing the main collector sewers to which the individual block sewers drain. It is often possible to make a distinction between the block sewers and the street collector sewers, because the members of the community often prefer to maintain the block sewers themselves. Thus, only the external sewer needs to be maintained by the authorities.

The involvement of NGOs is particularly useful when the entire capital cost of the scheme needs to be raised prior to initiating construction. However, given the scale at which most shallow sewer schemes are implemented, the capital cost of the system is usually met by some form of government loan which, together with the cost of operation and maintenance, is recovered through a monthly tariff, often represented as a percentage of the water tariff. All lift stations and sewage treatment plants will naturally come under the jurisdiction of the local authority.

E. Community involvement in construction of shallow sewers

Whatever the organizational pattern of the agency entrusted with the programme, planning, construction and operation of shallow sewers require extensive community involvement, acceptance and participation. Based on the findings of the sample survey and when funds have been allocated for the scheme, promotional activities must be undertaken, with the objective of introducing the sanitation programme to the community. Community leaders should be initially identified and informed of the benefits of the programme, and the need to stimulate the participation of all community members emphasized.

With the consent and involvement of the leaders, general community meetings can be convened, to explain the programme and obtain the agreement of the householders to conduct door-to-door surveys. These will establish the location of existing plumbing installations and the householders' preferred locations for the inspection chambers to be constructed within their premises and the corresponding elevations. A brief description of the shallow sewer concept is presented to the community at the meetings, together with its advantages and disadvantages. Small-scale physical models are sometimes used to help communities understand the system.

At the end of the first meeting, the project staff agrees with the community to undertake the following:

(a) Arrange individual meetings for each block to present a proposed block sewer layout based on the physical, topographical and door-to-door surveys conducted. (The layout is usually presented on a 1:500 map showing all buildings, boundary walls and block sewers and inspection chambers.)

(b) Obtain consent on the proposed layout for the block sewers.

(c) Obtain agreement as to the delineation of responsibility between the community and the authorities. (Community responsibility for operation and maintenance of the block sewers keeps down costs and ensures that the system is not abused. Each household is usually made responsible for that length of sewer passing through its property. A feeling of obligation to one's neighbours is usually instilled through discussions at these meetings. Street collector sewers are usually maintained by the local authority.)

(d) Present estimates of the cost of the system and obtain agreement on the amount and mode of repayments, usually in the form of a monthly tariff.

Agreement is also obtained from the community to provide free access to its properties to project staff and to survey and construction teams.

Even if majority consent is given on all the above issues, it is possible that some community-group pressure and persuasion will be required to ensure that all households participate, in order that the overall costs may be minimized and the health impact of the intervention maximized. It is also possible that some doubts may arise in the minds of community members as to the technical and social feasibility of the system, especially with regard to blockages which could lead to gross nuisance within their premises. The construction of a single block sewer serving an entire block may be implemented as a pilot scheme to demonstrate both the technical and social feasibility of the shallow sewer system. (The sewage drained from the pilot block may be treated in a communal septic tank and disposed of through infiltration trenches.) Once the pilot scheme has been shown to operate without problems, and other members of the project community are able to discuss the benefits and problems of the system with those served by the scheme, the pilot scheme itself acts as the main motivating force in creating acceptance of and a demand for shallow sewers.

Since the blocks are seen as the basic units of social organization, all sewer layouts within the block are established in consultation with the community. The block layouts subsequently determine the final layout of the street sewers. When the invert levels of all block sewers emerging from the various blocks in the project area are known the street collector sewer layout may be established with its corresponding elevations.

Construction is first initiated with the implementation of the street collector sewers and treatment works. Block sewers are subsequently connected, according to priorities established by the community. All house connections are then made to the respective block sewers. The entire system is thoroughly tested before commissioning. The involvement of the community at all stages ensures a very high percentage of house connections and a level of sanitation service which is in no way inferior to that of conventional sewerage.

The implementation of the block sewer usually necessitates a day or two in each house for purposes of constructing the sewer, inspection chamber and associated house connections. This work is often conducted by small subcontractors and supervised by local authority technicians trained specifically for this purpose as part of a special unit created for the execution of shallow sewer systems.

The technicians are also trained in simple maintenance procedures, including the proper operation of all appurtenances associated with the system.

The time spent by the technicians in each house during the construction process presents an ideal opportunity for transmitting information to the householders. It is, also, often advantageous to employ both skilled and unskilled labour from the community itself for construction, in order that indigenous knowledge about the system is built up for future maintenance purposes. This also ensures that investments in infrastructure within the community bring direct economic benefit to its members.

F. Worker requirements

The planning and implementation of shallow sewer systems require a multidisciplinary team of engineers, social scientists, technicians, masons and unskilled personnel. A list of the various functions and activities in the planning and implementation of shallow sewer schemes and their associated skill requirements is presented in table 3.

Table 3. Nature of skills required to execute various activities related to shallow sewer planning and construction

Activity	Skill required
Execution of physical and topographical surveys of roject area	Engineers/surveyors
Social mobilization including identification of community leaders	Sociologist
Execution of socio-economic and water usage surveys	Sociologist/technicians
Conducting community meetings	Sociologist
Location of block sewer inspection chambers	Householder/ technicians
Determination of elevation at block sewer inspection chamber locations	Surveyor/technician
Planning and designing of block sewer layout	Technician
Planning and designing of street sewer layout	Engineer
Planning and design of pumping stations and treatment works <u>a/</u>	Engineer
Construction of block sewers and house connections	Small subcontractor
Supervision of block sewer and house connection construction	Technician
Construction of street sewers	Small subcontractor
Supervision of street sewer construction	Engineer/technician
Construction of pumping stations and treatment works <u>a/</u>	Large contractor
Supervision of pumping station <u>a/</u>	Engineer/technician and treatment works construction
Determination of cost estimates and appropriate tariff structure for cost recovery	Engineer

a/ Where applicable; they are rarely required for shallow sewer schemes.

A majority of the duties associated with the design of shallow sewer schemes requires only a low-level cadre of technicians: overall supervision by qualified engineers and sociologists will, however, be necessary. The simple nature of most of the construction associated with shallow sewers means that small (local) subcontractors may be engaged for implementing the system, instead of large constructors as is usual with conventional sewerage. The reduced overheads associated with small contracting companies reduces the overall cost of the scheme considerably and offers potential for engaging local community members in the construction process. Attempts by many authorities to employ direct labour for construction have proved to be inefficient, and this is therefore not usually recommended.

G. Project drawings

Simple engineering drawings are produced to facilitate the construction of shallow sewer systems. They include:

(a) A map of the project area, showing elevations by means of contours distributed every metre, existing roads, buildings, property boundaries etc., upon which is superimposed the location of street sewers, suitably referenced, and all road inspection chambers along its length. (A scale of 1:2000 is usually adopted for this purpose although, in congested areas, a scale of 1:1000 may be more appropriate - see figure 14.)

(b) A second layout plan showing the street sewers with their corresponding reference numbers, lengths, pipe diameter, gradients and bedding details, and the ground and pipe invert level information at each inspection chamber (see figure 14). (Usually house and street layout lines are omitted from the second drawing, eliminating the need to produce longitudinal cross sections of the sewers, since all the information can be readily abstracted from this second plan.)

(c) A plan of each block of houses, usually to a scale of 1:500, showing the layout of each block sewer and inspection chamber along its length in relation to the position of each house and property boundary. (In the case of a planned low-income housing scheme a typical layout plan would be adequate, but, in unplanned settlements, it is necessary to prepare a specific plan for each block - see figure 15.)

(d) A typical plan and appropriate sections depicting house connections and plumbing installations to an acceptable scale, usually 1:50.

(e) Plans and sections of inspection chambers and sections showing pipe bedding and trench excavation to suitable scales (see figures 8 and 9).

(f) Plans and sections of sewage pumping and treating facilities.

IV. CONSTRUCTION AND MAINTENANCE OF SHALLOW SEWERS

The techniques used for the construction of shallow sewers are the same as those used in conventional sewerage, except that, owing to their shallow depth and the use of small subcontractors for their construction, simple methods of maintaining horizontal and vertical controls and ensuring quality in construction have been developed to minimize costs while still achieving acceptable standards. These and other measures necessary for maintaining construction quality control and preparing construction cost estimates are presented in this chapter. Requirements and procedures for maintaining shallow sewer systems are also included.

Usually, construction begins at the treatment and disposal facilities, with the street sewers being laid next, in the upstream direction, before finally construction of the block sewers and house connections. The construction of the block sewers, generally through private property boundaries, presents certain problems of a social nature that can only be overcome by active community participation and unqualified community acceptance of the system. Construction procedures should, therefore, be designed so as to create the least inconvenience to householders.

A. Block and street sewer installation

1. Preliminary layouts

The construction of block sewers for a new housing scheme presents fewer problems than their construction in existing unplanned settlements. In the latter case, the community must be kept informed and must participate at every stage of planning and construction, and its agreement on all proposals, including sewer layouts and mode of construction, must be obtained and respected. During the initial planning stage, when house calls are made to establish the householders' preferred locations for the inspection chambers, wooden stakes or pegs are used to mark the exact locations. The sewers follow a linear alignment between the pegs or inspection chambers. The street sewers require some consultation with the community to establish layouts and construction methods, but they are, generally, determined in relation to the emerging block sewers. Pegs are generally used to mark the location of inspection chambers along street sewers.

2. Setting line and grade

The line of the sewer should follow, as far as possible, that which was established during the design and agreed with the community. The centre line of the trench must usually coincide with the centre line of the sewers between adjacent inspection chamber pegs. Benchmarks established within the block and along streets are used for sewer line and grade control.

It has proved adequate to control levels by the use of a simple mason's barometric level. The barometric level is composed of a simple transparent plastic tube (usually 5 mm in internal diameter) open at both ends and filled with water in such a way that, when held in the form of a U-tube (the normal position of use), it has a sufficient column of air above the water surfaces in each leg of the tube. The two legs of the tube are held against metre rules placed at the two points whose difference in level is required. Since the water

levels in each leg of the tube are at a constant elevation, because they are both subject to atmospheric pressure, the difference in the heights of water columns in each, as read from the metre rules, represents the difference in level between the two points upon which the metre rules were placed. An illustration of this simple level device is presented in figure 10. This form of level instrument is especially useful in controlling and establishing sewer grades in existing unplanned settlements where the construction of the block sewer often requires the partial demolition of boundary walls during construction. The level can be passed through the portion of wall demolished for trench excavation to obtain the level difference between adjacent inspection chambers, and where more conventional survey instruments could not be used due to the obstruction of the instrument's line of sight by the intervening wall. Conventional level instruments have, however, been adapted for this purpose by placing them on stilts and using a step ladder to obtain instrument readings.

When the required difference in level between adjacent inspection chambers has been established, the constant sewer grade required between them is ensured by placing a taut piece of string between the two points at a height above the pipe bedding equivalent to the external diameter of the pipe socket, in such a manner that the top surfaces of all laid pipe sockets would be just in contact with the string. In determining the required trench invert depth for pipe laying and inspection chamber construction, allowances must be made for pipe wall thickness and depth of bedding, and for inspection chamber base and benching. Where automatic or other level instruments are used to obtain the depth and slope of the bottom of the trenches and the levels of the inverts of pipes, the usual method of sight rails and boning rods (or travellers) is employed. Street sewers are usually set out and graded by this method.

3. Excavation

Extreme care is necessary to locate and protect existing utilities and foundations of structures. Care must also be taken to ensure that boundary walls, when partly demolished to facilitate sewer construction, are broken in an arched form, straddling the trench, in order to avoid cracking and collapse. All demolitions must be made good upon completion of sewer laying. Sides of excavation walls may be vertical, in favourable ground conditions, or inclined at a suitable angle of repose, when excavated deep in unfavourable ground. The width of the trench must permit the laying of pipes with ease and accuracy, and, although the width of the trench will vary with the type of soil and ground condition, the values presented in table 4 serve as a useful guide for both cost estimation and control to avoid over-excavation.

Excavation is usually performed manually, but, where rock is encountered, some mechanical assistance may prove useful. The shallow depths to which excavation is usually performed for shallow sewer systems imply that there is little need for trench support apparatus, but, when the depth of excavation is such that the soil type does not provide sufficient safety against trench collapse through caving in, the sides of the trench should be supported by timbering. Timbering consists of vertical poling boards supported by waling boards, placed horizontally and at right angles and securely held in place with horizontal struts, fixed across the trench about 2 m apart. The distance apart of poling boards and waling boards depends upon the

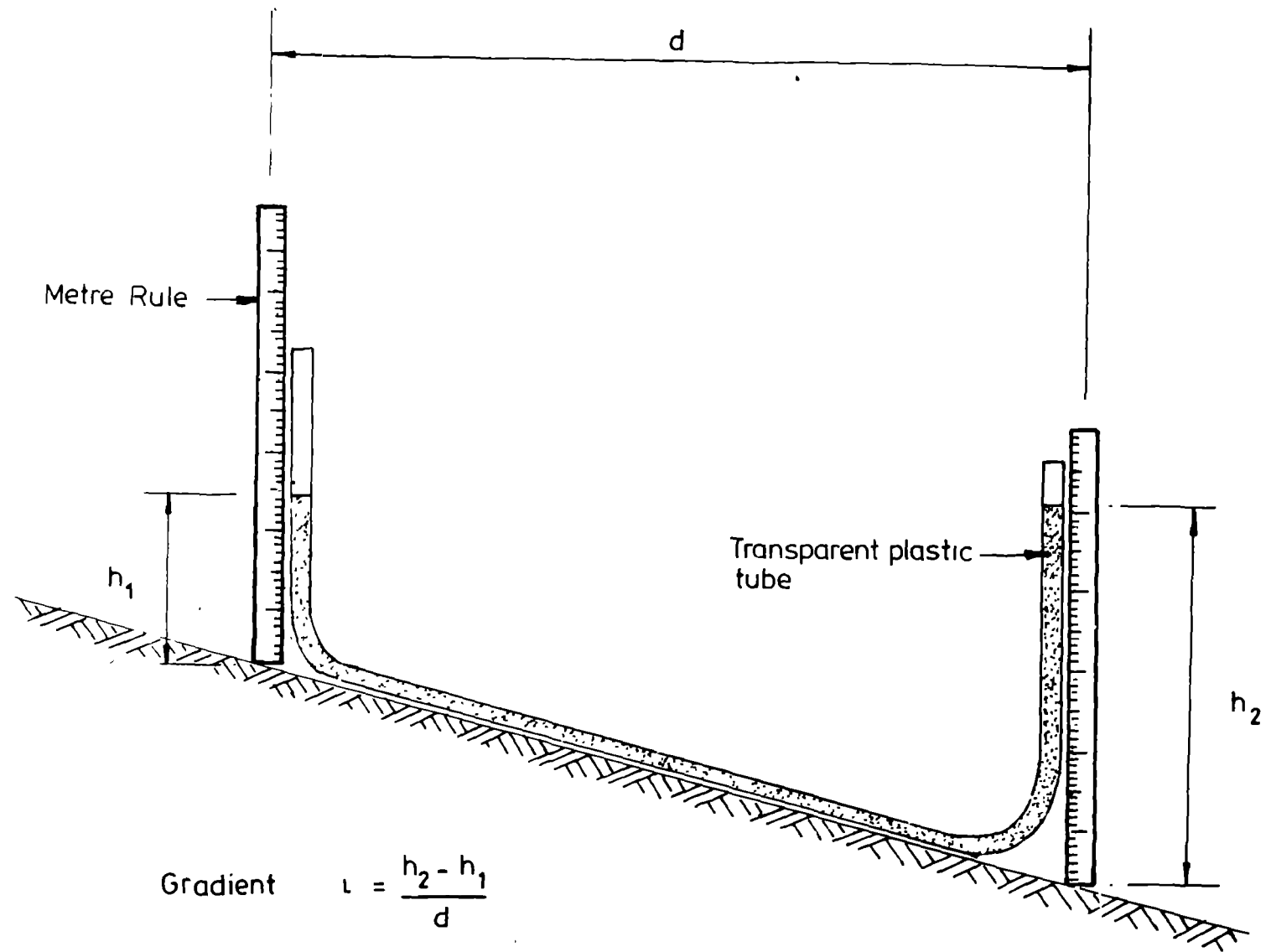


Figure 10. Barometric level

looseness of the soil to be supported: the bottom set of poling boards should be driven at least 230 mm below the trench-bed level. The trench should be sufficiently wide to allow space for timbering: a space of 150 mm to 230 mm on either side of the body of the sewer is considered sufficient. Steel (or wooden) interlocking sheet piles are used where water or running sand is encountered.

Table 4. Approximate trench widths for different pipe depths and diameters

Pipe diameter (mm)	Depth to pipe invert (m)				
	Up to 0.6	0.6-1.0	1.1-1.5	1.6-2.0	2.1-2.5
100	0.40	0.50	0.65	0.70	0.75
150	0.45	0.60	0.70	0.75	0.80
200	0.50	0.70	0.75	0.80	0.85

4. Pipe bedding and backfilling

Depending on the depth of pipe laying and expected superimposed loads on the pipe, one of the types of pipe bedding suggested in chapter II is required. Where rock is encountered, the sand cushion usually provided throughout the length of shallow sewers normally proves to be adequate bedding. In some grounds, where the finished surface of the formation becomes soft after levelling, a firm bottom may be obtained by spreading and compacting a 75 mm layer of gravel or broken stone over the trench bottom which should be further excavated to receive this. Excess excavations should also be similarly filled, and the trench bottom levelled to the appropriate grade. Extra excavation is required under sockets, to allow hands to pass for making joints and to ensure that the body of the pipe is suitably supported on the bedding. Backfilling materials should be free from stones, hard materials, waste, objectionable organic matter, rubbish and boggy or other unsuitable materials. Such selected material must extend to 300 mm above the top of the pipe and across the full width of the trench. Backfilling must be done in 230 mm layers thoroughly rammed, and excessive watering should be avoided. Excess backfilling to form a dome shaped surface above the trench is desirable to take account of future settlement.

5. Laying and jointing pipes

Each pipe should be carefully examined for soundness before laying: concrete and clayware pipes should be rung with a light hammer, and those that do not ring true and clear should be rejected. All sewer pipes are laid with the socket at the higher end, and, consequently, it is necessary to begin at the low end of a drain and to work upwards. Bad pipe jointing is the cause of a majority of pipe

blockages 12/ and the need for good construction and quality control during execution cannot be overemphasized. The nature of pipe jointing differs for different pipe materials.

(a) Jointing clayware pipes

The spigot of each pipe should be placed in the socket of the one previously laid, the spigot ends in the direction of the flow. Socket ends are useful for adjustment of small angles in the alignment during laying. Before laying the second pipe, the socket of the first is thinly painted all around on the inside with cement mortar (1 part cement to 2 parts clean sharp sand). A ring of rope yarn (closely twisted hemp or jute, called a "gasket"), dipped in neat cement grout (thick paste), tar or bitumen, is usually inserted in the socket of the pipe and driven home with a wooden caulking tool and wooden mallet. The rope should fully encircle the spigot with a slight overlap and should not occupy more than one fourth of the total depth of the socket. Where the spigot end of the pipe is made for receiving the gasket (the exterior of the spigot end and interior of the socket are provided with grooves and left unglazed), it should be wrapped round with two or three turns of tarred spun yarn as near the end as possible before inserting into the socket. This helps to keep an even space all around the spigot in the socket.

The joint is then completely filled with cement mortar (1:5) which should have very little water, and bevelled to form a splayed fillet at an angle of 45 degrees with the outside pipe. The lower half of the socket must be first spread evenly with cement mortar before introducing the spigot of the fresh pipe, in order to ensure that the underside of the finished socket is adequately filled with mortar. Care must be taken to ensure that any excess of cement mortar etc., left inside the pipe joint, is neatly cleaned off immediately each joint is made. This is best achieved by passing a cloth plug attached to a piece of wire through the pipe to be laid, so that the plug rests inside the previously laid pipe before jointing and can be pulled through the newly jointed pipe immediately after jointing. A tightly fitting cloth plug usually produces a smooth bore at the joint, but a semi-circular wooden scraper or a rubber disc attached to a long handle may also be used for this purpose. The backfilling of the trenches or the concreting of the haunching or surround, where specified, should not be undertaken until the joints of the pipes are thoroughly set and have been inspected, tested and approved.

(b) Jointing concrete pipes

Concrete spigot and socket pipes are laid and jointed as described above for clayware pipes. For reasons of water-tightness, concrete pipes having spigot-and-socket joints should be used where practicable in preference to those having ogee joints. Ogee joints are used to join pipes with the same internal diameter by using a concentric, concrete collar at the joint. Joint preparation and casting, as described above for clayware pipes, are used to produce a double splayed fillet at an angle of 45 degrees with the outsides of the two pipes.

6. Testing sewer pipes for leakages

All sewer pipes should be subjected to either a smoke or water test to detect leakages before backfilling the trench in which they are laid. The sewers are usually tested in sections, but, while careful testing of all pipework is recommended, detailed testing is

usually only performed for street sewers. Many shallow sewer systems laid with simple cement mortar pipe joints, without gaskets and without any detailed testing procedures, have operated very satisfactorily for over five years.

(a) Smoke test

Smoke is made by firing oily waste (brown paper or cotton waste soaked in creosote), and the smoke is pumped into the pipework at the lower end with the aid of a smoke-testing machine. Smoke rockets may also be used for this purpose. Inadequately sealed joints will be seen to issue smoke when the opposite end of the pipework is plugged. The defective joints must then be repaired until they stop issuing smoke.

(b) Water test

After the joints have properly dried (usually after 48 hours but ideally after seven days) and before backfilling of trenches, the pipes may be tested for watertightness by filling the pipes with water to a level 1.5 m above the top of the highest pipe in the length to be tested by closing the opposite end and maintaining this water level for one hour. Water is introduced through a funnel fixed to a right angle bend at the top end of the pipework by means of a rubber tube. When air bubbles have escaped after the initial filling and absorption has ceased, water is again added to fill the pipe. A slight amount of sweating, which is uniform, may be overlooked, and a small amount of subsidence should not be taken as implying bad workmanship or defects.

A tolerance figure of two litres per cm diameter per kilometre may be allowed during a water-filled period of 10 minutes. Alternatively, if the water level does not fall more than about 14 mm in a length of 100 m, this may be considered satisfactory. The water put in the pipes for testing should not be drained out until the trenches have been filled in completely (for shallow trenches) or to about 90 cm (in deep trenches), to detect if any joints have given way during backfilling.

B. Inspection chamber installation

Depending on the invert level of the sewer at the point where an inspection chamber is required, one of the three types of inspection chambers specified in table 2 will be provided. Unreinforced concrete (1:3:6 mix) is usually provided for the base of the chamber, while reinforced concrete is used for the cover. Depending on whether the cover is for a chamber to be placed in private or public property, the precast reinforced concrete covers are made of 1:3:6 and 1:2:4 mix respectively. Walls of the inspection chambers are of different thickness for different types of chambers, and must be maintained plumb vertical. The walls are usually of brickwork or cement blockwork, made with cement mortar (1:8) and plastered smoothly on the inside with cement mortar (1:5). Where saturated soil is encountered, the plaster should be also applied on the outside up to a height of 30 cm above the highest subsoil water level. Excavations for inspection chambers should have 30 cm clearance on all sides.

The bottom of inspection chambers should be adequately "benched", to have a fall towards the invert of about 1 in 6. The benching should be at least as high as three quarters of the diameter of the outgoing pipe, and should be floated to a smooth surface with cement plaster (1:2). In the case of branch drains, the benching should be

so shaped round the channel branches as to guide the flow of sewage in the desired direction. Channels of at least half the diameter of the outgoing pipe should be provided at the base to which all benching must fall. Channels must also be suitably plastered with cement mortar (1:2) and finished smooth, and the ends of channels should fit sewer ends accurately. Branch sewers and house connections may be connected at the level of the chamber channel or benching, or, where necessary, at some point in the chamber wall. The shallow depths to which sewers are usually laid in shallow sewer systems imply that drop connections are not required. In deep inspection chambers, all pipes exceeding 150 mm diameter passing through the chamber walls should have an arched form over them in order to relieve the pipe of the weight of the wall above. All foreign materials, such as excess cement mortar and sand, should be removed from the chamber base before commissioning.

C. As-constructed drawings

At the end of all construction work, the complete system must be illustrated on detailed as-constructed plans, similar to those produced originally for construction. The actual depths and locations of sewers and the location of each inspection chamber must be specified on these plans.

D. Maintenance of shallow sewers

Shallow sewers require very little maintenance: the only routine maintenance which must be performed is the removal of grit and grease from individual household grit/grease chambers. Routine flushing of the sewer lines, both block and street sewers, has not been necessary in any of the systems currently in use, and periodic flushing has not been necessary even in areas where water consumption is low. Good quality control during construction, especially in the execution of pipe jointing, and the prevention of extraneous matter gaining access to the pipes are two important measures for reducing to a minimum the maintenance required on shallow sewer systems.

The responsibility for operating and maintaining shallow sewer systems is usually divided between the community and the local authority (e.g., municipality or local water and sewerage organization). The community is usually entrusted with responsibility for maintaining the house connections and block sewers, while the local authority remains responsible for the external street sewers, sewage disposal facilities and ancillary works. The benefits of community participation in sewer operation and maintenance is often reflected in terms of reduced sewerage tariffs. Agreement from each householder to operate and maintain all house connections to the system, the inspection chamber and that length of block sewer located within his premises is obtained during the block community meetings. Where possible, such agreement is obtained and maintained in good faith between the community and the authority, but the legal ramifications of the agreement may also be spelt out on an official agreement form to be signed by each household member requesting a connection to the system. Where the latter approach is adopted, the construction of the block sewers may be initiated only when an adequate number of signed requests have been obtained. In cultures where the community members cannot, for religious or other reasons, perform such simple maintenance tasks as unblocking of the sewer passing through their premises, this work is usually entrusted to a specialized group of persons who can undertake such work and who should be trained in the appropriate maintenance procedures by the

local authority. In any event, sufficient information should be transferred to the community, during the construction process, to ensure that its members are fully informed on the proper operation and maintenance of the block sewers.

Blockages in properly constructed shallow sewer systems are very rare. When they do occur, however, they are readily removed by using long lengths of split bamboo or any other commercially available rodding device. Location of the blockage, however, may require some community co-operation. The blockage may be located by opening all inspection chambers along the block sewer line until two adjacent chambers are found where the upstream chamber is filled with sewage while the downstream chamber is dry. Rodding may be performed from either end, although rodding from the downstream end usually results in creating splash spillage at the chamber, as the sewage under pressure is allowed to flow through it. Some form of simple screening device, e.g., chicken mesh wire, is used to cover the downstream outlet in order to trap the object which created the blockage. Besides simple rodding devices, any of the modern mechanized devices may be used for cleaning sewer blockages. Where blockages have been caused by sewer failure, the length of failed pipe must be replaced and, depending on the cause of failure, provided with suitable pipe protection to avoid future failure.

V. PROJECT COSTS, APPRAISAL AND AFFORDABILITY

Compared with conventional sewerage, shallow sewer systems are significantly less costly to construct and operate, and yet provide a similar level of service. Depending on the density of settlement, shallow sewer systems can also be less costly than on-site sanitation systems, while providing a means of disposing of household sullage. The various material and construction costs which comprise the overall cost of shallow sewer schemes are considered in this chapter, together with methods of project appraisal which permit the comparison of shallow sewer schemes with other forms of sanitation. Methods of determining affordability through financial costings are also reviewed.

A. Project costs

Shallow sewer project costs are composed essentially of the following:

- (a) Cost of planning and supervision;
- (b) Cost of house connections, block and street sewers and appurtenances;
- (c) Cost of pumping stations (where necessary), sewage treatment facilities etc.

1. Planning, design and supervision

These costs vary widely from project to project, since the cost of planning, designing and supervising the construction of shallow sewer systems for new low-income housing and sites-and-services schemes is far less than the corresponding cost of installing these systems in existing unplanned settlements. However, the cost of undertaking surveys and investigations, preparing the design, mobilizing the community and supervising construction is usually found to lie within the range of 2 to 8 per cent of the cost of construction, including the block and street sewers and sewage treatment facilities.

2. House connections, block and street sewers and appurtenances

The cost of house connections is composed of the cost of laying the pipes connecting the water closet, the grit/grease trap and any other direct sullage connections to the inspection chamber. Where water closet pans or seats are not already available, the cost of supplying and installing these and the grit/grease traps may also be included in the cost of house connections. The items of work to be considered in preparing bills of quantities and estimating the overall cost of house connections are presented in table 5. Similarly, items of work to be considered for block and street sewers are presented in table 6. To the costs derived from tables 5 and 6 are added the following:

- (a) Initial cost of setting up construction site office;
- (b) Final cleaning-up of site after construction;
- (c) Preparation of as-constructed drawings;
- (d) Other miscellaneous costs.

Table 5. Construction work associated with house connections

Item	Unit
Supply and fix WC pan or seat	Number
Pipe trench excavation:	
- in soil (class 1).	m3
- in soft rock (class 2).	m3
- in hard rock (class 3).	m3
Supplying and laying PVC or AC pipework:	
- 75 mm diameter	m
- 50 mm diameter	m
- 38 mm diameter	m
Supplying and fixing grit/grease trap	Number
Supplying and fixing ventilation column (75 mm diameter) and associated T-connection	Number

Table 6. Construction work associated with block and street sewers

Item	Unit
Purchase and supply clay or concrete pipes:	
100 mm diameter	m
150 mm diameter	m
200 mm diameter	m
etc..	
Pipe trench excavation:	
In soil (class 1)	m3
In soft rock (class 2)	m3
In hard rock (class 3)	m3
Removing and making good existing surfaces:	
Roads	m2
Footpaths	m2
Concrete surfaces	m2
Demolishing and making good partition walls	m2
Pipe laying and jointing	m
Pipe bedding and surround:	
Sand	m3
Concrete (1:3:6)	m3
Backfilling of pipe trenches	m3
Construction of inspection chambers:	
Type IC1	Number
Type IC2	Number
Type IC3	Number

Pumping stations are rarely required for shallow sewer systems, but, where they are required, their cost must be established and included in the overall cost of the scheme. The cost of sewage treatment facilities will depend on the form of treatment to be provided. Where waste-stabilization ponds are used, Brazilian experience suggests that the cost of this form of treatment varies from 30 to 40 per cent of the total cost of the scheme. Detailed bills of quantities will, however, be required to determine the cost of treatment which must then be included as part of the overall cost.

B. Project appraisal

Having identified technically feasible options for sanitation, it is necessary to make an objective comparison which results in the selection of the most cost-effective one. While the final selection of the most appropriate sanitation technology should be left to the community or its representatives, the basis for selection is often that of cost comparisons reflecting both the positive and negative consequences of choosing each sanitation option.

There is no completely satisfactory method by which this may be achieved. Economic benefit-cost analysis is often used for this purpose and aims to quantify the social advantages and disadvantages of each choice in terms of a common monetary unit. While benefits may either be positive or negative (an example of negative benefit is the increase in water use for flushing that results from the provision of sewerage systems), it is however impossible to quantify many of the positive benefits, such as improved health, greater well-being, higher productivity etc., resulting from improved sanitation. Each alternative considered could give different benefits and, since in many cases the benefits remain unquantifiable, inconsistencies could arise with the result that the approach may give rise to the selection of an alternative that is not necessarily the least costly solution. Despite its apparent deficiencies benefit cost-analysis, if applied properly, will provide a reasonable objective basis for comparison that reflects the cost trade-offs corresponding to different levels of service. ^{14/} Detailed procedures for undertaking economic cost-benefit analyses for sanitation programmes and adjusting market prices so that they reflect the opportunity costs of capital (the process of converting market prices to reflect opportunity costs is often termed "shadow pricing") is discussed in detail elsewhere. ^{14/ 26/}

In brief, the method entails a rational assessment of the long-term marginal cost of each option, so that it reflects demand for different levels of capital outlays at different times, resulting from differing capacity-utilization rates. The average incremental cost (AIC) method is generally utilized for this purpose and is given by:

$$\begin{aligned}
 & t = T \\
 & \sum_{t=1}^{t-1} (C_t + O_t) / (1+r)^{t-1} \\
 \text{AIC} & = \frac{\quad}{\sum_{t=1}^{t-1} N_t / (1+r)^{t-1}}
 \end{aligned}$$

where t = time in years

T = design lifetime in years (measured from start of project at $t = 0$)

C_t = construction costs incurred in year t

O_t = incremental operation and maintenance costs incurred in year t over previous year

N_t = additional people or households served in year t over previous year

r = opportunity cost of capital in percentage times 10

Four shadow factors need to be incorporated in the economic costing of sanitation technologies. These are:

- (a) The opportunity cost of capital;
- (b) The unskilled labour wage shadow factor;
- (c) The foreign exchange shadow factor;
- (d) The shadow price of water, land and other resource inputs.

Appropriate values for the first three factors are usually readily obtained from economists working in the country, but the shadow price of water is perhaps the most significant of all scarce resource inputs to sanitation programmes in developing countries. The cost of additional water consumption resulting from improved sanitation is priced at its marginal or future rate rather than at its current production cost.

Conventional sewerage, because it uses large quantities of water for flushing and is capital-intensive, with only a small proportion of the potential beneficiaries being served during the early years of its life, has a very high average incremental cost. This, however, is not the case with shallow sewer systems, since they require no more than 3 litres per flush, make a limited demand on capital and serve a large proportion of, if not all, the households immediately upon completion of the system. With regard to the use of water for flushing, shallow sewer systems require no more water than on-site sanitation systems such as pour-flush waterseal latrines. In shallow sewer networks, sullage provides the main means of flushing and, hence, while eliminating the negative benefits of increased water use, this form of sanitation also has the positive benefit of disposing of sullage in the same system, which most on-site sanitation systems cannot offer (often a separate unit, usually a sullage soakaway or infiltration field, is required).

The average incremental cost is often represented as the total annual costs per household (TACH) for purposes of comparing the cost of one sanitation option with another, since the life-span and capital operating and maintenance costs differ from one technology to another. A summary of TACH for various sanitation technologies is presented in table 7. From this table, it is evident that shallow sewerage is indeed a low-cost sanitation technology.

The TACH of shallow sewerage decreases markedly as the density of settlement increases: this phenomenon is well illustrated in the case of Natal, Brazil, and is clearly depicted in figure 4. Above a density of settlement of 160 persons per hectare, the TACH of shallow

Table 7. Total annual (economic) costs per household of different sanitation technologies (\$US at 1978 values)

Technology	Observations (number)	Mean	Median	Highest	Lowest
Low-cost:					
Pour-flush toilet	3	18.7	22.9	23.3	10.1
Pit latrine	7	28.5	26.0	56.2	7.6
Communal septic tank ^{a/}	3	34.0	39.0	48.0	15.0
Vacuum-truck cartage	5	37.5	32.2	53.8	25.7
Low-cost septic tank	3	51.6	45.0	74.5	35.4
Composting toilet	3	55.0	56.2	74.6	34.3
Bucket cartage ^{a/}	5	64.9	50.3	116.5	23.1
Shallow sewerage ^{b/}	20			35.8	13.8
Medium-cost:					
Sewered aquaprivy ^{a/}	3	159.2	161.4	191.3	124.8
Aquaprivy	2	168.0	168.0	248.2	87.7
Japanese vacuum-truck cartage	4	187.7	193.4	210.4	171.8
High-cost:					
Individual Septic tank	4	369.2	370.0	390.3	306.0
Conventional Sewerage	8	400.3	362.1	641.3	142.2

Source: J.M. Kalbermatten and others, *Appropriate Technology for Water Supply and Sanitation in Technical and Economic Options*, (Washington D.C., World Bank, 1981) (modified to include shallow sewerage costs.)

Notes: ^{a/} Per capita costs were used and scaled up by the cross-country average of 6 persons per household to account for large differences in the number of users.

^{b/} Computed from sources: 6/, 26/, 38/, 39/, 40/, 41/, 42/, 43/, 44/, 45/, 46/

sewer systems was found to be lower than the cheapest on-site waste disposal system. The capital cost and, hence, TACH of shallow sewer systems are usually higher for existing settlements than for new housing and site-and-services schemes of comparable settlement density, the main reason for this being the need to transport sewage long distances to treatment works and, occasionally, also to lift it.

Mean and median values of TACH have not been specified for shallow sewer systems, because, unlike a majority of other sanitation systems listed in the table, the TACH of shallow sewers are extremely

sensitive to the type of settlement and, particularly, to its density of occupation. Computing mean and median values will, therefore, have little meaning. The total recurrent cost of operation and maintenance comprise approximately 18 per cent of the total cost of shallow sewer systems, including capital, operating and maintenance costs. Percentage investment and recurrent costs of various sanitation systems are shown in table 8.

Table 8. Percentage investment and recurrent cost of community sanitation systems

Technology	Percentage of total	
	Investment cost	Recurrent cost
Sewerage	81	19
Sewered aquaprivy	84	16
Japanese vacuum-truck cartage	68	32
Other vacuum-truck cartage	48	52
Bucket cartage	57	43
Communal toilets	88	12
Shallow sewerage	82	18

Source: J.M. Kalbermatten and others Appropriate Technology for Water Supply and Sanitation in Technical and Economic options, (Washington D.C., World Bank 1981) (modified to include sewer costs).

Note: Percentages are calculated excluding costs of water in flushing.

C. Affordability

Economic costing offers a basis for deriving least-cost comparisons of sanitation technologies and thus is extremely useful to planners and policymakers in identifying suitable sanitation options: they reflect the true cost of each sanitation programme to the natural resource endowment of the country. The beneficiary, however, is most interested in financial costs, that is, how much he will be expected to pay and over what period of time. Financial appraisal is a means of assessing the costs and revenues associated with sanitation investments and it is concerned with forecasting the effect of investment proposals in financial terms and with establishing their impact on the consumers' pockets. The financial cost of a project to the consumer is greatly influenced by governmental policies, unlike economic costing where distortions in market prices introduced by governmental policies are ironed out by shadow pricing. Although financial analysis cannot be used in determining least-cost alternatives, it is the fundamental basis for measuring consumer affordability of the economically viable solutions.

Financial appraisal differs fundamentally from economic appraisal

in that the prices used for quantifying the benefit-cost streams are market prices. Whereas economic costs are based on the physical conditions of the community (for example, its abundance or scarcity of labour, water and so forth) and, therefore, are quite objective, financial costs are entirely subject to interest-rate policy, loan-maturity term, central-government subsidies and the like.^{14/} For example, the financial costs of a sanitation system for a community can be zero, if the central government has a policy of paying for them out of general tax funds. It is for this reason that financial costings cannot be used as a basis for least-cost comparisons.

The ideal requirement for financial costing in establishing affordability is one in which the beneficiaries pay for the entire service without recourse to government subsidies. Urban communities, irrespective of their levels of income, often demand a sophisticated sanitation technology, such as some form of waterborne sanitation system, especially when the proposed intervention is to be executed by government agencies. Shallow sewer systems, being waterborne, are readily accepted by urban communities, and, where their costs can be fully recovered through monthly repayments, they have proved exceptionally acceptable and affordable to even the poorest of communities, without the need for any government subsidy.

The methodology adopted for financial costing consists of discounting the net values of the benefit and cost streams at an appropriate discount rate which would generally be the implementing organization's borrowing rate. Because of the great security or collateral that the public sector possesses, together with the fact that it does not pay income tax, public sector borrowing rates are usually well below those of the private sector. The annual financial cost per household may be obtained from the engineering estimate of construction cost (in market prices), as presented at the start of this chapter, and simply apportioned annually over the life of the facility at the prevailing interest rate. If self-help labour is used for part of the construction, this cost must be subtracted from the total before annuitizing annual apportionment.

Because the total investment costs of shallow sewers are incurred during the year of construction and most (if not all) households are connected to the system during the same year, the financial cost of a shallow sewerage scheme may be given by the following simplified equation, assuming a constant value for annual operation and maintenance costs.

$$\text{Annual financial cost per household} = \frac{(\text{CRF} \times \text{investment cost}) + \text{annual operation and maintenance cost}}{\text{Number of houses served}}$$

$$\text{where CRF} = \text{capital recovery factor} = \frac{r(1+r)^N}{(1+r)^N - 1}$$

r = interest rate
 N = loan maturity period

Where investment is staggered and different capacity utilization rates are likely to be encountered, the annual financial cost per household should be determined using the average incremental method discussed above, using market costs and interest rates.

Affordability is then determined by comparing household incomes to the financial cost of the service. The general policy of international lending agencies, such as the World Bank, is that, if the cost of the service facility is more than a small part of the household income, usually between 5 and 10 per cent, some form of government subsidy is called for. 14/ The Brazilian Government, for example, has established, through legislation, a minimum consumption tariff which, for water and sanitation, should each not exceed 5 per cent of the minimum wage (approximately \$55 per month) and should not exceed 7 per cent for the combined charge for both services. Even so, it has proved possible to deliver shallow sewer systems to many low-income communities in Brazil without recourse to subsidies of any kind. 26/

A competent and efficient institution is, however, required to raise the initial funds to execute the system and implement an adequate mechanism to recover all expenditure through a suitable tariff charge. Although it is conceivable that the community could raise the entire investment cost itself, efforts to undertake such an exercise in Pakistan have not proved entirely successful. 21/ Monthly repayments pose fewer hardships for the urban poor, and hence promote their desire to participate in the programme.

The financial costs per household and their implications for affordability of a variety of sanitation options, is presented in table 9. Cost information gathered from over 20 projects executed in two countries was used to indicate the range of costs included in the table for shallow sewer systems.

Table 9. Financial costs per household of different sanitation technologies (\$US at 1978 values)

Technology	Total investment cost	Monthly recurrent cost	Monthly water cost	Hypothetical total monthly cost <u>a/</u>	Percentage of income of average low-income household <u>b/</u>
Low-cost					
PF toilet	71	0.2	0.3	2.0	2
Pit latrine	123	—	—	2.6	3
Communal toilet <u>c/</u>	355	0.3	0.6	8.3	9
Vaccum-truck cartage	107	1.6	—	3.8	4
Low-cost septic tanks	204	0.4	0.5	5.2	6
Composting toilet	398	0.4	—	8.7	10
Bucket cartage <u>c/</u>	192	2.3	—	5.0	6
Shallow sewerage	85-325 <u>d/</u>	0.2	0.3	1.2-3.3	2-6
Medium-cost					
Sewered aquaprivy	570	2.0	0.9	10.0	11
Aquaprivy	1,100	0.3	0.2	14.2	16
Japanese vaccum-truck cartage	710	5.0	—	13.8	15
High-cost					
Individual septic tank	1,645	5.9	5.9	46.2	51
Conventional sewerage	1,479	5.1	5.7	41.7	46

Source: J.M. Kalbermatten and others, *Appropriate Technology for Water Supply and Sanitation in Technical Options* (Washington D.C., World Bank 1981) modified to include shallow sewerage costs.

Notes: a/ Assumes that investment cost is financed by loans at 8 per-cent for 5 years for the low-cost systems (except shallow sewerage), 10 years for the medium-cost systems, and 20 years for the high-cost systems and shallow sewerage.

b/ Assumes that average annual income is \$180 per capita with six persons in a household.

c/ Based on per capita costs scaled up to household costs to account for multiple household use in some of the case studies.

d/ Depending on type and density of settlement. **Sources:** 6/, 21/, 26/, 38/, 39/, 40/, 41/, 42/, 43/, 44/, 45/, 46/, and 47/.

The fact that the cost of providing, installing, operating and maintaining these systems demands no more than 2 to 6 per cent of the income of average low-income households would indicate that they are affordable to these communities and should not require subsidies of any kind. The fact that a sanitation system is affordable to a community does not, however, imply that the community will be willing to pay for the system, and this is especially true in low-income communities. The community's priorities and its perceptions of the need for a given sanitation technology will, to a large extent, determine the level of acceptance of that technology and its willingness to pay for it. The fact that shallow sewer systems are waterborne and dispose of both excreta and sullage makes them especially attractive to urban communities served with some form of piped water-distribution system. A successful shallow sewer programme will, however, require adequate institutional capacity to implement and administer it.

VI. CASE STUDIES

This chapter describes the implementation of shallow sewer networks in human settlements under three different sets of physical and social conditions. All three case studies, however, relate to low-income settlements. The first two case studies are derived from experience in the implementation of the system in spontaneous and planned low-income housing areas in the north-east of Brazil. The third case study is derived from the extension of the shallow sewer technology to a low-income squatter settlement in Karachi, Pakistan. Water availability and usage patterns and the social and cultural patterns observed in the Brazilian and Pakistani case studies differ considerably, and the successful utilization of the technology under these contrasting conditions appears to endorse its almost universal applicability. The technology has, however, still to be tried out in cultures where the use of bulky anal cleansing materials is common.

A. Rocas and Santos Reis, Natal, Brazil (Two spontaneous squatter settlements) 26/, 39/, 42/, 47/

Shallow sewerage was first developed in the city of Natal, the capital of the north-eastern Brazilian State of Rio Grande do Norte, by the Sanitation Research Unit of the State Water and Sewerage Company (CAERN). Rocas and Santos Reis are two neighbouring squatter settlements situated in Natal, and approximately 15,000 people were settled in these areas which had an overall population density of 350 persons per hectare. The settlements resulted from spontaneous development activities and, hence, possess only vestiges of intentional planning.

The 3100 houses and buildings in the area were distributed over 86 blocks. Over half the houses were located on plot sizes less than 80 m² and had constructed areas less than 60 m²; they were therefore contiguous on at least one side with neighbouring properties with little or no lateral space. Some space was usually available at the back of the house for a small garden. Levels of income were noted to be exceptionally low with two thirds of the population earning subsistence wages below the country's poverty line.

Although levels of income were exceptionally low, the issuance of land titles to the dwellers had, over the years, encouraged the use of good quality material in construction throughout most of the two areas. A yard tap level of water supply was available in the area, and a minimum water tariff was applied to a majority of the premises by virtue of their small plot sizes. A quarter of the houses were not connected to any water-supply service, and these shared supplies with their neighbours. Most houses had a conventional but manually-flushed ceramic toilet bowl which was connected to leachpits constructed within the plot area; sullage was discharged into the street in front. The high density of the settlement and the need for frequent leachpit desludging created a sense of dissatisfaction with the system in the community.

Although CAERN had a plan to serve the area with conventional sewers, it was evident that such a proposal would prove neither technically nor economically feasible under the conditions in which it was intended to be applied, and hence would only yield a small proportion of house connections. The technical feasibility of

conventional sewerage was impaired by the need for deep excavation in an area of precarious, dense housing, and the cost of a conventional sewerage service was far beyond the community's means to pay. The CAERN research unit developed the concept of shallow sewerage as being the only way in which sewers could be financially feasible and could serve a large proportion of the community. A high rate of house connections was necessary in order to ensure that the sanitary intervention would have the maximum impact on the health of the community and that the cost of the intervention would be minimized.

Meetings were held with the community to discuss the problem of sanitation in the area and the advantages and disadvantages of various sanitation systems, including conventional and shallow sewerage. It was evident that the community held certain reservations about the trouble-free operation of the shallow sewer system, the feasibility of passing sewers through private properties and the maintenance implications. One pilot block, consisting of 28 houses, was mobilized, and plans for laying block sewers were prepared. Each householder consented to the construction of a common house connection - the block sewer - in his/her backyard and agreed to be responsible for the maintenance of the length of sewer laid within the property; a simple inspection chamber was built at each connection for this purpose. The sewage was treated in a communal septic tank and infiltrated into trenches designed for this purpose in a nearby open field.

The pilot block sewer was constructed and operated for over a year while planning of other block and street sewers proceeded. Then block meetings were arranged for the remaining 85 blocks, and residents in these blocks were encouraged to visit the pilot block and to talk to the people living there to obtain their views on the system. This led to spontaneous acceptance of the system and a great demand to extend it to the remaining blocks. The community collaborated with the research unit by providing access to their houses for purposes of executing the necessary surveys and, subsequently, for the construction of the block sewers and house connections. The community assumed responsibility for maintaining the block sewers, as in the case of the pilot block sewer, while CAERN is responsible for maintaining the street sewers. The lengths of both the house connections and street sewers were reduced considerably by virtue of the fact that common block sewers were installed. A layout of the shallow sewer network adopted for Rocas and Santos Reis is shown in figure 11.

An unprecedented connection rate of 97 per cent was achieved in the year of construction. Small subcontractors were used to construct the block sewers, while the street sewers were constructed by large contractors. Efforts were made to employ local labour in construction. Water closet and sullage house connections (including a grit/grease chamber), block and street sewers and one pumping station and rising main were provided.

The total capital cost of the systems in Rocas and Santos Reis was \$325 per household, and full cost recovery is being achieved by a surcharge on the water bill of only 40 per cent. The surcharge for conventional sewerage is 100 per cent on a much higher water bill and, even then, it often entails some form of subsidy. Most of the households in Rocas and Santos Reis are unmetered and pay only the minimum tariff. The system has operated satisfactorily for over five years, and a study of the total annual cost per household of various sanitation options for settlements of different population densities

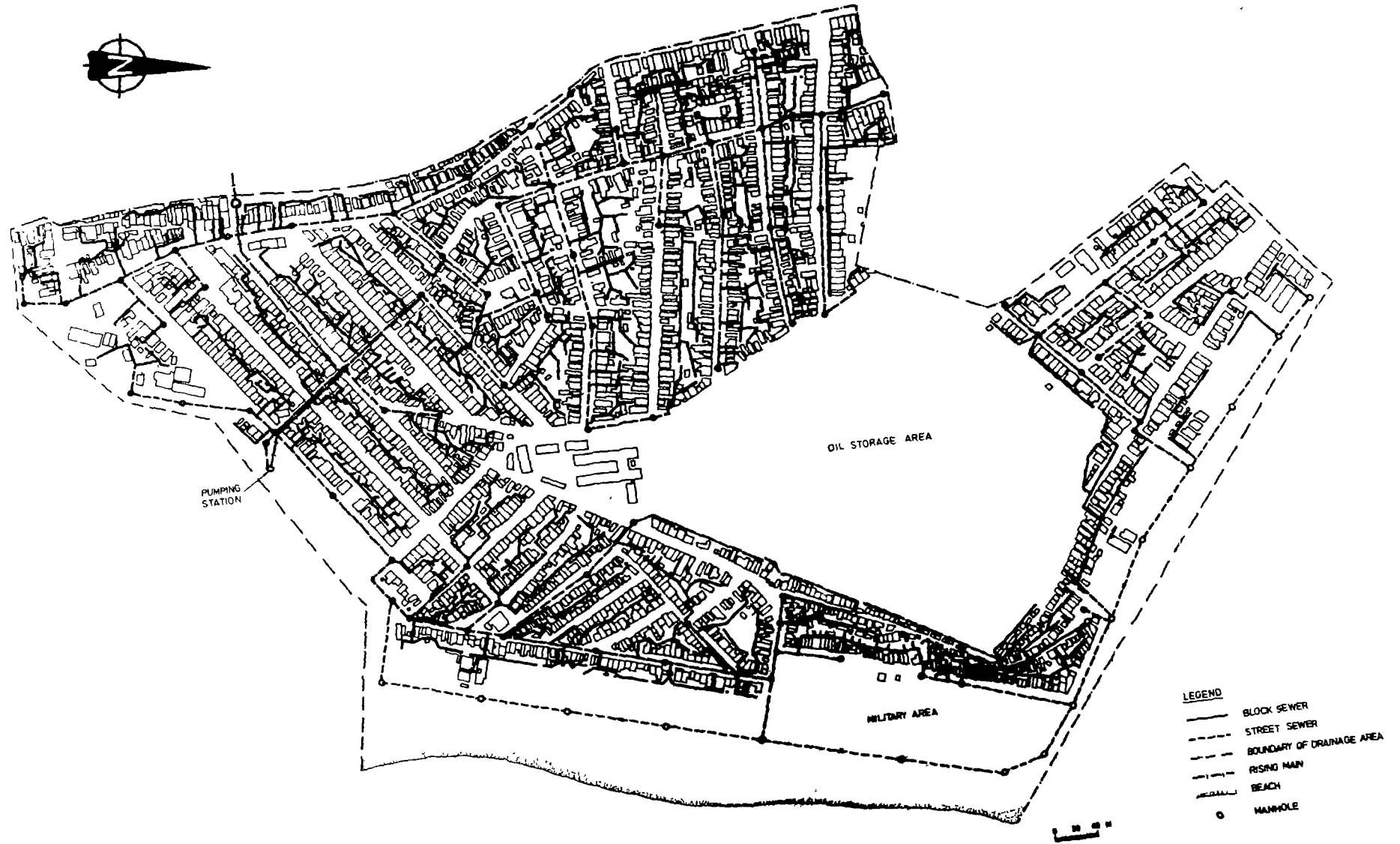


Figure 11. Shallow sewerage layout for the spontaneous settlements of Rocas and Santos Reis, Natal, Brazil

Source: Companhia de Aguas e Esgotos do Rio Grande do Norte (CAERN),
 Projecto dos Sistemas de Esgotos Sanitarios da Cidade do Natal

found that shallow sewers were cheaper than even on-site sanitation systems at densities in excess of 160 persons per hectare (see figure 5. Changes in conventional approaches in executing the system to accommodate community participation in planning and maintenance work, and in adjusting tariffs to take account of the low investment costs, were successfully introduced by CAERN. The Sanitation Research Unit established by CAERN developed the methodology used and justified the changes in tariff structure introduced for the new system. Evaluations of the system undertaken at frequent intervals during the past five years have detected a gradual process of upgrading of plumbing installations through the provision of kitchen sinks, laundry sinks, showers etc. No problems have been observed, and information transferred during construction to the community in relation to maintaining the block sewers has proved adequate to ensure a high level of self-help maintenance. Blockages in block sewers have proved to be rare and, whenever these have occurred, they have been effectively removed by members of the community themselves.

Within five years, the shallow sewer system had spread to various towns within Rio Grande do Norte and was being implemented in all low-income housing schemes in Rio Grande do Norte without exception. During this period, it also spread to other states such as Pernambuco, Rio de Janeiro, Minas Gerais and Sergipe. 47/48/ The concept of a common house connection through the use of shallow block sewers is now being extended to the supply of water in order that the same basic unit of social mobilization - the block - can be used to supply water through a single meter for subsequent assessment of water and sewage tariffs amongst the householders connected to a common water meter and sewage house connection. Supplying, maintaining and reading water meters have been problem in developing countries, and the reduced number of meters achieved by adopting block meters, as opposed to individual household meters, creates considerable savings.

B. Planned low-income housing schemes in the State of Rio Grande do Norte, Brazil.
6/,38/,39/,41/,43/,44/,45/,46/

Concomitant with the development of the shallow sewer system in the unplanned, spontaneous squatter settlements of Rocas and Santos Reis in 1981, the concept was also extended to a low-income housing scheme in Santa Cruz, a city in the interior of the State of Rio Grande do Norte.6/ Eight hundred low-cost houses were built with an average gross population density of 110 persons per hectare, the houses intended for one of the poorest groups in Santa Cruz's community who had been made homeless during a flood earlier in the year. The houses were constructed to standard designs and were provided with in-house water connections and a pour-flush ceramic toilet bowl, a bathing area, and kitchen and clothes washing sinks. The kitchen and clothes-washing sinks were connected to a grit/grease trap and discharged to shallow sewers. Shallow sewers were laid through the back gardens and connected to a sparsely distributed street-collector sewer network which was laid in sidewalks to enable it to maintain its shallow depth. The topography of the project area was such that it covered parts of three separate drainage basins, and the sewage drained from each basin was connected to a different treatment works, consisting of a combination of anaerobic and facultative pond, a communal septic tank and a facultative pond, and also direct discharge to a facultative pond. The treated effluents were used for irrigating fodder crops.

Owing to the weak institutional structure in this interior town, no social mobilization was initially undertaken to inform the occupants of the system before they occupied the houses. Some householders even extended their houses towards the back of the plot over the shallow sewers, without any precaution to protect the pipeline against future settlement. Despite the failure to inform the community of the system, in order that they could take due precautions when extending their houses and could maintain the sewer, no problems occurred, and the system, which cost, on average, \$150 per household (including the treatment facility), has functioned very satisfactorily. Water consumption in this housing settlement, as in the Rocas and Santos Reis settlements, was observed to average 45 lpd, and cost recovery through a surcharge on monthly repayments for the house was introduced. Systematic evaluations undertaken by CAERN have failed to identify any means by which the system could be improved either in its layout, appurtenances or operation.

Following the successful development and implementation of both Rocas and Santos Reis shallow sewer systems, the concept has been applied to over 20 low-income housing schemes within the country and, in particular, in the states of Rio Grande do Norte and Pernambuco. The number of houses in each scheme has varied from a mere 56 to 1312. The same model of shallow block sewers, sparsely distributed street collectors (located wherever possible under sidewalks) and sewage treatment through the use of a combination of anaerobic ponds or communal septic tanks and facultative ponds, has been adopted in most cases. The capital cost per household was found to vary from \$85 to \$150. A comparison of the cost of the shallow sewers with that of leachpit and soakaway and conventional sewerage options found that shallow sewerage systems, despite the low population densities (on average 110 persons per hectare), were consistently the least demanding on capital and were only 9.5 to 15 per cent of the cost of conventional sewerage.^{38/} On-site sanitation technologies were found to average between 14 and 21 per cent of the cost of conventional sewerage. The shallow sewer design standards adopted for Rocas and Santos Reis and all new low-income housing schemes were similar to those described in this manual. A typical shallow sewerage and sewage treatment layout plan for a low-income housing development in Macau, in Rio Grande do Norte, is presented in figure 12.

In a majority of the housing schemes, one block meeting was undertaken by the governmental agency involved - usually the State Water Authority - in the presence of community development officers who were then entrusted with the task of replicating the exercise in the other blocks. Information regarding the sewer layout, proper operation and maintenance of the system and repayment for the service was provided through leaflets, meetings and demonstrations. Small contractors were used to execute most, if not all, of the shallow sewer schemes.

C. Orangi, Karachi, Pakistan
(spontaneous squatter development)
21/, 22/, 23/

Approximately 40 per cent of Karachi's population is accommodated in squatter settlements (locally termed katchi abadies). Orangi, the largest squatter settlement in Karachi and, in fact, in Pakistan, is situated 12 km from the centre of the city. It has an estimated population of 800,000 who are settled in substandard conditions in an

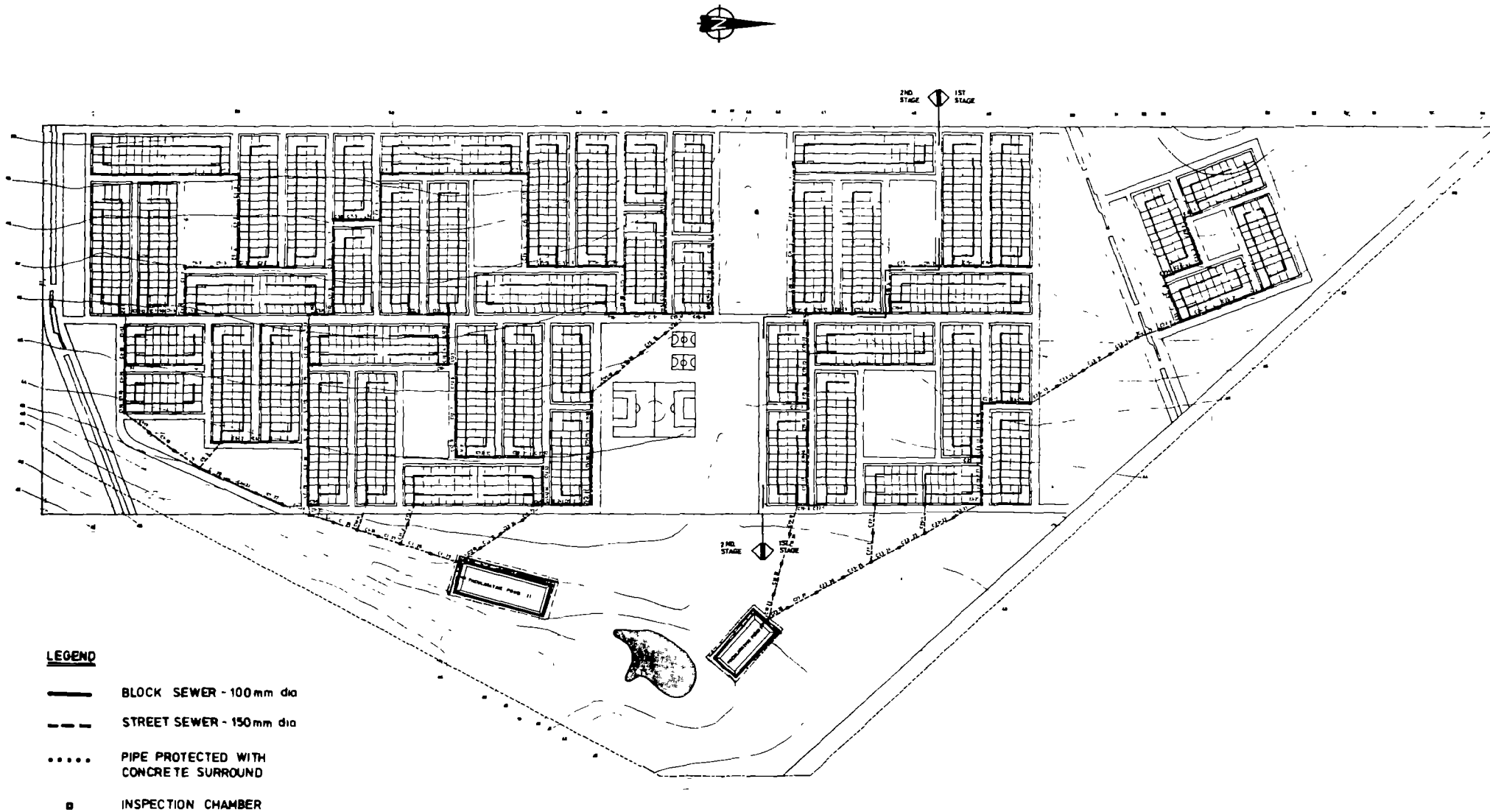


Figure 12. Shallow sewerage layout for a planned low-income housing scheme in Macau, State of Rio Grande do Norte, Brazil

Source: C.O. de A. Neto, Sistema de Esgotamento Sanitario em Macau - RN, Project prepared for COHAB-RN, Natal, Brazil, January 1983.

area covering approximately 2000 hectares. Average household incomes were at subsistence levels, and infant mortality and the incidence of excreta-related infections were both high.

The settlement resulted from the migration from the former East Pakistan which occurred during the period immediately before and after the creation of Bangladesh. Although the largest of the katchi abadies, Orangi lacked the minimum of basic infrastructure and essential amenities. In March 1983, the Bank of Credit and Commerce International Foundation, in collaboration with UNCHS (Habitat), initiated a three-year community development project, aimed at ameliorating the living conditions of the people of Orangi.

One of the activities of the project was the promotion and implementation of low-cost infrastructure interventions, amongst which sanitation was given high priority, owing to the urgent need for it in the project area. The bulk water supply to Orangi was through unevenly distributed communal standposts which operated four hours a day in the afternoon. Water was stored in compound tanks in a majority of the houses, and, on average, 20 to 30 litres were used by each household member each day. Only rudimentary plumbing fixtures were present in the area, and most washing was confined to a special wet room used for both bathing and washing clothes and utensils. Bucket latrines were predominantly used in the area, together with vault toilets. Except in the case of bucket latrines, standard cistern-flush ceramic and mosaic squat pans, operated in the manual pour-flush mode, were the norm. The socio-religious custom of using water for anal cleansing necessitated the carrying of water to the toilet. Scavengers, who undertook the removal of excreta from the bucket latrines, charged \$1.00 per month for the service, but no provision existed for the disposal of sullage.

In 1984, Chisty Nagar, a Bihar community within Orangi, was identified to initiate the sanitation programme. The project area contained 555 plots, of which 408 had houses built on them, and had an average gross population density of 193 persons/hectare. A remarkable feature of the area was its regular urbanization, with average plot sizes of 100 m² of which, on average, 50 per cent was constructed area. Even more remarkable was the existence of a service lane, designed to provide access to scavengers for removing nightsoil from the houses.

General community meetings were held after midday prayers at the mosque on Fridays. Local community leaders were identified, and the programme was described. Discussions held with the community revealed a preference for some form of waterborne sanitation, but conventional wisdom dictated that the unreliable intermittent water supply and the low levels of water consumption in the area would rule out the use of any form of waterborne sanitation system (average consumption was measured to be 27 lcd).

Only shallow sewers, because of their mode of operation, offered any chance of success. Although shallow sewers had not been previously installed under similar conditions of limited water use and manually flushed ceramic toilet squat pans, their mode of operation suggested that, even under such conditions, they should function satisfactorily. An analysis of the cost of various sanitation options also indicated shallow sewers to be one of the cheapest options. It was, therefore, decided that it should be implemented in Chisty Nagar.

Meetings were held with the community to present the designs and establish a procedure for raising the required capital which had to be raised in full by the community. A trusted member of the community was nominated by it to be the custodian of all funds raised. It was also envisaged that maintenance committees would be established as social mobilization advanced, in order to maintain the completed sewerage system.

Shallow sewers, laid in the service lanes (until then only used by scavengers for emptying nightsoil buckets), were designed according to criteria similar to those developed in Brazil, and they received the wastewater from manually flushed squat pans and all household sullage. A grit/grease trap, made of cement mortar including fine aggregates was provided in each house, to act as a focus for sullage collection and, also, serve as a preventive maintenance device. One inspection chamber was provided to serve two plots, and each water closet connection was appropriately ventilated. Besides the service lane sewers, an interceptor channel was provided to drain the lane sewers to a common communal septic tank, and the effluent from the tank was discharged to the nearby dry water course. The shallow sewer layout adopted in Chisty Nagar is shown in figure 13.

The internal plumbing and lane sewers comprised 30 and 31 per cent respectively of the total cost, which amounted to approximately \$45 per plot. Because only 408 of the 555 plots had houses on them, the cost per household was just over \$61. A twin pit pour-flush toilet, which disposes of excreta only, cost approximately \$51. The project endeavoured to reduce costs through local manufacture of specific components, such as the grit/grease trap and pipes. The cost of inspection chambers was also reduced by using locally available stone instead of bricks or cement blocks.

Despite the low flows, the system has functioned perfectly well for over a year: no blockages have occurred, showing that properly designed and constructed sewers do not require large quantities of water for trouble-free operation. This first attempt by an NGO to introduce shallow sewers to low-income settlements was, however, not without problems. A recent evaluation of the Chisty Nagar sanitation programme has attempted to identify some of these problems. 21/

The principal objective of community motivation was to generate a financial contribution to the scheme. Little effort was devoted to creating a community organization capable of taking on other development projects on completion of construction and also maintaining the newly introduced system. Efforts to raise the entire capital cost prior to construction proved somewhat difficult, not so much as a result of financial limitations but rather as a result of weak community organization.

A contractor approach to the provision of sanitation rather than a community development approach, an initial construction failure when attempting to construct a septic tank in a service lane and the inability of the project to stick to a single price without introducing additions at a later stage raised doubts. Technically, however, the evaluation proved extremely positive, except for noting some build-up in the sewers of sand that is thought to have entered the system at the inspection chambers during the execution of the house connections and, perhaps, during the construction of the sewers themselves. Some spillover from the grit/grease trap may also have been responsible, although this could be eliminated by informing householders of the need to clean out the trap frequently.

LEGEND

- Channel Inspection Chamber
- 6 Dia R C C Pipe
- Concrete Protection
- || Watercourse
- Inspection Chamber
-)) Culvert

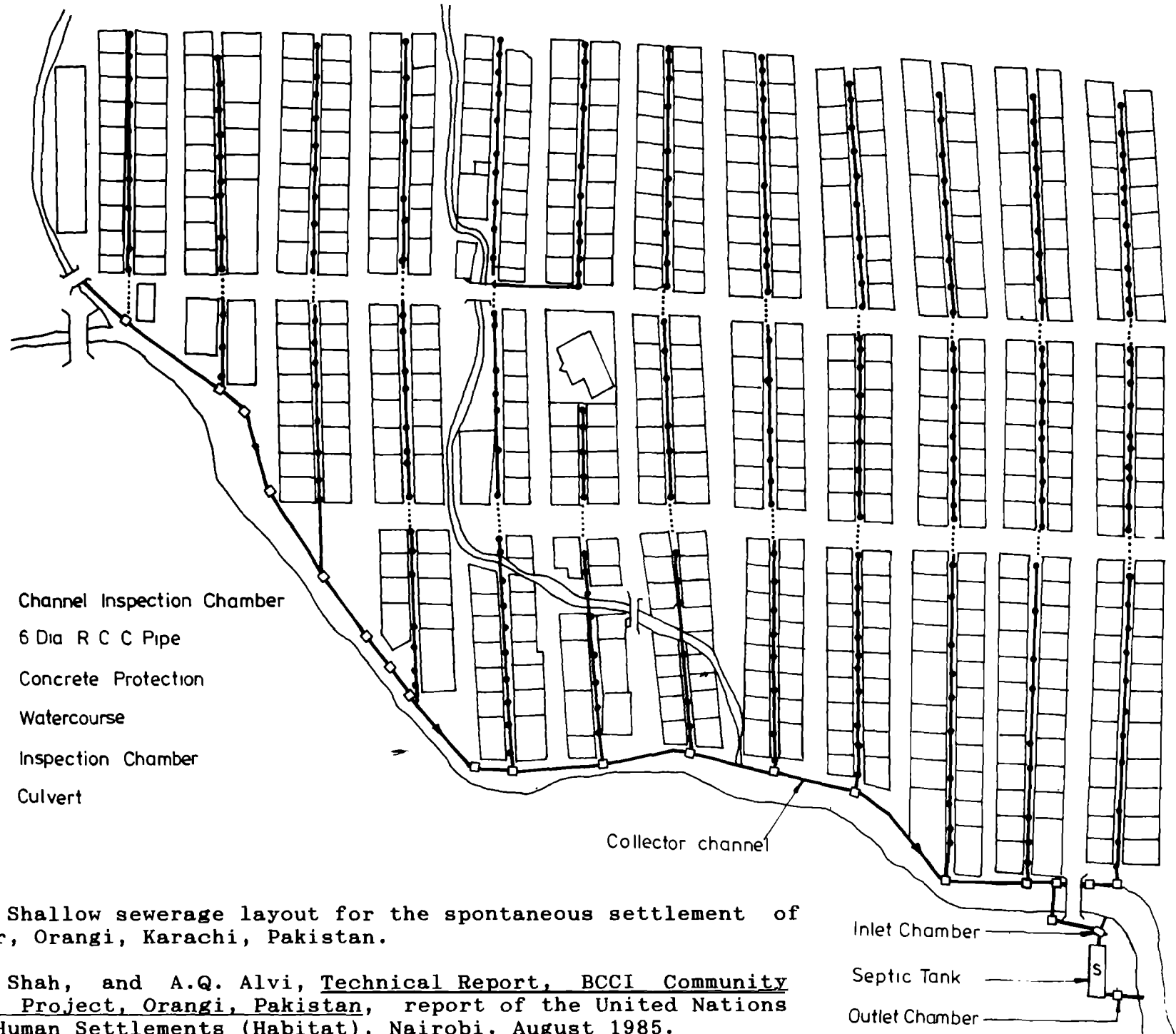


Figure 13. Shallow sewerage layout for the spontaneous settlement of Chisty Nagar, Orangi, Karachi, Pakistan.

Source: J. Shah, and A.Q. Alvi, Technical Report, BCCI Community Development Project, Orangi, Pakistan, report of the United Nations Centre for Human Settlements (Habitat), Nairobi, August 1985.

Inlet Chamber
 Septic Tank
 Outlet Chamber

One of the chief constraints to expanding the scheme to other areas at a very fast pace is the need to raise the total capital cost prior to construction. This impediment is best removed by creating a revolving fund and a suitably efficient institution to apply and recover funds for the provision of shallow sewerage schemes. As Karachi launches its ambitious programme to develop the katchi abadies, it is expected that the technology introduced through the present programme will serve as a model for adoption in other low-income areas.

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Annex I

SHALLOW SEWER DESIGN EXAMPLE

A shallow sewer scheme is proposed for the new low-income housing scheme illustrated in figure 1. Each house is to be provided with a pour-flush ceramic toilet bowl and a single tap located within the house in a room designated for washing clothes and utensils and for bathing. A grit/grease trap is provided in this wet room. Because the population of the settlement has already reached saturation, no provision is required for future development, although the householders are expected to upgrade their plumbing fixtures to have, in the future, a multiple-tap, in-house, water-supply service, with wash basins, kitchen sinks, showers etc. Water consumption is, therefore, expected to rise from the current 50 lcd to an estimated final value of 120 lcd. Being located in a semi-arid region, no significant infiltration to the sewer is expected, and any small infiltration will be controlled through good construction. The following design criteria are assumed:

Flow estimation

Maximum water consumption, $q = 120$ lcd

Coefficient of peak daily flow variation, $k_1 = 1.2$

Coefficient of peak hour flow variation, $k_2 = 2.0$

Ratio of sewage generated to water consumed, $C = 0.8$

Average number of persons per house = 5

Number of houses served = N

$$\begin{aligned}\text{Flow in sewers} &= \frac{0.8 \times 1.2 \times 2.0 \times P \times 120}{86400} + 0 + Q_2 \\ &= 0.002667P + Q_2 \\ &= 0.0133N + Q_2 \text{ l/sec}\end{aligned}$$

Minimum peak flow in any block or street sewer = 2.2 l/sec.

Minimum and maximum depth of flow at peak flow

Minimum depth of flow = 0.2 x pipe diameter

Maximum depth of flow = 0.8 x pipe diameter

Minimum gradient

Minimum gradient to achieve a self-cleansing velocity of

0.5 m/sec at minimum depth of flow = 0.006 (1 in 167)

Minimum pipe diameters

Block sewers = 100mm

Street sewers = 150mm

Minimum depth of pipe soffit

For block sewers, = 0.3 m

For street sewers in footpaths, = 0.4 m

For street sewers under vehicular loads, = 0.8m (or with concrete protection for shallower depths)

Hydraulic design

Using Colebrook-White equation presented in a tabular form in the Hydraulic Pipe Design Tables.30/ (For purposes of this example, the pipe design table corresponding to a roughness (k) value of 1.5 (slimed clay pipes) has been presented in annex II.)

Maximum number of houses to be connected to a 100mm diameter sewer

= 100

Maximum spacing between inspection chambers = 40m

Solution

The block sewer at the head of street collector sewer C1 (see figure I.1) is considered in this example and is illustrated in figure I.2). The hydraulic calculations are presented in table I.1). Similarly, the hydraulic calculations for collector sewer C1 are presented in table I.2. Both tables are described, column by column, below.

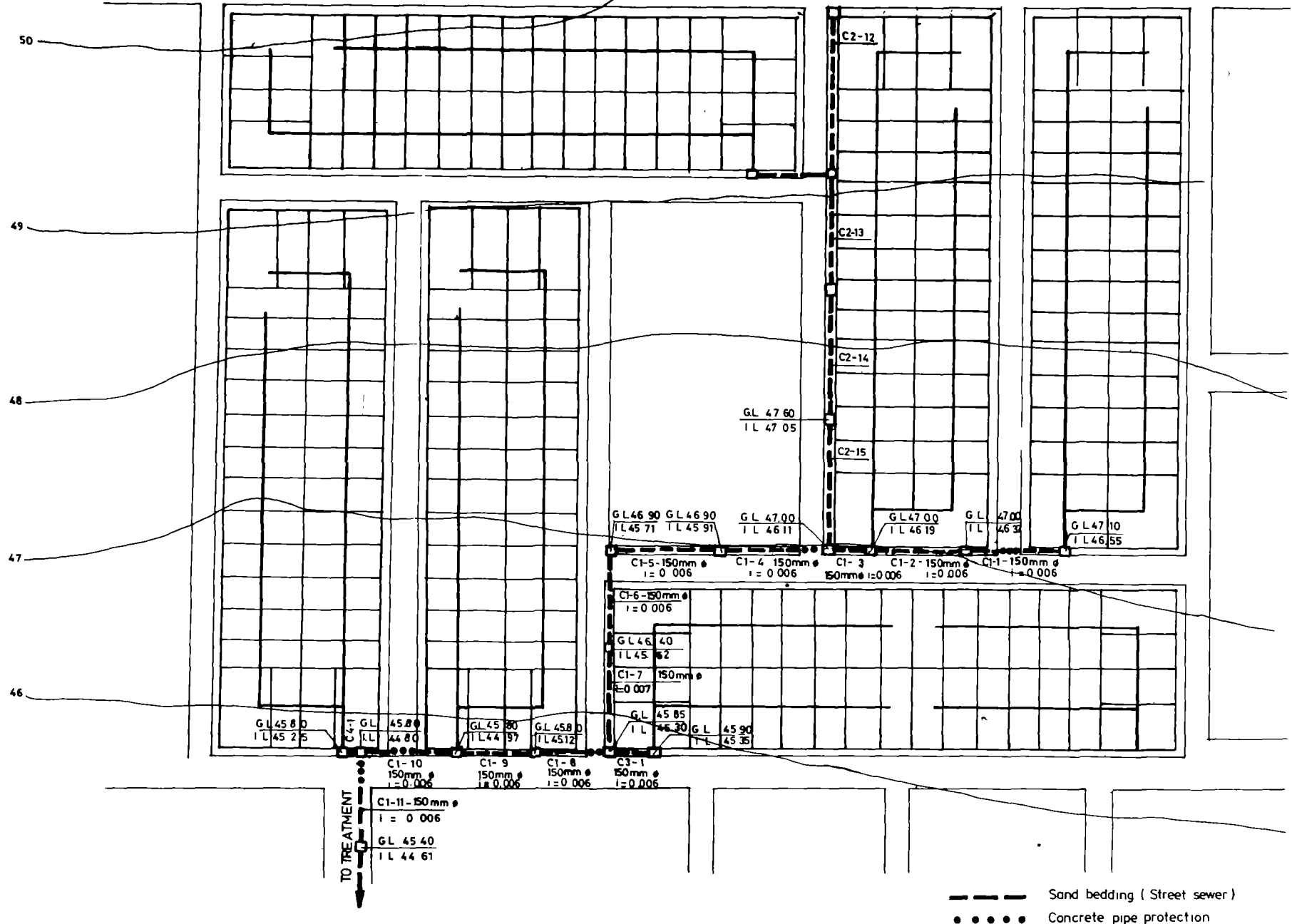


Figure I-1. Street sewer construction drawing for design example.

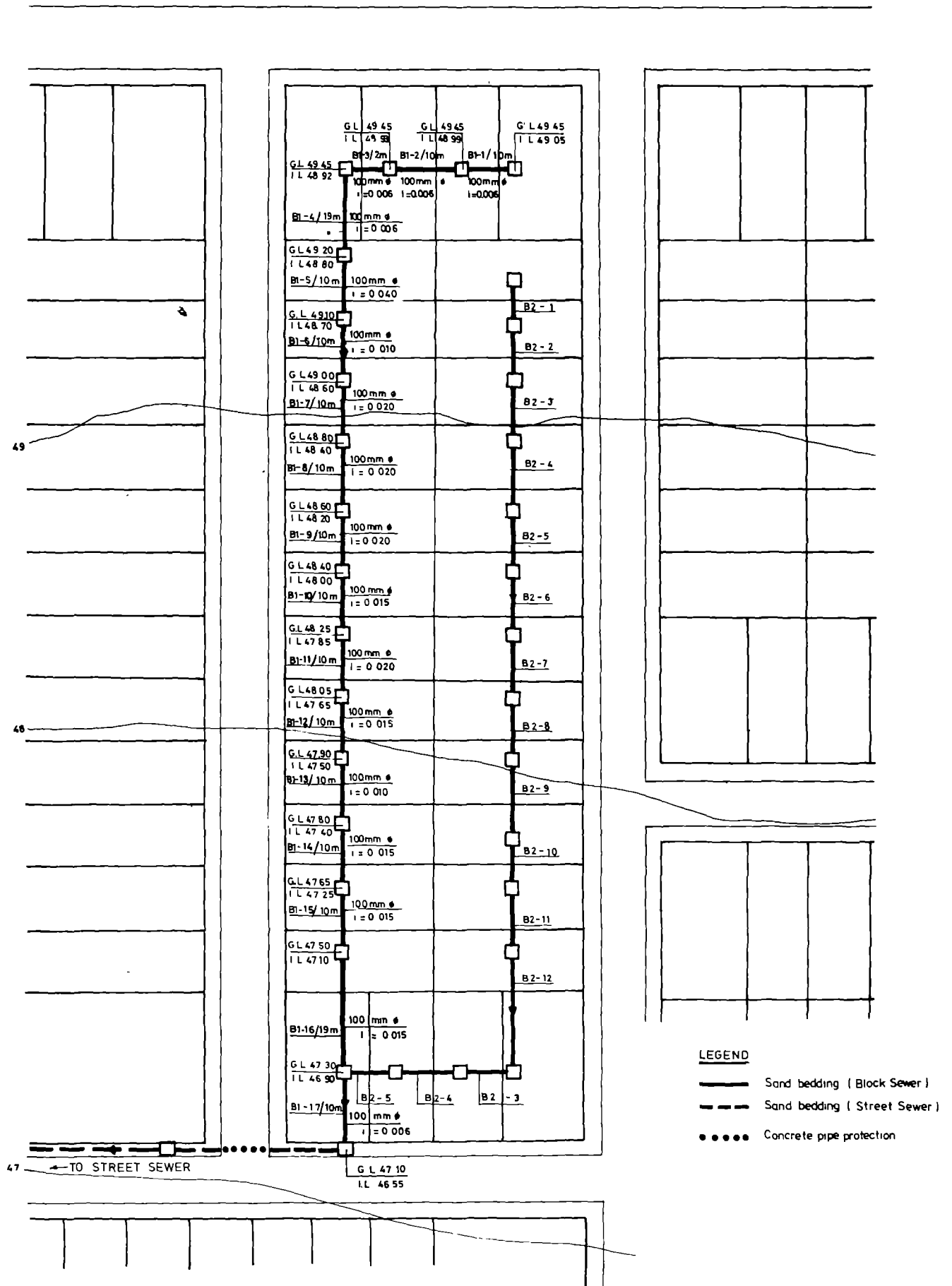


Figure I-2. Block sewer construction drawing for design example

Table 1.1 Hydraulic calculations for block sewer design example

Sewer reference	Length	Number of houses served	Flow a/ upstream	Flow along the stretch	Flow down stream	Groundlevel		Invertlevel		Difference in invert level	Gradient	Diameter	Flow at full section	Velocity of flow	Depth of sewer		Depth of downstream chamber b/	Observation
						Upstream	Downstream	Upstream	Downstream						Upstream	Downstream		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
B1-1	10	1	2.2	-	2.2	49.45	49.45	49.05	48.99	0.06	0.006	100	4.03	0.50	0.40	0.46	0.46	
B1-2	10	2	2.2	-	2.2	49.45	49.45	48.99	48.93	0.06	0.006	100	4.03	0.50	0.46	0.52	0.52	
B1-3	2	3	2.2	-	2.2	49.45	49.45	48.93	48.92	0.01	0.006	100	4.03	0.50	0.52	0.53	0.53	
B1-4	19	4	2.2	-	2.2	49.45	49.20	48.92	48.80	0.12	0.006	100	4.03	0.50	0.53	0.40	0.40	
B1-5	10	5	2.2	-	2.2	49.20	49.10	48.80	48.70	0.10	0.010	100	5.22	0.55	0.40	0.40	0.40	
B1-6	10	6	2.2	-	2.2	49.10	49.00	48.70	48.60	0.10	0.010	100	5.22	0.55	0.40	0.40	0.40	
B1-7	10	7	2.2	-	2.2	49.00	48.80	48.60	48.40	0.20	0.020	100	7.40	0.80	0.40	0.40	0.40	
B1-8	10	8	2.2	-	2.2	48.80	48.60	48.40	48.20	0.20	0.020	100	7.40	0.80	0.40	0.40	0.40	
B1-9	10	9	2.2	-	2.2	48.60	48.40	48.20	48.00	0.20	0.020	100	7.40	0.80	0.40	0.40	0.40	
B1-10	10	10	2.2	-	2.2	48.40	48.25	48.00	47.85	0.15	0.015	100	6.40	0.73	0.40	0.40	0.40	
B1-11	10	11	2.2	-	2.2	48.25	48.05	47.85	47.65	0.20	0.020	100	7.40	0.80	0.40	0.40	0.40	
B1-12	10	12	2.2	-	2.2	48.05	47.90	47.65	47.50	0.15	0.015	100	6.40	0.73	0.40	0.40	0.40	
B1-13	10	13	2.2	-	2.2	47.90	47.80	47.50	47.40	0.10	0.010	100	5.22	0.55	0.40	0.40	0.40	
B1-14	10	14	2.2	-	2.2	47.80	47.65	47.40	47.25	0.15	0.015	100	6.40	0.73	0.40	0.40	0.40	
B1-15	10	15	2.2	-	2.2	47.65	47.50	47.25	47.10	0.15	0.015	100	6.40	0.73	0.40	0.40	0.40	
B1-16	19	16	2.2	-	2.2	47.50	47.30	47.10	46.90	0.20	0.011	100	5.47	0.70	0.40	0.40	0.54	
B1-17	10	32	2.2	-	2.2	47.30	47.10	46.76	46.70	0.06	0.006	100	4.03	0.50	0.54	0.40	0.55	
c/ B2-15	2	15	2.2	-	2.2	47.30	47.30	46.77	46.76	0.01	0.006	100	4.03	0.50	0.53	0.54	0.54	

a/ Since the flow from the number of houses considered was less than the minimum 2.2 l/sec, this minimum value was used.

b/ All inspection chambers will be of type ICI.

c/ Block sewer B2 is calculated in a similar manner of sewer B1. Only the calculation for the last stretch of block sewer B2 has however been shown here.

Table 1.2 Hydraulic calculations for collector street sewer design example

Sewer reference	Length	Number of houses served	Flow a/ upstream	Flow along the stretch	Flow down stream	Groundlevel		Invertlevel		Difference in invert level	Gradient	Diameter	Flow at full section	Velocity of flow	Depth of sewer		Depth of downstream chamber b/	Observation
						Upstream	Downstream	Upstream	Downstream						Upstream	Downstream		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
C1-1	30	32	2.20	-	2.20	47.10	47.00	46.55	46.37	0.18	0.006	150	11.96	0.50	0.55	0.63	0.63	
C1-2	30	32	2.20	-	2.20	47.00	47.00	46.37	46.19	0.18	0.006	150	11.96	0.50	0.63	0.81	0.81	
C1-3	14	32	2.20	-	2.20	47.00	47.00	46.19	46.11	0.08	0.006	150	11.96	0.50	0.81	0.89	0.89	
C1-4	34	319	2.20	3.40	4.25	47.00	46.90	46.11	45.91	0.20	0.006	150	11.96	0.62	0.89	0.99	0.99	
C1-5	34	319	4.25	-	4.25	46.90	46.90	45.91	45.71	0.20	0.006	150	11.96	0.62	0.99	1.19	1.19	
C1-6	31	319	4.25	-	4.25	46.90	46.40	45.71	45.52	0.19	0.006	150	11.96	0.62	1.19	0.88	0.88	
C1-7	31	319	4.25	-	4.25	46.40	45.85	45.52	45.30	0.22	0.007	150	12.92	0.66	0.88	0.55	0.58	
C1-8	25	337	4.25	0.24	4.49	45.85	45.80	45.27	45.12	0.15	0.006	150	11.96	0.62	0.58	0.68	0.68	
C1-9	25	337	4.49	-	4.49	45.80	45.80	45.12	44.97	0.15	0.006	150	11.96	0.62	0.68	0.83	0.83	
C1-10	29	369	4.49	0.43	4.92	45.80	45.80	44.97	44.80	0.17	0.006	150	11.96	0.65	0.83	1.00	1.00	
C1-11	32	401	4.92	0.43	5.35	45.80	45.40	44.80	44.61	0.19	0.006	150	11.96	0.66	1.00	0.79	0.79	
b/ C2-15	40	255	3.40	-	3.40	47.60	47.00	47.05	46.45	0.60	0.015	150	18.96	0.80	0.55	0.55	0.89	
C3-1	14	18	2.20	-	2.20	45.90	45.85	45.35	45.27	0.08	0.006	150	11.96	0.50	0.55	0.58	0.58	
C4-1	7	32	2.20	-	2.20	45.80	45.80	45.25	45.21	0.04	0.006	150	11.96	0.50	0.55	0.59	1.00	
B2-15																		

a/ $e = 64 \text{ (houses)} \times 0.01333 + 3.4 = 4.25 \text{ l/sec.}$

b/ Calculated as in collector sewer C1. Only the calculation for the last stretch of collector sewer C2 has however been shown here.

Column 1: Sewer reference

Each length of sewer between adjacent inspection chambers is given a reference number. The numbering is started at the head of the sewer with the prefix B or C, depending on whether the sewer is a block sewer or street collector sewer. The sewer branch reference number is presented next followed by a hyphen and the number of the stretch of sewer. Hence C4-5 refers to the fifth stretch along collector sewer C4. In the case of block sewers, it is usual to prefix the reference number with the number of the block. Hence 20B2-3 refers to the third stretch along the second branch of the sewer to be laid in block 20.

Column 2: Length

The distance, in metres of the stretch of sewer.

Column 3: Number of houses served

Number of houses drained by the stretch of sewer under consideration.

Column 4: Flow upstream

The design flow determined at the head of the stretch of sewer from the flow estimation equation given above, but also satisfying a minimum flow condition of 2.2 l/sec.

Column 5: Flow along the stretch

Additional flows entering from branch connections and infiltration.

Column 6: Flow downstream

The sum of the upstream flow and the flow along the stretch, i.e., the sum of columns 4 and 5 for the stretch under consideration. Where the flow in both columns represents minimum flow conditions, then the flow downstream does not represent the sum of these flows (i.e., 4.4 l/sec), but must be determined from the flow estimation equation using the total number of houses draining downstream. Where this total flow is less than the minimum 2.2 l/sec, then this value must be adopted for the downstream flow. Where the estimated flow exceeds the minimum value, then this value must be used for the design flow.

Column 7: Ground level upstream

The ground level at the upstream inspection chamber.

Column 8: Ground level downstream

The ground level at the downstream inspection chamber.

Column 9: Invert level upstream

The invert of the exit pipe at the upstream inspection chamber.

Column 10: Invert level downstream

The invert level of the entry pipe at the downstream inspection

chamber along the stretch under consideration. Often column 12 and hence column 11, are established before computing column 10.

Column 11: Difference in invert level

The difference between the upstream and downstream invert levels, i.e., the difference between columns 9 and 10.

Column 12: Gradient

The gradient of the sewer. A minimum gradient of 0.006 (or 1 in 167) is usually maintained. Satisfaction of the minimum gradient condition automatically satisfies minimum velocity of flow in pipe. Wherever possible, attempts are made to lay the sewer at the same grade as the ground. The following cases are exceptions to this rule:

(a) When the ground slopes at a gradient flatter than the minimum gradient. In this case, the minimum gradient is applied;

(b) When the ground is steeper than the minimum gradient, but the upstream sewer is laid at a depth greater than the minimum depth of pipe cover. In this case, opportunity should be taken to lay the pipe at a gradient that will recover the depth of pipe cover to, or as near as possible to, the required minimum, while also ensuring that the gradient is not flatter than the minimum.

Column 13: Diameter

The diameter of the pipe which, when laid at the specified grade, will have a capacity sufficient to ensure the non-surcharged discharge of the design flow (maximum permissible depth of flow = 0.8).

Column 14: Flow at full section

The flow at full section is approximately equal to the flow at a proportional depth of 0.8 and, hence, may be assumed to be the corresponding capacity of the pipe. The flow at full section is obtained from table II.1 in annex II. If more precise values are required for the flow at a proportional depth of 0.8 these may be obtained from table II.1 with the factor for part-full pipes obtained from table II.2 (see annex II) which corresponds to that proportional depth and coefficient for part-full pipes obtained from the bottom of table II.1.

Column 15: Velocity of flow

The velocity of flow at full bore is once again obtained directly from table II.1. In order to establish the velocity with which the design discharge will flow, it is necessary once again to use table II.2. The proportional depth of flow corresponding to the proportional discharge calculated by dividing the design flow by the full or pipe capacity, is read off from table II.2. The proportional depth of flow thus obtained is used to determine the proportional velocity multiplying factor from table II.3 (see annex II). The velocity of flow of the design discharge is obtained by multiplying the factor obtained from table II.3 with the full bore velocity initially determined from table II.1. It is worth noting that at the minimum design discharge of 2.2 l/sec the corresponding velocity of flow equals 0.5m/sec.

Column 16: Depth of upstream sewer

This is the depth to invert of the outlet sewer of the upstream inspection chamber. This depth is obtained from the differences in level between columns 7 and 9, or from column 18 of the preceding calculation line, i.e., the depth of downstream chamber of the preceding stretch of sewer.

Column 17: Depth of downstream sewer

This is the depth to invert of the downstream end of the stretch of pipe under consideration. This depth is obtained from the differences in level between columns 8 and 10.

Column 18: Depth of downstream chamber

It is possible that while designing a particular stretch of sewer, other branch sewers will connect to the sewer under consideration at some inspection chambers along its length. These sewers may have a depth to invert greater than the main sewer under consideration. In such cases, it is necessary to ensure that the outlet of this inspection chamber is laid at a depth which will ensure the unobstructed drainage of both sewers entering the chamber; it must therefore be at a depth equal to, or greater than, the deeper branch sewer. In such instances it is possible that the depth of the downstream chamber is not the same as the depth of the downstream sewer and the greater depth must, therefore, be specified for purposes of abstracting quantities for excavation and establishing the type of inspection chamber to be specified downstream.

Column 19: Observations

This column is reserved for any special remarks or observations. Having completed the hydraulic calculation charts, the information contained therein is transferred on to design drawings and used for determining civil engineering works quantities and subsequently for estimating the cost of the entire scheme. Block and street sewer construction drawings for the present design example are shown in figures I.1 and I.2 respectively.

Annex II

Table II.1. Hydraulic design of pipes

ks = 1.500mm
 i = 0.00015 to 0.004
 ie hydraulic gradient =
 1 in 6667 to 1 in 250

Water (or sewage) at 15°C
 full bore conditions
 velocities in m/s
 discharges in l/s

Gradient	Pipe diameters in mm -											
	50	75	80	100	125	150	175	200	225	250	275	300
0.00015 1/ 6667	0.046 0.090	0.062 0.275	0.065 0.329	0.077 0.604	0.090 1.108	0.103 1.814	0.114 2.748	0.125 3.936	0.136 5.400	0.146 7.162	0.156 9.243	0.165 11.664
0.00016 1/ 6250	0.048 0.093	0.065 0.285	0.068 0.340	0.080 0.625	0.093 1.146	0.106 1.876	0.118 2.842	0.130 4.070	0.140 5.584	0.151 7.405	0.161 9.556	0.171 12.058
0.00017 1/ 5882	0.049 0.096	0.067 0.294	0.070 0.351	0.082 0.646	0.096 1.183	0.110 1.936	0.122 2.933	0.134 4.200	0.145 5.761	0.156 7.640	0.166 9.859	0.176 12.440
0.00018 1/ 5556	0.051 0.099	0.069 0.304	0.072 0.362	0.085 0.665	0.099 1.219	0.113 1.995	0.126 3.022	0.138 4.326	0.149 5.934	0.160 7.869	0.171 10.154	0.181 12.811
0.00019 1/ 5263	0.052 0.102	0.071 0.312	0.074 0.373	0.087 0.684	0.102 1.254	0.116 2.052	0.129 3.108	0.142 4.449	0.153 6.102	0.165 8.091	0.176 10.440	0.186 13.172
0.00020 1/ 5000	0.054 0.105	0.073 0.321	0.076 0.383	0.090 0.703	0.105 1.288	0.119 2.107	0.133 3.191	0.145 4.569	0.158 6.266	0.169 8.398	0.180 10.719	0.191 13.523
0.00022 1/ 4545	0.056 0.111	0.076 0.338	0.080 0.403	0.094 0.739	0.110 1.353	0.125 2.214	0.139 3.353	0.153 4.799	0.166 6.581	0.178 8.725	0.190 11.257	0.201 14.201
0.00024 1/ 4167	0.059 0.116	0.080 0.353	0.084 0.422	0.099 0.774	0.115 1.416	0.131 2.316	0.146 3.507	0.160 5.020	0.173 6.883	0.186 9.124	0.198 11.771	0.210 14.848
0.00026 1/ 3846	0.062 0.121	0.083 0.369	0.087 0.440	0.103 0.807	0.120 1.476	0.137 2.414	0.152 3.655	0.167 5.231	0.180 7.172	0.194 9.507	0.206 12.264	0.219 15.470
0.00028 1/ 3571	0.064 0.126	0.087 0.383	0.091 0.457	0.107 0.839	0.125 1.534	0.142 2.509	0.158 3.798	0.173 5.434	0.187 7.450	0.201 9.876	0.214 12.739	0.227 16.068
0.00030 1/ 3333	0.067 0.131	0.090 0.398	0.094 0.474	0.111 0.869	0.130 1.590	0.147 2.600	0.164 3.935	0.179 5.631	0.194 7.719	0.208 10.231	0.222 13.197	0.235 16.644
0.00032 1/ 3125	0.069 0.135	0.093 0.411	0.098 0.490	0.114 0.899	0.134 1.644	0.152 2.688	0.169 4.068	0.185 5.821	0.201 7.979	0.215 10.575	0.230 13.640	0.243 17.203
0.00034 1/ 2941	0.071 0.140	0.096 0.425	0.101 0.506	0.118 0.928	0.138 1.697	0.157 2.773	0.174 4.197	0.191 6.005	0.207 8.231	0.222 10.908	0.237 14.069	0.251 17.743
0.00036 1/ 2778	0.073 0.144	0.099 0.437	0.104 0.522	0.122 0.956	0.142 1.748	0.162 2.856	0.180 4.322	0.197 6.183	0.213 8.475	0.229 11.232	0.244 14.486	0.258 18.269
0.00038 1/ 2632	0.076 0.148	0.102 0.450	0.107 0.536	0.125 0.983	0.146 1.797	0.166 2.937	0.185 4.444	0.202 6.357	0.219 8.713	0.235 11.547	0.251 14.892	0.266 18.780
0.00040 1/ 2500	0.078 0.152	0.105 0.462	0.110 0.551	0.129 1.010	0.150 1.846	0.171 3.016	0.190 4.563	0.208 6.527	0.225 8.945	0.241 11.854	0.257 15.287	0.273 19.277
0.00042 1/ 2381	0.080 0.156	0.107 0.474	0.112 0.565	0.132 1.036	0.154 1.893	0.175 3.092	0.195 4.679	0.213 6.692	0.231 9.171	0.248 12.153	0.264 15.672	0.280 19.763
0.00044 1/ 2273	0.082 0.160	0.110 0.486	0.115 0.579	0.135 1.061	0.158 1.939	0.179 3.167	0.199 4.792	0.218 6.853	0.236 9.392	0.254 12.445	0.270 16.048	0.286 20.237
0.00046 1/ 2174	0.084 0.164	0.113 0.497	0.118 0.593	0.138 1.086	0.162 1.984	0.183 3.241	0.204 4.902	0.223 7.011	0.242 9.608	0.259 12.730	0.276 16.416	0.293 20.700
0.00048 1/ 2083	0.085 0.168	0.115 0.508	0.121 0.606	0.141 1.110	0.165 2.028	0.187 3.312	0.208 5.010	0.228 7.165	0.247 9.819	0.265 13.010	0.282 16.776	0.299 21.154
0.00050 1/ 2000	0.087 0.171	0.118 0.519	0.123 0.619	0.144 1.133	0.169 2.071	0.191 3.382	0.213 5.116	0.233 7.317	0.252 10.026	0.271 13.284	0.288 17.129	0.306 21.598
0.00055 1/ 1818	0.092 0.180	0.124 0.546	0.129 0.650	0.152 1.191	0.177 2.175	0.201 3.552	0.223 5.372	0.245 7.682	0.265 10.525	0.284 13.945	0.303 17.980	0.321 22.671
0.00060 1/ 1667	0.096 0.189	0.129 0.571	0.135 0.680	0.159 1.245	0.185 2.274	0.210 3.714	0.234 5.617	0.256 8.031	0.277 11.003	0.297 14.577	0.316 18.794	0.335 23.696
0.00065 1/ 1538	0.100 0.197	0.135 0.595	0.141 0.709	0.165 1.298	0.193 2.370	0.219 3.869	0.243 5.851	0.266 8.366	0.288 11.461	0.309 15.183	0.330 19.575	0.349 24.679
0.00070 1/ 1429	0.104 0.205	0.140 0.618	0.147 0.737	0.172 1.348	0.201 2.462	0.227 4.019	0.253 6.077	0.277 8.688	0.299 11.902	0.321 15.766	0.342 20.326	0.363 25.626
Coefficient for part-full pipes												
	9	14	14	18	25	30	30	35	40	45	50	60

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Source: Hydraulic Research Station, Tables for the Hydraulic Design of Pipes and sewers, 4th edition, (Oxford, Hydraulics Research, 1983).

ks = 1.500mm
i = 0.00015 to 0.004

ie hydraulic gradient =
1 in 6667 to 1 in 250

Water (or sewage) at 15°C
full bore conditions

velocities in m/s
discharges in l/s

Table II.1
(continued)

Gradient	Pipe diameters in mm:											
	50	75	80	100	125	150	175	200	225	250	275	300
0.00075 1/ 1333	0.108	0.145	0.152	0.178	0.208	0.236	0.262	0.286	0.310	0.333	0.354	0.375
	0.212	0.641	0.764	1.397	2.550	4.163	6.295	8.999	12.327	16.329	21.051	26.539
0.00080 1/ 1250	0.112	0.150	0.157	0.184	0.215	0.244	0.270	0.296	0.320	0.344	0.366	0.388
	0.219	0.663	0.790	1.444	2.636	4.303	6.505	9.299	12.739	16.873	21.752	27.422
0.00085 1/ 1176	0.115	0.155	0.162	0.190	0.222	0.251	0.279	0.305	0.330	0.354	0.378	0.400
	0.226	0.684	0.815	1.490	2.719	4.438	6.710	9.591	13.137	17.401	22.432	28.278
0.00090 1/ 1111	0.119	0.159	0.167	0.195	0.228	0.259	0.287	0.314	0.340	0.365	0.389	0.412
	0.233	0.704	0.839	1.534	2.800	4.570	6.908	9.874	13.524	17.913	23.092	29.109
0.00095 1/ 1053	0.122	0.164	0.172	0.201	0.235	0.266	0.295	0.323	0.350	0.375	0.400	0.423
	0.240	0.724	0.863	1.578	2.879	4.698	7.101	10.149	13.901	18.412	23.734	29.918
0.00100 1/ 1000	0.125	0.168	0.176	0.206	0.241	0.273	0.303	0.332	0.359	0.385	0.410	0.434
	0.246	0.744	0.886	1.620	2.955	4.822	7.289	10.417	14.268	18.897	24.359	30.705
0.00110 1/ 909	0.132	0.177	0.185	0.217	0.253	0.286	0.318	0.348	0.377	0.404	0.430	0.456
	0.259	0.781	0.930	1.701	3.102	5.062	7.651	10.934	14.975	19.833	25.564	32.223
0.00120 1/ 833	0.138	0.185	0.194	0.226	0.264	0.299	0.332	0.364	0.394	0.422	0.450	0.476
	0.271	0.817	0.973	1.778	3.243	5.292	7.997	11.428	15.651	20.727	26.715	33.674
0.00130 1/ 769	0.144	0.193	0.202	0.236	0.275	0.312	0.346	0.379	0.410	0.440	0.468	0.496
	0.282	0.851	1.014	1.853	3.379	5.512	8.329	11.902	16.299	21.584	27.820	35.065
0.00140 1/ 714	0.149	0.200	0.209	0.245	0.286	0.324	0.360	0.393	0.426	0.457	0.486	0.515
	0.293	0.884	1.053	1.924	3.509	5.723	8.648	12.358	16.923	22.410	28.883	36.404
0.00150 1/ 667	0.155	0.207	0.217	0.254	0.296	0.335	0.372	0.407	0.441	0.473	0.504	0.533
	0.304	0.916	1.091	1.993	3.634	5.928	8.957	12.798	17.525	23.206	29.908	37.696
0.00160 1/ 625	0.160	0.214	0.224	0.262	0.306	0.347	0.385	0.421	0.455	0.488	0.520	0.551
	0.314	0.947	1.127	2.060	3.755	6.125	9.255	13.223	18.107	23.976	30.900	38.946
0.00170 1/ 588	0.165	0.221	0.231	0.271	0.316	0.357	0.397	0.434	0.470	0.504	0.536	0.568
	0.324	0.977	1.163	2.125	3.873	6.317	9.544	13.636	18.671	24.723	31.862	40.157
0.00180 1/ 556	0.170	0.228	0.238	0.279	0.325	0.368	0.408	0.447	0.483	0.518	0.552	0.585
	0.334	1.006	1.198	2.187	3.987	6.503	9.824	14.036	19.219	25.447	32.795	41.333
0.00190 1/ 526	0.175	0.234	0.245	0.286	0.334	0.378	0.420	0.459	0.497	0.533	0.567	0.601
	0.343	1.034	1.231	2.249	4.099	6.684	10.097	14.426	19.752	26.152	33.703	42.476
0.00200 1/ 500	0.180	0.240	0.251	0.294	0.343	0.388	0.431	0.471	0.510	0.547	0.582	0.617
	0.353	1.061	1.264	2.308	4.207	6.860	10.363	14.805	20.271	26.839	34.588	43.590
0.00220 1/ 455	0.189	0.252	0.264	0.308	0.360	0.407	0.452	0.495	0.535	0.574	0.611	0.647
	0.370	1.114	1.327	2.423	4.415	7.200	10.876	15.537	21.271	28.163	36.293	45.738
0.00240 1/ 417	0.197	0.264	0.276	0.322	0.376	0.426	0.473	0.517	0.559	0.599	0.638	0.676
	0.387	1.165	1.387	2.533	4.615	7.524	11.365	16.235	22.227	29.428	37.922	47.790
0.00260 1/ 385	0.205	0.275	0.287	0.336	0.392	0.443	0.492	0.538	0.582	0.624	0.665	0.704
	0.403	1.213	1.445	2.638	4.806	7.836	11.835	16.906	23.144	30.641	39.484	49.758
0.00280 1/ 357	0.213	0.285	0.298	0.349	0.407	0.460	0.511	0.559	0.604	0.648	0.690	0.731
	0.419	1.260	1.500	2.739	4.990	8.135	12.287	17.551	24.026	31.808	40.988	51.652
0.00300 1/ 333	0.221	0.295	0.309	0.361	0.421	0.477	0.529	0.578	0.626	0.671	0.715	0.757
	0.434	1.305	1.554	2.837	5.168	8.424	12.723	18.173	24.877	32.935	42.438	53.479
0.00320 1/ 313	0.229	0.305	0.319	0.373	0.435	0.493	0.546	0.598	0.646	0.693	0.738	0.782
	0.449	1.349	1.606	2.931	5.339	8.704	13.145	18.775	25.701	34.024	43.841	55.246
0.00340 1/ 294	0.236	0.315	0.329	0.385	0.449	0.508	0.563	0.616	0.666	0.715	0.761	0.806
	0.463	1.391	1.656	3.023	5.506	8.975	13.554	19.358	26.499	35.080	45.201	56.959
0.00360 1/ 278	0.243	0.324	0.339	0.396	0.462	0.523	0.580	0.634	0.686	0.736	0.783	0.829
	0.477	1.432	1.705	3.112	5.668	9.238	13.951	19.925	27.274	36.105	46.522	58.623
0.00380 1/ 263	0.250	0.333	0.349	0.407	0.475	0.537	0.596	0.652	0.705	0.756	0.805	0.852
	0.490	1.472	1.753	3.198	5.825	9.494	14.337	20.476	28.028	37.102	47.806	60.240

Coefficient for part-full pipes

14	20	20	25	35	40	45	50	60	70	70	80
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ks = 1.500mm i < 0.004

Table II.1
(continued)

ks = 1.500mm
i = 0.004 to 0.1
re hydraulic gradient =
1 in 250 to 1 in 10
Water (or sewage) at 15°C
full bore conditions
velocities in m/s
discharges in l/s

Gradient	Pipe diameters in mm											
	50	75	80	100	125	150	175	200	225	250	275	300
0.00400 1/ 250	0.256	0.342	0.358	0.418	0.487	0.551	0.612	0.669	0.723	0.776	0.826	0.875
	0.503	1.511	1.799	3.282	5.978	9.743	14.713	21.013	28.762	38.074	49.057	61.816
0.00420 1/ 238	0.263	0.351	0.367	0.428	0.499	0.565	0.627	0.686	0.741	0.795	0.846	0.896
	0.516	1.549	1.844	3.365	6.127	9.986	15.080	21.536	29.478	39.021	50.277	63.353
0.00440 1/ 227	0.269	0.359	0.376	0.439	0.511	0.579	0.642	0.702	0.759	0.814	0.867	0.917
	0.528	1.586	1.888	3.445	6.273	10.224	15.438	22.047	30.177	39.946	51.468	64.854
0.00460 1/ 217	0.275	0.367	0.384	0.449	0.523	0.592	0.656	0.718	0.776	0.832	0.886	0.938
	0.540	1.622	1.931	3.523	6.416	10.456	15.788	22.547	30.860	40.850	52.633	66.320
0.00480 1/ 208	0.281	0.375	0.393	0.458	0.534	0.605	0.671	0.733	0.793	0.850	0.905	0.959
	0.552	1.658	1.973	3.600	6.555	10.683	16.130	23.035	31.529	41.735	53.773	67.756
0.00500 1/ 200	0.287	0.383	0.401	0.468	0.545	0.617	0.685	0.748	0.809	0.868	0.924	0.978
	0.564	1.692	2.014	3.675	6.692	10.905	16.466	23.514	32.184	42.602	54.889	69.162
0.00550 1/ 182	0.301	0.402	0.421	0.491	0.572	0.648	0.718	0.785	0.849	0.911	0.970	1.026
	0.592	1.776	2.114	3.857	7.022	11.443	17.276	24.671	33.766	44.695	57.585	72.558
0.00600 1/ 167	0.315	0.420	0.440	0.513	0.598	0.677	0.750	0.820	0.887	0.951	1.013	1.072
	0.618	1.856	2.209	4.030	7.337	11.956	18.051	25.776	35.278	46.695	60.161	75.802
0.00650 1/ 154	0.328	0.438	0.458	0.534	0.623	0.704	0.781	0.854	0.924	0.990	1.054	1.116
	0.644	1.933	2.301	4.197	7.640	12.448	18.794	26.836	36.728	48.614	62.632	78.915
0.00700 1/ 143	0.341	0.454	0.475	0.555	0.646	0.731	0.811	0.887	0.959	1.028	1.095	1.159
	0.669	2.007	2.389	4.357	7.931	12.922	19.508	27.856	38.123	50.460	65.009	81.910
0.00750 1/ 133	0.353	0.470	0.492	0.574	0.669	0.757	0.840	0.918	0.993	1.064	1.133	1.200
	0.693	2.078	2.474	4.511	8.212	13.379	20.198	28.840	39.470	52.241	67.303	84.799
0.00800 1/ 125	0.365	0.486	0.508	0.593	0.691	0.782	0.867	0.948	1.025	1.099	1.170	1.239
	0.716	2.147	2.556	4.661	8.484	13.822	20.865	29.792	40.772	53.964	69.522	87.594
0.00850 1/ 118	0.376	0.501	0.524	0.612	0.713	0.806	0.894	0.978	1.057	1.133	1.207	1.278
	0.738	2.214	2.635	4.806	8.747	14.250	21.512	30.715	42.034	55.634	71.673	90.303
0.00900 1/ 111	0.387	0.516	0.540	0.630	0.734	0.830	0.920	1.006	1.088	1.166	1.242	1.315
	0.760	2.279	2.712	4.946	9.002	14.666	22.139	31.611	43.259	57.255	73.761	92.933
0.00950 1/ 105	0.398	0.530	0.555	0.647	0.754	0.853	0.946	1.034	1.118	1.199	1.276	1.351
	0.781	2.342	2.788	5.083	9.251	15.071	22.750	32.482	44.451	58.832	75.792	95.491
0.01000 1/ 100	0.408	0.544	0.569	0.664	0.774	0.875	0.971	1.061	1.147	1.230	1.309	1.386
	0.802	2.404	2.861	5.216	9.493	15.465	23.345	33.331	45.612	60.368	77.770	97.983
0.01100 1/ 91	0.429	0.571	0.597	0.697	0.812	0.918	1.018	1.113	1.203	1.290	1.374	1.454
	0.841	2.522	3.002	5.473	9.960	16.225	24.491	34.967	47.850	63.329	81.583	102.786
0.01200 1/ 83	0.448	0.597	0.624	0.728	0.848	0.959	1.064	1.163	1.257	1.348	1.435	1.519
	0.879	2.636	3.137	5.718	10.406	16.951	25.586	36.530	49.968	66.158	85.226	107.375
0.01300 1/ 77	0.466	0.621	0.650	0.758	0.883	0.999	1.107	1.210	1.309	1.403	1.494	1.581
	0.916	2.744	3.266	5.954	10.834	17.648	26.637	38.029	52.039	68.871	88.721	111.776
0.01400 1/ 71	0.484	0.645	0.674	0.787	0.916	1.037	1.149	1.256	1.358	1.456	1.550	1.641
	0.951	2.849	3.390	6.180	11.246	18.318	27.648	39.472	54.012	71.482	92.083	116.012
0.01500 1/ 67	0.501	0.668	0.698	0.815	0.949	1.073	1.190	1.301	1.406	1.508	1.605	1.699
	0.984	2.950	3.510	6.399	11.643	18.964	28.623	40.864	55.916	74.001	95.328	120.099
0.01600 1/ 62	0.518	0.690	0.721	0.842	0.980	1.109	1.229	1.344	1.453	1.557	1.658	1.755
	1.017	3.047	3.626	6.610	12.027	19.590	29.567	42.210	57.758	76.437	98.466	124.051
0.01700 1/ 59	0.534	0.711	0.744	0.868	1.010	1.143	1.267	1.385	1.498	1.605	1.709	1.809
	1.049	3.142	3.739	6.815	12.400	20.196	30.481	43.515	59.543	78.799	101.507	127.882
0.01800 1/ 56	0.550	0.732	0.766	0.893	1.040	1.176	1.304	1.425	1.541	1.652	1.759	1.862
	1.079	3.234	3.848	7.014	12.761	20.784	31.369	44.782	61.276	81.092	104.460	131.602
0.01900 1/ 53	0.565	0.752	0.787	0.918	1.069	1.209	1.340	1.465	1.584	1.697	1.807	1.913
	1.109	3.323	3.954	7.208	13.113	21.357	32.232	46.014	62.961	83.322	107.332	135.220
Coefficient for part-full pipes												
	18	25	30	35	45	50	60	70	80	90	100	110

ks = 1.500mm i < 0.1

ks = 1.500mm
 i = 0.004 to 01
 re hydraulic gradient =
 1 in 250 to 1 in 10

Water (or sewage) at 15° C
 full bore conditions
 velocities in m/s
 discharges in l/s

Table II.1
 (continued)

Gradient	Pipe diameters in mm :											
	50	75	80	100	125	150	175	200	225	250	275	300
0.02000 1/ 50	0.580 1.138	0.772 3.410	0.807 4.058	0.942 7.396	1.096 13.456	1.240 21.914	1.375 33.073	1.503 47.214	1.625 64.603	1.742 85.494	1.854 110.130	1.963 138.743
0.02200 1/ 45	0.608 1.195	0.810 3.578	0.847 4.257	0.988 7.759	1.150 14.116	1.301 22.989	1.442 34.695	1.577 49.528	1.704 67.768	1.827 89.682	1.945 115.523	2.059 145.536
0.02400 1/ 42	0.636 1.248	0.846 3.738	0.885 4.448	1.032 8.106	1.202 14.747	1.359 24.016	1.507 36.244	1.647 51.738	1.780 70.792	1.908 93.682	2.032 120.675	2.151 152.026
0.02600 1/ 38	0.662 1.300	0.881 3.892	0.921 4.631	1.075 8.439	1.251 15.352	1.415 25.001	1.569 37.730	1.714 53.859	1.853 73.693	1.987 97.520	2.115 125.618	2.239 158.251
0.02800 1/ 36	0.687 1.349	0.914 4.040	0.956 4.807	1.115 8.760	1.298 15.934	1.468 25.949	1.628 39.159	1.779 55.899	1.924 76.483	2.062 101.212	2.195 130.373	2.324 164.241
0.03000 1/ 33	0.711 1.397	0.947 4.182	0.990 4.977	1.155 9.069	1.344 16.496	1.520 26.863	1.685 40.539	1.842 57.868	1.991 79.176	2.134 104.775	2.272 134.961	2.405 170.021
0.03200 1/ 31	0.735 1.443	0.978 4.320	1.023 5.141	1.193 9.368	1.389 17.040	1.570 27.748	1.741 41.873	1.903 59.772	2.057 81.781	2.205 108.221	2.347 139.399	2.484 175.611
0.03400 1/ 29	0.758 1.488	1.008 4.454	1.054 5.300	1.230 9.657	1.431 17.566	1.619 28.605	1.795 43.166	1.961 61.617	2.120 84.305	2.273 111.561	2.419 143.701	2.561 181.029
0.03600 1/ 28	0.780 1.531	1.038 4.584	1.085 5.455	1.265 9.939	1.473 18.078	1.666 29.437	1.847 44.422	2.018 63.409	2.182 86.756	2.339 114.804	2.490 147.877	2.635 186.289
0.03800 1/ 26	0.801 1.574	1.066 4.710	1.115 5.605	1.300 10.212	1.514 18.575	1.712 30.247	1.898 45.643	2.074 65.152	2.242 89.140	2.403 117.958	2.558 151.939	2.708 191.406
0.04000 1/ 25	0.822 1.615	1.094 4.833	1.144 5.751	1.334 10.479	1.553 19.059	1.756 31.035	1.947 46.832	2.128 66.849	2.300 91.462	2.466 121.030	2.625 155.895	2.778 196.389
0.04200 1/ 24	0.843 1.655	1.121 4.953	1.173 5.894	1.367 10.739	1.592 19.532	1.800 31.805	1.995 47.993	2.181 68.505	2.357 93.726	2.527 124.026	2.690 159.754	2.847 201.250
0.04400 1/ 23	0.863 1.694	1.148 5.071	1.200 6.033	1.400 10.993	1.629 19.993	1.842 32.555	2.042 49.125	2.232 70.121	2.413 95.938	2.586 126.951	2.753 163.522	2.914 205.996
0.04600 1/ 22	0.882 1.733	1.174 5.185	1.227 6.170	1.431 11.241	1.666 20.444	1.884 33.290	2.088 50.233	2.282 71.701	2.467 98.099	2.644 129.811	2.815 167.205	2.980 210.635
0.04800 1/ 21	0.901 1.770	1.199 5.297	1.254 6.303	1.462 11.484	1.702 20.886	1.924 34.008	2.133 51.316	2.332 73.247	2.520 100.214	2.701 132.610	2.876 170.809	3.044 215.174
0.05000 1/ 20	0.920 1.807	1.224 5.407	1.280 6.434	1.492 11.721	1.737 21.318	1.964 34.711	2.178 52.377	2.380 74.762	2.573 102.286	2.757 135.350	2.935 174.339	3.107 219.620
0.05500 1/ 18	0.965 1.896	1.284 5.672	1.343 6.749	1.566 12.296	1.822 22.362	2.060 36.411	2.284 54.941	2.496 78.420	2.698 107.290	2.892 141.971	3.079 182.866	3.259 230.361
0.06000 1/ 17	1.009 1.980	1.341 5.926	1.403 7.050	1.635 12.845	1.904 23.360	2.152 38.034	2.386 57.390	2.607 81.916	2.819 112.071	3.021 148.297	3.216 191.013	3.404 240.623
0.06500 1/ 15	1.050 2.062	1.396 6.169	1.460 7.340	1.702 13.371	1.981 24.316	2.240 39.592	2.484 59.740	2.714 85.268	2.934 116.657	3.145 154.365	3.347 198.827	3.543 250.466
0.07000 1/ 14	1.090 2.140	1.449 6.402	1.516 7.618	1.767 13.877	2.057 25.237	2.325 41.090	2.578 62.000	2.817 88.494	3.045 121.070	3.264 160.203	3.474 206.346	3.677 259.937
0.07500 1/ 13	1.128 2.216	1.500 6.628	1.569 7.886	1.829 14.366	2.129 26.126	2.407 42.536	2.668 64.182	2.916 91.607	3.152 125.328	3.378 165.836	3.596 213.601	3.807 269.075
0.08000 1/ 13	1.166 2.289	1.550 6.846	1.621 8.146	1.889 14.839	2.199 26.985	2.486 43.935	2.756 66.291	3.012 94.617	3.256 129.446	3.489 171.285	3.714 220.618	3.932 277.914
0.08500 1/ 12	1.202 2.359	1.598 7.058	1.671 8.397	1.948 15.297	2.267 27.818	2.563 45.290	2.841 68.336	3.105 97.535	3.356 133.437	3.597 176.565	3.829 227.419	4.053 286.480
0.09000 1/ 11	1.237 2.428	1.644 7.263	1.719 8.642	2.004 15.742	2.333 28.626	2.637 46.606	2.924 70.321	3.195 100.368	3.453 137.313	3.701 181.693	3.940 234.023	4.171 294.798
0.09500 1/ 11	1.271 2.495	1.689 7.463	1.767 8.879	2.059 16.175	2.397 29.413	2.710 47.887	3.004 72.252	3.283 103.124	3.548 141.082	3.803 186.680	4.048 240.446	4.285 302.888
0.10000 1/ 10	1.304 2.560	1.733 7.658	1.813 9.111	2.113 16.596	2.459 30.179	2.780 49.133	3.082 74.133	3.368 105.808	3.641 144.754	3.902 191.537	4.154 246.701	4.396 310.768
Coefficient for part-full pipes												
	20	35	35	45	50	70	80	90	100	110	120	130

ks = 1.500mm i < 0.1

Table II.2 Proportional discharges in pipes running part-full

(a) Circular sections

Proportional depth

Coefficient for part-full pipes = $\left[\frac{k}{D} + \frac{1}{3600DS^{1/3}} \right]^{-1}$ for water at 15°C (k. and D in metres)

	5	10	20	50	100	200	500	1000	2000
0.02	0.000	0.043	0.073	0.100	0.116	0.128	0.140	0.148	0.154
0.04	0.073	0.121	0.154	0.184	0.200	0.213	0.226	0.235	0.242
0.06	0.143	0.191	0.224	0.254	0.270	0.283	0.297	0.305	0.312
0.08	0.207	0.254	0.286	0.316	0.332	0.345	0.358	0.366	0.373
0.10	0.267	0.313	0.344	0.372	0.387	0.400	0.412	0.420	0.427
0.12	0.324	0.367	0.396	0.423	0.438	0.450	0.462	0.469	0.476
0.14	0.377	0.418	0.446	0.471	0.485	0.496	0.508	0.515	0.521
0.16	0.428	0.466	0.492	0.516	0.529	0.539	0.550	0.557	0.562
0.18	0.475	0.511	0.536	0.558	0.570	0.580	0.590	0.596	0.601
0.20	0.521	0.554	0.577	0.598	0.609	0.618	0.627	0.633	0.638
0.22	0.564	0.595	0.616	0.635	0.645	0.654	0.662	0.668	0.672
0.24	0.606	0.634	0.653	0.670	0.680	0.688	0.696	0.700	0.704
0.26	0.645	0.671	0.688	0.704	0.713	0.720	0.727	0.731	0.735
0.28	0.683	0.706	0.722	0.736	0.744	0.750	0.757	0.761	0.764
0.30	0.719	0.740	0.754	0.767	0.774	0.779	0.785	0.789	0.792
0.35	0.802	0.817	0.827	0.837	0.842	0.846	0.850	0.852	0.854
0.40	0.877	0.886	0.892	0.898	0.902	0.904	0.907	0.908	0.910
0.45	0.942	0.947	0.950	0.953	0.954	0.955	0.957	0.957	0.958
0.50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.55	1.050	1.046	1.043	1.041	1.039	1.038	1.037	1.037	1.036
0.60	1.092	1.084	1.080	1.075	1.073	1.071	1.069	1.067	1.066
0.65	1.126	1.116	1.109	1.103	1.099	1.097	1.094	1.092	1.091
0.70	1.152	1.140	1.131	1.124	1.120	1.117	1.113	1.111	1.109
0.75	1.169	1.156	1.146	1.138	1.133	1.130	1.126	1.124	1.122
0.80	1.177	1.163	1.153	1.145	1.140	1.136	1.132	1.129	1.127
0.85	1.174	1.160	1.151	1.142	1.137	1.134	1.130	1.127	1.125
0.90	1.158	1.145	1.136	1.129	1.124	1.121	1.117	1.115	1.113
0.95	1.120	1.111	1.104	1.098	1.095	1.092	1.090	1.088	1.087

Note. Values of the coefficient for part-full pipes for use with this table are given at the foot of each column of the tables for full-bore conditions.

Source : Hydraulic Research Station Tables for the Hydraulic Design of Pipes, and sewers, 4th edition,

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Table II.3 Proportional discharges in pipes running part-full

(a) Circular sections

Proportional depth

Coefficient for part-full pipes = $\left[\frac{k}{D} + \frac{1}{3600DS^{1/3}} \right]^{-1}$ for water at 15°C (k, and D in metres)

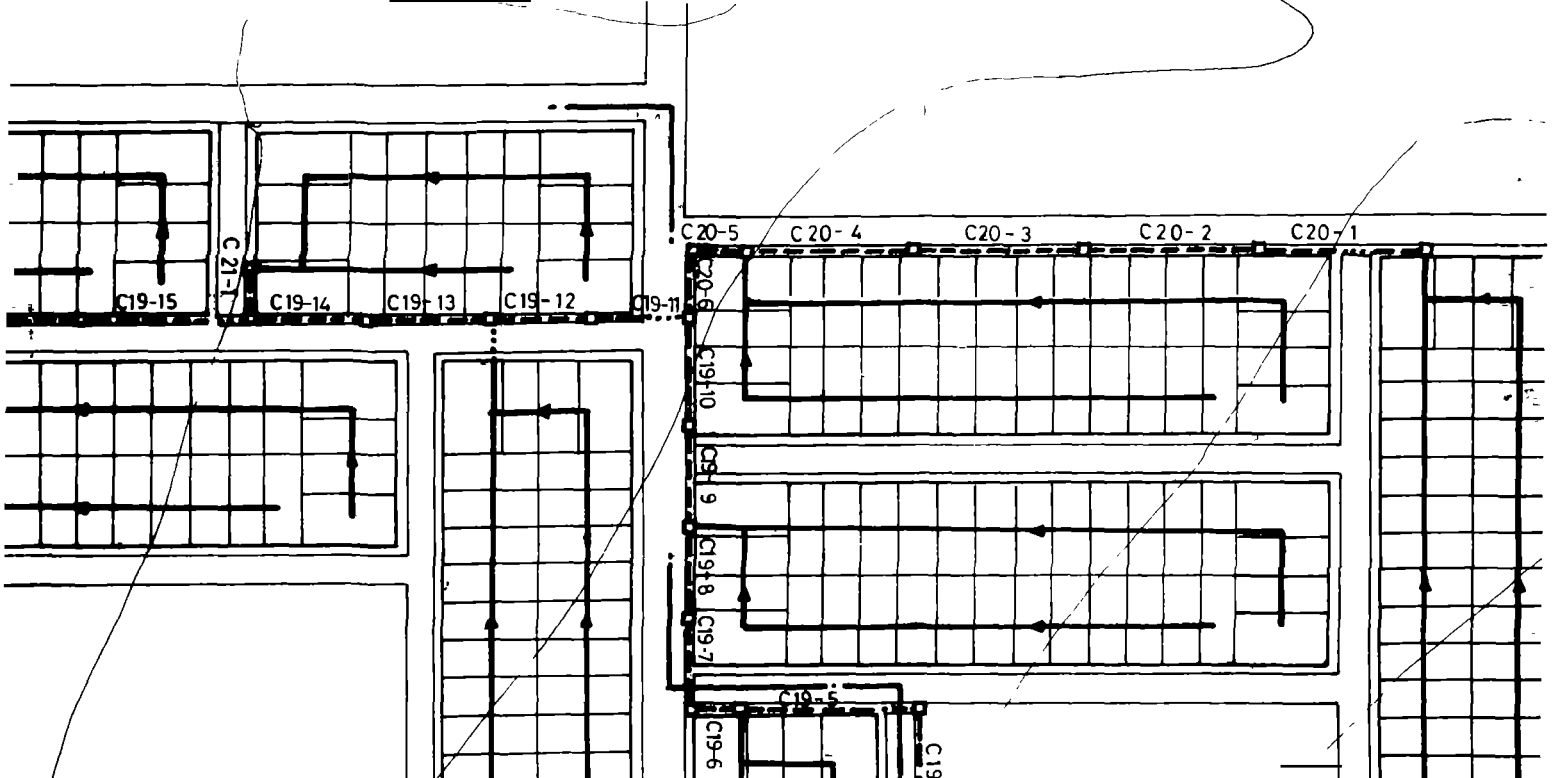
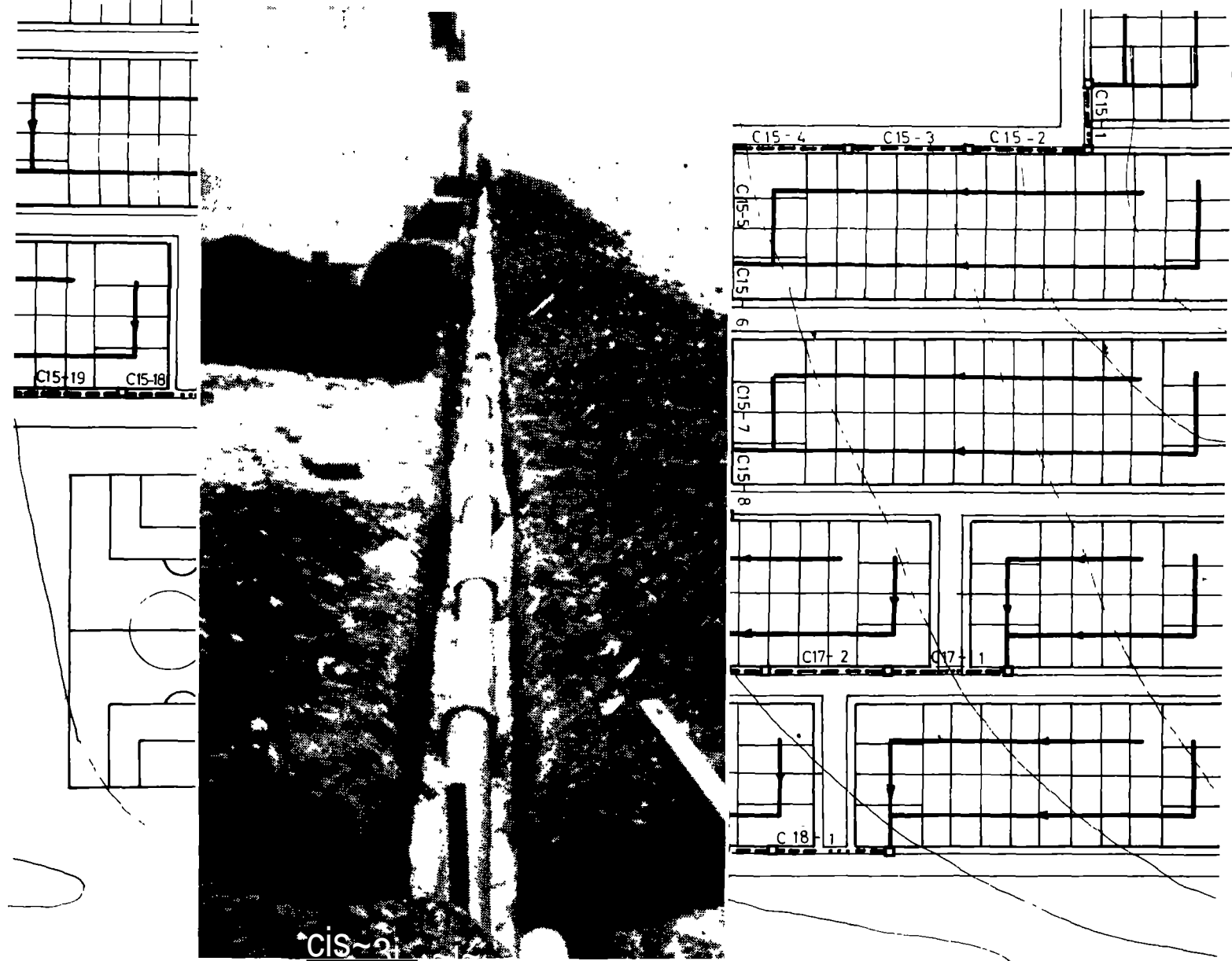
	5	10	20	50	100	200	500	1000	2000
0.02	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001
0.04	0.001	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003
0.06	0.003	0.005	0.005	0.006	0.007	0.007	0.007	0.007	0.008
0.08	0.008	0.010	0.011	0.012	0.012	0.013	0.013	0.014	0.014
0.10	0.014	0.016	0.018	0.019	0.020	0.021	0.021	0.022	0.022
0.12	0.022	0.025	0.027	0.029	0.030	0.031	0.031	0.032	0.032
0.14	0.032	0.036	0.038	0.040	0.041	0.042	0.043	0.044	0.044
0.16	0.044	0.048	0.051	0.053	0.055	0.056	0.057	0.057	0.058
0.18	0.058	0.063	0.066	0.068	0.070	0.071	0.072	0.073	0.074
0.20	0.074	0.079	0.082	0.085	0.087	0.088	0.089	0.090	0.091
0.22	0.092	0.097	0.100	0.104	0.105	0.107	0.108	0.109	0.110
0.24	0.112	0.117	0.121	0.124	0.126	0.127	0.128	0.129	0.130
0.26	0.133	0.139	0.142	0.145	0.147	0.149	0.150	0.151	0.152
0.28	0.157	0.162	0.165	0.169	0.171	0.172	0.173	0.174	0.175
0.30	0.181	0.187	0.190	0.193	0.195	0.197	0.198	0.199	0.200
0.35	0.250	0.255	0.258	0.261	0.263	0.264	0.265	0.266	0.267
0.40	0.327	0.331	0.333	0.336	0.337	0.338	0.339	0.339	0.340
0.45	0.411	0.413	0.415	0.416	0.416	0.417	0.417	0.418	0.418
0.50	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
0.55	0.592	0.589	0.588	0.587	0.586	0.585	0.585	0.584	0.584
0.60	0.684	0.679	0.676	0.673	0.672	0.671	0.669	0.669	0.668
0.65	0.775	0.768	0.763	0.759	0.756	0.755	0.753	0.751	0.750
0.70	0.861	0.852	0.846	0.840	0.837	0.835	0.832	0.831	0.829
0.75	0.941	0.930	0.922	0.916	0.912	0.909	0.906	0.904	0.902
0.80	1.010	0.997	0.989	0.982	0.977	0.974	0.971	0.969	0.967
0.85	1.064	1.051	1.043	1.035	1.030	1.027	1.023	1.021	1.019
0.90	1.097	1.085	1.077	1.070	1.066	1.063	1.059	1.057	1.055
0.95	1.099	1.090	1.084	1.078	1.075	1.072	1.069	1.068	1.066

Note Values of the coefficient for part-full pipes for use with this table are given at the foot of each column of the tables for full-bore conditions.

Source: Hydraulic Research Station, Tables for the Hydraulic Design of Pipes, and sewers, 4th edition.

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