

3

The planning and design process

The theory introduced in Section 2 allows a sewer system to be analysed in order that sewer diameters and gradients can be determined. This is only one part of the overall planning and design process. In this section, we set out the steps in this process and explain how the PC-based design program presented in Section 4 fits into this overall process. The section is subdivided as follows:

Section 3.1 is concerned with the initial assessment of sanitation options. The assessment of technical options is explained and the issues relating to the management options for simplified sewerage are explored.

Section 3.2 sets out the sewerage planning process, from the decision to adopt simplified sewerage to the development of the overall sewerage layout. It explains what information is needed for the planning process and explores the factors that will influence the area to be included in a sewerage scheme. This leads in to the development of a draft sewerage plan. In most cases, it will then be necessary to carry out physical and social surveys before finalising sewer routes.

Planning leads into detailed design. Section 3.3 considers various aspects of detailed design, including the selection of design parameters (input parameters, those that over-ride design calculations, and output parameters), and the design of condominal sewers and public collector sewers.

3.1 INITIAL ASSESSMENT OF SANITATION OPTIONS

Two basic questions should be asked at the beginning of the planning process. These are:

- What sanitation options are feasible in the local situation? And
- Assuming that simplified sewerage is feasible, what arrangements are possible for managing the construction and subsequent operation and maintenance of the local condominal systems?

Each of these questions is considered below, and in the case of the first with particular reference to simplified sewerage.

3.1.1 Technical options

This is the stage at which the decision to use simplified sewerage will be made. Simplified sewerage should only be considered where a reliable water supply is or can be made available on or near each plot so that total water use is at least 60 litres per person per day. Where this basic criterion cannot be met, other options should be evaluated. Sewers, preceded by settlement tanks and carrying 'settled' wastewater might be considered when water use is lower, perhaps down to 30 litres per person per day. Settled sewerage (also called small-bore, or solids-free, sewerage) is described by Otis and Mara (1985) and in Mara (1996).

Other factors to be considered are population density, the arrangements for effluent disposal and the preferences of the local people; for evaluating on-site sanitation options the plot size, the infiltration capacity of the soil and the potential for groundwater pollution should also be considered (see Franceys *et al.*, 1992; Cotton and Saywell, 1998; and GHK Research and Training, 2000). Figure 1.5 shows that in Natal, northeast Brazil, the household cost of simplified sewerage reduced rapidly up to population densities of around 80 people per hectare. Thereafter, there was a more gradual reduction in cost as the population density increased. Simplified sewerage became cheaper than on-site systems at a population density of around 160 people per hectare. While the precise figures were particular to northeast Brazil at that time, the broad pattern may be expected to occur elsewhere. Simplified sewerage should always be considered as an option when population densities exceed about 150 people per hectare.

When comparing costs between different sanitation technologies, the following points must be taken into account:

- The cost of sewerage is not confined to the cost of local sewers. The cost of any collector and trunk sewers and that of treatment have also to be included.
- Most on-plot sanitation systems do not cater for sullage (i.e. the wastewater from sinks, showers etc.). It may be necessary to include separate drainage facilities for sullage and this cost has to be taken into account in any cost comparison.

Simplified sewerage is more likely to be viable where an existing collector sewer with spare capacity is available reasonably close at hand. The existing sewer represents a sunk cost and the cost of simplified sewerage is therefore reduced.

In theory, the cost of sewered sanitation can be reduced by treating wastewater locally, thus removing the need for expensive trunk mains. In practice, lack of both land and the skills necessary to operate local treatment facilities may prevent the adoption of this option.

The operating costs of the various sanitation systems need to be considered when choosing an appropriate technology. For sewerage, the cost of any pumping that may be required must be considered, together with who is going to pay for it. The cost (and availability and reliability) of WC flushing water also needs to be included.

User preferences are likely to influence choice when there is little to choose between two sanitation technologies. In general, users prefer sewers because they remove all wastewater (i.e. both toilet wastewater and sullage) from the house and, if properly constructed, they require relatively little maintenance. In some cases, local people may be opposed to sewers because of previous bad experiences. These normally relate to bad design, bad operation and maintenance, misuse (for instance dumping solid waste in the sewers) or some combination of the three. In such circumstances, the reasons for the previous problems should be ascertained and the ways in which they can be overcome should be discussed with the users.

3.1.2 Management options

It is important to consider the possible management options for any proposed sanitation system from the very beginning of the planning process. In general, the more small-scale and local a sanitation system, the better the prospects for local management. So, it would appear that on-plot sanitation systems such as pit latrines and pour-flush toilets discharging to leach pits can be managed by individual householders, while city-wide sewage disposal systems must be managed at the municipal level. In practice, household sanitation facilities, sewers and wastewater disposal facilities together form a hierarchical wastewater disposal system, as shown diagrammatically in Figure 3.1.

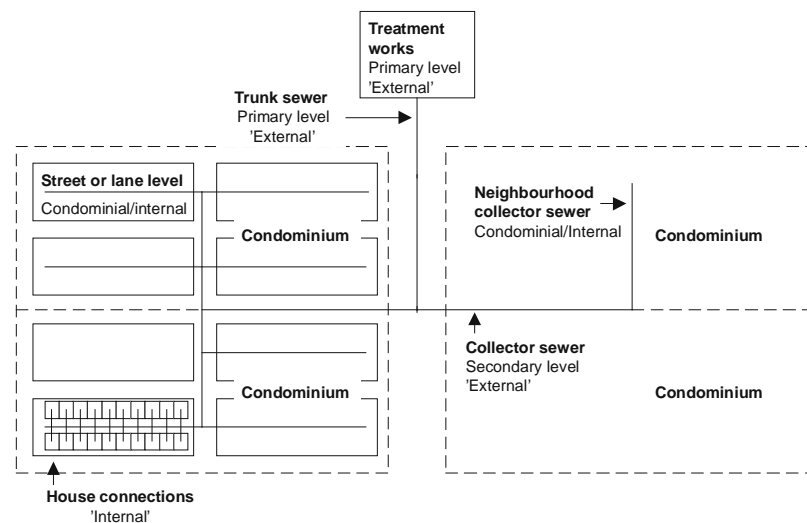


Figure 3.1 Sewerage as a hierarchial system.

In northeast Brazil it was originally assumed that each household should be responsible for the facilities within its plot boundary while all other facilities are managed by an organisation operating at the municipal or even the regional or national level, typically the municipality itself, a specialist sewerage agency or a department of regional or national government (see Section 5.2). Figure 3.1 suggests that a second division is possible, between those system components that serve particular areas or 'condominiums' and those that have a wider city or city district function. A condominium will normally include a number of streets or lanes that can be sewered to one connection with a higher-order collector sewer. The condominial systems do not have to be managed by the same organisation that manages the higher-order facilities and may be suitable for management by a local

organisation, either the local community itself or a contracted private sector organisation (Section 5.2). In the latter case, the contract should ensure that the contractor is responsible to the local community for the performance of the system.

This division of responsibilities can result in better management of local facilities because it ensures that responsibility for the local facilities lies those (the community members) who are directly affected by the performance of these facilities. At the same time, it ensures that organisations such as municipalities, specialist sewerage agencies and government departments can make the best use of their resources by focusing on the operation and maintenance of the higher-order facilities that are not suitable for local management.

This is the thinking behind the condominial approach as originally developed in Brazil. It also underlies the similar division between 'internal' and 'external' facilities developed by the Orangi Pilot Project (OPP) in Pakistan. The OPP philosophy is that users should take full responsibility for providing and managing all internal facilities, while the government should similarly take full responsibility for managing external facilities, including collector and trunk sewers and wastewater treatment facilities. The exact details of the division of responsibilities should be decided in the light of the local situation under consideration.

Local management does not mean that all the tasks associated with operating and maintaining sewers have to be carried out by users themselves. Management options for operation and maintenance are extremely important in ensuring system sustainability; these are considered in Section 5.2.

It is extremely important to evaluate what management arrangements are possible in the local situation. In particular, community management should not be considered an option for a local simplified sewerage schemes connected to a municipal system when the operators of the municipal system do not recognise the right of local users to manage their own system.

3.2 PLANNING FOR SEWERAGE

In this section we describe the steps that lead from the decision to adopt simplified sewerage to the development of a sewer layout that can be analysed using the PC-based sewer design program detailed in Section 4. These steps can be summarised as follows:

- (1) Collect existing information, focusing particularly on maps and plans of the area to be sewered and adjacent areas,
- (2) Determine the area to be included in the sewerage plan, based on topography, the location of existing sewers and the limits of existing and future development,
- (3) Develop a draft sewerage plan, showing the routes of the main collector sewers and the approximate areas of the various condominial systems,

- (4) Undertake additional surveys as required to allow sewer routes and the areas of condominial systems to be confirmed, so that detailed design can be carried out, and
- (5) Finalise the overall sewerage plan and plot the sewer routes at an appropriate scale or scales.

3.2.1 Collection of existing information

The first task in the planning process is to collect all available information on the area to be sewered. In particular, existing topographical maps and any maps showing the routes of existing drains and sewers should be collected, as these are needed to define the area to be sewered and determine the overall sewer layout. This information may be available on a number of maps and plans; if this is the case, as much information as possible should be transferred to one base plan.

Information on existing management arrangements and responsibilities also needs to be collected. This provides a sound basis for developing institutional arrangements to manage the proposed system. One of the advantages of dividing sewerage schemes into condominial and collector systems lies in the possibilities for local management of the former. With this in mind, information on existing community structures and systems should be collected, so that the potential for local management of condominial systems can be assessed.

3.2.2 Area to be included

The next task is to decide the area to be included in the scheme. There are two possible situations. The first is that the design is for an exclusively local system, which can be connected to a local treatment facility or an existing collector sewer. The second is that there is a need to look at the sewerage needs of a wider area, including both local condominial sewers and public collector sewers.

In the first case, the decision on the area to be included in the scheme is relatively straightforward. In general, its boundaries will coincide with those of the existing or planned housing scheme that is to be sewered. The main task will be to determine the routes of the internal condominial sewers and the points at which they will discharge to a treatment site or existing sewer.

The second situation is more complicated in that the boundaries of the area to be drained by the collector sewers may not be immediately obvious. The important point is to ensure that the overall situation is taken into account, as defined by natural drainage areas, the location of existing sewers and possible treatment/disposal locations. The boundaries of natural drainage areas should be fairly obvious in hilly or undulating areas. They may be much less obvious where the topography is flat. Where this is the case, the routes of existing natural watercourses, drains and sewers will give a good idea of existing drainage patterns. By plotting existing drains on a suitable plan (typically at a scale of between 1:2000 and 1:10,000, depending on availability and the area to be sewered), the approximate boundaries of drainage areas and the main drainage paths should be able to be defined. As this 'context plan' is developed, any land that might be

available for local treatment should be identified. This allows the relationship between the scheme area and possible treatment/disposal facilities and sites to be explored. This in turn enables the possible advantages of enlarging the scheme to cover surrounding areas to be assessed.

3.2.3 Development of a draft sewerage plan

It should now be possible to develop a draft sewerage plan. Whether this covers a local system or the sewerage needs of a wider area, the same basic principles apply. Sewers should be routed as close as possible to natural drainage routes, while taking into account existing land development and ownership patterns. In general, collector sewers should be routed in public rights of way which are close as possible to natural drainage routes. Where an existing drainage channel is located along a narrow right of way between existing houses, the sewer should preferably be rerouted along adjacent roads where there is better access for maintenance.

The first step is to decide the routes of the main public collector sewers and then consider how local condominial systems can be joined to them. In general, public collector sewers should be designed to include flows from all parts of the drainage area that are or are likely to be sewered. Failure to do this will mean that the sewers will be undersized, if not immediately then certainly in the future.

Once the routes of the main public collector sewers are decided, preliminary proposals can be made for the routes of condominial systems. It is possible that as this is done, minor adjustments to the routes of the main sewers may need to be made.

Figure 3.2 shows a possible sewer layout for an area including a single public collector sewer and a number of condominial sewers. Note that the main collector sewer is routed along roads, keeping as close as possible to the natural drainage route that can be determined by the contours. Some of the condominial systems connecting to the main sewer are routed along roads, while those at the top of the figure are assumed to be in-block systems, passing through the private space between houses.

The accuracy with which sewer layouts can be plotted at this stage will depend on the accuracy of the available plans and the availability of information on ground levels. Final decisions on the limits of condominial systems may also be influenced by social factors. The next section considers the steps to be taken to collect and record the physical and social information necessary for detailed design.

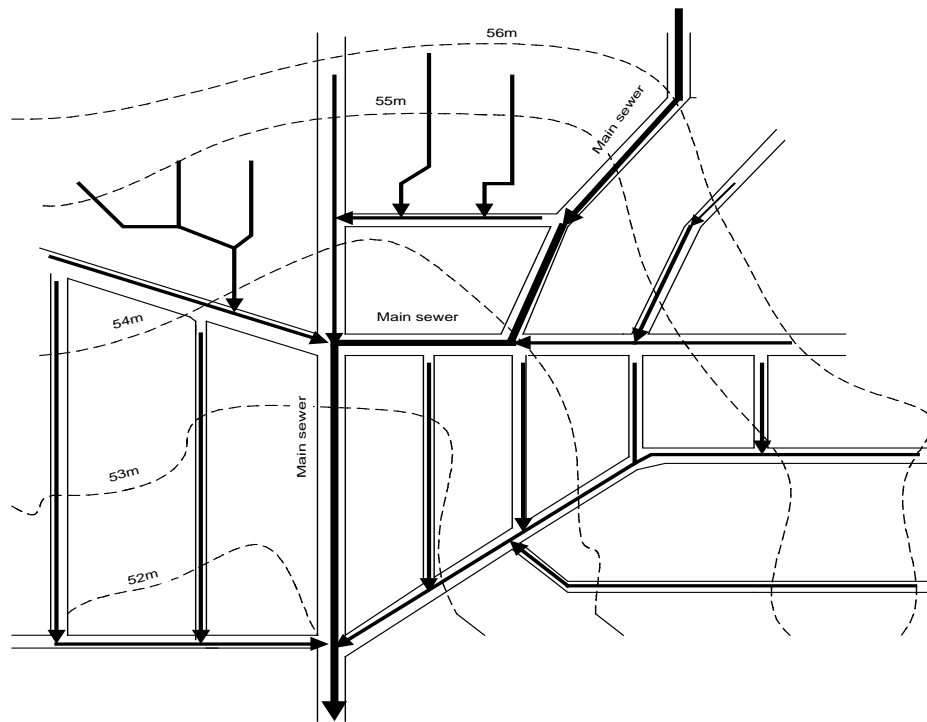


Figure 3.2 Sewer plans should respect the natural topography.

3.2.4 Physical and social surveys

If accurate survey information is not available, detailed physical and social surveys are generally required. Each is briefly considered in turn below.

Physical surveys

Physical surveys are required in order to determine sewer routes and levels. If existing plans exist, it may be possible to use them, at least for preliminary design. However, checks on their accuracy should always be made, and they must be updated to include any developments that have taken place since they were produced.

Where plans are non-existent or insufficiently detailed, additional surveys will be required to provide information on the overall layout of the area. A full triangulated survey will normally be necessary for larger areas, although there may be the possibility of developing a municipal base-map from satellite imagery or aerial photographs. Plane table survey methods are often used to provide surveys at the condonial level, although a tape survey may provide all the information that is necessary for the design of a small, relatively uncomplicated area.

Context plans showing the overall drainage situation should normally be at a scale of 1:2000 or 1:5000. Smaller-scale plans may be necessary to show the city-wide situation. These should show rights of way, the routes of public collector sewers and the limits of natural drainage areas. They do not need to show individual plots, although it will be useful if they distinguish between built-up and non built-up areas.

Plans for detailed sewer design should normally be at a scale of 1:500 or 1:1000. If sewers are to be routed in public rights of way, the plans should show the frontages of individual plots. (Normally the full plot will be shown but the boundaries between plots do not have to be accurately shown.) Where condominiumal sewers passing *through* plots are envisaged, the survey has to show each building on the plot so that the detailed sewer route can be planned. It may be advisable to use a larger scale, perhaps 1:200 or 1:250, in such cases.

Surveys of the sites proposed for any local wastewater treatment facilities will also be required. The scale will depend on the size and type of facility. A waste stabilisation pond system covering an area of 10 hectares and serving a population of 50,000 to 100,000 might require a survey at a scale of 1:500. The sites for small local treatment facilities will normally require more detailed surveys. For such facilities, the site should be mapped at a scale of 1:100 or 1:200.

Levels are required for detailed sewer design. Where sewers are located in public rights of way, levels should be taken at every intersection and at intervals of perhaps 20–25 metres along roads and access paths. House plinth levels should also be recorded. It is not necessary to record every plinth level; rather the focus should be on the lowest plinths since these will be critical to the sewer design.

Where the possibility of using an in-block system exists, levels will also be required within plots along possible sewer routes. The plinth levels of existing sanitation facilities, particularly those located at the back of plots, may also have to be recorded.

Social surveys

Simple social surveys should be used to provide information on household sizes and incomes, existing sanitation and water supply facilities, attitudes to sanitation and user preferences. Questionnaire surveys are useful for providing quantitative information. Semi-structured interviews and focused group discussions are more likely to provide information on attitudes and preferences.

The options for management can be explored in community meetings, although it will be wise to back these up with smaller meetings with particular groups. This is because minority viewpoints may not emerge in open community meetings.

It will be particularly important to explore the degree of cooperation present within the community when in-block sewers are being considered. This is because the sewers pass through private property and it will be necessary to negotiate agreements on access for routine maintenance and dealing with blockages and other problems. Ideally, there should be some form of written agreement between the households concerned regarding access to the sewer. Where this is not

possible, there should at the very least be a strong verbal agreement, agreed in a community meeting and backed by the leaders of the community. If surveys reveal uncertainty about the degree of cohesion present within the community, it will probably be wiser to route sewers in public rights of way.

3.2.5 Final sewer routes

Once good survey information has been obtained, it can be recorded on suitable plans and detailed design of the system can commence. Minor changes to the routes of collector sewers may be required as a result of improved survey information. More substantive changes may be necessary in condominiumal systems as a result of the findings of both the physical and social surveys.

The preferred options for condominiumal sewers should be decided in consultation with local people, bearing in mind the management arrangements to be adopted. (Statutory providers are much less likely to agree to route sewers through private land than community management groups.)

3.3 DETAILED DESIGN

3.3.1 Introduction to the design process

Detailed design requires a combination of hydraulic calculations and the application of standard designs, procedures and details. In some cases, for instance the minimum allowable sewer diameter, the application of a design standard may override the results of design calculations.

Sections 3.3.2 to 3.3.5 are concerned with design parameters. The way in which they can be categorised is explained first in Section 3.3.2, and then input parameters, parameters that over-ride design calculations and output parameters are discussed in Sections 3.3.3 – 3.3.5.

Attention then turns to the design calculations. It is possible to carry out these for sewer systems as a whole. Alternatively, it is possible to design individual condominiumal systems first and then to input some of the data from these calculations into the calculations for the design of public collector sewers. The most appropriate approach will depend on the designer's preferences and the local situation. The design of a local condominiumal system is considered first in Section 3.3.6, and the design of public collector systems in Section 3.3.7.

3.3.2 Categories of design parameter

Design parameters include those that are required for calculation purposes and those that over-ride design calculations. The former include the average household size, the average per caput water consumption, the return factor and the various factors that affect the total design flow. These are introduced in Section 3.3.3. Parameters that over-ride design calculations are the minimum sewer diameter and the minimum design flow, and these are considered in Section 3.3.4. There is only

one design output parameter and this is the minimum sewer gradient which is considered in Section 3.3.5.

There is a further category of design parameters which emerge from investigations of field conditions. These include the type of access allowable, the manhole/chamber spacing and the minimum allowable chamber dimensions, and these are considered in Section 5.

3.3.3 Design input parameters

Average household size. This is multiplied by the number of houses in an area or along a sewer leg to determine the design population in that area or contributing to the sewer leg. Results from the social survey (Section 3.2.4) will provide information on the average household size in the area to be sewered.

Average per caput water consumption. This is multiplied by the design population for any area or sewer leg to calculate the total amount of water used during a typical day. Information on average per caput water consumption may be available from meter readings. Failing this, the local water authority may keep records of average per caput consumption in different areas and types of development. The likely per caput water consumption at both the beginning and the end of the design period (which will typically be 30 years) has to be considered.

Return factor. This defines the percentage of total water consumption that will be discharged to the sewer. It is often assumed to be 80% or 85%, although there are indications that lower return factors may be appropriate in some areas (see Section 2.1). The wastewater flow from an area will be equal to the water consumption in the area multiplied by the return factor.

Peak wastewater flow factor. This is required to allow for the fact that the wastewater flow varies through the day, reaching a peak when people get up in the morning and falling to almost nothing during the night. The peak *foul* flow in any sewer can be taken as the average flow in that sewer multiplied by the peak factor. Peak factors tend to decrease as the population contributing to the flow increases. However, even for a population of a few hundred, the peak factor is unlikely to exceed 2 (see Section 2.1.1). (Higher peak factors might occur in areas where the water supply is intermittent and households have made little or no provision for water storage, but these conditions are unlikely to be suitable for sewerage in any case.)

Groundwater infiltration. This needs to be considered where some sewers are laid below the groundwater table. Infiltration is commonly estimated on the basis that it is a set percentage of the average per-caput wastewater flow. A theoretically more accurate approach will be to assume an infiltration rate per unit length of sewer. The first method is simpler. Furthermore the accuracy of available information will normally be insufficient to justify the adoption of the second approach. However, laying sewers below the groundwater table should be avoided wherever possible.

Allowance for stormwater. Sewers can be designed as separate, partially combined or combined. Separate sewers carry only wastewater, partially combined

sewers are designed to carry some stormwater in addition to wastewater, while combined sewers are designed to carry the full wastewater and stormwater flows.

Combined sewerage has several disadvantages. In all but the driest climates, the size of sewer required to carry the full stormwater run-off is likely to be much larger than that required for the wastewater flow. Combined sewerage thus requires a high level of investment, which is not utilised except in wet weather. Combined sewers also have the disadvantage that stormwater run-off often carries a high concentration of grit and other suspended solids and this can lead to higher rates of silting. Sewers have therefore to be laid at greater gradients than would be required if they carried only wastewater. For these reasons, simplified sewer systems should not be designed as combined.

Normal practice in many industrialised countries is to provide nominally separate wastewater and stormwater systems. However, in practice, it is extremely difficult to exclude all storm flows and so separate systems are always designed with some allowance for the entry of storm flows. As already indicated, the peak wastewater flow will not exceed twice the average dry weather wastewater flow. Despite this, sewers in the United Kingdom are normally designed for a peak flow of six times the average dry weather flow plus any allowance for industrial flows and groundwater infiltration. In effect, the sewers are designed on the assumption that they may be expected to carry a peak storm flow equivalent to about twice the peak wastewater flow.

The situation in low-income periurban settlements in developing countries is unlikely to be different. Even if householders are educated about the problems that are likely to be caused if stormwater run-off is introduced into sewers, some will still connect their yard or roof water into the sewer. For example, in low-income areas in Brasília and Natal around a quarter of households discharge some stormwater into their simplified sewer (Sarmientos, 2000), despite the fact that CAESB and CAERN officially ban this practice. In other cases, people will take the path of least resistance when faced with the possibility of flooding. For instance, it is not uncommon for people in Pakistan to lift manhole covers to allow water to run away into the sewers during and after storms.

So, it would appear to be unrealistic to design simplified sewerage systems to be completely separate. However, as explained in Section 2.1.1, there is some “automatic” provision for stormwater flows in short lengths of simplified (i.e. condominial) sewer. For public collector sewers some provision for stormwater flows should be made at the design stage (see Section 4.7.3). Where surface water drainage is a major problem, greater attention to the alternatives will have to be paid at the design stage; for more detailed information on planning for stormwater drainage, reference should be made to Kolsky (1998).

Minimum cover. Cover is required over a sewer for three reasons:

- (1) To provide protection against imposed loads, particularly vehicle loads,
- (2) To allow an adequate fall on house connections, and
- (3) To reduce the possibility of cross-contamination of water mains by making sure that, wherever possible, sewers are located below water mains.

Simplified sewerage should be designed with the objective of minimising cover by locating sewers away from heavy traffic loads and as close as possible to existing sanitary facilities. In most cases, the loading criterion will be more critical than that to ensure adequate falls on house connections. The minimum cover criteria adopted will depend on local factors, in particular on the pipe material used. In northeast Lahore, Pakistan 230 mm diameter reinforced concrete sewers were laid successfully in lanes with minimal traffic loading at covers of only around 250 mm. In Britain, good quality clay pipes can be laid through gardens at a depth of 350 mm. In Brazil a minimum cover of 200 mm is used for in-block clay or uPVC sewers, and 400 mm for in-pavement sewers (Sinnatamby, 1986; see Section 5.1.2).

The need to prevent cross-contamination of water mains also has to be considered. In northeast Lahore, the issue was avoided because galvanised steel pipes, laid above ground on brick-tile ledges along the edges of lanes, were used. This solution is not applicable in all situations and in most cases water mains should be buried. The cover over water pipes can be reduced by laying them, like sewers, away from heavily trafficked areas whenever possible. Another possibility is to use small diameter polyethylene or uPVC pipes (typically with diameters of 50mm or 63 mm rather than 100mm) for tertiary distribution. These can be laid at relatively shallow depths. Wherever possible, water mains and sewers should also be separated horizontally.

3.3.4 Design over-riding parameters

Minimum sewer diameter. It is necessary to specify a minimum sewer diameter because sewers transport wastewater which contains gross solids. As indicated in Section 2, there is no theoretical reason why the minimum sewer diameter should not be 100mm. However, statutory authorities tend to be conservative on this point: for example, the minimum acceptable sewer diameter in Cairo, Egypt, is 180 mm, while that in Pakistan is 230 mm. Engineers are often reluctant to change. Every effort should be made to introduce appropriate standards, but it may be necessary to accept a higher minimum diameter than is absolutely necessary. In such circumstances, it is best to seek what is possible rather than the ideal. For instance, the acceptance of a 150 mm minimum diameter would be a big step forward in Pakistan.

Minimum flow. Conventional sewer calculations assume steady-state conditions. In practice, the flow in sewers at the upper end of the system is highly transient. The amount of flow at any time depends on the number of taps running to waste and WCs being flushed. By far the largest flows occur when a WC is flushed. A wave passes down the house connection and into the sewer, becoming attenuated all the time by the effects of friction. Of course, the attenuation will tend to be greater if there is any interruption to its smooth flow – for instance, where a house connection enters a connection chamber above the sewer invert so that flows from the connection have to drop into the main sewer. The current practice in Brazil is to assume a minimum flow of 1.5 litres per second for the wave created by a flushed toilet (see Section 2.1.1).

3.3.5 Design output parameter – minimum sewer gradient

There is still considerable uncertainty about the factors that influence solids deposition and movement in sewers. Research suggests sewers laid at flat gradients can remain free of settled solids even at very flat gradients. An example is provided by Gidley (1987), who reports on 6 and 8 inch (150 and 200 mm) diameter sewers laid at gradients of 0.11 and 0.2 percent (i.e. 1 in 900 and 1 in 500) in Ericson, Nebraska. The scheme served 80 households, a school and several commercial establishments; no operational problems occurred during 1976-1987, and there was no special maintenance. Lillywhite and Webster (1979) investigated the operation of a hospital drainage system in the United Kingdom, much of which had been laid to very flat gradients. They found that blockages rarely occurred except at points where there were faults in construction (for example, badly aligned sewer pipes) that broke the smooth flow in the sewer. Their conclusion was that poor construction quality is likely to have a bigger effect on the performance of a sewer than its gradient.

Both these systems can be assumed to have been essentially separate with no possibility of the entry of stormwater. Ackers *et al.* (1996) found that steeper gradients were necessary to avoid siltation in combined sewers receiving occasional high-sediment loads associated with stormwater flows.

What do these findings suggest for the design of simplified sewerage systems? The first point is that the minimum permissible sewer gradient should be related to the construction quality – the better the quality, the flatter the allowable gradient. The second is that flatter slopes will be possible if stormwater, and the silt loading associated with it, can be excluded from sewers or trapped in a gully before entering the sewer (see Section 5.1.3).

Methods for calculating the minimum sewer gradient were introduced in Section 2.5. The key parameter in determining the theoretical minimum gradient is the value adopted for minimum tractive tension. If the sewer can be constructed to a high standard and most stormwater can be excluded from the sewer, a value of 1 Pa can be used. This will give a minimum self-cleansing gradient of 1 in 213. As noted in Section 2.5, CAESB uses a minimum value of 1 in 200, and this has been found satisfactory for condominial PVC sewers in low-income areas. For public collector sewers designed as partially combined sewers with some provision for the ingress of silt a minimum tractive tension of 1.5 Pa may be more appropriate; the corresponding minimum sewer gradient is 1 in 130. This higher value for minimum tractive tension may also be appropriate when there are doubts about the standard of construction, perhaps because only locally made sewer pipes of varying quality are available.

In situations where in practice it is considered that a minimum gradient of 1 in 200 is difficult to achieve, especially in flat areas if pumping is to be avoided, the designer is faced with two options:

- (1) Accept that some siltation will occur and design the sewer on the assumption (which needs, of course, to be translated into a practical O&M requirement) that it will have to be regularly desilted; or

- (2) Provide interceptor tanks on all house connections to remove all but the smallest and lightest solids, i.e. design the system as a settled sewerage system (Otis and Mara, 1985; Mara, 1996). This allows much lower gradients to be used, but the system will eventually fail if the interceptor tanks are not desludged at the correct frequency.

3.3.6 Design of condominium sewers

This section details the steps necessary to prepare design information for a condominium sewer system to be input into the design program detailed in Section 4. It uses the example of a module forming part of a new sites-and-services housing scheme.

Figure 3.3 shows this module, together with a sewer layout to serve it. Plot boundaries are represented by thin lines and sewers by thick lines. No access points are shown at this stage. The plot sizes are small, representing typical practice in a new sites-and-services scheme in South Asia. The five cul-de-sacs are relatively narrow lanes that are not intended for vehicular traffic. (The width of the right of way scales about 7.5 metres on the drawing but it can be assumed that the actual right of way is somewhat narrower.) Sewers are proposed along the centres of these pedestrian lanes. Elsewhere inside the module, sewers are alongside the sides of streets, as close as possible to the front plot lines. The housing module fronts onto a main street, along which runs a public collector sewer. The larger plots that face onto the main street are connected to a local sewer that runs under the pavement, rather than directly to the collector sewer.

All the sewers serving the housing module thus form a condominium system that is self-contained and can be analysed and designed regardless of the arrangements that are made elsewhere.

Similar arrangements, but including back-yard and/or front-yard sewers, could be adopted for a scheme with considerably larger plot sizes.

This is, of course, a very regular layout. In practice, many layouts will be less regular with some interconnections between different housing areas so that the limits of each 'condominium' may be more difficult to define. Nevertheless, the basic approach described here is valid for these more complex situations.

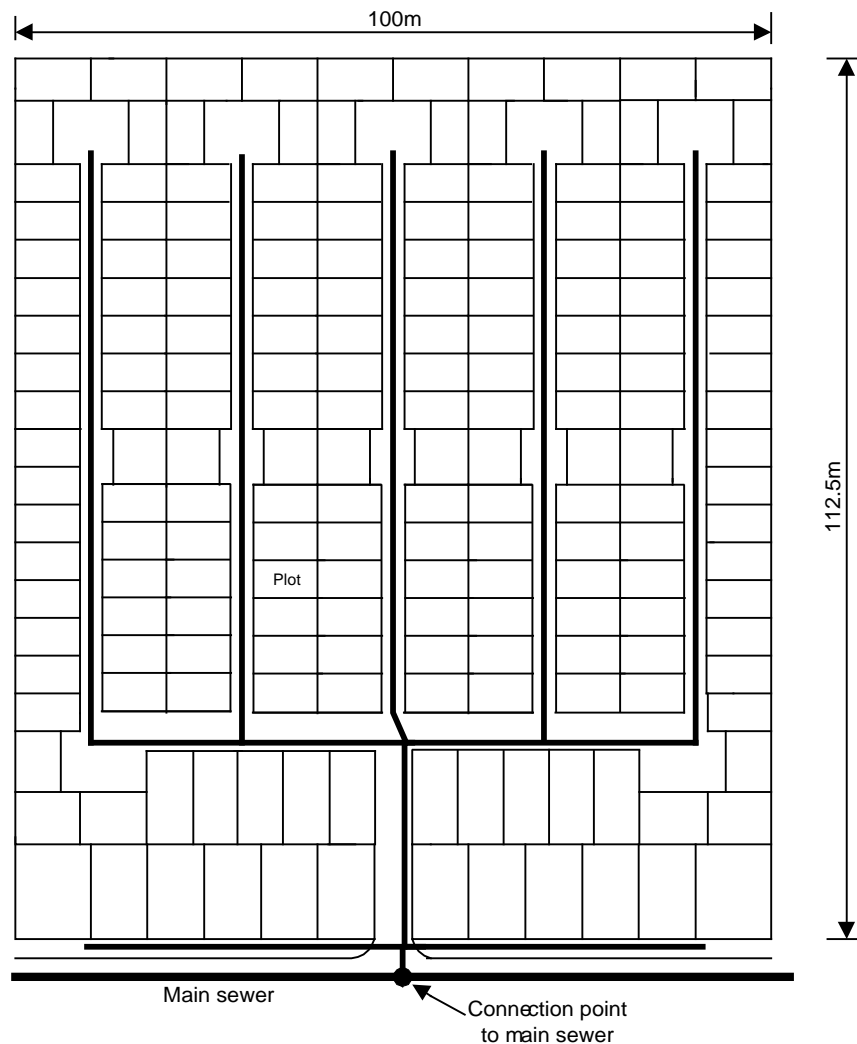


Figure 3.3 Sewer layout for a typical sites-and-services housing module.

The first step in the design process is to represent the system as a series of sewer 'legs' running between junctions or 'nodes'. In theory every house connection could be a node, but this would require a large number of calculations. The actual calculations are not a problem for the PC-based design program detailed in Section 4, but data entry would take a considerable amount of time. Fortunately such a detailed approach is not necessary since the change in flow at each house connection will be infinitesimally small. Rather, the need is to develop a 'model' of the system that reduces the amount of calculation effort required, while retaining sufficient accuracy to ensure that the sewers are correctly sized.

Figure 3.4 illustrates this process of simplification for part of the layout shown in Figure 3.3. Three nodes have been assumed on the sewer that runs along one of the five pedestrian 'lanes'.

Inspection suggests that the four plots at the head of the lane will drain to a chamber at node J3. Fourteen plots will discharge to sewer leg C1-3 and a further two plots can be connected directly at node J4. Twelve plots will discharge to sewer leg C1-4. For calculation purposes, the number of connections to any sewer leg can be taken as the connections at the upstream node plus those along the length of the sewer

leg itself. Thus, the number of connections to sewer legs C1-3 and C1-4 will be 18 (4+14) and 14 (2+12), respectively.

This process should be repeated for the whole system. The result is shown in Figure 3.5.

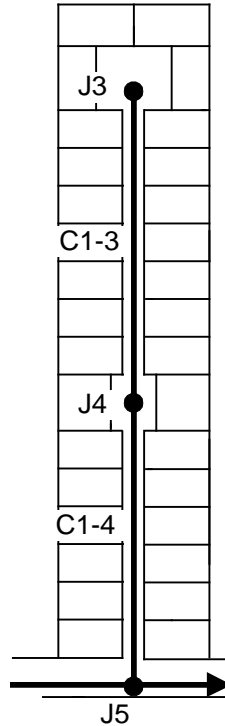


Figure 3.4 Sewer divided into legs running between nodes.

The PC-based design program will work whatever the numbering system, but interpretation of the results will be easier if there is some logic to the numbering system. With this in mind, the nodes and sewer legs have been numbered starting from the head of the left hand sewer.

The numbering system used for the sewers indicates that a condominal system, rather than public collector sewers, is being designed.

The figures given in brackets beneath the sewer leg numbers in Figure 3.5 are the number of house connections along those legs of the sewer.

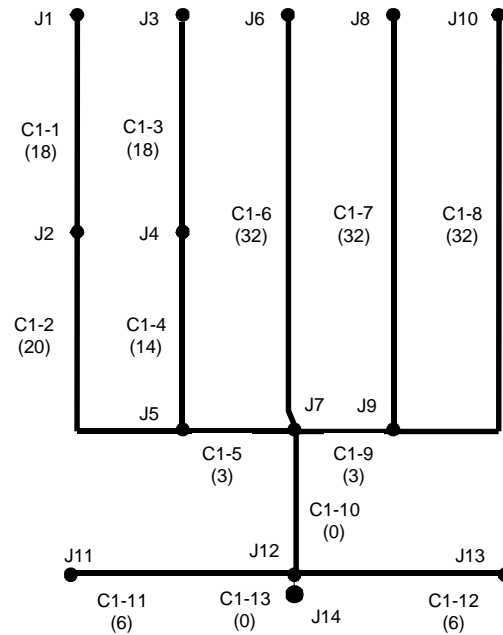


Figure 3.5 Numbering system for sewer legs and nodes.

Note that the two lane sewers on the left of Figure 3.5 have intermediate nodes, which are omitted from the other three nodes. This has been done in order to test the sensitivity of the model to the number of nodes assumed. In practice, the intermediate nodes are not really required if the average ground slope along the sewers is fairly constant. Additional nodes should be inserted where there is a significant change in ground gradient since the sewer slope will have to be changed at this point and this needs to be reflected in the calculations.

At this point there is much of the information required to input the sewer system into the PC-based design program. Additional information on the sewers themselves is required as follows:

- (1) The lengths of all sewers – obtained by scaling off from the layout drawing.
- (2) The ground level at each node – this is available from the physical survey of the area.
- (3) The minimum allowable cover for different situations – see Sections 3.3.3 and 5.1.2.

The normal procedure will then be to start at the head of the system, in the case illustrated in Figure 3.5 at J1 or J10, and set the sewer invert at that point such that the cover is the minimum allowable for the particular situation.

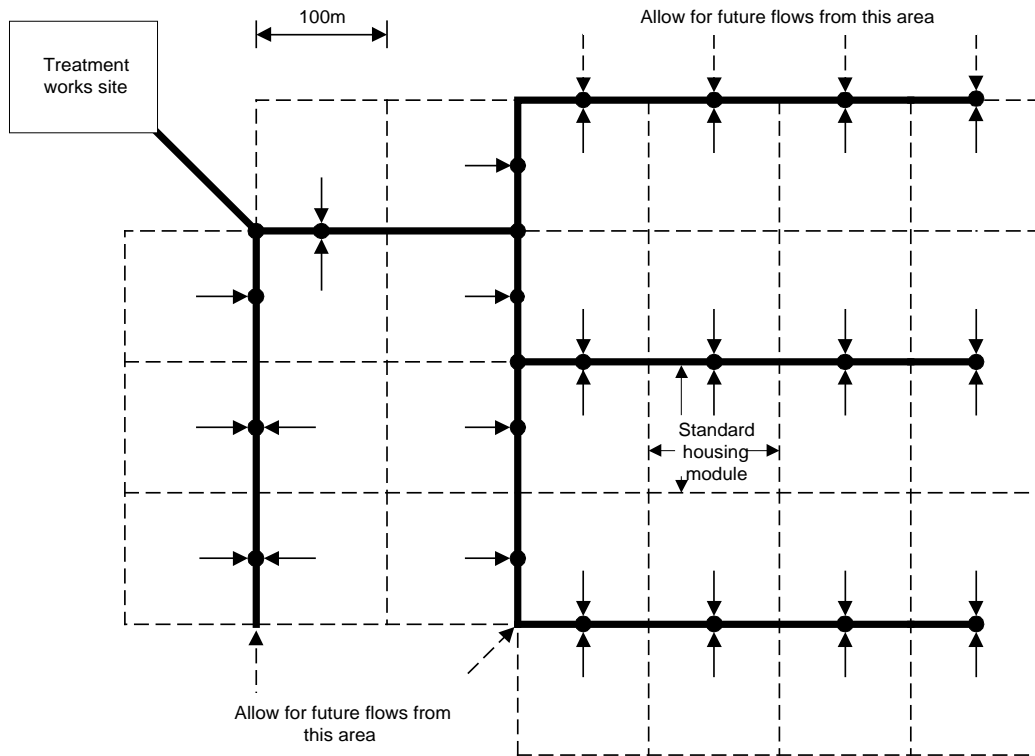


Figure 3.6 Layout for public collector sewers for a sites-and-services housing scheme.

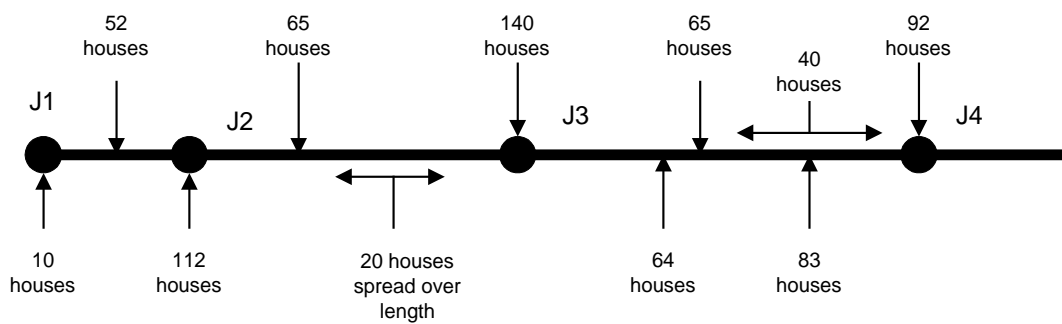


Figure 3.7 Selection of node location.

As the design proceeds, it will be found that the slope of many sewers near the head of the system will be governed by the minimum wastewater flow (1.5 l/s), while their diameter is governed by the minimum permissible sewer diameter (100 mm). The number of houses that can be connected to a standard minimum-diameter sewer laid at the minimum gradient based on the minimum peak wastewater flow can be calculated (see Section 2.7). Once this has been done, these minimum parameters can be assumed for any sewer leg that receives flow from a smaller number of houses than the number calculated for the minimum diameter and gradient. This reduces the design task considerably since many smaller condominiumal systems will consist of only minimum-diameter sewers laid at the minimum gradient based on the minimum peak wastewater flow.

3.3.7 Design of public collector systems

The design approach for public collector systems is essentially the same as that used for condominiumal systems in that, for calculation purposes, the sewer system is divided into legs connected at nodes. Figure 3.6 illustrates a sewer layout for a sites-and-services scheme based on the module that has already been used to illustrate the design of a condominiumal system. The dashed lines indicate the borders of individual housing modules and the thick black lines represent the public collector sewers. The arrows indicate the points at which flows from the various modules are discharged to the public collector sewers. Arrows on dashed lines indicate possible future flows to be considered in the design. The black circles indicate the positions of nodes. It will be seen that a node is located at each junction on the collector sewer system and at the points where flows from the modules discharge to the collector sewers. Any direct inflows to the collector sewer between nodes are assumed to be concentrated at the downstream node, as in the case of condominiumal systems.

This is a regular layout with inflows to the public collector sewers concentrated at nodes. In practice, most systems are more complex and it may be that inflows are spread along the length of the collector sewer rather than concentrated at one point, as shown in Figure 3.7. In such situations, it is necessary to use judgement in the selection of node locations. Figure 3.7 suggests that:

- nodes should be located at all points where there are relatively large inflows to the sewer; and
- closer node spacing is needed near the head of the system.

