A comparison of sewer reticulation system design standards gravity, vacuum and small bore sewers

CJ Little

Ninham Shand (Pty) Ltd, PO Box 1347, Cape Town 8000, South Africa

Abstract

The introduction of waterborne sewerage in the villages and towns of Botswana has highlighted a number of problems in the design of the reticulation systems. The first of these is that not many people connect to the system once it is installed. The second problem is that there are not always the skills required to maintain the systems in the rural areas. Thirdly Botswana being a dry country does not always have the water supply available and only some households have a house connection which provides enough water to flush a gravity sewer.

Coupled to this is the low housing density and generally flat landscape in rural Botswana that means the conventional gravity sewer soon requires deep excavations and the consequent need for pumping stations. It became apparent that gravity sewer systems were not always the best means of providing waterborne facilities.

It was found that in certain circumstances the alternative options of vacuum and small-bore sewers were more appropriate and so design standards were developed for gravity, vacuum and small-bore sewer systems. This allows for a uniform approach to design in order to achieve a functioning system.

Introduction

Current developments in the sanitation and wastewater field in Botswana necessitated the development of a uniform approach to its development in order to avoid fragmentation, environmental pollution and a waste of resources. The Government of Botswana commissioned an overall Master Plan for the sector so that all the planning, legal, institutional and technical matters could be addressed.

As part of the technical investigation it was required of the Study Team to provide planning and design standards for all infrastructure associated with sanitation and wastewater. Part of this Design Manual set out the requirements with regard to sewer reticulation with the focus on gravity, vacuum and small bore systems. Pumping stations and force mains were also addressed in the Botswana context.

A brief description of the sanitation and wastewater environment, as it relates to sewer reticulation, is provided in order to give the reader some insight into the status quo in Botswana. In general, the landscape in Botswana is relatively flat and large areas are covered by Kalahari sand. Potable water is provided to virtually every household throughout Botswana whether it is via public standpipes, yard taps or house connections. The country is politically stable and the income from the mining sector has been used to raise the living standards of the general population. This has been done in a number of ways including the construction of infrastructure such as roads, dams, pipelines etc. and by investing in education and business development. One of the current focuses is to replace the standpipes with either yard taps or house connections. It has been found that this leads to an increase in water consumption and hence the possibility of environmental pollution. In order to counter this aspect, a programme of sewering major villages has commenced.

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☎+2721 481 2491 ; fax:+2721 424 5588;
e-mail: Chris.Little@shands.co.za

For the most part conventional gravity sewers have been used but a vacuum system is also currently being installed. The possibility of using small-bore sewers has been examined but not yet used in Botswana although they are in use in neighbouring countries. This paper looks at the advantages and disadvantages of these three systems and provides design guidance for Botswana.

Gravity sewer reticulation

Gravity sewer design is very well documented and it is not the intention here to reiterate the commonly accepted. Rather, the focus will be placed on the aspects that are particular to Botswana and any other developing country.

It was found in numerous places in Botswana that the provision of a sewer pipe did not mean the household would connect to it. In fact the connection rate is extremely low. This could be for a number of reasons not least of which are household priorities. With time the connections will be made and water usage will increase but in the interim the design flows will not be attained and so scouring velocities will not occur. In common with other countries, experience dictates that as living standards are raised so water use increases and this will also impact on flows and velocities.

As only one sewer is laid in a street it is necessary to design it to overcome both the initial and final situation. The parameters used are given in Table 1 below:

TABLE 1
Gravity sewer parameters

Parameter	Initial situation	Final situation
Water use per person (house connection)	100 ℓ/d	165 ℓ/d
Return flow per person	80 ℓd	132 ℓ/d
Percentage of population connected	20%	100%
Minimum scour velocity	0.6 m/s	0.7m/s
Manning n factor	0.011	0.013

It was recommended that the Manning formula be used to calculate the velocity in pipes.

Wet weather flow is provided for by sizing pipes smaller than 375mm diameter to flow 50% full at peak dry weather flow and at 40% full for pipes greater than 375mm diameter.

It was found that the peak dry weather flow, as commonly calculated from the Harmon formula, was not reliable for populations of less than 7000 and the Legg formulae was adopted below this figure. The two formula are given below:

Legg formula:

$$\textit{Dry weather peak factor} = 6.51/(p^{0.38}) \qquad \textit{for populations less than } 7000 \qquad [1]$$

Harmon formula:

$$\textit{Dry weather peak factor} = 1 + \{14/(4 + p^{0.5})\} \quad \textit{for populations more than } 7000 \qquad [2]$$

where p = the population in thousands

The recommendations for the slope requirement at the head of the sewer are given in Table 2 (the recommended minimum diameter of the sewer main is 150 mm and 100 mm for house connections):

TABLE 2
Slope requirements at head of sewers (ND 150 pipe)

No. of people	Slope required (low connection rate)	Slope required (rapid connection rate)
1 to 50	1 in 80	1 in 80
51 to 250	1 in 80	1 in 120
251 to 650	1 in 120	Determined by normal hydraulics

The above design parameters are represented graphically in Fig. 1. A special case exists for gravity sewers below pumping stations. Pump capacities to meet the peak wet weather flow are required and so even in the early years of a scheme the flows to flush the downstream pipes are assured. The above design guidelines are used in the illustrative comparison in the discussion section of this paper.

Vacuum sewers

Vacuum systems have not yet been used in South Africa but there are over one thousand systems installed in numerous countries around the world. The first in Africa is currently being installed in Shoshong, Botswana. A brief description of the system is given here to help the reader with the subsequent discussion. A schematic section of the vacuum system is shown in Fig. 2.

A collection chamber is placed either on or near the plot in order to receive the wastewater from the household. The wastewater drains from the household to the collection chamber by gravity. The liquid level in the collection chamber rises until it triggers the normally closed interface valve to open. This interface valve connects the collection chamber to the vacuum sewer and as a result of the negative pressure in the sewer, the liquid (with some air) is sucked into the sewer. When the collection chamber is empty the interface valve closes and the cycle is repeated.

The liquid and air is sucked along the sewer as the various interface valves open and close in the network until it discharges into the vacuum vessel (vacuum station) or pump sump from where it is pumped in the normal manner. The peaks discharged to the system are attenuated by the sewer because the sewer temporarily stores the liquid (when it comes to rest). The negative pressure that forces the wastewater along the pipelines is created at the vacuum station. The pipelines do not have to be laid to falls and in fact can be laid uphill. Flushing velocities are taken care of by the vacuum applied.

The vacuum station comprises a sump or vacuum vessel, a set of vacuum generators and normal wastewater pumps. The sewers discharge into the vacuum vessel which is maintained under negative pressure by the vacuum generators. The liquid level in the vacuum vessel is monitored and the wastewater pumps are activated at a pre-determined level. The pressure in the vacuum vessel

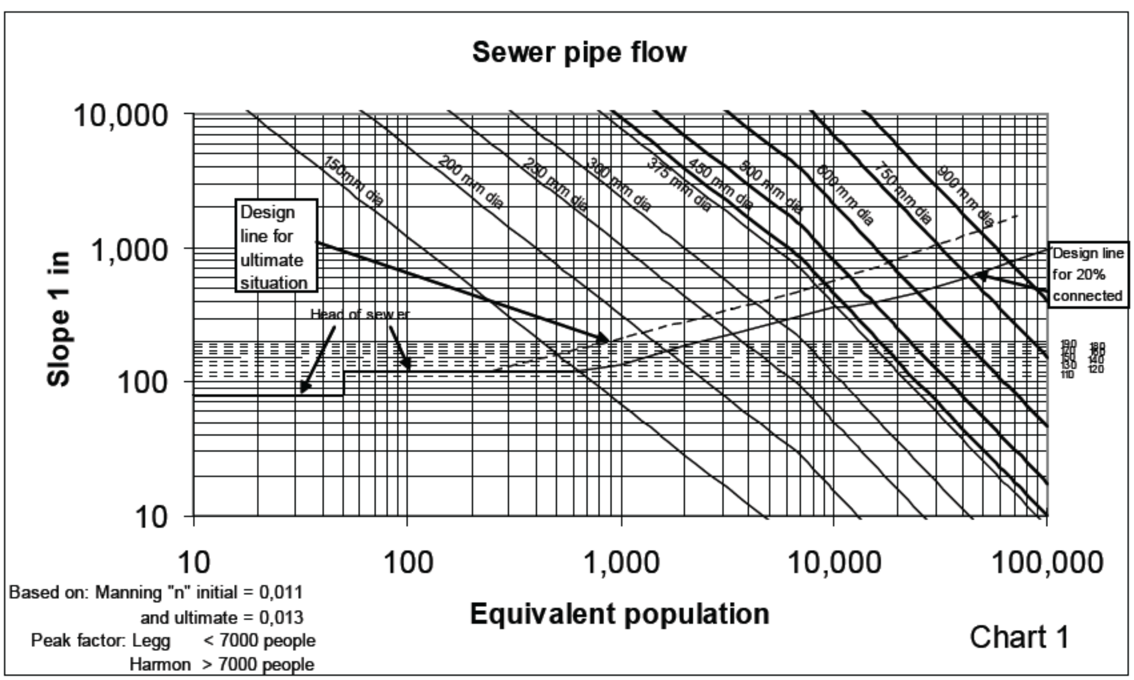
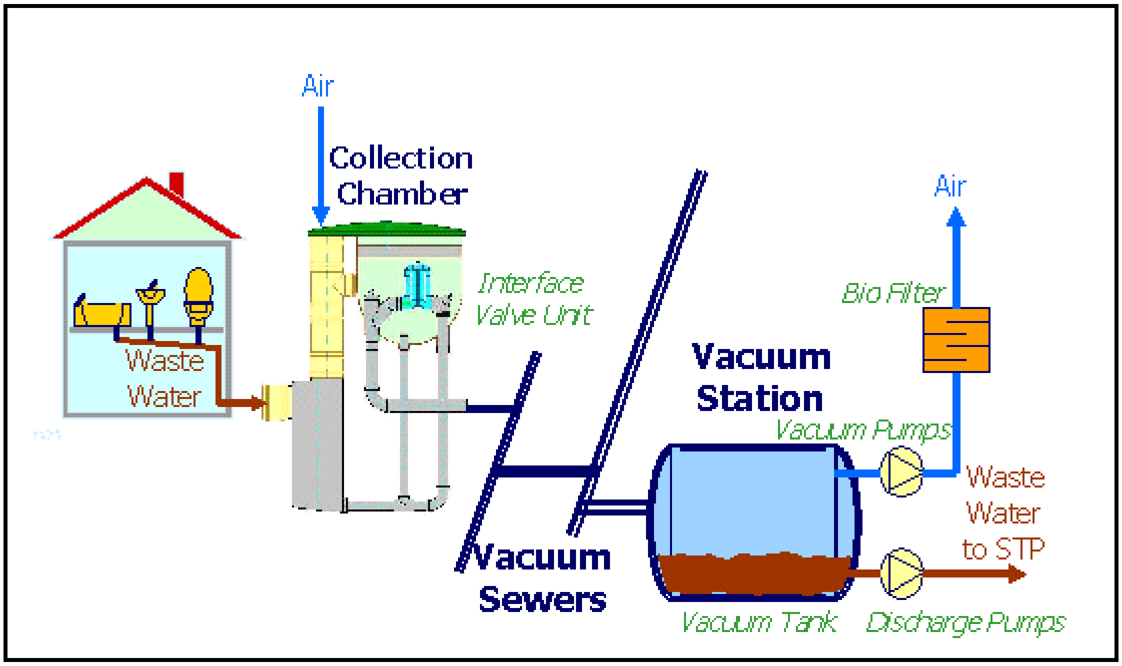


Figure 1
Sewer design chart



Source of picture: Roevac manual

Figure 2
Schematic section of the vacuum system

is monitored by pressure switches which switch the vacuum generators on and off.

Areas of application

There is often a particular reason why the vacuum system and not the more conventional gravity system is adopted. In some cases gravity sewers were not feasible and in other cases they are more expensive. It should also be noted that the system can be used to augment or extend a gravity sewer or small bore system and does not have to be used exclusively in a centre.

The situations where vacuum sewers have been or could be considered are given below:

- Where the slope of the ground is relatively flat. A gravity sewer becomes deep in these cases in order to adhere to minimum velocities and it becomes necessary to install pumping stations. In certain circumstances, the number of pumping stations can be excessive and they require specialised maintenance.
- If there is rock close to the ground surface, running sand or a high water table it is expensive and difficult to dig deep trenches.
- In situations where potable water is in short supply and/or the people are poor, it has often been found that flushing velocities in gravity sewers are difficult to attain and maintain. A vacuum system relies on the negative pressure to propel the liquid at scouring velocities and it is largely independent of the volumes of water used.
- Where the population density (people per hectare) is low.

The situations described above invariably result in a lower capital cost for installation (have lower excavation costs, smaller diameter pipes, no manholes to be built, fewer pumping and lift stations). No life cycle costing of the system is possible because there is no experience of the system working in African conditions. The electrical costs to run the vacuum generators will usually be minor (about 30 to 40 kWh per person per year).

The disadvantages of the system hinge around the following:

- Operation and maintenance of the system in remote areas may be a problem. From literature it would appear that the system can easily be kept operating successfully but only time will tell if this can be done given the present skills level available in rural communities. Outsourcing of operation and maintenance may be a viable alternative.
- The fact that the system is unknown to sewerage practitioners in Southern Africa. This may mean that contract specifications may not be up to standard and inferior installations are constructed.

Design criteria

It is not the intention here to provide all the design criteria required to design a vacuum system. The following overview of the design guidelines is provided so that the reader can make a comparison with the gravity system:

Gravity connections to collection sumps

The sewer must have a minimum diameter of 100mm and be laid at 1:60 or steeper. Air venting must be provided.

Collection sumps

It should be sited so that it prevents flooding back into homes. These must be watertight and structurally designed to withstand the forces exerted on them without excessive deflection. They must be sized to take 25% of the average daily flow (volume can include the useful volume in the gravity collector) before overflowing. It should be made of corrosion resistant material. The inside should be smooth and suitably benched. If additional venting is required it should be provided so that nuisance free operation is provided (noise of sucking must not be a nuisance).

Interface valve

The interface valve should be capable of operating without electricity. It will normally be closed and act as a non-return valve to prevent backflows. The valve gate should not obstruct the flow passage when open. It should be capable of operating in all situations even when submerged. It should allow the full volume of the collection sump to pass each time it opens. It should be easily accessed so that suitably trained personnel can replace it without safety concerns.

Level sensor

The level sensor should be designed to not easily foul and if a pipe is used it should be not less than DN50.

Pipes, fittings and jointing

The pipe size downstream of the interface valve should always be larger than the valve and in all cases the service connections should be DN 75 or larger. The minimum size of the vacuum sewer should be DN 90. Pipelines should be designed to withstand the negative internal pressure and temperature. The minimum pressure rating of pipes should be 9 bar. Where pipelines are exposed they should be protected from extremes of temperature and ultra-violet radiation. Vacuum sewers should have a minimum gradient of 1 in 500. Pipe lifts (H) can be used to ensure that the pipes do not have to be laid at excessive depths or to avoid objects. Many lifts are preferable to one large lift. It is recommended that the pipe should be laid with a saw tooth profile.

Service connection to vacuum sewer

Service connections should initially fall away (>0,2%) from the interface valve and should connect into the top sector of the vacuum sewer within 60^o of the top of the pipe. It must connect at 45^o to the main vacuum pipeline in the direction of flow. All bends should have a radius of 300 mm or more. All branch sewer connections should be made with a standard junction fitting. The minimum cover to the vacuum main pipeline should be 1m in road reserves and public open spaces and 1.2m under roads. The minimum cover to the vacuum service connection should be 900mm.

Isolating measures

The vacuum sewer main should be capable of being isolated in lengths of not more than 500 m. All branch connections longer than 200 m should be provided with an isolation valve at the connection. Buried valves should have surface boxes and an extension spindle if the cap cannot be reached with the standard spindle key of 1m. The valve should have a clear opening of not less than the DN of the pipe. The valve should be suitable for service in wastewater under both vacuum and pressure and be capable of maintaining a differential vacuum of 80 kPa below atmospheric pressure. Inspection pipes should be installed a short distance up- and downstream of division valves.

Vacuum vessel

The vessel should be provided with the following facilities:

- Inlet and outlet connections of the required size and at the required elevation.
- It should be provided with an access hatch to allow for internal inspection and cleaning.
- The vessel should be equipped with a level control system which is suitable for the conditions under which it will operate and can be easily adjusted or replaced.
- The vessel should be sized to limit the number of starts of the vacuum generators to a maximum of 12 per hour at peak flow with 25% of the tank volume reserved for liquid.
- The required volume of the vacuum vessel should be provided in two or more vessels for ease of maintenance.

Electrical controls

The controls should allow for selection of duty, duty assist and standby vacuum generators and pumps and for the automatic introduction of standby units in the event of failure. The vacuum generators should be controlled by pressure switches in the pressure vessel. All electrical equipment in the pressure vessel should be explosion proof.

Standby generator

At least one standby generator should be provided to provide back-up power for all the essential equipment. It should start automatically in the event of a power failure.

Vacuum generators

They should be of the rotary vane type. At least two generators of equal capacity should be provided to act in a duty/ standby mode. They should be sized to operate for 30% of the time but should be capable of both continuous operation and a minimum of twelve starts per hour. The system should be designed to achieve a minimum partial vacuum of 25kPa at each interface valve under no-flow conditions. The system should have a maximum recovery time of 30 minutes in the event of a mechanical breakdown, electrical failure or intentional switch off.

Pumps

The pumps are similar to those serving a gravity system except that they must allow for pumping from a partial vacuum. They should be capable of passing a 100 mm diameter solid and operate under negative pressure without cavitation. At least two pumps of equal capacity should be provided to act in a duty/ standby mode. The pumps should be of the dry well/wet well type and capable of 12 starts per hour. Submersible pumps should be avoided because of the difficulties of maintenance.

Odour and noise

Both of these aspects should be addressed if necessary so that no nuisance is caused.

The design flows should be based on the type of water connection that is provided as given in Table 4 below:

TABLE 4
Design flows

Type of water connection	Water returned to sewer (litres/person/day)
House	132
Yard	40
Public standpipe	40

As with gravity sewer systems the effluent from a vacuum system will need to be treated before being discharged to the environment. While the vacuum system will tend to keep the wastewater aerated it does not provide any form of treatment.

Wastewater treatment is similar to that of a gravity sewer with the following exception:

- The daily flows may be substantially lower than from a gravity system because it can serve households that use less water. Gravity sewers tend to require more water to work because they

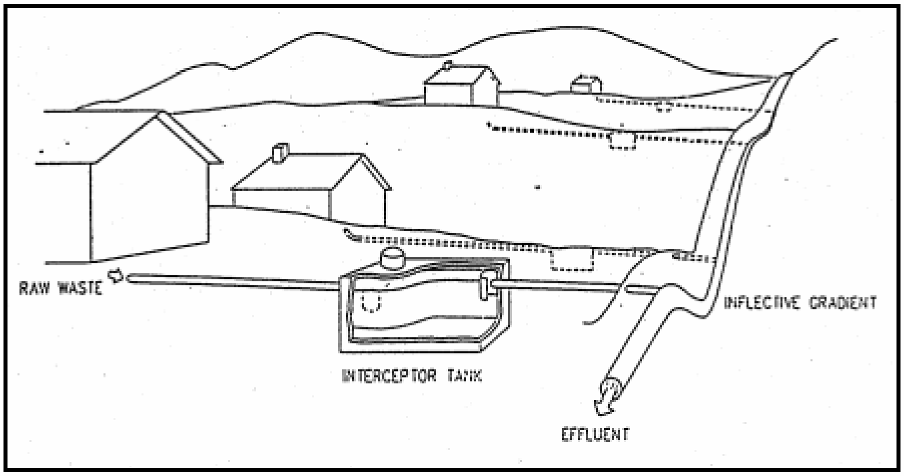


Figure 3
Diagrammatic view of the small-bore system

require reasonable volumes of water for flushing. The fact that less water may be used will impact on the treatment in two ways namely:

- The strength of the wastewater will be higher. This is because a person generates about the same amount of waste per day and so if less water is used the concentration will be higher. The designer should conduct tests on the effluent of a similar vacuum system in order to establish the strength of the wastewater.
- The hydraulics of the treatment works can be sized to cope with lower peaks because not only is the flow lower but the infiltration into the system is also lower. The peak will be established when the output of the pump is selected which is a function of the supplier of the system.

An illustrative example is provided in the discussion section of this paper but it can be seen from the above that the sewers will generally be laid between 1 and 2m deep which reduces construction costs and also means that it is feasible to use manual labour. The pipes used would be smaller than a gravity sewer system.

The system always requires a vacuum station and pumping station. It is recommended that vacuum systems are only considered in situations where a gravity sewer system requires a pumping station.

Small-bore systems

A small-bore sewer is also known by the term "solids free sewer" or "common effluent drain". In this paper the term "small-bore sewer" is used. A diagrammatic view of the system is given in Fig. 3.

A household served by a small-bore sewer will not be aware of any difference between it and a gravity sewer other than the periodic emptying of the interceptor tank. The use of small-bore sewers is not restricted to developing countries. They have been successfully used in Australia and the United States.

The small-bore system requires interceptor tanks at the head of the sewer to prevent gross solids entering the sewer. A household that already has a septic tank can therefore readily connect to a small-bore system. Households that do not have a septic tank will first have to construct a tank which may make the cost similar to the conventional gravity sewer system. Nevertheless, a major advantage of the system is that a relatively poor household can be provided with the benefits of waterborne wastewater on low water consumption figures.

There are many small-bore systems installed around the world with numerous examples in Africa. A number of systems were installed in Zambia in the 1950s a few of which are still functioning.

Advantages and disadvantages

The system has the following advantages:

- The system can be used by people who are poor and cannot afford tissue paper for anal cleansing. Very often poor people use newspaper, stones etc for anal cleansing which results in blockages in a gravity sewer.
- The system can be used by people using very little water because the sewers do not need to be flushed.
- The sewer pipes can be laid at flat gradients as they do not carry solids that require transportation at scouring velocities. This means that trench excavations do not become so deep and less pumping stations are required. As a result, the system is cheaper to construct and requires less skills to maintain (always a problem in rural areas). In addition, the pipes can be smaller.
- The labour content in construction and hence the benefit to the community is much larger than a gravity sewer contract because the shallower trenches can be hand dug.
- The sewer can be laid with inflective grades which is useful in flat areas.
- The wastewater treatment works can be smaller than for a conventional gravity sewer because the septic tanks provide partial treatment.

The system has the following disadvantages:

- If an interceptor tank has to be built (i.e. no existing septic tanks) at each connection point then it makes the cost approximately the same as a gravity system.
- The wastewater that comes out of the small-bore system is septic so it can be odorous and corrosive. These can be accommodated with careful design.
- The interceptor tanks have to be monitored and pumped from time to time. As the users of this system would normally have to use a VIP, the number of tankers would not change but compared with a gravity sewer system the tanker is an extra.
- The fact that the system is relatively unknown to sewerage practitioners in Southern Africa. This may mean that designs may not be up to standard and inferior installations are constructed.
- Difficulties may also arise if the interceptor tanks are not monitored and pumped out correctly. This is an administration

problem and not a technical difficulty.
- The system cannot tolerate gross solids so direct connections to the system cannot be tolerated. It is important to remember this fact so that connections made in the future (say in 15 years time) do not connect directly.

Areas of application

The situations where small-bore sewers could be considered are given below:
- In high density areas where the population is relatively poor.
- Where the slope of the ground is relatively flat. A gravity sewer becomes deep in these cases in order to achieve minimum velocities and it becomes necessary to install pumping stations. In certain circumstances the number of pumping stations can be excessive and they require specialised maintenance.
- If there is rock, running sand or a high water table close to the ground surface it is expensive and difficult to dig deep trenches.
- Where the population density (people per hectare) is low. This often results in deep sewers because the designer is working with minimum grades for scouring purposes.

It needs to be pointed out that the system can be used in centres in conjunction with both gravity sewers and vacuum sewers with each system serving a different area. The cost of the small-bore and gravity sewer system is usually similar because of the interceptor tank but it provides the benefits of waterborne wastewater to a wider range of the community.

Design guidelines

A small-bore system consists of a pipe that conveys the effluent from the house to a tank where the solids are intercepted. From there a sewer conveys the liquid to a treatment works. The system may or may not include a pumping station. The essential components of the system are described below.

Connection pipe

The connection pipe allows the effluent to gravitate from the house to the interceptor tank. A 100mm diameter pipe at a slope of at least 1 in 60 is required. The maintenance of this pipe is the responsibility of the plot owner.

Interceptor tank

The tank is used to settle the solids that are carried in the effluent from the house. It is designed to remove both floating and settleable solids from the liquid stream and so typically the tank is similar to a septic tank. As with a septic tank, it has to be de-sludged regularly so as to prevent solids from entering the sewer. Technically, it would be acceptable to provide a tank to be shared by adjoining plots. The level of the tank should be no deeper than necessary so that the maximum potential energy (arising from its elevation) is available to conduct the flow in the sewer main.

Sewers

It is recommended that at least the first two metres of the connecting pipe from the interceptor tank to the plot boundary should have a diameter slightly smaller (50mm diameter) than the sewer main. This would reduce the chances of a blockage in the main sewer. Possible misuse of the tank would then result in the plot owner being inconvenienced rather than the neighbourhood.

The small-bore sewer mains should consist of plastic pipe with a minimum diameter of 100 mm as this is economical, smooth and resistant to corrosion. They are laid at a depth sufficient to collect the settled wastewater from the tanks by gravity. Unlike gravity sewers, small-bore sewers are not necessarily laid to uniform grades. The sewer may have low points or dips which may remain full under static conditions. The horizontal alignment can also curve to avoid objects. The design of the sewer makes maximum use of the energy resulting from the difference in elevation between the upstream and downstream ends of the sewer. The sewer is not intended to carry solids so is designed on hydraulic considerations only.

Clean-outs and manholes

These provide access points to the sewer for the purpose of maintenance and inspection. Manholes are not favoured because they allow the ingress of grit and other solids and they also cost more. Clean-out points are used as a flushing point during sewer cleaning.

Vents

The sewers have to be vented to prevent air-locks. The normal vent required under the Building Control Act is sufficient except where inflective grades are used. In these cases the high points of the sewer should be ventilated either by placing a house connection at this point or by installing a clean-out with a ventilation cap.

Pumping stations

These are required where elevation differences do not permit gravity flow.

The design procedure for a small-bore system is much the same as a gravity sewer design with the following aspects being calculated in the design of a small-bore system:

Sewer flows

Unlike a gravity sewer, the small-bore sewer can operate on the effluent from a toilet with low water usage. This means that households served by a standpipe or yard tap can also contribute to sewer flows and so must be included when sizing the sewers. The return flow for these categories as well as households with a house connection are given in Table 6:

TABLE 6
Return flows for various domestic consumers

Type of consumer	Water consumption (ℓ/cap·d)	Return flow (ℓ/cap·d)
House connection	165	132
Yard or standpipe	35 to 50	40

The amount of effluent that is generated in a drainage area is calculated from the number of people in that area using the return flow given above plus the flow from industries and institutions.

Peak flows

The flows that reach the small-bore sewer are attenuated markedly in the interceptor tanks. The attenuation is a function of the liquid surface area in the tank and the length of time over which the wastewater is discharged into the tank.

A conservative peak flow factor of 2 is recommended for domestic users. Table 7 gives the flows from domestic sources based on the above peak flow factor and the consumption and return factors shown above:

TABLE 7 Peak flows per person from domestic sources	
Type of water connection	**Peak flow per person (ℓ/s)**
Yard tap	0.00093
Tap in house	0.00306

In addition, an allowance must be made for infiltration. The amount of infiltration will depend on the quality of workmanship, the type of pipe used (uPVC pipes are easier to lay than vitrified clay and are longer, so have less joints) and the dryness of the ground. A conservative allowance of 20 m^3/ha·d should be allowed for if clay pipes are used and 10 m^3/ha for uPVC pipes.

The peak flow from institutional, commercial and industrial contributors must be assessed individually.

Pumping stations capacities should be equal to the calculated peak inflow rate to the pumping station.

Hydraulic design

Unlike conventional gravity sewers which are designed for open flow channel conditions small-bore sewers can be installed with sections below the hydraulic grade line. Thus flow in a small-bore sewer may alternate between open channel and pressure flow.

Separate design calculations or analysis must be made for each sewer section in which:

- the type of flow does not vary, and
- the slope of the pipeline is reasonably uniform

The Manning equation with "n" equal to 0.013 is recommended.

Pipes of 50 mm diameter have been used successfully in America but because they require specialised equipment to maintain should not be used. A minimum pipe diameter of 100 mm is recommended in sewer mains.

The design must ensure that an overall fall exists across the system and that the hydraulic grade line during peak flow does not rise above the invert of the interceptor tank outlets.

The critical points are:

- the high points where the flow changes from pressure flow to open channel, and
- points at the end of long flat sections

Care with these points must be taken during construction to ensure that the pipe is not laid above the designed elevation. Between these critical points, the sewer can be laid with any profile as long as the hydraulic gradient remains below all interceptor tank outlet inverts and that no additional high points are created.

The hydraulic design of the pipeline shall be checked to ensure that it can be flushed between successive cleanouts at 0.5m/sec without backing up into adjacent septic tanks.

Pipelines should be kept at depths which provide at least the following:

- 300 mm cover on plots
- 1 m cover on public land such as in road reserves
- 1.2 m cover when crossing roads.

Clean-outs should be located as follows:

- at the upstream ends of the system
- at the intersection of sewer lines
- major changes of direction
- at high points, and
- at intervals of 150 to 200 m in long flat sections.

In America, pumping stations are sometimes used to overcome adverse elevation conditions at individual connections. Although these are simple installations (low-lift, low capacity, corrosion resistant, controlled automatically by floats) they are not recommended except in exceptional circumstances.

Major pumping stations to serve large drainage basins are conventional in design except that the pumps do not have to have such large capacities because the peak flows are attenuated significantly in the system. It is recommended that pumps that can pump 100mm diameter solids be installed, although the pumps theoretically should not have to pump solids. Corrosion and odours are major problems because of the septic nature of the effluent in small-bore sewers. All equipment exposed to the atmosphere in the wet well should be made from non-ferrous materials. All concrete surfaces above the low water mark should be coated with a chemically resistant material.

A fresh air vent should be provided at all pumping stations to ventilate the wet well. This should be at least 150mm in diameter and extend at least 9m above ground level so that odours are not a nuisance to the neighbours.

Self-priming pumps, with suitable corrosion resistance, situated above the wet well would be ideally suited to this application.

Wastewater treatment

The effluent from small-bore systems can be treated at conventional treatment works. It can safely be assumed that the organic contribution (COD) of the effluent from a small-bore system is only 50% of the normal gravity sewer effluent from the same source. The nitrogen and phosphorus load will remain the same as for gravity sewer systems.

The average daily flow per person will tend to be lower than that of the gravity sewer because the small-bore can serve households with yard connections. A survey of the catchment area should be made to establish the proportion of households using house, yard and standpipe connections. The peak wet weather flow should be based on the average flow per person plus the allowance for infiltration of 10 m^3/ha for uPVC pipes and 20 m^3/ha for clay pipes.

Discussion

A hypothetical example to compare the above systems is provided below. It is assumed that about half the people have house connections and half have yard taps.

Gravity system

Using the gravity sewer criteria for a village in Botswana where a slow connection rate is expected it can be shown that a sewer serving an area where 2 000 people at a density per hectare of 25 people requires a fall of about 9 m. Note that only half of the 2 000 can be sewered (they have house connections and hence enough water to flush the pipes) If the ground surface falls at 1 in 400 the end of the sewer will be about 8m deep. This is often impractical to excavate especially as rock is usually encountered before this depth. To avoid excessively deep sewers it would be necessary to either use a flushing tank or construct a pumping station. Both have their disadvantages. It is estimated that about 6 000 m of sewer main would be needed (5 400 m of 150 mm dia, and 300 m each of 200 and 250 mm dia) and one pumping station. Indicative costs of the system will be provided on the poster display. The maintenance of the reticulation system plus the operation and maintenance of the pumping station and treatment works make up the operating costs.

Vacuum sewer

For the above situation a vacuum sewer may require slightly less than 6 000 m of pipe because it does not need to follow the contours. In addition, even people with yard taps can connect so all 2 000 people have the benefit of waterborne wastewater. All the pipes would be at the minimum diameter of DN 90 and they would all be laid between 1 and 2m below ground level. About 300 collection chambers are required. In addition, a vacuum station and pumping station (usually combined) are needed. Once again indicative costs will be provided on the poster display. The maintenance of the reticulation system plus the operation and maintenance of the vacuum and pumping station and treatment works make up the operating costs.

Small-bore sewer

Once again for a similar situation with a small-bore sewer, the length of pipe required may be slightly less than the 6 000 m required for a gravity system because one is not forced to follow contours. Once again, all the people can connect and get the benefits of waterborne wastewater. Nearly all the pipe would be the minimum diameter of 100 mm but about 300 m of 160 mm diameter would be required. Once again, it is estimated that the depth of the trenches would be in the range of 1 to 2.5 m deep and 330 interceptor tanks would need to be constructed. The treatment works would only need to treat half the COD load generated by the gravity system and in addition, the peak hydraulic load would be calculated on a factor of 2 and not 6. Once again, indicative costs will be provided on the poster display. The maintenance of the reticulation system plus the operation and maintenance of the treatment works plus the emptying of the interceptor tanks make up the operating costs.

Conclusion

The conventional gravity sewerage system is well know to both the layman and practitioner and is often exclusively associated with waterborne sewer facilities. This often restricts the extent of provision of these services because of either practical restraints or lack of capital. With appropriate design standards the service reliability and functionality of both vacuum and small-bore systems can be ensured thus allowing the benefit of waterborne sanitation to be brought to a wider public.

In countries with poor water resources, including nearly all the countries in Southern Africa, these systems also promote water saving as they can operate with low water usage.