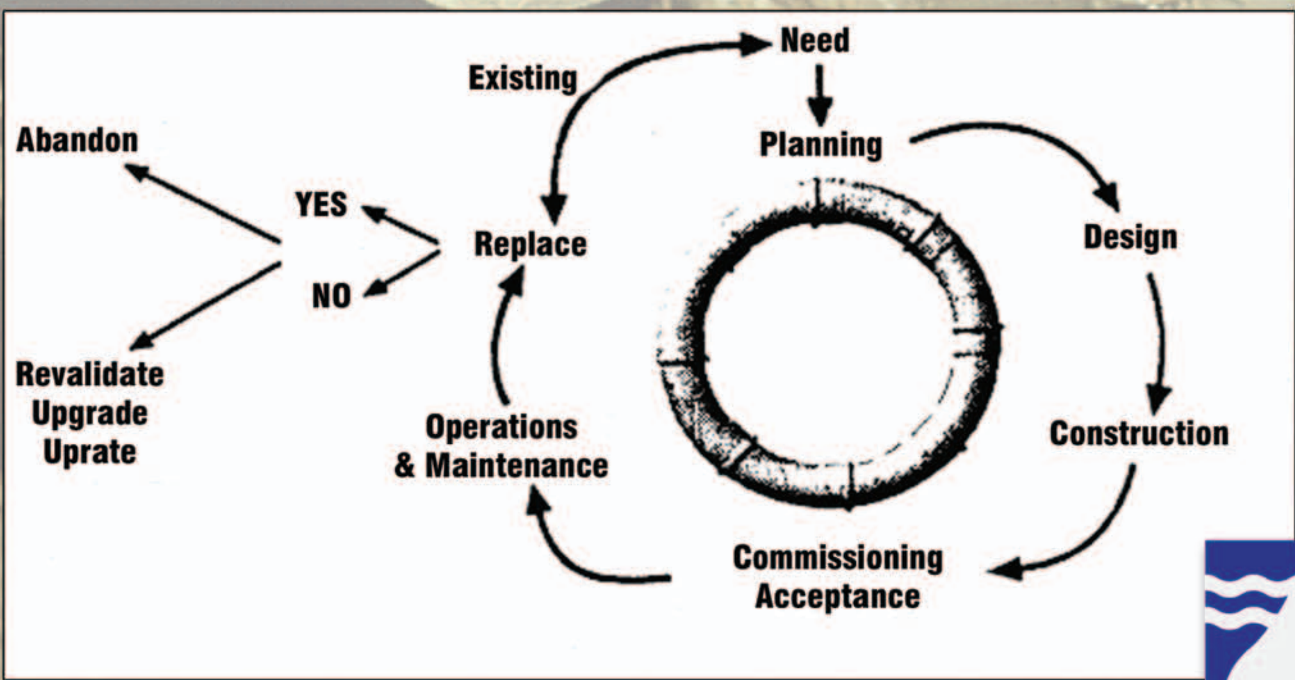
Guidelines on Reduction of the Impact of Water Infiltration into Sewers

D Stephenson and B Barta



Water Research Commission

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Guidelines on reduction of the impact of water infiltration into sewers

Report to the Water Research Commission

by

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GLOSSARY

Aerobic: Condition in which dissolved oxygen is present

Anaerobic: Condition in which dissolved oxygen is not present

Attentuation: The reduction in peak flow or concentration and increase in minimum flow and concentration of the diurnal variation in wastewater flow as it passes through the sewerage system

Bedload: That part of the sediment load that travels by rolling or sliding along the sewer invert or deposited bed, or by saltating

Biochemical oxygen demand: The amount of dissolved oxygen consumed by microbiological action when a sample is incubated in the dark at 20^{o}C

Black water: Wastewater consisting of human excreta, urine and the associated sludge

Blockage: A deposit in a sewer or drain resulting in restriction of flow

Catchment: An area served by a single drainage system

Chemical oxygen demand: The measure of oxygen required to oxidize all organic material in a water sample with a strong chemical, usually potassium dichromate

Combined sewer Sewer conveying both wastewater and surface water

Diurnal variation: The variation in flow rate or in the concentration (or mass flow) of a substance over a period of 24 hours

Domestic wastewater: Wastewater discharged from kitchens, washing machines, lavatories. bathrooms and similar facilities

Drain: A pipeline, usually underground, designed to carry wastewater and/or surface water from a source to a sewer; a pipeline carrying land drainage flows or surface water from a highway

Effluent: Liquid discharged from a given process

Exfiltration: The escape of wastewater from the sewerage system into the surrounding soil via cracks or malfunctioning pipe joints

Foul sewage: Waterborne waste of domestic or industrial origin excluding rainwater and surface water

Grey water: Wastewater from kitchen and bath effluent

Gross solids: Large faecal and organic matter and other wastewater debris

Infiltration (to sewer): The ingress of groundwater into a drain or sewer system through defects in pipes, joints or manholes

Inflow: Stormwater runoff that enters a sewer indirectly through deficient manholes, etc.

Invert: The bottom of the inside of a pipe or conduit

Lateral: A private drain carrying drainage flows from a property to a public sewer

Manhole: A chamber with a removable cover constructed on a drain or sewer to permit entry by personnel

Partially separate system: Separate system in which some surface water is admitted to the sewers that convey foul water

Pollutant: Any substance conveyed in solution, suspension or as a discrete solid and discharged to a water course, thus adversely affecting its quality

Pressure sewerage system: A system that operates under positive pressure to pump drainage flows from a property or group of properties into a public sewer; the system may consist of one or more pumps, storage chambers, pipework and non-return valves

Receiving water: Watercourse, river, estuary or coastal water into which the outfall from a combined sewer overflow or wastewater treatment works discharges

Runoff: Water from precipitation which flows off a surface to reach a drain, sewer or receiving water

Sediment: Material transported in a liquid that settles or tends to settle

Separate system: A drain or sewer system, normally of two pipelines, one carrying wastewater and the other surface water

Sewage: Wastewater

Sewer: Pipeline or other conduit, normally underground, designed to convey wastewater, stormwater or other unwanted liquids

Sewer flooding: The unintentional escape of sewage from a sewerage system; the inability of drainage flows to enter a sewerage system because of surcharging

Sewerage system: System of sewers and ancillary works that conveys wastewater to a treatment works or other disposal point

Soffit: The top of the inside of a pipe or conduit

Specific gravity: The mass of a substance divided by the mass of the same volume of water

Surcharge: The condition in which wastewater and/or surface water is held under pressure within a gravity drain or sewer system, but does not escape to the surface to cause flooding

Suspended solids: Solids transported in suspension in the wastewater flow and prevented from settling by the effects of flow turbulence

Wastewater: Water discharged as a result of cleansing, culinary or industrial processes to a drain or sewer system

ABBREVIATIONS

ADWF: Average dry weather flow (ℓ/s)
$BOD_{(5)}$: Biochemical oxygen demand (five day)
COD: Chemical oxygen demand
CSO: Combined sewer overflow
CCTV: Closed-circuit television
DO: Dissolved oxygen
DWF: Dry weather flow
DWL: Dry weather load
EBOD: Effective biological oxygen demand
EDU: Equivalent discharge unit (100 ℓ/day)
ERWAT: East Rand Water Care Company
FFT: Flow to full treatment
FOG: Fat, oils and greases
GIS: Geographic information system
HRT: Hydraulic retention time
IDP: Integrated development plan
MDPF: Maximum daily peak flow
MH: Manhole
MPN: Most probably number
NWA: National Water Act (Act 36 of 1998)
pH: Hydrogen-ion capacity
PDWF: Peak dry weather flow (ℓ/s)
PWWF: Peak wet weather flow (ℓ/s)
PS: Pumping station
PSS: Pressure sewerage system
SS: Suspended solids
TOC: Total organic carbon
TSS: Total suspended solids
UDF: Urban development framework
UPM: Urban pollution management
WSA: Water Services Act (Act 108 of 1997)
WSDP: Water services development plan
WWTP: Wastewater treatment plant
WWTW: Wastewater treatment works

1. BACKGROUND TO THE PROBLEM

1.1 Rationale

During the past two decades significant changes in land use, particularly in urban areas, have highlighted several problems present in municipal water supply and sanitation systems, particularly the impact of extraneous flows on municipal waterborne sanitation services.

Changes in water legislation and environmental protection laws as well as concerns over increasing pollution of groundwater resources have increased pressures on the Water Services Authorities and Providers to optimise the allocation of capital between new developments and upgrading of existing sanitation infrastructure and wastewater treatment processes.

This set of guidelines deals primarily with identifying and evaluating stormwater inflows and groundwater infiltration into municipal waterborne sanitation systems to facilitate decision-making and capacity building. Various options based on international and local practices are indicated for remedial procedures, rehabilitation or replacement of components which form part of municipal waterborne sanitation systems.

A need and justification for these guidelines was identified from a survey on the status of municipal waterborne sanitation infrastructure which was conducted under the scope of the Water Research Commission's project K5/1386. Although there are numerous problems inherent to municipal sanitation systems, extraneous flows (i.e. inflow and infiltration or I/I events) which were taking place specifically in waterborne sewers, appeared to be generally underestimated and thus seriously unattended.

1.2 Scope

The guidelines are aimed at:

- *The decision-makers of the Water Services Authorities and Providers*
- *The participants in planning, design, construction, operation and rehabilitation of municipal waterborne sanitation systems*

with the following objectives:

- *To build an awareness and insight into the issues inherent to municipal waterborne sanitation systems with specific emphasis on extraneous flows (i.e. inflow and infiltration events)*
- *To consolidate past and present South African design standards and criteria in respect to the changes in recently promulgated water legislation and environmental conservation laws*
- *To formulate a set of guidelines for the purpose of capacity building and procedures for adequate evaluation and assessment of extraneous flows in municipal waterborne sanitation services systems, and*
- *To provide guiding criteria for effective decision-making on the rehabilitation or replacement of faulty infrastructural components in a municipal waterborne sanitation system.*

1.3 Status of municipal waterborne sanitation in South Africa

Since 1994, water supply and sanitation services in South Africa have been developed according to general legislation for the equitable delivery of services and redistribution of available resources under the philosophy of integrated economic development.

Sanitation services are generally regarded as secondary to water supply services thus resulting in a considerable backlog and wide diversity in sanitation facilities installed. The following is a breakdown of recent statistics by DWAF (2003) on the installation of sanitation facilities:

Table 1.1. Levels of sanitation services installed in South Africa

Type of sanitation facility installed	**(%)**	**Number of households (million)**
None	13,6	1,6
Chemical toilets	1,9	0,2
Bucket collection system	4,1	0,5
Pit latrines without ventilation	22,8	2,6
Ventilated Improved Pit (VIP) latrines	5,7	0,7
Flush toilet (septic tank and soakaway)	2,8	0.3
Flush toilet (waterborne sewer)	49,1	5,6
Total for South Africa	**100,0**	**11,5**

Sources: Sanitation – DWAF (2003), households – STATSSA (2003)

At present, the basic sanitation facility in South Africa is regarded as the Ventilated Improved Pit (VIP) toilet. The desired level of sanitation service is a flush toilet connected to a waterborne sewer, where the residential/industrial wastewater is collected and treated before it is released into the receiving water source, thus providing for environmental control requirements.

The national aim in the implementation of water services (i.e. water supply and sanitation as per Act 108 of 1997 and Act 36 of 1998) will inevitably generate extensive demand from previously disadvantaged communities who wish to be provided with not only potable water but also desired sanitation facilities (i.e. waterborne sewerage, etc.). The new water legislation and more stringent environmental requirements for better protection of river ecosystems are indirectly supporting more extensive development of urban sanitation services, strongly emphasizing development of waterborne or water added sanitation systems.

Along with the development of new sanitation infrastructure in South Africa, several urgent problems were identified from the operation and maintenance of existing municipal waterborne sewerage subsystems. The problems are primarily related to the extent of inflow/ infiltration to sewers. Inflow/infiltration can significantly disturb the management of municipal sanitation subsystems, resulting in excessive financial consequences in the long run for those Water Services Authorities (mainly municipalities) not undertaking regular proactive maintenance.

1.4 Separate waterborne municipal sanitation systems

Most of the municipal waterborne sanitation systems installed in South Africa are separate systems. In separate systems, wastewater and stormwater are carried in separate pipelines which are usually laid side-by side. Theoretically, stormwater does not mix with the wastewater and is usually discharged directly into a river ecosystem at suitable locations. On the other hand, the wastewater generated in urban areas is collected and conveyed commonly to centralised WWTPs and discharged after treatment to the receiving river ecosystem.

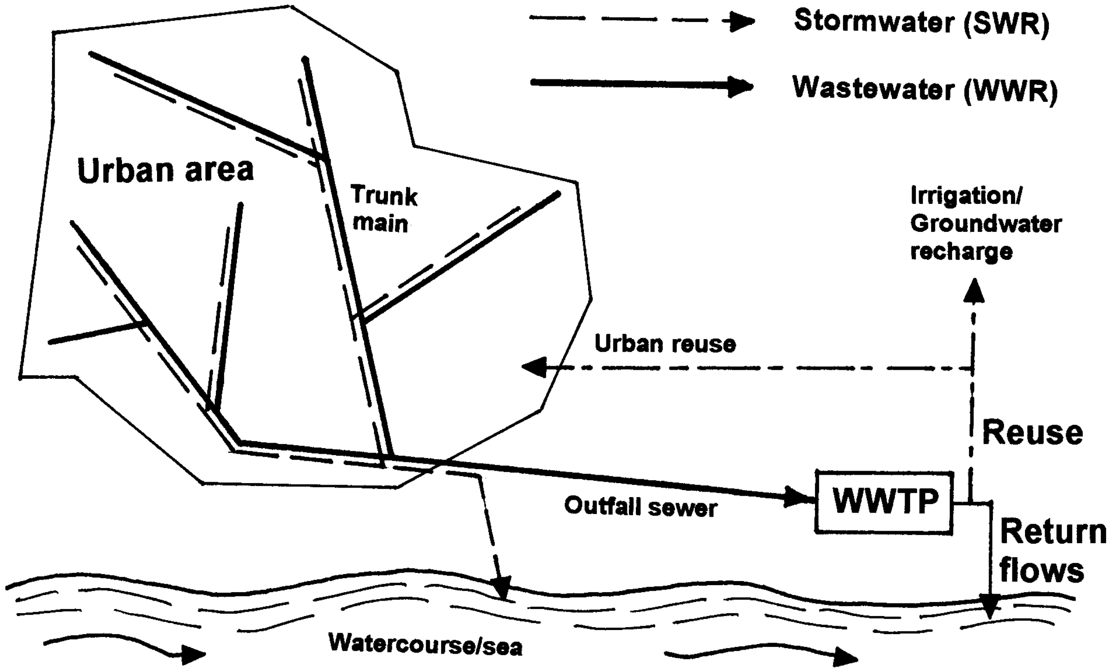


Figure 1.1. Hypothetical layout of separate wastewater from stormwater system

The key drawback of separate systems is that perfect separation of wastewater and stormwater is almost impossible to achieve. Extensive inflow/infiltration into the separate systems mitigates the function of separation and such a system becomes a hybrid system.

Table 1.2. Summary of advantages and disadvantages of separate systems

Advantages	**Disadvantages**
• *Smaller WWTP* • *Collection sewer pipe smaller maintaining greater velocities* • *Less variation in flow and strength of wastewater* • *Limited surface area grit in collected wastewater*	• *Extra cost of two pipes* • *Additional excavation space and volumes* • *More house drains with risk of wrong connections* • *No regular flushing of wastewater deposits* • *No treatment of stormwater*

1.5 Extraneous flows (or stormwater inflow/groundwater infiltration)

Extraneous flows can be defined as an excessive inflow/infiltration of water into the existing sewerage system due to uncontrolled surface inflow and/or groundwater infiltration on account of infrastructural deficiencies (e.g. missing manhole covers, damaged pipes due to poor trench bedding, etc.) or incorrect management practices of urban stormwater. The problem of extraneous flows is particularly pertinent in the operation and maintenance of municipal waterborne sanitation systems where stormwater is separated from the collection and treatment of wastewater. Practically all municipal wastewater systems in South Africa separate stormwater from domestic wastewater and industrial effluents.

The inflow of stormwater and infiltration of groundwater (or I/I events) into sewers are considered common phenomenon, but often given low priority by the Water Services Authorities (Providers).

In the South African context, I/I events are seasonal, depending on the precipitation intensity, patterns of land use and other parameters of a drainage catchment. Excessive inflow/infiltration may cause sewer surcharges, local flooding and unnecessary pumping where required. At the wastewater treatment plant, hydraulic overload may adversely affect both the physical and biological treatment processes. Wet weather periods may require overflow bypassing or additional storage capacity and/or treatment capacity. Typical conditions of extraneous flows are illustrated in Figure 1.2 below:.

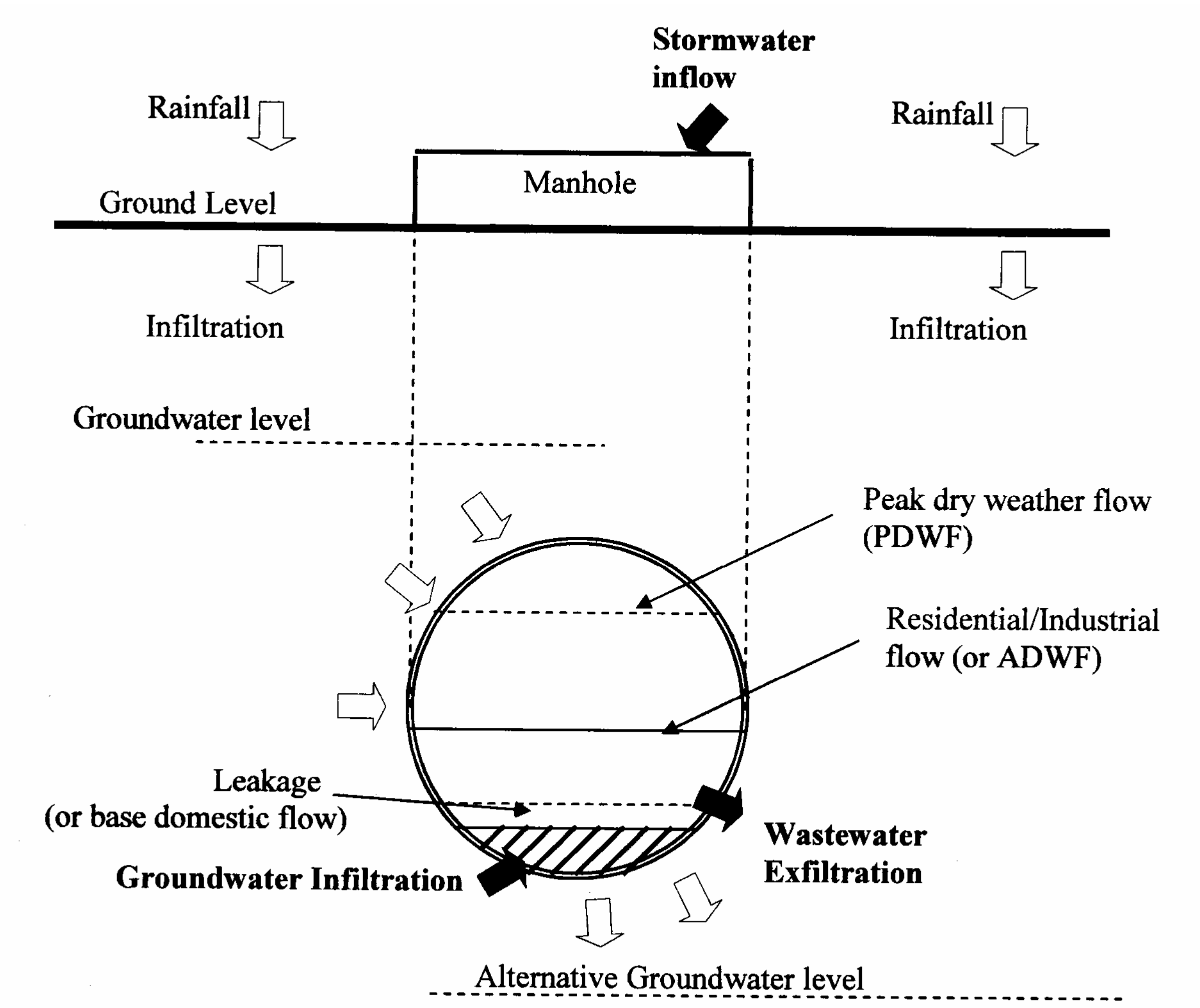


Figure 1.2. Hypothetical illustration of extraneous flows in a waterborne sewer

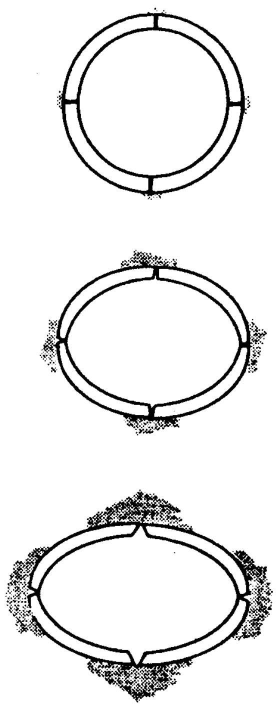
- *Residential/industrial sewer flow (or Average Dry Weather Flow)* – is determined from the land use parameters per typical urban erf size or other land use unit. A 24-hour unit hydrographs is determined from field measurements for a specific urban area. The hydrographs will differ in terms of volume and peak flow size for different land use. Unit of measurement is typically ℓ/day/erf or m^3/day/single family unit or 100 m^2 floor area, etc. The flow volume for the larger area is expressed as Average Daily Dry Weather Flow (ADDWF) in m^3/day
- *Leakage (or base domestic flow)* – is a relatively marginal subcomponent of residential/ industrial wastewater flow, generated typically from leaking plumbing devices collected by a waterborne sewer system.

- *Peak Dry Weather Flow (PDWF)* – the hydraulic capacity of a waterborn sewer is determined from anticipated peak flow conditions, including extraneous flows (i.e. I/I events). Peak Daily Dry Weather Flow (PDDWF) is PDWF expressed in daily flow volume. Both ADDWF and PDDWF are envisaged to increase over time.

1.6 Sewer exfiltration

Exfiltration can occur when the elevation of the sewer liquid level is above the groundwater table. The positive head created by such circumstances can cause the raw sewage to exfiltrate through open joints into the surrounding ground with a strong possibility of polluting the groundwater. Exfiltration can also cause a concentrated flow in the sewer trenches and the raw sewage can find its way into ground and surface water sources (i.e. boreholes, streams, etc.) introducing a serious environmental and health hazard. Exfiltration may also occur when the water leaves the sewer line through structural defects during periods of hydraulic surcharge. In theory, infiltration of groundwater carries particles from the soil into the sewer pipe through existing structural defects creating or increasing the size of voids. Generally, the effects of infiltration on void formation are made worse by the processes of exfiltration.

Either infiltration of groundwater and/or exfiltration of wastewater from a waterborne sewer may take place already during stage 2 of a rigid sewer pipe failure process as illustrated in Figure 1.3 below.



STAGE 1
Pipe cracking caused by poor construction practice or subsequent over-loading or disturbance. The sewer remains supported and held in position by the surrounding soil.

STAGE 2
Infiltration of groundwater or infiltration/exfiltration (egress) caused by surcharging of the sewer washes in soil particles. Side support is lost, allowing further deformation so that cracks develop into fractures. Side support may also be insufficient to prevent deformation if the original backfill was either poorly compacted or of an unsuitable material.

STAGE 3
Loss of side support allows side of pipe to move further outwards and the crown to drop. Once deformation exceeds 10%, the pipe becomes increasingly likely to collapse. Development of zones of loose ground or voids caused by loss of ground into the sewer

Figure 1.3. Typical progress in failure of a rigid sewer pipe

2. COMPLIANCE WITH LEGAL PROVISIONS AND SEWER DESIGN CRITERIA

2.1 Criteria guiding wastewater services provision in South Africa

2.1.1 General legislative guidelines

(i) Basic sanitation requirements for municipal wastewater disposal

To maintain basic sanitation requirements, water services institutions (WSI) in South Africa must take measures to prevent objectionable substance from entering a watercourse. Such a substance can be domestic wastewater, industrial effluent, petroleum products, chemicals, leachates from solid waste dumps, etc. In principle, the standards promulgated under the NWA (1998) require the following:

- *Any water services institution is only obliged to accept the quantity and quality of industrial effluent or any other substance into a sewerage system that the WWTW linked to that system is capable of purifying or treating to ensure that any discharge to a water resource complies with prescribed standards"*

(ii) National Water Act (NWA)

Section 21 of the NWA (1998) requires that a water use license is to be authorised by the State through the DWAF, for discharging an effluent into a watercourse. Authorization would specify the types and maximum levels of contaminants that the effluent is allowed to contain. If accepting that discharge would pose a risk to the treatment process or lead to a breach of the permit, the WSI should only agree to accept the effluent once the harmful substances have been removed or reduced. Subsequently, some industries may need to comply with the following:

- *Pre-treating the effluent such that it complies with the permit conditions;*
- *Separating effluent discharges and treating the harmful component of the discharges separately; or*
- *Collecting harmful matters that are then removed by appropriate waste disposal contractors.*

2.1.2 Urban wastewater quality criteria and guidelines

Both the quantity and concentration of urban wastewater must be considered together to obtain the total contaminant load. The pertinent requirement is that industries or businesses are not allowed to dilute effluent in order to comply with set concentration limits.

The principle parameter of the contaminant load in residential sewage is biochemical oxygen demand (BOD) which can be calculated by multiplying the average dry weather flow (DWF) and the average BOD concentrations. In the absence of relevant measurements, the values commonly used are listed in Table 2.1 below.

Table 2.1. Parameters for identifying crude sewage

Parameter	Crude sewage (mg/ℓ)			Settled sewage (%)
	Weak	Medium	Strong	
$BOD_{5\ days}$	200	350	550	30 – 40
COD	350	600	950	30 – 40
SS	200	350	500	50 – 70
NH_3-N	25	35	60	-
ORG.N.	10	15	20	15 – 20
Chloride (Cℓ)	70	100	130	-
ORG.C.	140	210	300	30 – 40

Source: Civil Engineering Reference Book (1995)

2.2. Municipal wastewater services system standards and codes

2.2.1 History of design standards used in the development of municipal services

Historically, most municipal water services systems were developed according to design standards which evolved through technological, socio-economic and political changes. The following standards have to be considered when evaluating the performance of a water services system:

(i) Blue Book

The full title of this publication is “Guidelines for the Provision of Township services in Residential Townships”. It was prepared by the CSIR for the then Department of Community Development and has been use extensively by design engineers over the last decade. Currently it remains the most widely used source of design standards. The document includes practical formulae, graphs and details.

(ii) Green Book

The full title is “Towards Guidelines for Services and Amenities in Developing Communities”. Also prepared by the CSIR, it takes a different approach to the “Blue Book” in that it includes more of a planning overview, with little quantitative information. This has meant that it is not widely used for design purposes.

(iii) Brown Book

This document was prepared and used by the Cape Provincial Administration. It was originally written in Afrikaans but has been translated under the title “Proposed Development Guidelines for Housing Projects”. In the tradition of naming design guidelines after colours, the authors of the book refer to it as the “Brown Book”.

(iv) British Standards

The “Manual of British Water Engineering Practice” is used in Britain primarily as a reference for application in the developed world. In 1983 a companion to it was published, orientated towards the limited resources of the developing world entitled “Water Supply and Sanitation in Developing Communities” in South Africa.

(v) RSA/Kwazulu Guidelines

This document was drawn up for the RSA/Kwazulu Development Programme (RKDP) under the previous political dispensation with the objective of coordinating the provision of services in the Durban and Pietermaritzburg metropolitan areas. It lays down design standards for a variety of situations, drawing primarily on the “Blue Book”, with modifications to allow services to be provided at lower cost.

(vi) Red Book

- *Old Red Book.* Compiled by the CSIR, this document has the full title “Guidelines for the Provision of Engineering Services and Amenities in Residential Township Development”. It was completed in 1992 and published in 1994. This manual has been widely used in the design and development of municipal services. It combines elements of both the blue and green books, giving a general approach to planning and specific quantitative design information. The information in it is very close to that of the two parent documents.
- *New Red Book.* Also prepared by the CSIR under the patronage of the SA Department of Housing and entitled “Guidelines for Human Settlement Planning and Design” (GHSPD), it was published in 2000 as a living document. Some sections have already been revised to accommodate the socio-economic realities which are taking place because of the political changes in South Africa since 1994.

2.2.2 Current design criteria for the development of wastewater systems

(i) South Africa legislation guiding provision of urban water services

Table 2.2 summarizes several South African laws that are related directly or indirectly to the development and management of urban water services.

Table 2.2. S.A. legislation related to the provision of urban water services

Sphere of legislation	Act	Abbreviated reference
Atmospheric Pollution Prevention Act, 1965	Act No 45 of 1976	APPA (1965)
Conservation of Agricultural Resources Act, 1983	Act No 43 of 1983	CARA (1983)
Environmental Conservation Act, 1989	Act No. 73 of 1989	ECA (1989)
Health Act, 1977	Act No 63 of 1977	HA (1977)
Local Government Transition Act, 1993	Act No 209 of 1993	LGTA (1993)
Minerals Act and its Regulations, 1991	Act No 50 of 1991	MAAR (1991)
Municipal Structures Act, 1998	Act No 117 of 1998	MSTA (1998)
Municipal Systems Act, 2000	Act No 32 of 2000	MSA (1998)
National Environmental Management Act, 1998	Act No 108 of 1998	NEMA (1998)
National Water Act, 1998	Act No 36 of 1998	NWA (1998)
National Water Amendment Act, 1999	Act No 45 of 1999	NWAA (1999)
Water Research Act, 1971	Act No 34 of 1971	WRA (1971)
Water Services Act, 1997	Act No 108 of 1997	WSA (1997)

Sources: DWAF and Government Gazettes (various)

(ii) National codes of practice relevant to sanitation services

The national codes of practice to be applied to on-site sanitation installations for the South African water industry are summarized below:

Table 2.3. National codes of practice for the S.A. water industry

SABS code of practice	Description	Abbreviated reference
SABS 090	Code of practice for community protection against fire	SABS 090 (1972)
SABS 0120	Code of practice for use with standardised specifications for civil engineering construction and contract documents	SABS 0120 (1981)
SABS 0252	Water supply and drainage for buildings, Parts 1 and 2	SABS 0252 (1994)
SABS 0306	The management of potable water in distribution systems	SABS 0306 (1999)
SABS 0400	Code of practice for the application of the National Building Regulations	SABS 0400 (1990)
SABS 1200	National Standardised Specifications for Engineering Construction	SABS 1200 (1996)

Source: South African Bureau of Standards (www.stansa.co.za)

(iii) Evolving municipal sanitation standards and by-laws

- *New DWAF wastewater quality standards.* The changes which emanated from implementing new NWRS (i.e. WSA, 1997 and NWA, 1998) affected all spheres of urban water management, and is also now influencing the performance parameters of numerous urban wastewater treatment plants. The more stringent DWAF standards which are being introduced in South Africa will considerably increase the cost of urban wastewater treatment. To meet the newly introduced standards, numerous municipal WWTPs will have to be rebuilt or rehabilitated by advanced technology
- *Updated Guidelines for Human Settlement Planning and Design (GHSPD).* In August 2003, revised Chapters 9 and 10 of the GHSPD were published by the CSIR. Appendix C in Chapter 10 deals with Design Guidelines for Waterborne Sanitation Systems and should be consulted in conjunction with these Guidelines in order to obtain detailed information on the design and construction of sewerage reticulation systems for undeveloped residential areas not dealt with in this Guideline document.
- *General Principles and Guidelines for Design and Construction of Water and Sanitation Systems in the City of Tshwane Metropolitan Municipality Area*. Tshwane MM revised this by-laws document in August 2003 to accommodate and facilitate all necessary legislative requirements that have been generated since 1994. The by-laws comprise chapters on general conditions, water services guidelines and sewerage reticulation and link sewers. No particular comments or guidelines are mentioned on aspects of extraneous flows or exfiltration.
- *Guidelines and Standards for Design and Maintenance of Water and Sanitation Services***.** This document is under revision by the Johannesburg Water (Pty) Ltd attending to levels of service for urban water and sanitation, water reticulation and sanitation design guidelines. The sanitation design guidelines are based on the former City of Johannesburg Wastewater Department's 'Township Sewer Design Standards/Procedures (1994)'. The design infiltration rate is interpreted as a function of sewer diameter and length at 0,08 ℓ/second per 100m of sewer per metre diameter. Infiltration rate values for diameter 1800 to 300 mm are indicated.

(iv) Essential standard criteria applicable

- *Minimum and maximum flow velocity.* A minimum of 0,6m/s should be maintained in all gravity mains to ensure that sufficient scouring of the mains can take place. Maximum flow velocity under full flow conditions should not be more than 2,5m/s to prevent damage to pipelines, although up to 4,0m/s velocities may be permitted for a short period. In the rising mains, a minimum velocity of 0,6m/s is recommended to prevent deposition of solids. To reduce turbulence causing gas release and to minimize water hammer, the maximum flow velocity should be limited to 1,8m/s.
- *Minimum gradient.* Since mean design velocities are not allowed to fall below the minimum self-cleansing value, there is a minimum gradient for each diameter and class of pipe. In theory, smoother pipes can be laid at slightly flatter gradients. The suitability of various materials for pipes is based on the specific Manning coefficient. Refer to the "Red Book" for details.

(iv) Hydraulic capacity of sewers

The capacity of a wastewater system is based on assessing essential parameters including dry weather flow (DWF), average dry weather flow (ADWF), peak dry weather flow (PDWF) and peak wet weather flow (PWWF), as well as estimates of groundwater infiltration and stormwater inflows.

The hydraulic capacity of sewers (i.e. gravity sewers) is usually designed to accommodate the Peak Dry Weather Flow (PDWF) whilst flowing partially full. Certain of the pipe flow area is allocated to extraneous flows. Over time, this allowance is commonly taken up by infiltration of groundwater leaving very little space for stormwater inflows.

- *Dry Weather Flow (DWF).* The DWF should be the first hydraulic capacity parameter to be established. Both quantity and quality parameters need to be determined.

Table 2.4. Definition of quantity and quality of dry weather flow (DWF)

Definition of DWF in terms of wastewater quantity	**Definition of DWF in terms of wastewater quality**
DWF = POP * ADW + INF + IED Where: POP = Population served ADW = Average domestic wastewater contribution (m^3/cap/day) INF = Infiltration (m^3/day) IED = Industrial effluent discharged (m^3/day)	DWF = POP * ADP + IPD Where: POP = Population served ADP = Average domestic pollutant contribution (g/capita/day) IPD = Industrial discharge of pollutants (g/day)

Source: Based on CIRIA Report No. 177 (1998)

- *Average Dry Weather Flow (ADWF).* In South Africa, the ADWF is based on the unit flow from either a single-family dwelling unit or the erven size. The nationally recognised approach adopted in the "New Red Book" (i.e. GHSPD Manual – revised Version, 2003) refers to the ADWF per single family dwelling. The recommended values are given in Table 2.5 below:

Table 2.5. ADWF per single-family dwelling (SFD) unit on formally serviced sites

Urban income group	ADF (ℓ/day/SFD)	Number of residents
Lower	500	7
Middle	750	6
Higher	1 000	5

N.B: The unit wastewater return flow commonly used in the design of commercial erven situated within residential areas is 850 ℓ/day/erven.

- *Approach to sewer design using municipal by-laws*. It is noted that Water Services Authorities and Providers in South Africa adopted either existing municipal design by-laws or developed their own design standards based on specific sanitation circumstances prevailing in their area of jurisdiction. Two foremost sets of municipal by-laws were analysed and excerpts from the Tshwane MM by-laws is illustrated below:

Table 2.6. Design sewerage outflow rates for urban sanitation systems

Item	Zoning/category	Measuring unit/ day	Design sewerage outflow
1.	RESIDENTIAL		
1.1	Low cost housing – erf up to 250 m^2	kℓ per erf	0,6
1.2	Small sized erf up to 500 m^2	kℓ per erf	0,7
1.3	Medium sized erf up to 1000 m^2	kℓ per erf	0,8
1.4	Large sized erf up to 1500 m^2	kℓ per erf	0,8
1.5	Extra large erf in excess of 1500 m^2	kℓ per erf	0,8
1.6	Cluster housing up to 20 units/ha	kℓ per unit	0,7
1.7	Cluster housing up to 40 units/ha	kℓ per unit	0,6
1.8	Cluster housing up to 60 units/ha	kℓ per unit	0,6
1.9	High rise flats (± 50 m^2 per unit)	kℓ per every 50 m^2	0,6
1.10	Guest and boarding houses, hostels, hotels, retirement centers and villages, orphanages, etc.	kℓ per 100 m^2 development	0,9
1.11	Agricultural holdings (house plus out buildings)	kℓ per holding	1,4
2.	BUSINESS/INDUSTRIAL DEVELOPMENT		
2.1	General business with an FSR	kℓ per 100 m^2	0,8
2.2	Warehousing (including up to 20% offices)	kℓ per 100 m^2	0,4
2.3	Industrial (dry)	kℓ per 100 m^2	0,3
2.4	Industrial (wet)	kℓ per 100 m^2	Specific
2.5	Garage or filling station	kℓ per 100 m^2	1,0
2.6	Car wash facility	kℓ per wash bay	10,0
Note: For general type of development outflow rates, see Appendix A of this Guideline			

Another approach to the application of unit sewer flows in urban areas is based on the sewer flows generated by the different land uses by so-called equivalent discharge unit (EDU = 100 ℓ/day). The EDU values are based on zoning and stand sizes since this allows flexibility in the allocation procedure and a closer calibration to actual flows experienced in the system.

This approach has been developed for the Ekurhuleni Metropolitan Municipality regional sewers and applied by ERWAT in the Gauteng Province. The method allows for more detailed evaluation of urban wastewater catchments with highly diversified levels of service. The designer should contact ERWAT for more details if required.

- *Peak and minimum dry weather flow*. The peak to average and minimum to average flow ratios depend on the population size and level of service of an urbanized area. Large urban areas have less deviation from the average than smaller areas.
- *Peak Flow Factor (PFF).* The ratio of extreme flow to average flow is represented by a peaking factor, which depends mainly on the size of the population contributing to the sewerage collection system. The design peak factor may be reduced on account of predicted future population increases in the sewer catchment area (or contributor area) and attenuation of the capability of peak flows in municipal gravity sewers. See Red Book for attenuation of peak factors.
- *Peak Wet Weather Flow (PWWF).* The conventional approach in determining the PWWF is based on the assumption that some of the wastewater produced in a contributing urban area is due to leakages of rainwater into the sewer pipes and stormwater inflows. An arbitrary value of 15 percent over and above the total residential/industrial wastewater influent accounting for I/I events is commonly adopted in design.

It is also noted that in South Africa, the design criteria for large diameter separate sewers applied by some designers, determine the pipe size in a gravity main in a way that the Peak Dry Weather Flow occupies 70% or less of pipe capacity. The remaining 30% of the pipe flow area is allocated for stormwater inflows. Should the stormwater inflows cause this “spare capacity” to be exceeded resulting in pipe overflow, urgent measures should be taken by the Water Services Authority/Provider to prevent, for example, the illegal drainage of stormwater into the sewer system. This approach, however, may require a considerably large capital investment in mainly proactive maintenance.

(v) Design flow in waterborne sewers

The common procedure in determining design flow for the development (or enhancement) of a new (or existing wastewater system) is based on the application of a peak flow factor and the unit average wastewater contribution in the following equation:

$$\text{Design flow} = PFF * URE + INF + IED \qquad (2.1)$$

Where: PFF = Peak flow factor (between 1,3 and 2,5) depending on the land type and use
URE = Average contribution from urban residential erf (ℓ/day/EDU or ℓ/day/SFD or specific by-laws unit)
IED = Industrial effluent discharge (ℓ/day/erven)
INF = Infiltration of groundwater and leakage from plumbing devices (ℓ/day)

It should be noted that the INF component is normally determined from field investigations. Guidelines on various methods how to determine extraneous flows are detailed in Chapter 4.

Development or enhancement of a wastewater system must take into consideration possible future reduction in wastewater flow volumes. Reasons for possible reduction are:

- *Water conservation / demand management*
- *Increase in grey water reuse in households*

- *Reduction of infiltration (i.e. groundwater infiltration)*
- *Reduction of stormwater inflows*

2.2.3 Definitions and criteria for regional sewers

The following definitions and criteria were applied in the past for regional sewer investigation by ERWAT and metropolitan municipalities in Gauteng province:

(i) Peak Flow Factor

The peak flow factor (PFF), which is the ratio of the expected peak design flow (PDF) to the calculated average daily flow (ADF), can be calculated by the formula developed by Harman (1918):

$$PFF = 1 + [14/(4 + \sqrt{POP}] \qquad (2.2)$$

Where: POP = population in thousands

(ii) Municipal outfall sewer

A municipal outfall sewer is the main sewer which links a developed area (minor or sub-drainage district) with a regional sewer or the water care works.

(iii) Pipe capacity

The peak design flow will be taken as 60% of the full bore capacity of the pipe, to provide for infiltration and unforeseen peak flows.

(iv) Monitoring station

A monitoring station is a flow and load measuring point on a regional sewer or at a water care works. The data obtained from a monitoring station will be used, firstly as input for the Technical Information System, and secondly to determine the flow and chemical load from a contributing Information System, and secondly to determine the flow and chemical load from a contributing town.

(v) Guidelines on classification as a regional sewer

An outfall sewer can be classified as a regional sewer by negotiation, and the conditions for a regional sewer may vary from time to time. For a municipal sewer to be classified as a regional sewer, it should comply with three or more of the following criteria:

- *An outfall sewer line serving two or more local authorities or major contributors. The minimum flow contribution from any one contributor should not be less than 10% of the total flow in the pipe.*
- *An outfall sewer line with no other main sewer lines connecting to it, between the last connection and the water care works.*
- *An outfall sewer line with an internal diameter larger than 500mm.*
- *The minimum length of a regional sewer is considered as 500m.*

Due to the changes taking place within the local authorities environment, it is recommended that the following criteria should be added:

(vi) Existing outfall sewers

The aim of such an investigation is to identify which sections of existing outfall sewers can be, according to the criteria above, classified as regional outfall sewers.

(vii) Future regional sewers

It should be the aim of each WSA/WSP to identify future regional sewers. Regular flow and chemical load measurements should form an integral part of the monitoring programme of a total wastewater system. The aspect of the location of suitable monitoring stations should also be addressed during each investigation.

2.2.4 Procedures for re-evaluation of waterborne sewer flow parameters

(i) Analysis of existing or design of a new system

The procedures for developing minimum, average and peak dry weather flows (ADWF, PDWF), infiltration/inflow (I/I) allowances, and peak wet weather flows (PWWF) are commonly based on long-term flow measurements at an existing WWTP and correlated to newly developing areas. It is recommended that eight steps are taken:

Step 1: Determine population size, industrial and commercial growths and land use patterns for the initial and design horizon years.

Step 2: Estimate water demand and average water usage data for the initial and design horizon years.

Step 3: Average wastewater flow data are developed from water usage data for a specific land use. The consumptive water use (i.e. system losses) and wastewater that may be lost due to exfiltration should also be considered in the analysis.

Step 4: Peak and minimum dry weather flows are either obtained from field measurements or are estimated from several equations and graphical relationships. The advantage of attenuating peak flows in a gravity sewer system and reduce peak factor are as per Red Book. Larger urban areas have less deviation from the average than smaller areas. Peak and minimum flows last only for brief periods (commonly less than 2 hours).

Step 5: Peak hourly wastewater flow is the peak dry weather flow plus the infiltration/inflow. In relation to the water supply, this is the peak hourly rate of water demand multiplied by the proportion of the water supply reaching the collection system, plus infiltration/inflow (excluding fire demand)

S*tep 6*: Determine minimum rates of wastewater flow for designing pumping stations and velocities in the sewers during low flows.

Step 7: Determine or estimate the sustained flows for the design of wastewater treatment facilities. Sustained flows are the flows that persist for various time durations. Unusual dry or hot weather may cause sustained low extremes. Special events in community life (e.g. games, exhibitions) can cause high sustained flows.

Step 8: In the absence of flow measurement records and other pertinent data, typical unit sewage flows for urban areas should be applied to the design of laterals and sub-mains as well as for mains and trunk mains. The use of local by-laws is recommended in metropolitan areas.

(ii) Water use and wastewater production

- *Water supply and consumption*. The amount of current and projected water supply and consumption for a municipal area connected to a separate waterborne sanitation system are essential in order to determine the wastewater produced. Such information should be available from the Water Services Authority/Producer or gathered from an area survey.
- *Total wastewater produced*. This refers to the total amount of wastewater produced in the WWTP catchment area (or contributor area) plus any additional wastewater that may originate outside the drainage area of the WWTP under consideration. The total amount of wastewater produced will also include groundwater infiltration and stormwater inflows minus wastewater that might have exfiltrated from the system.
- *Wastewater imports.* Numerous wastewater services providers treat urban wastewater and/or industrial effluent from areas other than their own collection areas. Such wastewater imports also include I/I volumes depending on the situation within collection area and existing infrastructure circumstances.
- *Net wastewater produced (or net return flows).* The total wastewater influent minus total extraneous flows will represent the net wastewater produced within a specific catchment area (less wastewater imports where applicable). A small amount of wastewater due to treatment needs to be deducted to obtain net return flows into the receiving water (i.e. river ecosystem).
- *Extraneous flows (stormwater inflow and groundwater infiltration).* From an overview of established design practices on extraneous flows in South Africa, the following may apply:
  (a) Building laterals and conventional street sewer systems – the design criteria to allow for extraneous flows amounts to 15 percent above the peak flow rate.
  (b) Municipal gravity sewer main – the peak design flow is commonly taken as 70 percent of the full bore capacity of the pipe to provide for infiltration and unforeseen peak flows and operational constraints.
  (c) Regional sewer – the peak design flow is commonly taken as 60 percent of the full bore capacity of the pipe, to provide for infiltration and unforeseen peak flows.
- *Ratio of wastewater discharged to water supplied*. In principle, urban water services generate treated wastewater return flows of between 35 and 65 percent of the total original water supply input. The ratio, r, of wastewater discharged to water supplied depends on the extent of the consumptive water use (e.g. distribution losses, diffused effluent, etc.). However, the ratio value is also a function of stormwater inflows and groundwater infiltration into the sewers. The relationship between water supply and wastewater generated in urban areas can be represented as follows:

$$WW_{generated} = r * W_{supplied} \tag{2.3}$$

Where: $WW_{generated}$ = wastewater generated from a household or industry (ℓ/unit/day)
$W_{supplied}$ = water use per household or industry (ℓ/unit/day)
r = return factor (see Table 2.7 for example on selected water use categories)

- *Sewerage discharge charges using return factor* – WRC (TT 98/98) describes various methods applicable for WSAs/WSPs to determine tariffs for waterborne sanitation services to residential users. These methods are based either on the actual costs of service provision, property rates, total water bill, property physical characteristics (e.g. plot size, plot frontage, etc.) or wastewater return factor. The wastewater charge (WWC) formula commonly applied is as follows:

  WWC = (water consumed) * (return factor) * (wastewater tariff) (2.4)

  The return factor is an estimate of the average percentage of water supplied that is returned to the municipal waterborne sewer system. The wastewater tariff is the unit cost of wastewater conveyance and treatment expressed as c/kℓ of the total billable volume of wastewater. If this tariff method is combined with a fixed monthly charge (i.e. related to fixed overheads and other costs), then the tariff structure is most closely linked to actual costs. However, this method of charging cannot be used effectively where water usage is not metered.

Table 2.7: Typical return flow factor for residential and industrial water use

Category	Appliance or unit	Volume per use	Return factor (r)
Residential/domestic	Drinking water	2 ℓ	zero
	Toilet	9 ℓ	1,0
	Bath	75 ℓ	1,0
	Shower	40 ℓ	1,0
	Wash basin	4 ℓ	1,0
	Kitchen sink	7 ℓ	1,0
	Washing Machine	120 ℓ	1,0
	Car washing	Occasional	zero
	Garden use	Varies seasonally	zero
Commercial	Offices	65 ℓ/employee/day	0,95
	Stores	100 ℓ/employee/day	0,95
	Hospitals	400 ℓ/bed/day	0,98
	Hotels	600 ℓ/bed/day in hot climate	0,98
Industries/ manufacture	Brewery/soft drinks	7000 ℓ/m^3	0,5
	Cheese making	3000 ℓ/t	0,65
	Fish processing	15000 ℓ/t	0,65
	Electrical products	1500 ℓ/m^2	1,0
	Small car	5000 ℓ/unit	0,8
	Bicycle	130 ℓ/unit	0,8
	Pair of shoes	55 ℓ/unit	0,9
	Textiles	250 m^3/t	1,0

Sources: Based on data from CIRIA (1998), Butler and Davies (2000)

A detailed procedure for determining wastewater production values using Tshwane MM by-laws design parameters for water supply and sewerage outflow for various consumer groups is illustrated in Appendix A. The return ratios determined indicate the base for billing of wastewater discharges by that WSA.

3. PROBLEMS ENCOUNTERED IN MUNICIPAL WATERBORNE SEWERS

3.1 Most common problems in municipal waterborne sanitation systems

3.1.1 Consequences of improper design

(i) Drainage of low lying areas

Individual urban properties are commonly affected when overflows from sewer systems start spilling out at gullies in lower lying areas due to improper design. Local pollution due to overflowing of pumpstations may occur. The overflows may affect the running costs of sewer pumpstations and wastewater treatment plant and also impact on the quality of the return flows, and ultimately the natural river system where the polluted and untreated water will be received.

(ii) Topographical configuration

Typically, the slope of a drainage basin at the central reach of a catchment can be fairly flat with slopes of less than 3% or varies between 3% and 6%. Regarding the position of a river in a catchment, its drainage channel does not have very steep valleys and riverbanks. The topography therefore lends itself to easy flooding as a result of small changes in the water flow patterns.

3.1.2 Consequences of improper construction

(i) Improper installation

Defects in a sewer may have been generated during installation (e.g. deflections, punctures, cracks, rolled joints, etc.) or over the life span (e.g. corrosion, erosion, root penetration, etc.). Installation of sewer systems may at times be of an unacceptably low standard and can be shadowed from building inspectors. Also, alterations can be made later after the system construction plans have been approved or sewers installed.

(ii) Gullies and terraces

At several stands (erven), proper excavations and terracing may not have been considered in detail, leaving yard drainage compromised. Gullies may have been constructed facing the stormwater flow direction and mostly at the same level as the surrounding ground. Such alignment connects the stormwater directly to the sewer system. Stormwater should be directed into the gardens where space is available, or to roads where it will be collected by the stormwater system. The serviced area can become drenched and the water flow sheet becomes pronounced in heavier downpours at the terraces which may result in stormwater flowing directly into gullies.

3.1.3 Problems arising from civil disobedience

(i) Theft of manhole covers

In the past, the lids of manhole covers were made of cast iron, but became vulnerable to theft and trading as scrap metal. These manhole covers are being systematically phased out and replaced by lockable or concrete manhole lids. Where the covers have been stolen and have not been replaced or broken during routine maintenance or deteriorated (rundown), the stormwater gains free or unhindered entrance into the sewer system during heavy rainfall.

(ii) Linkage of stormwater to sewer

Gutters form part of a house roof stormwater drainage system. However, in reality the down pipes from the roof are linked in many instances to the sewer gullies. Yard paving has become a convenient way of keeping homes looking splendid all year round, but this trend increases the quantity of water to be drained. To get rid of this water (in some instances), private manholes are constructed which drain directly into the sewer system. Some stormwater is also led into the sewer system via rodding eyes and inspection eyes.

(iii) Swimming pool overflows

Private swimming pools may also be a contributing factor as overflows due to rainfall and backwash water are linked directly or indirectly to the sewer drainage system.

(iv) Excessive littering

Increased littering and pollution are the result of catchment mismanagement. Due to relaxation on street sweeping, inefficient refuse disposal and removal, excessive littering can increase sewer blockages and subsequent overflows.

3.1.4 Other factors causing less common problems

(i) Inadequate inspecting

Inadequate inspections and control will encourage discharges of excess water into the sewer networks potentially due to a lack of knowledge or improper advice as well as illegal discharging of unprocessed effluents into the sewer network on account of general disobedience.

(ii) Inadequate budgeting

Inadequate inspections and attention to existing infrastructure will cause inadequate budgeting for operation, maintenance and further development.

(iii) Lack of maintenance planning

Pro-active maintenance represents maintenance work carried out in a planned manner at key points in a sewerage system to ensure that the hydraulic capacity is not reduced by blockages or by the build-up of sediment deposits or excessive sliming in the pipes. Monitoring of the maintenance results must be carried out to determine its effectiveness and, if necessary, to adjust the frequency of maintenance activities.

Pro-active maintenance can sometimes be a very cost-effective way in dealing with sewer flooding problems and may save a considerable amount of capital expenditure, although an increase in operational costs is inevitable. It is important that the financial controls of the capital and operational budgets for the sewerage maintenance are strictly adhered to. The WSAs/WSPs should explain to the consumers increases in their operational budgets against the trade-off benefits.

3.2 Specific physical factors which may cause problems

3.2.1 Pipe component age factor

(i) Blockages/stoppages and collapses

Stoppages and collapses, which are inherent to municipal sewer pipes, can increase on account of the high levels of pathogenic micro-organisms, suspended solids, toxic pollutants, floating objects, nutrients, oil and grease, and other pollutants over the life-span of a pipe. Blockages due to intrusion of tree roots are a significant everyday problem in many municipal waterborne sanitation systems.

(ii) Obsolete or inadequate pipe material

Over time, specific pipe materials have proved inadequate (e.g. pitch fibre) and are no longer used or recommended for installation of waterborne sewers. Existing sewer pipelines using these materials need to be replaced throughout following an adequate budgeting and replacement programme.

3.2.2 Long-term performance factors

(i) Changes in loading or stress conditions

A specific problem encountered in the mining areas of South Africa (particularly in the Gauteng province) is that some gold mine dumps are being reprocessed through improved extraction technologies, resulting in the removal or even relocation of the overburden on the natural ground. During the period of the dumps' existence, the natural ground experienced loading strain, stress and consolidation. Once the overburden is removed, the soil undergoes stress relief, with the potential for recourse on the loading history over time causing misalignment and possible damage to buried sewer pipes, leading to excessive infiltration/ exfiltration.

(ii) Changes in soil retention conditions

At some locations, the mining industry practices reed bed reclamation leading to the soils developing spongy characteristics, retaining more water and becoming swampy, thus increasing the potential for infiltration to the sewer pipeline which might be installed in proximity to such swampy area.

(iii) Failure of sewer pipe due to loading or stress changes

Changes in loading (on stress) or soil retention conditions are typically common factors leading to progressive deterioration of a sewer pipe as illustrated earlier in Figure 1.3. The life-span of an installed rigid pipe is characterized by three stages in its deterioration. The second deteriorating stage could already allow for significant infiltration/exfiltration.

3.3 Non-effective utilisation of existing storage in sewer systems

3.3.1 Reduction of peak flows

Options for making better use of existing storage in sewerage systems tend to be specific to the particular circumstances, but can either be passive or active. An example of a passive type is the addition of flow control devices in the upstream part of a system to make use of available unused storage in manholes and thereby reduce peak flows downstream of such manholes.

3.3.2 Better use of auxiliary facilities

Effective utilisation of auxiliary facilities can improve interaction between flow conditions and the operation of equipment such as pumps, gates and off-line storage tanks. Interaction may be achieved through the application of better operating rules based on past experience, perhaps supported by analysis of the behaviour of the system using a hydraulic model. Alternatively, the operating rules may be implemented automatically by means of electronic links between the flow control equipment and sensors located at key points in the system. Full real-time control may become an option, with a computer model forecasting flow conditions in the sewerage system and evaluating alternative strategies for operation of the control equipment. This type of option will normally tend to be applicable only on a catchment-wide basis.

3.3.3 Malfunction of diversions and bifurcations

External overflows, bifurcations or diversions can be located at points of hydraulic overloading to remove excess flows from sewerage systems (more common with combined sewer overflows), and allow for discharge of excess sewer flow to open land or a watercourse. Diversions, together with bifurcations, are used to divert excess flows either into another part of the same system with spare capacity or into another adjacent system.

3.3.4 Inadequate overflow facilities

Adequate peak storm overflow facilities can be provided in front of the WWTP within a sewer collection system. The overflows should flow to two containment dams and be recycled back to the inlet of the works when the storm flows have subsided. The dams must be designed so that they can be periodically drained, dried out and cleaned (desludged) during the dry season. For this purpose, they must be fitted with vehicle ramps for access by front-end loaders and tipper trucks. The outlets of the dams should be fitted with scum baffles.

3.4 Low attention to overall enhancement of sewer system

3.4.1 Pipeline network

(i) Hydraulic enhancement

Together with the provision of storage, this is the most commonly used method of solving flooding problems. Existing systems are replaced or enhanced to remove the hydraulic restriction(s) that cause the sewer flooding problems. In some cases this may be achieved by replacing an existing length of sewer by one of high flow capacity (i.e. having a larger diameter or smaller hydraulic resistance). Alternatively, a length of by-pass sewer may be constructed to carry some of the flow from the existing sewer over the section where it has insufficient capacity.

There is a significant risk that works to improve conditions at one location may transfer the problem farther downstream unless equivalent improvements are made all the way through the system.

(ii) Flow control devices

Together with construction works to increase sewer capacity, this is the another commonly used method of solving flooding problems. Flows upstream of a critical part of the system are restricted to the capacity of the pipes by controlling and storing excess flows until the system can cope. Peak flows may be attenuated by providing purpose-built storage, usually in the form of on-line or off-line detention tanks, or by temporarily holding back surface water run-off (e.g. in detention ponds or in open areas such as car parks). Flow control devices are used to control the onward flow to the downstream part of the system and/or to divert flows into storage.

3.4.2 Problems association with pump size and pumping

(i) Pumping operational costs

Excessive inflow/infiltration increases demands on existing pump size and pumping schedules. The operational costs will inevitably increase with increases in stormwater inflow and groundwater infiltration.

(ii) Suitable location of sewer pumpstation

Typically, the pumped sections should be kept to a minimum due to the high level of maintenance required and the sewer should revert to gravity flow as much as possible.

WSAs/WSPs administering wet pit wastewater pump installations must accept that there are costs arising from maintenance of wet well pumping equipment. This applies equally to submersible as well as the wet well of a dry installation. The problems and costs are related primarily to regular remove of settled solids, sludge and grit. Removal of floating solids (e.g. wood) must be also part of the maintenance programmes.

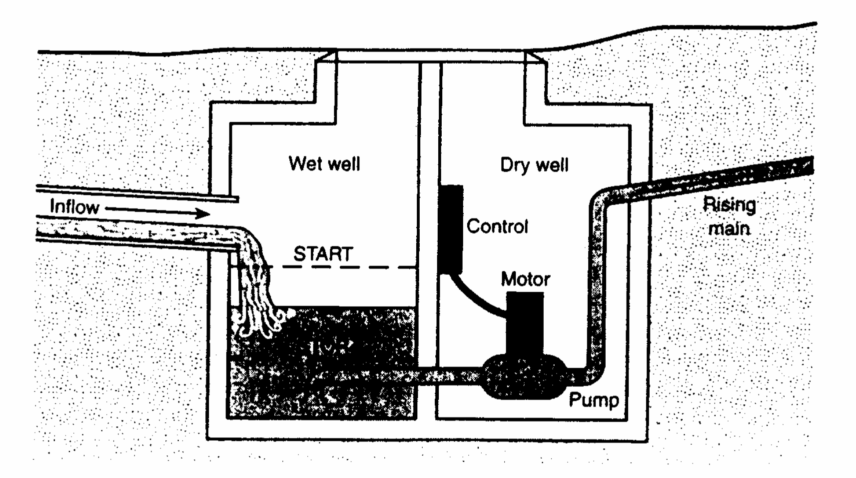


Figure 3.1. Example of recommended sewage pump wet well design

3.5 Other possible problems

3.5.1 Installed vacuum and small–bore sewers

These systems transport sewage by inducing and maintaining a vacuum in the collecting pipes by means of central vacuum pumps and a reservoir. Conventional gravity drains connect one or more properties to a sewage collection chamber. When the sewage reaches a preset level, a pneumatic “interface” valve opens and the contents of the chamber are sucked into the vacuum line. When the chamber is almost empty, the valve closes.

Vacuum systems should normally deal only with domestic wastewater because satisfactory performance depends on their being sized accurately in relation to the maximum design rate of flow. These systems should not be expected to cater for overland flow, infiltration or roof run-off, and additional flows should not be added without considering the limitations of the original design. Operation and maintenance of the vacuum systems in peri-urban/rural areas may be problematic.

A small-bore system requires an interceptor tank at the head of the sewer to prevent gross solids entering the sewer. If the interceptor tank is not monitored and pumped from time to time, the wastewater can become odorous and corrosive. The system can become blocked as it cannot tolerate the gross solids.

3.5.2. Existing protective structures

The existence of a wall or bund constructed around a single property, or a group of properties, offers protection from sewer flooding, but may have not been used and should be reconsidered. Bunds placed around manholes in sewerage systems as a temporary measure to minimise the extent of flooding at low points in gardens and open spaces should be regularly maintained or eventually removed.

3.5.3 Operation of purchased land (or properties)

In some cases where flooding is difficult to avoid, a change of usage for the property might need to be negotiated. The WSA/WSP who purchases a property either to remove it from a list of occupied properties affected by flooding or to change its usage so as to mitigate the effects of flooding will face extra O&M problems. In all cases, the proposed course of action should not be imposed on the owners of the properties, but must be carried out by mutual agreement.

3.5.4 Further changes in water legislation and environmental laws

The ongoing process of implementation of the environmental protection law and promulgated water laws has increased the urgency to observe the new criteria and constrained evaluation procedures in municipal wastewater collection and treatment services. All Water Services Authorities/Providers administering municipal waterborne sanitation are urged to review their municipal by-laws to adjust and comply with recent legislative changes.

4. METHODOLOGY FOR ASSESSING EXTRANEOUS FLOWS

4.2 Assessment of wastewater system integrity

4.2.1 Wastewater system evaluation analysis

(i) General approach

A thorough evaluation analysis is required to determine the extent of the problems related to the integrity of the whole or a particular component of a wastewater system. An evaluation of the problems will indicate what alternative approaches and costs for rehabilitation versus replacement would be required. The required information must come essentially from the flow monitoring and physical condition assessment (or assets condition assessment). Four phases of evaluation are usually considered.

- *Planning and data gathering*
- *Field inspection programmes*
- *Action plan for measures to be taken*
- *Implementation*

(ii) Planning of investigation and data gathering phase (Phase 1)

- *Information database.* A Water Services Authority/Provider should evaluate the extent and severity of a problem as well as the risks associated with attending to or postponing finding a solution. A preliminary costing outlay has to be prepared. To build up an adequate information database, the following categories of data are required:

  (a) *Maps and drawings, preferably in GIS data form*
  (b) *Maintenance and operation records*
  (c) *Geophysical and weather data*
  (d) *Water supply and wastewater works inflow rates and pollutant loadings*
  (e) *Relevant information from the stormwater and water supply sectors, such as losses, control, etc.*
  (f) *Records of land development in the catchment, i.e. rate of expansion in industrial and residential construction*

The wastewater collection system is normally divided into network zones based upon hydrographic or grade parameters. The location of monitoring points should be identified and methods of diverting flows during inspections and repairs should be considered. An assessment of staff capabilities is essential for successful implementation of OMR programmes. In some instances, staff should been trained beforehand according to the OMR requirements.

- *Data requirements.* The contemporary approach in data requirements for the purposes of effective decision-making are listed in Table 4.1:

Table 4.1: Data attributes and required procedures

Data attribute	Required procedure
Accuracy	All pipe and channel sizes and other physical attributes are known and the connectivity of the system is confirmed
Completeness	All constructed works are identified with no gaps existing in the pipe and channel networks unless confirmed by field study
Spatially defined (GIS)	The location of the network should be referenced to the cadastral or property and road base for presentation of the data in a GIS format
Data transfer (GIS)	Information should be easily transferred to the format required by modern hydraulic modelling products and GIS software
Asset management/ asset condition	Business decision rules using asset condition (likelihood of failure) and consequences of failure should be used to define proactive maintenance, inspection or rehabilitation programmes
Maintenance management	The data information system should link to a maintenance management system for recording incidents and for recording the nature of field operational work undertaken
Quality assurance (QA)	The procedures for editing existing information or adding in more information need to be covered by sound QA programme and incorporate security on who can edit the data
Maintenance reports	The compilation of structural and maintenance grading reports through capturing CCTV inspections in digital and database mode

(iii) System assessment phase/inspection programmes (Phase 2)

Three categories of inspection programmes are recommended to be developed and implemented:

- *Re-evaluation of hydraulic performance*. The original hydraulic parameters need to be re-evaluated by means of existing or developed hydraulic model against real field conditions and demands on a system.
- *Extraneous flows assessment programme.* This programme includes assessment of inflow/infiltration and exfiltration conditions.
- *Structural condition assessment*. A critical issue for all inspections is misinterpretation of the severity of physical defects. A key objective of physical/structural condition assessment procedure is how to effectively detect and locate defects/potential failures to prevent extensive I/I events, exfiltration and collapses which can cause street surface hazards and pipeline blockages and subsequent flooding of properties.

(iv) Action plan for rehabilitation/replacement measures (Phase 3)

During this stage, all feasible rehabilitation/replacement options should be considered and optimised in order to propose and develop suitable and affordable methods and procedures.

- *Preventative and remedial measures* – including sealing of sewers replacing of missing or broken manhole covers, raising manholes above flood lines, introducing regular measures and training programmes, increasing the capacity of the sewer system or the WWTP, etc.
- *Rehabilitation measures* – including non-structural lining and/or structural lining.

- *Replacement measures* – including trenchless replacement, pipe bursting microtunneling, horizontal directional drilling and open trench replacement.

(v) Rehabilitation/replacement implementation phase (Phase 4)

This phase is organised and procured according to the implementation schedule including all project activities. Recommended corrective actions will be implemented according to recognised tendering (or public-private-partnership, outsourcing, etc.) procedures. Factors influencing the choice of methods and materials during the implementation phase are as follows:

- *Accessibility to the construction site*
- *Magnitude of flows during the implementation period*
- *Availability of bypassing or rerouting flows during construction*
- *Soil conditions*
- *Stress conditions*
- *Level of groundwater conditions*
- *Lateral connections and dissolved oxygen levels*
- *Length and size of damaged pipelines*
- *Bedding and backfill materials*

This phase should also include preparation of monitoring programme for the post rehabilitation/replacement period. As-built details should be strictly recorded for further reference and adjustment of hydraulic model parameters.

Table 4.2: Summary on sewer system rehabilitation/replacement programme

Assessment phase	**Key objectives**	**Key activities**
Phase 1: Planning and investigation, and data gathering	Preliminary determination of extent and severity of problem	• Assemble relevant data sources and establish GIS database • Outline networks (or zones) with problems • Identify locations of monitoring points • Propose field monitoring methods • Determine staff training requirements
Phase 2: System assessment/ inspection programmes	Establish all necessary inspection programmes and costs resulting from monitoring	• Inspect and determine extraneous flows • Re-evaluate hydraulic performance and parameters • Inspect and determine structural condition of relevant components
Phase 3: Action plan for rehabilitation/ replacement	Propose, design and cost relevant rehabilitation/ replacement and preventative maintenance measures	• Propose remedial measures • Propose rehabilitation measures • Propose replacement measures • Tender for procurement
Phase 4: Implementation of Action Plan	Organise and supervise procurement and assurance of quality control	• Determine implementation schedule • Process and evaluate all factors which might influence procurement • Establish adequate quality testing • Test and monitor post procurement performance

4.2.2 System field flows monitoring

(i) Common objectives for flow monitoring

There are several reasons for monitoring the flows in a wastewater collection system, such as determining total systems flows, customer billing, identification of capacity problems, monitoring system performance for operation and maintenance, detection and quantification of bypasses or overflows, measurement of the PWWF, inflow/infiltration events, exfiltration and to calibrate flow models.

(ii) Flow monitoring programme

A well prepared and executed field flow monitoring programme will enable a WSA/WSP to isolate areas or specific reaches of a wastewater collection system which has excessive inflows and infiltration and/or exfiltration.

(iii) Field flow metering equipment

There are three major methods where gravity flow metering can be deployed:

- *Critical-depth metering,* which may include flumes and weirs
- *Area-velocity metering,* which offers a choice of different technologies for depth (e.g. air bubblers, pressure transducers, etc.) and velocity measurements (e.g. electromagnetic sensors and acoustic devices).
- *Combination of flumes and electromagnetic sensors*

Modern flow monitoring equipment has a data logging function, which allows the operator to collect "real time" flow records over an extended period of time. Such data can then be correlated with rainfall events to determine the inflows into a system.

The accuracy and reliability of different monitoring devices together with data transmission and energy provision are criteria for choosing suitable monitoring technology.

4.1.3 Assessment of the condition of wastewater infrastructure assets

(i) General assessment methods

Assessment of the physical condition of the various components of a wastewater system is critical for the repair or replacement programmes based on the inspection programmes (or sewer testing) determining I/I and exfiltration. Although increased flows at the WWTP would indicate problems in the system, location and the associated risks have to be determined from field inspection and testing. Assessments are based on inspections and include smoke testing, man entry, flow isolation, dye-water-flooding and use of closed circuit television (CCTV).

It should be noted that most inspection techniques depend on visual observation and subjective judgments. The location of potential defects may be missed or misinterpreted if the evaluator has not had adequate training.

(ii) House-to-house surveys

This type of field survey is conducted in order to identify sources of inflow originating within homes and other buildings. During a home inspection, the evaluator (or inspector) may identify the non-compliance of residential properties with municipal stormwater and wastewater disposal by-laws requirements.

(iii) Visual inspection by man entry to sewers

Physical inspections by workers are costly and potentially dangerous due to possible rapid flooding, toxic gases and potential sewer collapses, and used only if no other means are available.

(iv) Testing by smoke draft method

The smoke test method cannot usually locate small leaks. However, this method of testing is relatively inexpensive and quick in detecting inflow sources in a sewer system, particularly from roof down pipes, area drains, foundation drains, abandoned building sewers and faulty service connections. The smoke will escape from all inflow sources that are cross-connected to the sewer section being tested.

(v) Flooding or dye-water testing

The dye (Rhodamine B) is used in table form to minimise exposure to field personnel. The nearest downstream maintenance hole is used to watch for the appearance of the dye. Dye testing is normally used to complement smoke testing of suspect areas.

(vi) Closed Circuit Television (CCTV) monitoring

In principle, all CCTV inspection methods are limited by the diameter of the sewer, type of pipe material used and odd shapes and sumps built into the collection system.

- *Mainline CCTV monitoring.* The speed and travel direction of the camera is controlled by the operator who can identify actual leaks, pipe cracks or accumulations of mineral build up. Significant flows of clear water from a service tributary line can also be identified. It is imperative to clean the sewer system prior to CCTV monitoring for effective observations.
- *Service line mini-camera CCTV monitoring*. Inspection of service (or lateral) lines is conducted with specially designed equipment and the objective is to gather detailed information on the sources of the infiltration and an essential insight into rehabilitation costs and techniques.

(vii) Testing by pressure on seals

It is internationally recognized that this testing method is economical to apply, but requires a specific type of equipment which includes a cylindrical packer with inflatable end elements. Defects might be present at lateral service mount connector fittings and sewer joints. The rubber end elements are inflated to isolate the pipe joint, which is then tested under air or water pressure. The test is normally controlled and monitored by CCTV.

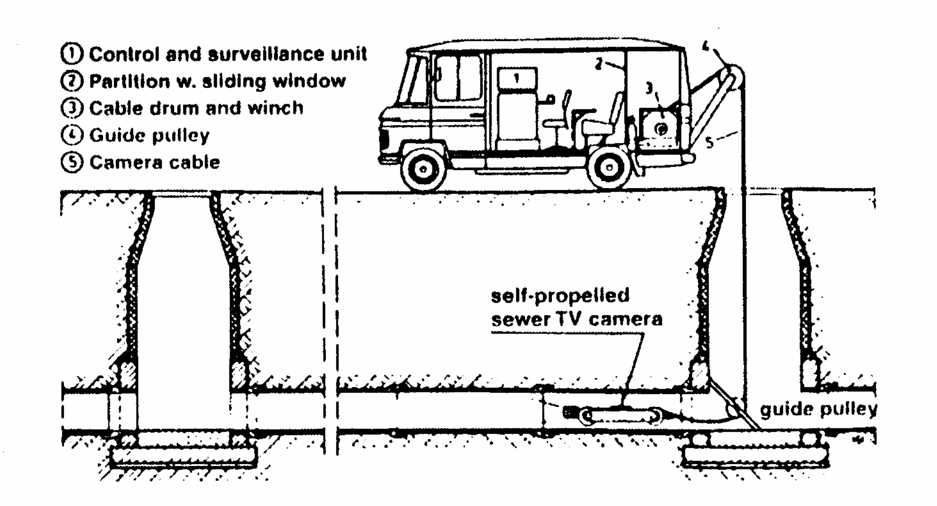


Figure 4.1. Schematic representation of current visual sewer inspection

(viii) Sewer manhole and junction chamber surveys

Manhole surveys are normally conducted during wet weather (preferably during heavy rainfall periods) when physical observations can be effectively conducted. Rainfall inflow or ponding round or over the manhole cover will indicate that corrective action needs to be taken such as sealing the manhole or lifting it above ground level, etc.

(ix) Pumpstations and other appurtenances

Pumpstations and other appurtenances (e.g. wet wells, siphons, etc.) are typically inspected during routine maintenance of mechanical and electrical components. It is estimated that between 30 and 50 percent of sewer system I/I events are due to defects in or near a system's appurtenances. The rehabilitation of manholes, pumping stations, wet wells and siphons can include spray-on coatings, spot repairs, structural liners (e.g. high density polyethylene), grouting or replacement of whole components.

4.1.4 Management alternatives in waterborne sewer collection systems

(i) Management of sewer flushing

To alleviate sedimentation particularly of new sewer systems due to dry-weather deposition, regular sewer flush waves can effectively convey sewer deposits including organic matter.

(ii) Polymers to increase sewer capacity

Current international research has shown that polymeric injection can greatly increase flow capacity by reducing wall friction. Cost savings are realized by eliminating construction of relief structures.

(iii) Management of cross-contamination in separate sewers

In some instances extensive contamination between residential and industrial sewerage loads requires balancing by means of chemical and/or biochemical intervention. Investigation of domestic and industrial sewerage loadings in municipal wastewater systems can be done using visual observations and screening/mass balance techniques by quality sensing to determine the loading proportions. In extreme cases when industrial sewerage loadings are excessive, pretreatment of industrial sewerage has to be prescribed.

(iv) Managing lack of flow-control ability

Devices such as fluidic regulators, swirl and helical flow regulators, and vortex energy dissipators can be installed in the sewer systems. The main objective of these devices is to impact on liquid-solids separation or to sustain virtually constant flow rates, compatible with the sewer system capacity downstream.

4.2 Methods to determine extraneous flows and exfiltration

4.2.1 Groundwater infiltration into sewers

(i) Common conditions in most waterborne sewer systems

The sewers built in urban areas usually follow the watercourses in the valley close to (and occasionally below) the bed of a stream. As a result, such situated sewers may receive comparatively large quantities of groundwater, whereas sewers built at higher elevations will receive relatively small quantities of groundwater. With increasing percentages of paved and built-up areas, stormwater is diverted rapidly to the storm sewers and watercourses. With less stormwater percolating into the earth, stormwater inflows into sewers will inevitably escalate. Although the elevation of the water table varies with the quantity of rain percolating into the ground, leakage through defective joints, porous concrete and cracks can be large enough (in some cases) to lower the groundwater table to the level of the sewer.

The rate and quantity of infiltration depends on the length of the sewers, the area served, the soil and topographic conditions, and to a certain extent, the population density, which increases the number of house connections. The workmanship applied during sewer installation, type of pipe, number of joints and pipe size, together with the number and size of manholes all matter when determining I/I events.

(ii) Measurement of infiltration

The amount of groundwater flowing from a given area may vary from a negligible amount for a highly impervious area or an area with a dense subsoil to 25 or 30 percent of the rainfall for a semi-pervious area with a sandy subsoil permitting rapid passage of water. The percolation of water through the ground from rivers or other bodies of water sometimes has a considerable effect on the groundwater table, which rises and falls continually. The presence of high groundwater results in leakage into the sewers and an increase in the quantity of wastewater as well as the expense of disposing of it. According to Metcalf and Eddy (1991), the amount of flow that can enter a sewer from groundwater infiltration may range from 0,01 to 1 m^3 per day per mm diameter per km of pipe length depending primarily on the sewer age and the type of pipe material installed. A typical measurement of infiltration in a wastewater collection system is the sum of the products of sewer diameter in millimeters times the length in kilometres. Expressed in another way, infiltration may range from 0,2 to 28m^3/ha/d.

Although the information base on infiltration into sewer systems in South Africa is very limited, it has been recorded that infiltration may reach up to 35 percent of the Dry Weather

Flow (DWF) in certain localities due to the old age of pipelines. Internationally, Reynolds (1995) described a case where infiltration accounted for over 75 percent of total sewer flow.

Table 4.3 below summarizes available information on infiltration rates obtained from different data sources and brought to the same unit of measurement (ℓ/min/m-dia/m-pipe).

Table 4.3. Typical groundwater infiltration values (ℓ/min/m-dia/m-pipe)

Groundwater infiltration	Type of sewer	Remarks on sewer characteristics	Source of information
0,05	Separate	Monitored value from Johannesburg clay/ concrete sewers typically 30 to 60 years old	Hine & Stephenson (1985)
0,10	Combined/ separate	Textbook value. No details know on sewer material and age	Qasim (1986)
0,01-0,70	Combined/ separate	Internationally recognised range of values. No details known on sewer materials and age	Metcalf & Eddy (1991)
0,05	Separate	Measured value from Cape Town clay/concrete sewers typically 20 to 40 years old	Pollet (1994)
0,03-0,04	Separate	Measured values from Pretoria clay/concrete sewers of 150 to 900 mm in diameter typically not older than 40 years	GLS Inc (1997)
0,02-0,08	Combined	Estimated value for UK purposes predominantly for old clay sewer pipes	CIRIA (1998)
0,048 to add to design rate	Separate	Design allowance mainly for clay and concrete sewer pipelines	Johannesburg Water (Pty) Ltd
0,01	Separate	Permissible wastewater loss from new sewer	SABS1200
15% allowance of ADWF to add	Separate	Predominately for clay and concrete sewer pipes	Red Book (2003)

4.2.2 Stormwater inflows into sewers

(i) Steady inflow (or night flow)

A proportion of inflow to sewers is generated primarily from leaking toilets and bathroom appliances, building foundation drains, cooling water discharges, and in some cases also suppressed springs in urban areas if the outflow is connected to the sewer. This inflow component is difficult to identify and it is commonly measured with infiltration. A useful technique known as "night flow isolation" can be used to determine significant stead inflow and infiltration of groundwater into a sewer. The sewer system flows are measured in the hours between midnight and 06h00 when it is anticipated that sewerage flows should be virtually zero. However, a good knowledge of the users and their habits in the monitored area is required in adopting this method.

Table 4.4 illustrates various approaches in sizing residential sewerage outflow and leakage (or base flow) sewer flow components. The values indicated represent local and international methodology and preferably field measurements should be adopted rather than directly applying the values given.

Table 4.4. Sizing of residential water leakage into sewers

Residential outflow (or ADWF)	Leakage from households	Type of sewer and location	Source of data
1,17 ℓ/min/household	0,06 ℓ/min/household	Separate in Johannesburg	Hine & Stephenson (1985)
60-80% of water input	Included in residential flow	Combined/separate	Qasim (1986)
60-80% of water input	Included in residential flow	Combined/separate	Metcalf & Eddy (1991)
0,01 ℓ/min household	Included in residential flow	Separate in Cape Town	Pollet (1994)
0,60 ℓ/min/urban erf (UE)	0,15 ℓ/min/urban erf	Separate in Pretoria	GLS Inc (1997)
0,42 ℓ/min for every 100 m^2 of erf size	Included in residential flow	Average criterion for SA	Red Book (2003)

Sources: As stated above

(ii) Direct stormwater inflow

The direct inflow of stormwater can cause an almost immediate increase in flow rates in sewers. Typically, a paved area of some 100 m2 around a broken manhole cover can generate about 5 m3 of stormwater inflow during 50mm rainfall in one day. The effects of inflow on peak flow rates that must be handled by a wastewater treatment plant can be up to 5 times higher than the average dry weather flow. Stormwater inflow rates are usually determined by using a network of continuous flow meters that operate before and during a significant storm. The inflow rate can be determined from the flow hydrographs recorded with the flow meters by subtracting the normal dry weather domestic and industrial flow and the infiltration (including steady flow) from the measured flow rate.

(iii) Total inflow

Total inflow represents the sum of direct inflow at any point in the system plus any flow discharged upstream of the system through overflows, pumping station bypasses and the like.

(iv) Delayed inflow

Stormwater inflows may require several days to drain through the waterborne sewer system. The inflow volume can include the discharge of pumped water from flooded buildings as well as the slowed entry of surface water through manholes in ponded areas. GLS (1997) estimated that typically for South African conditions between 0,5 and 4,0% of all rain falling within 25 metres on either side of a sewer pipe may infiltrate/inflow into the sewer system.

4.2.3 Groundwater contamination by exfiltration from sewers

The age of buried sewer pipes of a municipal wastewater system is considered to be the most significant characteristic governing exfiltration from sewers. Leaking sewers should be of great concern if they are located in any area with high groundwater vulnerability (e.g. close proximity to a groundwater aquifer).

Exfiltration can occur when the level of the sewer liquid is above the groundwater table. The positive head created by such circumstances can cause raw sewage to exfiltrate through open joints into the surrounding ground.

Exfiltrating sewers may contaminate groundwater with a variety of contaminants including nitrates, heavy metals, sulphate and organic compounds. Traces of the following compounds will indicate sewer-related groundwater pollution.

- *Bacteria from domestic sewage (usually measured as faecal coliforms or E.coli),*
- *Inorganic nitrogen species (nitrate and ammonia) from domestic sewage,*
- *Inorganic ions such as sulphate, chloride and potassium,*
- *Phosphate and boron mainly from detergents*

4.2.4 Combined inflows and infiltration (or extraneous flows)

Both infiltration and inflow rates are variable portions of waterborne sewer flow depending on the quality of the material and the workmanship in the construction of sewer connections, the character of the maintenance and the elevation of the groundwater compared with that of the sewers. When the infiltration and inflow rates are determined for each sub-area, it will usually be found that only a small part of a collection system contributes most of the infiltration/inflow. Generally, about 75 percent of the inflow comes from 20 to 30 percent of the system, whereas 75 percent of the infiltration comes from 40 percent of the area.

(i) Simplified I/I assessment technique

Both components of extraneous flows (i.e. infiltration/inflow) into municipal sewers can only really be assessed by field measurements in the problem areas. The methods used in estimating I/I events are not covered extensively in the available literature although Qasim (1986), Metcalf and Eddy (1991) and CIRIA (1998a and b) offer examples on how to estimate such phenomena. The following approach represents a popular method to determine the severity of the impact of infiltration and inflows to the sewers of a specific subarea or a pipeline run. The steps to be taken are as follows:

Step 1: Determine the average flow during the dry period of the year: X_1 (m^3/day)
Step 2: During the wet period of the year, the flows are averaged, excluding flows subsequent to significant rainfall events: X_2 (m^3/day)
Step 3: Calculate infiltration component as follows: GWI = $X_2 – X_1 = X_3$ (m^3/day)
Step 4: The peak flow generated during a recent storm has been recorded or estimated to determine the inflow to sewers from the hydrograph as the difference between maximum hourly wet-weather flow (X_4) during the storm and comparable flow (X_5) on the *preceding/following* day: SWI = $X_4 – X_5 = X_6$ (m^3/day)
Step 5: Determine unit infiltration of investigated sewer considering the composite dia-length of the sewer system as X_7 mm-km: $X_3 / X_7 = X_8$ (m^3/day * mm-km)
Step 6: Using permissible limit as a criterion: X_9 (e.g. 0,1 ℓ/min/m-dia/m-pipe)
Step 7: Compare $X_9 \leq X_8$ (i.e. against recognised criteria) if infiltration is excessive or not

(ii) Wastewater processed to water supplied technique

Another useful technique in determining extraneous flows for a portion of an urban area (e.g. wastewater district) where all wastewater is drained into a specific WWTP, is based on a volumetric balance of the water input and output (represented as a net return flow into a river ecosystem). The analysed system is assumed to be a typical municipal water services system, where both water supply and sewer reticulation networks are interconnected within the reticulated urban area. A sewer reticulation network must separate residential and industrial effluent from stormwater. The records of water supplied and wastewater inflows collected should be available, preferably for at least a few recent years. The infiltration of groundwater (in Mℓ/day) for the whole system may be determined from the bulk water balance as follows:

$$GWI - EXF = (WWI + CWU + WEX) - (TWS + SWI) - IWW \qquad (4.1)$$

Where:
- GWI = groundwater infiltration
- EXF = exfiltration from sewers
- SWI = stormwater inflow
- TWS = total water supplies into investigated area (say 12 months average)
- WWI = wastewater influent from waterborne sewer area for dry and wet periods of the year (say 12 months average)
- WEX = water exported from a system,and/or IWW = imported wastewater
- CWU = consumptive water use = BWL + UAW + EDL + WWL
- BWL = bulk water losses (2 to 8% of bulk supply)
- UAW = unaccounted for water including unmetered use (10 to 35% of TWS)
- EDL = effluent diffused locally (i.e. wastewater not reaching a WWTP)
- WWL = wastewater treatment losses (2 to 5% of total wastewater influent)

The values required in Equation (4.1) should be available from a municipal database or from field measurements. The stormwater inflow (SWI) component is typically determined as an average of the difference between dry and wet periods from records of the WWTP influent. An adjustment must also be done for increased infiltration during wet periods. Barta (2004) compiled and computerised an urban return flows audit (URFA) model for the purpose of evaluating net return flows from urban water services systems including the non-potable reuse loop. The model allows for determining extraneous flows from the volumetric balance built into the URFA model.

4.2.5 Impacts of extraneous flows on wastewater treatment

(i) Collection network excessive sewer flow patterns

Excessive infiltration/inflow events will typically cause the peaks of infiltration to be higher and of a much longer duration. The effect of increased flows on treatment works can be dramatic such that the effluent to be released does not comply with applicable standards.

Areas with combined infiltration/inflow problems typically have the following consequences:

- *Additional load leaving the system due to poor treatment not complying with effluent standards (i.e. additional costs and the likelihood of environmental damage), and*
- *Excessive effluent after treatment complying with effluent standards (i.e. no additional costs), but the original design processes must provide sufficient allowance for I/I events (i.e. higher capital costs).*

If the additional load leaving the WWTP is higher than permitted effluent standards, then the problem must be addressed. In terms of legislation, it is the duty of WSI to ensure that no environmental pollution or damage takes place.

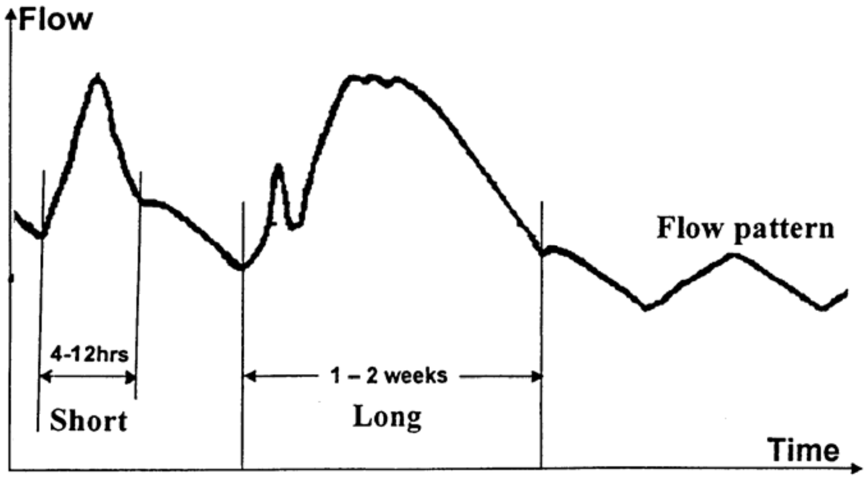


Figure 4.2: Flow pattern due to excessive extraneous flows

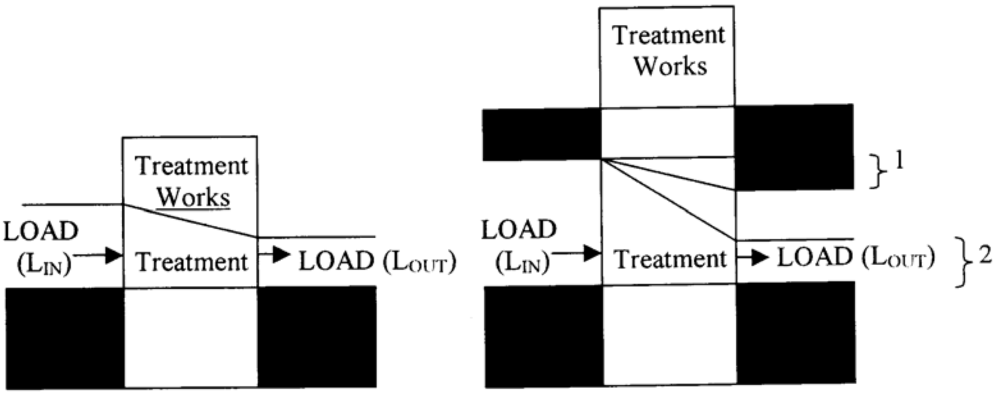
(ii) Wastewater treatment plant function and processes

The purpose of wastewater treatment is to rectify the quality of the wastewater collected from the urban area before it is released into the receiving water source. The return flows must comply with relevant legislation and environmental requirements. The processes taking place in a typical WWTP are as follows:

- *Preliminary treatment*. This process removes gross solids from the wastewater flow (e.g. sand and grits), Excessive stormwater should be separated from wastewater to protect other processes.
- *Primary treatment*. The function of primary treatment involves sedimentation of organic load on the plant.
- *Secondary treatment*. This phase of treatment introduces biological oxidation to remove remaining organic load.
- *Tertiary treatment*. This is an optional function in the overall process introducing further reduction of residual suspended solids and associated BOD to produce a high-quality effluent.
- *Sludge treatment and removal*. The sludge is a residue collected from the treatment processes, dewatered and treated prior to disposal. The cost of sludge disposal is a major factor in WWTP operational costs.

(iii) Normal and excessive WWTP load conditions

Under normal sewer flow conditions, the treatment plant will receive a wastewater influent (volume of wastewater) with a certain pollution load. After treatment, the effluent (return flow) leaving the plant will be rehabilitated to comply with the effluent standards and no pollution of the receiving water ecosystem will theoretically take place. However, when excessive infiltration and inflow occur, an additional volume of water will flow through the treatment plant reducing the retention time of the processes causing the plant not to cope as required. Figure 4.3 illustrates both scenarios in a schematic way.



Effective treatment under normal flow conditions

Overloading as a result of excessive extraneous flows

Notes: 1. Additional load leaving system due to poor treatment
2. Normal load after treatment complying with required standards

Figure 4.3: Representation of influent treatment under normal and excessive conditions

A common problem experienced by WSAs/WSPs due to excessive load conditions at the WWTP is related to the high costs of treating additional flow volumes in order to meet effluent standards. If increasing the capacity of a WWTP instead of controlling the rate of inflow/exfiltration within the collection system is the objective, there are wastewater treatment technologies available to increase treatment capacity. One known technology is a submerged fixed-film biological process which maintains the bacterial growth and at the same time handles increased flow rates during I/I events.

(iv) Direct and indirect reuse of treated effluent

Although most urban water services systems in South Africa make available rehabilitated wastewater for indirect reuse in the form of return flows into the adjacent river ecosystems, there are many other options available for direct reuse by WSAs/WSPs.

Typical applications for reuse of rehabilitated municipal wastewater or industrial effluent are summarized in Table 4.4 below:

To date only a few WSAs/WSPs are taking advantage of direct reuse of treated effluent within their water services systems. There are, however, urban water services systems where the urban wastewater is treated for groundwater recharge. In other instances, where direct reuse is applied for non-potable reuse (e.g. industrial and/or agricultural purposes), a water balance for such systems must be conducted according to the reuse loop principle. This means that projects for future demand for water within the system should incorporate increases in direct reuse of wastewater in parallel to the increase in demand for water by a system. For more details, see WRC Report K5/1386/1.

Table 4.5. Wastewater and effluent reuse applications

Wastewater reuse field	Reuse category	Possible application
Direct reuse	Urban non-potable use	• Residential on-site reuse • Landscape irrigation • Fire protection (dual water supply
	Industrial reuse	• Cooling • Boiler feed • Paper industry
	Agricultural reuse	• Irrigation of fibre crops • Aquaculture
	Potable use	• Stock feed water • Domestic household
Indirect reuse (or return flows)	Environmental and nature conservation	• Stream flow regulation • Wetlands maintenance • Recreation
	Groundwater recharge	• Aquifer recharge • Salt intrusion control

5. MANAGEMENT ALTERNATIVES TO CONTROL EXTRANEOUS FLOWS

5.1 Maintenance and enhancement of waterborne sewers

5.1.1 Assessment of reliability of a wastewater system

The economic management of a municipal waterborne sewer system can be ensured through effective system operation, maintenance and rehabilitation programmes. To enable this, a WSA/WSP must provide that the following objectives are accomplished:

- *the structural integrity of each component of the system is maintained most of the time,*
- *hydraulic parameters should comply with recognised standards and codes of practice,*
- *extraneous flows (infiltration/inflow events) are reduced to an acceptable minimum, and*
- *exfiltration and the potential for groundwater contamination and other environmental impacts are limited and preferably avoided altogether.*

Many WSAs/WSPs in South Africa do not have a formal method for determining how much maintenance is needed to achieve a specific level of system performance and therefore adequately justifying maintenance and expansion costs. Figure 5.1 illustrates the principle of regular maintenance against a no maintenance approach.

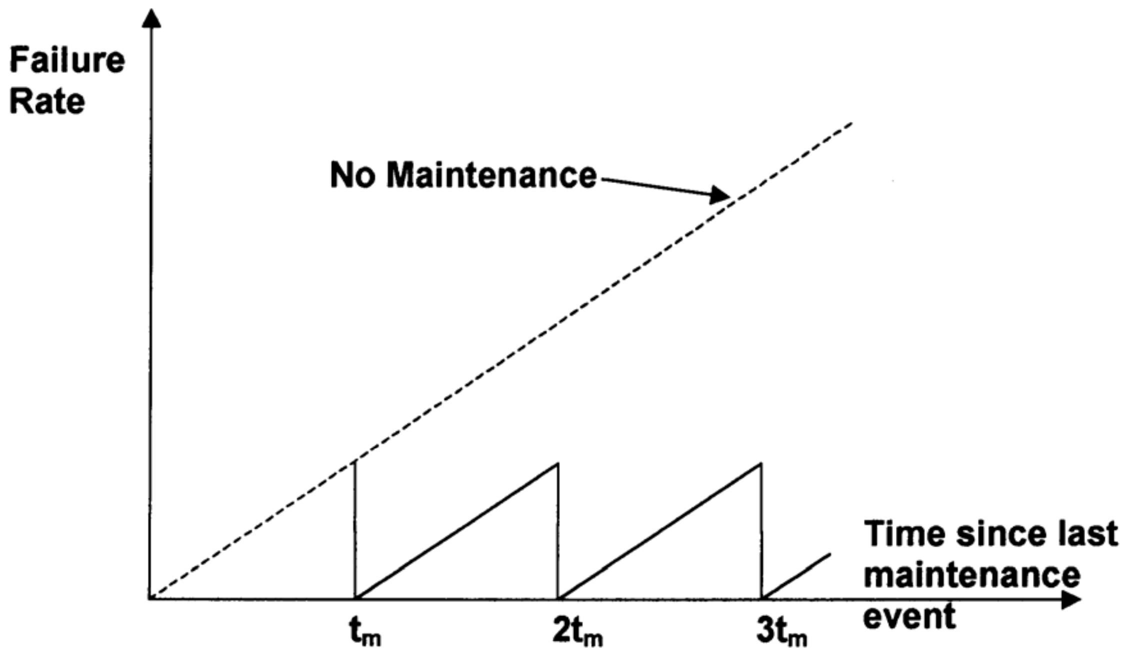


Figure 5.1. Maintenance event time vs. linear failure rate

From Figure 5.1 it can be seen that regular adequate maintenance will considerably decrease the failure rate of a system's components and subsequently upholding the integrity of the whole system.

Table 5.1. Maintenance activities to enhance wastewater system performance and reliability

Impacts on systems' reliability	**Possible structural defects / maintenance requirements**	**Possible operational defects / maintenance requirements**
Bottom line assessment	• apply previous inspection assessment if available • initiate field inspections and measurements in suspect areas	• apply previous inspection assessment if available • initiate field inspections and measures in suspect areas
Likelihood of failure	• installation history • type of material used • pipe component age • surface loads • soil type/acidity • wastewater BOD chemical content and temperatures • interior/exterior corrosion • manhole/sump structure	• tree root intrusion • wastewater velocity/debris problem • type of overflow events • recurrences of surcharging • inflow/infiltration • exfiltration • pumping station malfunction •power supply rehabilitation
Consequences of failure	• human health • environmental degradation • commerce/traffic • loss of income	• resurfacing costs • extra excavation or tunnelling • temporary access • redundancy issues

5.1.2 Poor wastewater infrastructure asset performance

The water services authorities (i.e. predominantly municipalities in South Africa) manage their water services infrastructure (i.e. water supply and sanitation assets) under the practices of scheduled and unscheduled maintenance programmes. However, the capital budgets for the maintenance of wastewater collection and treatment subsystems or their components are commonly determined from and based upon historical unscheduled (or reactive) maintenance events. This leads to inadequate maintenance, particularly of the buried infrastructural assets (e.g. pipelines). The "vicious circle" of poor wastewater infrastructural asset performance is caused usually by resuming to reactive maintenance as shown below:

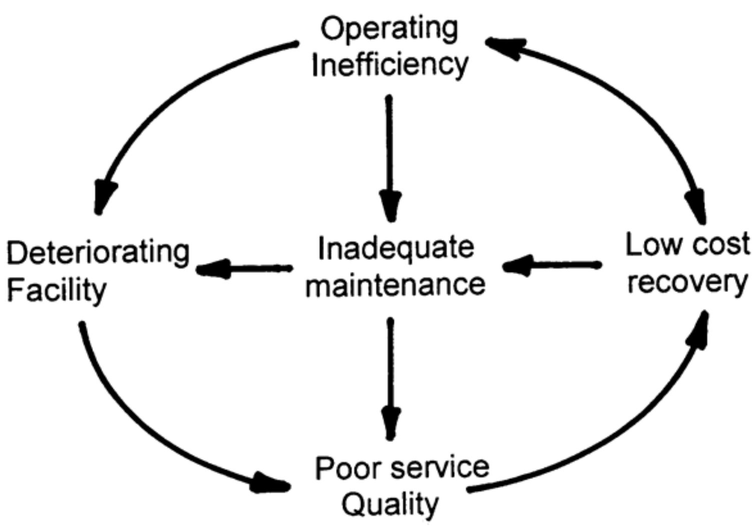


Figure 5.2: The vicious circle of inadequate performance of infrastructural assets

Typical consequences of inadequate infrastructural asset maintenance are as follows:

- *Inability to expand, modernise or improve the service*
- *Increased economic and financial costs*
- *Lost growth in income, lost development opportunities, environmental quality and social welfare*

5.2 Corrective and preventative maintenance

5.2.1 Corrective (or unplanned) maintenance

Corrective maintenance is an unscheduled activity in reaction to unexpected outages, blockages and breakages.

- *Mean corrective maintenance time (MCMT)* – is the ratio between the total number of maintenance hours to the total number of maintenance actions taken. It should distinguish between existing and new components (or equipment).

5.2.2 Preventative (or planned) maintenance

Preventative maintenance is scheduled activity which is proactive in maintaining a system's components to avoid possible outages, blockages and breakages.

- *Mean preventative maintenance time (MPMT)* refers to the procedures required to retain a system (or its components) at a specific level of performance and include periodic inspections, servicing, scheduled replacement of critical items, calibration and overhauls.
- *Mean active maintenance time (MANT)* is the average elapsed time required to perform scheduled (preventative) and unscheduled (corrective) maintenance.

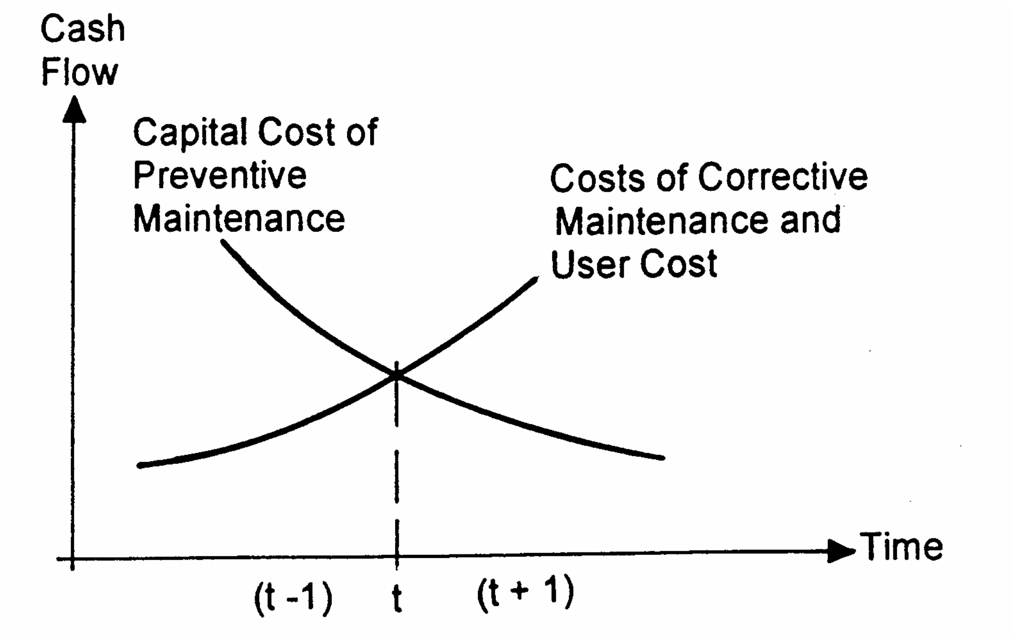


Figure 5.3: Optimal point in time for preventative maintenance

5.3 Preventative and remedial measures to extraneous flows

There are several methods available to be used in preventing stormwater inflows and groundwater infiltration into sewers. These methods can generally be classified as being either remedial or preventative in nature. Remedial methods are those methods that tend to accommodate infiltration and inflow (e.g. by building storage tanks at WWTP, etc.) Preventative methods on the other hand tackle the problem at the source and aim to eliminate infiltration instead of accommodating it. The critical decision is whether to solve, postpone or ignore inflow/infiltration problems.

5.3.1 Preventative measures in reducing I/I events

There are various methods that can be used to mitigate groundwater infiltration and stormwater inflow into sewers instead of remedying it.

(i) Waterborne sewer cleaning techniques

Sewer cleaning is needed to prevent blockages due to sedimentation and enable sewer inspection or flow monitoring to assess condition and to maintain sewer capacity. Typical techniques applied are related to physical cleaning methods.

- *Rodding or boring*. Flexible rods are screwed together and then inserted into the blocked sewer. This technique is limited by the pipe diameter up to 250mm and shallow pipe trench depth.
- *Winching and dragging*. In applying this technique, a bucket is dragged through the sewer (up to 900mm diameter) collecting sediment between manholes.
- *Jetting*. A high-pressure (100-350 bar) stream of water dislodges sedimentary materials and collected at the next manhole.
- *Flushing*. Short duration waves of water (or other liquid) are created to scour the sediment and transport it to the next manhole where it would be removed.
- *Hand excavation*. This technique is used to manually dig out deposited materials in large diameter sewers.

(ii) Mitigating measures to maintain sewer integrity

- *The sealing of sewers*. The sealing of sewers involves sealing cracked sewer pipes and manholes to prevent them from groundwater infiltration/exfiltration. It also involves realigning sewers that have become misaligned and sealing other defective joints.
- *Replacing missing or broken manhole covers*. Missing or defective manhole covers provide an access for stormwater to enter into sewer systems. Missing manhole covers on pavements are of concern because most of the surface runoff during heavy storms finds access into the sewer system through manholes that are not covered.
- *Raising manholes above flood lines*. Manhole levels are designed to be above flood lines so as to stop stormwater inflows. The higher flood lines due to urbanisation and legislation are in some instances now above than the existing manholes, thus increasing the amount of stormwater inflows into manholes. Raising manhole levels on parity with the increased flood lines will significantly eliminate the amount of stormwater inflow into sewers.
- *Training maintenance staff*. Builders and plumbers can be trained to familiarise themselves with combined and separate sewer system requirements and to prevent

households from diverting flow from household stormwater drains into sewers. This can prove to be very effective especially in townships where most builders and plumbers had never received any kind of formal training before.

- *Regulatory measures*. A rather unpopular method would be to enforce laws that prevent the diversion of stormwater gullies into sewers. Offenders would be liable to a fine and/or imprisonment.

5.3.2 Remedial measures in reducing inflow/infiltration

There is a growing awareness and recognition of the problems of groundwater infiltration and stormwater inflows into sewers. The methods that WSAs/WSPs use to control inflow/infiltration are currently remedial and not necessarily preventative in nature. Remedial solutions are merely temporary arrangements and do not necessarily solve the problem. Some of these methods involve:

- *Building holding tanks at WWTPs*. This solution is the most convenient and simplest of the methods available. Building holding tanks at the WWTPs has the effect of levelling high flow volumes during I/I events. The function of holding tanks is similar to balancing reservoirs used in water reticulation systems. They are there to ensure a constant supply rate at all times. This approach involves additional costs of tanks and piping.
- *Increasing the capacity of WWTP*. With this method, the capacity of the wastewater treatment plant is increased rather than trying to control the rate of inflow. The United States of America already has a number of wastewater treatment technologies, which can be integrated to create a WWTP of any desired capacity and treatment rate. However, the costs involved are highly significant.
- *Increasing the capacity of the whole sewer system*. Once the capacity of the sewer is exceeded due to wastewater production and the inflows of groundwater and stormwater, sewers are re-laid or duplicated to restore acceptable hydraulic capacity and structural integrity.

5.4. Decision making on replacement or rehabilitation

5.4.1 Evaluation of condition and performance of infrastructural assets

The condition and performance of water service infrastructure assets are key factors in the WSA/WSP delivery obligations. Ongoing assessment of asset conditions and therefore planned maintenance, rehabilitation or replacement, are critical to efficient and sustainable operation of water services systems over their designated life-span

Several components of a water services system have to operate on a 24 hour 365 days a year basis. Water/wastewater pipelines operate potentially in aggressive conditions and their performance can deteriorate fast. Decision-making in evaluating the performance and condition of an existing component of a system must commonly address the following issues:

- *Is the component (or module, subsystem, system) operating to its designated (designed) capacity?*
- *How serious is the problem of aging and deterioration?*
- *What are the reasons for the problem?*
- *Are they the real problems?*
- *What are the ramifications to deal with an identified problem?*

- *What is the probability of failure and its consequences?*
- *How quickly can the problem be rectified?*
- *What is the estimated remaining functional life of the component (or module, subsystem or whole system)?*

To conduct an educated and skillful assessment of the condition and performance of various components of a water services system, good knowledge and essential training in structural and hydraulic properties of various material are required. The assessor must also be well acquainted with the following definitions and ways of assessing water related assets:

- *Definitions of the aggressive environments,*
- *Methods of material properties assessment used in water engineering,*
- *Definitions of the current level of safety and serviceability,*
- *Methods in estimating future rates of material deterioration,*
- *Definitions related to the minimum acceptable levels of service*

A useful check-list in the first round of assessing conditions and performance is illustrated in Table 5.2 below:

Table 5.2. Check-list of key water services asset assessment objectives

Type of assessment	**Assessment objectives and means**	
	Water supply subsystem	**Wastewater subsystem**
Conduit function	Critical at bulk and trunk main	Critical at main interceptors / sewer outfall
Pipe network condition	Visual inspection, flushing, pigging, etc.	Visual inspection, internal inspection by CCTV
Water / waste-water quality	Fibroscopic examination, sampling (routine, series)	Sampling of toxicity levels, surveys of hydrogen sulphide for gases
Level of service	Consumer complaints, random questionnaires, breaks and outages	Customer complaints, breaks and blockages, stormwater overflows, flooding of properties
Operational performance	Water quality standards, pressure levels, modelling of network	Topographical and flow surveys, infiltration, storm inflow, egression
Specific assessment	Status of mechanical and electrical equipment	Status of rising mains and pumping stations, etc.

5.4.2 Application of routine maintenance rates

An internationally recognised standard (or routine) maintenance programme is based on established routine maintenance rates (or performance measure weights). The routine maintenance programme should include cleaning, removing or treating roots, cleaning the stoppages (at main and street sewers), and inspecting as well as servicing pumpstations. Table 5.3 illustrates performance measure weight at a typical municipal waterborne sanitation system.

Table 5.3. Typical routine maintenance relative importance values

Maintenance measures	Relative importance (%)	Indicative rates
Manhole and WWTP overflows/bypasses	24	
Pipeline failure	23	Stoppages at 0,14 km/year
Customer complaints	21	
Pumpstation failure	18	
Other maintenance measures (I/I mitigation, sewer testing, etc.)	14	

See Appendix F for further details on weighting factors for grading inspection of sewers

An overall maintenance and performance rating is established from maintenance frequencies that include:

- *maintenance activity rate*
- *normalized frequency to each maintenance activity*
- *activity weighting factor*
- *weighted normalized activity frequency*
- *system (or component) maintenance frequency*

Similarly, steps are taken to establish existing system performance ratings for the routine maintenance of municipal waterborne sewers in South Africa.

5.4.3. Quantification of condition and performance of a system

Typically, two techniques are used for assessing and analyzing the condition and performance of water engineering assets:

(i) Detailed approach of grading and reporting

Detailed approach of grading with a condensed system of reporting of data what uses the same notation (e.g. asset register).

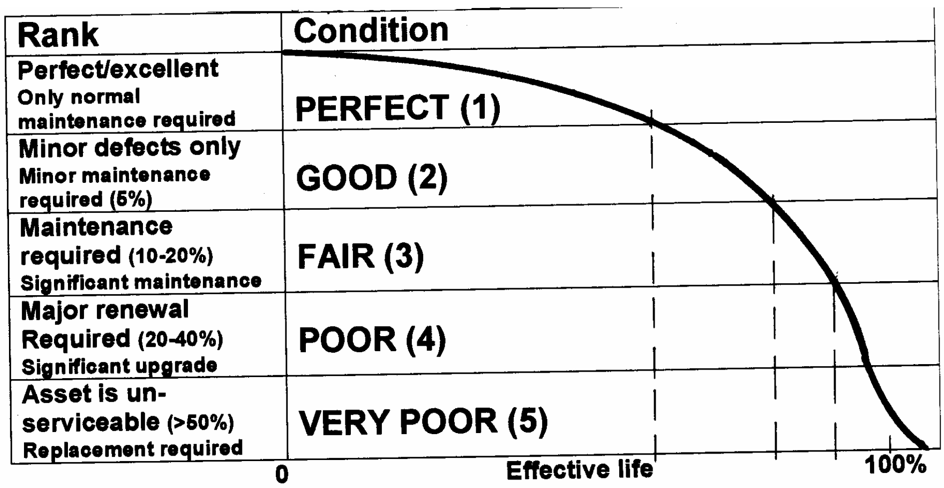


Figure 5.4: Typical asset condition ranking (adopted and adjusted from NZ Infrastructure Asset Municipal Manual, 1996)

The circumstances prevailing in the highly diversified South Africa water services provision sector would be satisfied by a simplified (at least for now) and practical approach for the asset condition assessment as illustrated in Figure 5.4. Both passive assets (e.g. trunk mains, pipe networks, etc.) and dynamic assets (e.g. pumps, plant and equipment) can be assessed according to five categories (or ranks) to determine the condition of the relevant asset. The asset condition method of ranking as illustrated in Figure 5.4 is explained further in Appendix C.

(ii) Evaluation of asset performance by structural distress

Red Book (2003) illustrates an evaluation technique using the structural distress determination principle. The main purpose of the determination of a representative level of service (LOS) for a system is to illustrate the associated life-cycle costs. This identification can enable decision makers at WSA to select an alternative which will be affordable and feasible. The costs associated with upgrading are made up of design and construction costs, maintenance costs and system-user costs. Construction costs are high for high LOS values and low for low LOS values. Maintenance cost curve has a typical minimum value between the highest and lowest LOS values. Figure 5.5 illustrates structural distress determination principles.

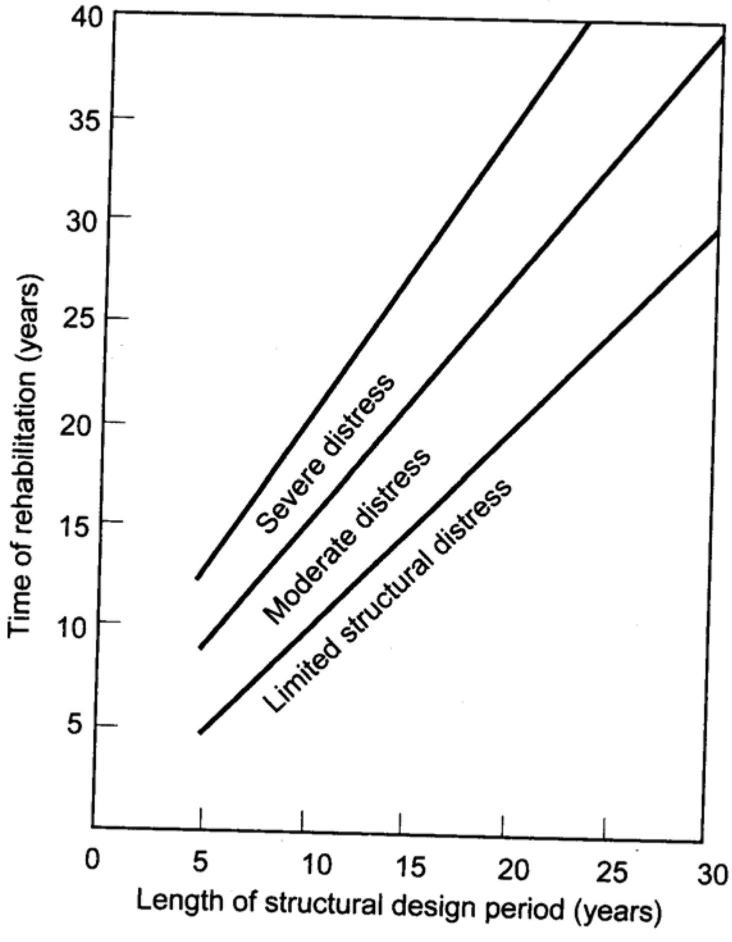


Figure 5.5. Degree of structural distress to be expected at time of rehabilitation

5.5 Methods of controlling I/I events at the WWTP

5.5.1 Bypassing wet weather overflow

At most municipal WWTPs, wet weather periods require overflow bypassing otherwise considerable washouts of biological solids occur. Local practice permits occasional violations of excessive BOD and TSS effluent concentrations caused by peak flow washing. The guiding standards are illustrated in Table 5.4 below:

Table 5.4: Different pollutants and their resulting effluent standards

Pollutant	**Effluent treatment**	**Guiding standards (mg/litre)**
Suspected Solids (SS)	No chemical treatment; needs retention time during treatment	> 25
Chemical Oxygen Demand (COD)	No chemical treatment; needs retention time during treatment	> 75
Nitrates (N)	No chemical treatment; needs retention time during treatment	> 15
Phosphates (P)	Chemical treatment, adding Ferric Chloride	> 1
E. Coli	Chemical treatment, adding chlorine	> 1000 per 100
Ammonia - N	Bio-chemical treatment, nitrification followed by de-nitrification.	> 10

5.5.2 Building holding tanks at WWTPs

Building holding tanks at WWTPs has the effect of levelling high flow volumes during wet weather periods. A holding tank represents a function of the balancing reservoir used in potable water reticulation systems, ensuring a constant supply rate at all times. However, the cost involved might be considerable. Another solution in reducing abnormal wastewater flows is to add more than one small wastewater tank (e.g. 100 to 200 kℓ) with a small filtration plant. The capital outlay of this solution might be lower than one large holding tank and auxiliary works.

5.5.3 Increasing the capacity of WWTP

With this method, the capacity of the wastewater treatment plant is increased rather than trying to control the rate of inflow. Internationally, a number of wastewater treatment technologies, which can be integrated to create a WWTP of any desired capacity and treatment rate, are available.

5.5.4 Increasing the capacity of the whole sewer system

Once the original design capacity of the sewer is exceeded due to increased wastewater volumes and infiltration/exfiltration, sewers are re-laid or duplicated to restore them to acceptable flow conditions. The increase in capacity of the whole system can be typically achieved by the replacement of old smaller diameter sewer pipes for larger new sewer pipelines and pumping equipment where required. The enhancement of functions of the old system must be considered before any decision is taken. A reduction in the infiltration rate by rehabilitation will not only save on sewerage treatment costs but may defer capital expenditure for the upsizing of sewer pipelines and water care works. The decision to solve or ignore an infiltration problem should therefore be based on a cost-benefit analysis.

7. MITIGATING EXTRANEOUS FLOWS BY STORMWATER DETENTION

6.1 Introduction

One of the most simple and economic methods of managing excess stormwater and extraneous flows into sewers is by means of detention storage. The detention could be provided on site but is more common at the entrance to the wastewater treatment works as the majority of ingress occurs along the sewers beyond the domestic inlets.

Although ingress is less polluted that the sewage, it does require better handling and storage facilities than stormwater.

An analogy may be made with the more common systems in Europe and North America with regard to combined sewerage. That is, storm water and sewage are often conveyed in the same conduits. There is also a legacy of discharging the combined stream, or at least excess flow from the combined streams, directly to water courses and the seas. In some cases, little or no treatment is made and at the most, there is gravitational separation of the streams. For example, skimming weirs skim off the so-called clear stream directly to water courses and the concentrated or densimetric sewage is assumed to flow to the treatment works. However, it is wise for our case not to assume stratification from the quality point of view and to consider all mixed sewage as requiring treatment.

6.2 Detention storage philosophy

Stormwater detention on its own has been promoted considerably in the literature and in various countries and stormwater management and best management practices are very advanced. There is however a different strategy required for sewage streams containing stormwater as indicated below.

In the case of stormwater drains, the design storm is the one which dictates the stormwater drain capacity. Although dual systems or single systems may be considered, they are designed for an extreme event such as a 20 year storm. In the case of sewage, the maximum storm flow is limited by the capacity of the sewer and this may be, for example, equal to the sewage flow rate if the sewer is designed for twice the sewage flow rate. There is no spectrum of extreme storms. For example a 100 year storm would be more extreme than a 20 year storm and stormwater detention has to consider the most extreme condition as flooding will obviously be more severe the bigger the storm. The storm duration is also of importance in stormwater drainage because the volume of under the hydrograph is a function of the intensity and the duration of a storm. In the case of sewers, the sewer may flow full for a considerable proportion of its time and more frequently. For example, a stormwater drain may only flow at its capacity every 5 to 10 years, whereas a sewer could be expected to flow at its capacity a number of times each year and for a considerable period of time owing to on-site backup.

The question of stormwater retention or detention would tend to favour retention in the case of clear storm water because it recharges the groundwater. Retention implies on-site recharge or evaporation, whereas detention is a temporary retaining and subsequent release of the excess flow. In the case of sewage-contaminated stormwater, the flow must be prevented from seeping into the ground and even evaporating or being exposed to winds, and it should be recharged to the wastewater treatment works as soon as possible.

In-channel storage is quite possible in the case of stormwater because the entire flow can be retarded that way. Off-channel storage implies pumping to an elevated storage reservoir, or diverting over a weir to catch only excess flow, or through an orifice to catch early flows. In the case of sewage, off-channel storage may be convenient in the attempt to separate skimmed, clearer water from the underflow, but it should nevertheless be recharged to the wastewater treatment works as soon possible after the flow in the system has subsided. On the other hand, in-channel storage would result in a retardation in the velocity of the entire inflowing sewage stream with consequent settling and flotation of solids leading to more difficult treatment later on.

6.3 Environmental considerations

Plane stormwater retention or detention has environmental attractions in many cases. It can be used for watering wetlands or conserving aquatic plants and fauna and be environmentally attractive. There is little danger associated with infiltration into the soil or down to the groundwater.

In the case of sewage, there are odours and more particularly there is a danger of contamination of groundwater if sewage is allowed to infiltrate through unlined ponds into the ground. In addition, there is a build up of sludge on the bottom of the pond and this can lead to anaerobic conditions subsequently causing smells or unsightly surface scum. Therefore, sewage storage ponds should be lined with plastic or rubber membranes and monitoring systems are required. The environmental impact study associated with the wastewater treatment works would normally include the study of the consequences of such storage and it is not an easy matter to retro-construct stormwater holding basins at the inlet to a wastewater treatment works.

6.4 Wastewater treatment works

Stormwater detention basins are normally constructed near the inlet to the wastewater treatment works as they will hold excess flow while the wastewater treatment works is under capacity. Sewage diluted by stormwater will then be subsequently released into the wastewater treatment works when the flow in the incoming sewer subsides.

Certain treatment is required for the stormwater holding system and these could be combined with the wastewater treatment works systems. Preliminary screening and even grit channels or settling or skimming facilities could be provided. I.e. these may have to be constructed to the full sewer flow rate capacity, and excess flow is subsequently diverted to the holding tank. Alternatively, if the storage is far removed from the wastewater treatment works, it may require its own pre-treatment system. This therefore points to the fact that consideration should be made for separation of storm water from sewage by means of skimming weirs or floating booms at the entrance to the off-channel holding tank.

6.5 Hydraulic design

Once the separation system has been selected, which may be a weir, a floating boom, mechanical gates or a mid-depth orifice, it should be designed to select the correct amount of flow. This would be equal to the sewer capacity minus the design peak capacity of the sewage treatment works. The gates and structures associated with the holding tank should be corrosion resistant and designed to be easily cleaned in order to be operative. The fact that there may be long periods when the holding tank is not in use means that it maybe forgotten about or neglected and will malfunction when the storms come. Therefore, hydraulic separation systems such as a weir would appear attractive. Then the outlet needs to be at a lower level as the holding tank must subsequently be drained back into the sewer. The outlet should be at a different point to the inlet to ensure circulation through the tank and therefore removal of any dead spots and the possibility of sludges turning septic and causing odours.

Facilities should be provided for washing down the tank when it is emptied in the dry season and also for scouring back to the sewer or sewage treatment works. Normally, the gradient through the holding tank will be less than that of the sewer so that the re-joining downstream of the inlet will enable flow from the tank back into the sewer.

The sizing of the tank should be based on the estimated quantity of stormwater ingress. Bear in mind that groundwater ingress, which is a continuous process, will have to go directly to the sewage works, or at least that capacity should be allowed for. The storms which should be considered when designing the detention storage should therefore be long duration storms, i.e. those associated with maximum volume rather than maximum peak flow rate. At least a 20 year 24 hour storm should be considered when sizing the detention basin. Although the entire capacity of the sewerage system may not cope with even this flow rate, remember there will be on-site detention if the sewage system is at capacity and this water may subsequently flow back into the sewers when the flow in the sewer pipes subsides. However, the on-site detention will be stormwater rather than mixed with sewage and therefore not as severe a problem as the holding tank at the bottom end of the trunk main into the wastewater treatment works.

The volume of flow into the sewer and the time processed could be obtained by computer modeling of the catchment. However, the modeling system should allow for limitations on the sewers in accepting the stormwater flow and an experienced modeler should therefore do the analysis. In the case of simple trunk mains, the volumes could be obtained using the rational method or other simplistic time-area methods (Stephenson, 1979).

6.6 Economics

Stormwater detention basins are fairly economic compared with the alternatives provided there is cheap land available for constructing the basin. However, a sewage holding tank would be a lot more costly than a simple stormwater detention basin. This is because lining is required and environmental considerations need to be taken care of. The use of corrosion-resistant materials and even the possibility of odour control or visual barriers will all add to the cost. Whereas stormwater detention dams costs are of the order of R20 per cubic metre of storage, sewage holding dams can cost R50–R100 per cubic metre of storage (2004). Nevertheless, this is considerably less than the alternative of increasing the capacity of the wastewater treatment works to cope with that flow as it arrives at the wastewater treatment works. All the hydraulics beyond the off-take to the holding dam can be made to a smaller capacity if separation is provided and the major components such as the settling basin and filters can be made to a smaller peak flow capacity.

The cost of sludge removal or scum removal and washing down needs to be included in the costing of the stormwater detention basin and it should receive the same sort of attention as a wastewater treatment works.

It should be borne in mind that groundwater ingress into sewers cannot be retained in a storage dam as it is a continuous process. Therefore, some additional sewer and WWTW capacity is required for this flow.

7. REHABILITATION OR REPLACEMENT OF WATERBORNE SEWERS

7.1 Capacity utilisation of existing wastewater infrastructure

7.1.1 Lifespan of wastewater infrastructure assets

By all practical terms, most of the existing urban water services infrastructure in South Africa (e.g. water supply distribution and wastewater collection networks) is relatively new and technologically compatible with international standards. Urban water services facilities are built on average for a minimum period of 30 years before full utilization is reached. The lead-time from inception to full commissioning of an urban water services project can reach up to five years. Some projects are augmented in stages over a period of 15 years before reaching full capacity utilization.

In the municipal sector, South African Government Treasury Department GAAP and GAMAP standards are required to be applied in the assessment of financial matters regarding infrastructural management. Standards on financial reporting by local government authorities (i.e. Water Services Authorities) are set out to assist them in making and evaluating decisions on allocating their scarce financial resources. life-cycle costing principles must be applied.

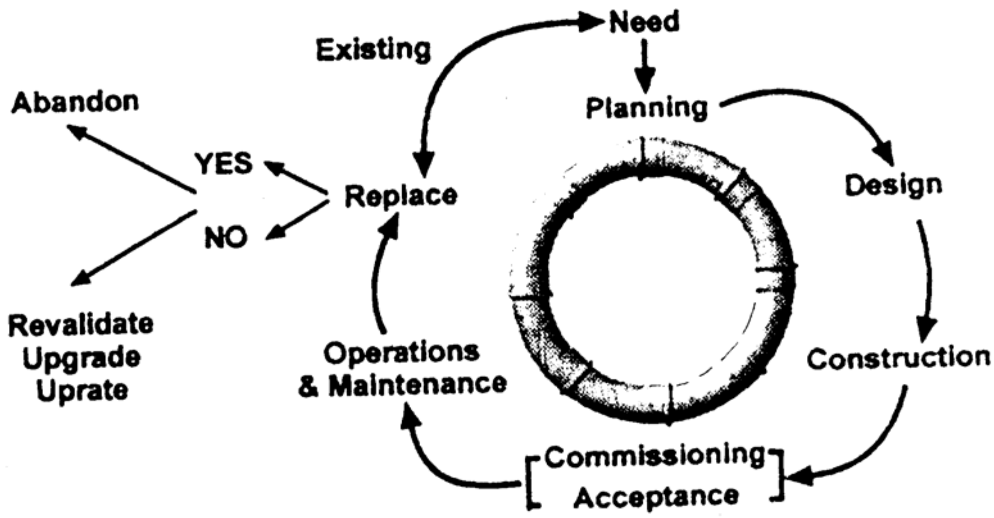


Figure 7.1. Life-cycle of a waterborne sewer pipeline (after Haswell, 1999)

The municipal wastewater infrastructure assets are the long-life passive assets and highlight the difficulty and inability to predict with a high degree of confidence the point of time when failure or decline in level of service is likely to occur. The ability of a WSA in managing its infrastructure asset base and particularly the ageing asset problem with its associated risks is a major issue for most WSA/WSPs in South Africa. Health, environmental and community complaints and hazards will increase with the deterioration particularly of service levels of the wastewater infrastructure and subsequently extent of recurring expenditure problems.

7.1.2 Larger or smaller wastewater system development

To optimize a partial or stage sewerage development, large schemes should be considered for eventual development. The shorter the period over which a facility is used at less than capacity, the higher will be the discounted cost of under-utilization, resulting in an increase of the unit cost. In general terms, the faster the utilization, the lower the unit cost in the intermediate years of the life span of an installation. Also, regional schemes rather than local schemes would produce services at a lower unit cost. This involves many smaller schemes being interlinked to form a regional grid. Although some WSPs in South Africa lean towards a regionalization of rural and semi-urban water services schemes, it appears that centralized urban wastewater plants are not favoured by municipalities. There is an ongoing debate as to whether to centralize or decentralize municipal wastewater treatment. The main argument is economies of scale versus a shift to placing more responsibility for treatment towards developers and/or individual house owners.

7.1.3 Capacity building of technologically educated staff

It is now becoming obvious that the local pool of technologically educated operators and managers undertaking maintenance and operational procedures started to lag behind the demand for such technological qualifications. Another worrying issue is a scarcity of general resources which is rapidly setting in within the aging and deteriorating South African civil engineering infrastructure industry. This is most obvious and urgent at local government level Ii.e. WSAs)..

7.2 Decision making on rehabilitation or replacement

7.2.1 Typical alternative methods for rehabilitation or replacement

(i) Choice of suitable pipe material

The choice of suitable pipe material and construction techniques could reduce future rehabilitation requirements as the wastewater collection system ages. It is now known that concrete sewer pipes corrode from sulphuric acid formation. Vitrified clay pipes (VCP) have historically had problems due to leaking joints, short segment lengths and brittleness. These conventional materials are gradually being replaced by plastic materials such as:

- *High density polyethylene (HDPC)*
- *Polyvinyl chloride (PVC)*
- *Reinforced plastic mortar (RPM)*
- *Centrifugally cast fibreglass reinforced plastic mortar (CCFRPM)*
- *Polymer concrete, and*
- *Acrylomitrile-but-adiene-styrene (ABS)*

It should be noted that although plastic materials resist chemical corrosion and provide a root free service, they are not rigid and tend to creep over time. Problems of damage by rodents and crushing from heavy loads are also rather common.

Pipeline rehabilitation methods use the existing pipe either to form part of the new pipeline or to support a new lining. Rehabilitation is preceded by cleaning the pipe to remove scale, tuberculation, corrosion and other foreign matter. Linings, to be effective, must make intimate contact with the pipe surface. Proper surface preparation significantly affects the strength and bonding of lining. These methods can be divided into two categories: non-structural and structural.

7.2.2 Rehabilitation by non-structural lining

Non-structural lining involves placing a thin coating of corrosion-resistant material on the inner surface of the pipe. The coating is applied to prevent leaks and increase the service life. However, coating does not increase the structural integrity of the pipe.

- *Cement mortar lining*. Cement mortar linings are unique because they are porous. Corrosion protection is achieved by the development of a highly alkaline environment within the pores, which is a result of the production of calcium hydroxide during cement hydration. Cement mortar is applied using a variety of equipment, depending on pipe size and overall project length. Access to the pipeline is accomplished by excavation and removal of a length of pipe.
- *Epoxy lining*. Epoxy resin lining of water mains is an alternative to cement mortar lining. It has not been widely used in the United States. However, it has been practiced in several other countries, including the United Kingdom and Japan. Epoxy lining with an investigated and estimated life in excess of 75 years is recommended by Watson (1998).

7.2.3 Rehabilitation by structural lining

Structural lining involves placing a watertight structure in immediate contact with the inner surface of a cleaned pipe. A variety of technologies are available, including sliplining, cured-in-place pipe, fold and form pipe, and closed-fit pipe lining. These rehabilitation techniques improve the structural integrity of a pipe.

- *Sliplining*. Sliplining is the oldest rehabilitation method. In this process a new pipeline of a diameter smaller than the pipe being repaired is inserted into the defective pipe and the annulus grouted. It has the merit of simplicity and is relatively inexpensive, but there is a reduction in flow capacity (35 to 60%), depending upon pipe size. Excavation is required for insertion and receiving pits. All service connections, valves, bends and appurtenances must be individually excavated and connected to the new main.
- *Cured-in-place pipe*. Cured-in-place pipe (CIPP) involves placing a fabric tube, impregnated with a thermosetting resin that hardens into a structurally sound jointless pipe when exposed to hot circulating water or steam into a cleaned host pipe, using the inversion process described below. Access to the pipeline is accomplished by excavation and removal of a length of pipe. There is no reduction in flow capacity. However, the flow must be completely stopped or by-passed during installation and curing. All service connections, valves, bends and appurtenances must be individually excavated and connected to the new main.
- *Fold and form pipe*. Fold and form pipe (FFP) utilizes thermoplastic materials polyvinylchloride (PVC) or polyethylene (PE) that are heated and deformed at the factory from a circular to a U-shape to produce a net cross section than can be easily fed into the pipe to be rehabilitated. According to Spero (1999), the FFP is fed from a spool into the existing pipe, where hot water or steam is applied until the liner gets heated enough to regain its original circular shape and create a snug fit within the host pipe. All service connections, valves, bends and appurtenances must be individually excavated and connected to the new main.
- *Close-fit pipe*. Close-fit pipe lining involves pulling a continuous lining pipe that has been deformed temporarily so that its profile is smaller than the inner diameter of the host pipe. This lining method is often referred to as the modified sliplining approach.

Close-fit pipe lining makes use of the properties of PE or PVC to allow temporary reduction in diameter and change in shape prior to insertion in the defective pipe. As with sliplining, excavation is required for insertion and receiving pits. All service connections, valves, bends and appurtenances must be individually excavated and connected to the new main. Close-fit pipe has a design life of greater than 50 years.

7.2.4 Trench replacement techniques

Replacement of pipelines can be accomplished by using either trenchless or open-trench techniques.

(i) Trenchless replacement

Replacement of pipelines means installing a new pipeline without incorporating the existing pipelines by either open-cut or trenchless replacement. Trenchless replacement involves inserting a new pipe along or near the existing pipe without requiring extensive excavation of soil. Trenchless replacement can be done with minimal disruption to surface traffic, business and other activities, in contrast to open trenching.

There is a significant reduction of the social costs associated with construction. The best-known trenchless replacement techniques are pipe bursting, microtunneling and horizontal directional drilling.

- *Pipe bursting*. Pipe bursting is a method for replacing pipe by bursting from within while simultaneously pulling in a new pipe. The method involves the use of a static, pneumatic or hydraulic pipe-bursting tool drawn through the inside of the pipe by a winched cable, with the new pipe attached behind the tool. The bursting tool breaks the old pipe by applying radical force against the pipe and then pushes pipe fragments into the surrounding soil. The liner pipe can be the same size or as much as two pipe sizes larger than the existing pipe. Excavation is required for insertion and receiving pits.
- *Microtunneling*. Microtunneling involves the use of a remotely-controlled, laser-guided, pipe-jacking system that forces a new pipe horizontally through the ground. This trenchless method is used for construction pipelines to close (250mm) tolerances for line and grade. This method can be cost-effective compared to open-cut construction when pipelines are to be installed in congested urban or environmentally sensitive areas, at depths greater than 0,6m in unstable ground, or below the water table. Microtuneling can be used in a variety of soil conditions from soft clay to rock, or even when there are boulders to deal with, and can be used at depths of up to 30m below the water table without dewatering.
- *Horizontal directional drilling*. Horizontal directional drilling (HDD) consists of a rig that makes a pilot bore by pushing a curing or drilling head that is steered and guided from the surface. Drilling fluid is pumped through the drill/push rods and displaces the cut soil. When the pilot bore is completed, pulling back a reamer enlarges the hole. Progressively larger back-reamers are used until the hole is large enough to pull in the pipe. HDD is suitable for installing pipes under waterways, major highways and other obstacles.

(ii) Open trench replacement

Open-trench replacement is the most commonly used method for replacement of water mains and sewers. This technique involves placing new pipe in a trench cut along or near the path of the existing pipe. This approach is cost intensive and problems of working within developed areas where pipes may be beneath streets, sidewalks, customer landscapes, utility poles are inevitable. There are two basic types of open trench replacement: (i) conventional, and (ii) narrow. The conventional open-trench method uses the same approach as that used to place new pipe. In using the narrow-trench replacement method, the trench width is kept to the absolute minimum excavation width possible. It is primarily used for installing polyethylene pipes.

Table 7.1. Summary of typical rehabilitation/replacement methods

Method	**Suitable pipe size**	**Common materials used in rehabilitation or replacement**
Cement mortar lining	100-1500	Cement-sand
Epoxy lining[a]	100-300	Epoxy resin
Sliplining	100-2500	HDPE, PVC, fibreglass reinforced polyester
Cured-in-place pipe	150-1300	Polyester resins
Fold and form pipe	200-450	HDPE, PVC
Close-fit pipe	50-1000	PE, PVC
Pipe bursting	100-1000	HDPE, PVC. ductile iron
Microtunneling	300-3600	HDPE, PVC, concrete, steel, fibreglass
Horizontal directional drilling	50-1500	HDPE, PVC. steel, copper, ductile and cast iron

Note: HDPE = high density polyethylene; PVC = polyvinyl chloride; PE = polyethylene
Source: Adapted from Selva Kumar et al. (2002)

7.3 Costing of various options of rehabilitation and alternative strategies

7.3.1 General background

When considering the price of a wastewater system development, upgrading or replacement project, required expenditure is broadly divided into three cost groups:

- *Capital cost* – initial cost of constructing the scheme
- *Operation and maintenance (or revenue costs)* – representing the costs incurred in running the scheme (e.g. power, labour, materials and routine maintenance)
- *Refurbishment costs* – representing costs involved in a major programme renovation (major refurbishment after 15-20 years is rather common)

According to contemporary trends in the economics of various options for the development of municipal wastewater systems, infrastructural asset management principles should apply.

Table 7.2. Levels of service versus cost of service

Requirements for level of service	**Required inputs on infrastructure asset**	**Cost of service and asset management**
• Reliability • Quality • Quantity • Safety • Low risk • Security	• Ways of creation • Procedures in operation • Means of maintenance • Performance monitoring • Risk assessment methods • Audit frequency • Renewal strategy	• Original costs • Cost of operations • Cost of maintenance • Cost of administration management • Cost of exposure to risk • Cost of replacement / rehabilitation / disposal

7.3.2 Costing of sewer flow monitoring and analysis

As stated previously, the first steps in determining a maintenance programme are to check on the accuracy and completeness of existing records of the system, and then initiate a survey on the parts of the system which are assumed to be most affected. To determine the extent of infiltration in waterborne sewers, field inspections and flow monitoring are essential in decision-making on the sewer repair, renovation or replacement.

(i) Close-circuit television (CCTV)

CCTV inspections for waterborne sewers are popular as they can be carried out quickly with minimal disruption and less of a hazard for people to enter a sewer. This way of inspection is used to locate and define the cause of a known condition or defect and enables inspectors to prepare a plan of action. Known rates of inspection are between 400 to 800 m/day in pipes from 100 to 1400 mm in diameter. The usual method is a propulsion camera winched between sewer manholes.

(ii) Costing of sewer flow metering and analysis

Table 7.3 illustrates costing of field flow metering as experienced by the researchers during metering of flows for this project.

Table 7.3. Costing of field flow metering (cost base 2003)

Item	**Activity**	**Unit cost**
1.	Client to define flow metering positions	R200/hr
2.	Contractor to establish flow measurement stations (a) Flume (b) Secure manholes	 Sum Sum
3.	Clean-up upstream sewer line from contingencies	Proportion of contingency
4.	Installation of measuring equipment (a) To purchase (b) To hire	 R12 500/device R3 000/week/site
5.	Cost for setting up metering device (including calibration of equipment)	R350/device
6.	Intermediate readings (including battery charges, etc.)	R200/device
7.	Removal of metering units and data downloading Add software package	R280/device R4 000
8.	Interpreting readings and reporting	R300/device

Note: VAT is excluded

(iii) Costing of preventative measures

There is a growing recognition of the problems of groundwater and stormwater inflow into sewers. The methods that most WSAs/WSPs should use to control infiltration are currently remedial and not preventative in nature. Remedial solutions are undesirable because they are merely temporary arrangements and do not necessarily solve the problem in the long-term. Some of these methods involve:

Table 7.4. Summary of costing preventative measures (cost base 2003)

Preventative measure	**Description of problem**	**Estimated cost**
Sealing of sewers	Remedial measures by rehabilitation methods	Depending on choice of measure
Replacing missing or broken manhole components	Covers only Covers and frames Covers and cover slabs Reconstruct manhole (e.g. raising manholes above flooding)	R450/unit R900/unit R1200/unit R4000/unit
Training of maintenance staff	Qualification and experience	LGWSETA rates based
Regulatory measures	Policing, etc.	Budget sum

Notation: LGWSETA = Local Government and Water SETA

(iv) Costing of increased capacity of WWTP

The design of WWTP to accommodate extraneous flows appears as one of the most expensive options but the one done most commonly. It may cost a WWTP on average R3 million per ℓ/d or R300 000 per ℓ/s of inflow. The cost is related to the hydraulic capacity and BOD loading. The hydraulic related components are the ones to consider, since inflow/infiltration are more hydraulic than quality problems. The components related to peak flow rate are:

- *Pipework* *(cost proportional to flow to the power of 0.5)*
- *Inlet works: screens, grit channels* *(cost proportional to flow rate)*
- *Settling tanks* *(cost proportional to flow rate)*

It must be noted that the costs of sludge handling, digesters, drying beds, aeration or filters and tertiary treatment depend primarily on the pollution load of the WWTP’s influent.

The cost of the hydraulic related components is approximately 30% of the cost of the works (i.e. R100 000 per ℓ/s of inflow). This type of expenditure could be used to rehabilitate or upgrade a considerable length of sewer. Peak flows could be reduced 10% by upgrading. At a rehabilitation cost of R1 000/m/m dia, and assuming 500 mm dia sewers with a capacity of 300 ℓ/s, then if flow could be reduced by 10% (i.e. by 30 ℓ/s), R3 million could be spent (i.e. R3 000 000 / R500 = 6 000 m could be renovated instead of extending the WWTP capacity).

If more flow reduction than 10% were possible, a greater length of sewer could be rehabilitated.

7.3.3 Costing of new sewer development

Costs are based on activities including: P & G, site clearance, excavation and backfill, rock excavation, bedding, supply, lay and test pipes, supply and construct manholes, house connection, contingencies (20%) and engineering fees (14%).

Table 7.5: Illustrative sewer pipe development material costs

Pipe material	**Diameter (mm)**	**New development area (R/m)**	**Development in existing area (R/m)**
Clay pipes	150	390	511
	200	383	531
	250	434	610
	300	542	749
Concrete pipes	375	700	802
	450	984	1053
	525	1187	1257
	600	1391	1515
	750	1870	1944
	900	2335	2567
	1050	2944	3103
	1200	3618	3792
	1350	4226	4568
	1500	4767	5455
	1650	6052	6200
	1800	6828	7310
	2000	9511	9402
	2250	11592	11592
	2500	13856	13670

Source: JHB Metro (2001)

Notes:
(i) Sewers up to 400mm are assumed to be on average 2m deep
(ii) Sewer outfalls are assumed to be on average 3m up to 1500mm dia and 4m deep > 1500 mm dia.
(iii) Unit cost exclude VAT
(iv) Cost escalations to date, add 10%

7.3.4 Costing approach to sewer rehabilitation

This costing approach is based on a WSA administering between 5000 and 8500 km of sewer pipe network Capital-intensive schemes to reduce flooding should not be conducted in isolation. They should be assessed on a catchment-wide basis, taking the opportunity to investigate the potential to improve receiving water quality by the reduction in the number and frequency of storm discharges. Similarly, any other operational shortcomings of the system should be addressed at the same time. This approach could improve the cost-benefit ratio of a capital-intensive scheme and thereby turn it into a "low-cost" option. All costs are illustrative only.

(i) Annual budget for infrastructure maintenance:

Sum: R20 to R50 million/annum

(ii) Maintenance and rehabilitation based on the following assumptions:

- *1,17 blockages/km pipe/year average,*
- *R400 per blockage to unblock,*
- *Cost of unblocking the blockage:*
  *R400 * 1,17 = R484/km pipe/year that should be replaced/year*

- *Prevention of extra loading on wastewater treatment works due to infiltration into the sewer:*

    Assume: 1,7 ℓ/s/km pipe infiltration during rainy season
- *Water purification cost @ R0,50/m^3.*

    Assume: 6 months for a season
- *Estimate of cost for the pipe which should be replaced*:

    *1,7 * 6 * 2592 * 0,50 = R13 219/km/year*

(iii) Capital cost of trenchless replacement:

Assume replacement cost:	*R230/m*
Useful life:	*60 yrs*
Interest rate:	*10%*

Then cost of replacement:

*R230/m * 1000 * 0,10033 = R23 075/km pipe replaced/year*

- *If sewer already collapsed:*

    Assume: open excavation rate: R1000/m
- *Cost of replacement by open excavation:*

    *(1000 – 230) * 1000 * 0,10033 = R77 254/km pipe/year (discounted)*

(iv) Conclusion on avoiding potential cost if trenchless technology is adopted in sewer/ maintenance programme:

Assume: R468 + R13 219 + R77 254 = R90 941/km of pipe replaced per year

Compared with estimated cost of trenchless technology:

Potential savings: R90 951 – R23 075 = R67 866/km/year

8. ECONOMICS IN CONTROLLING EXTRANEOUS FLOWS

8.1 Benefit-cost analysis framework

8.1.1 Cost-effectiveness analysis

(i) Excessive infiltration/exfiltration

An assumption that the required task or requirement to sustain the integrity of a sewer system can be accomplished by alternative rehabilitation options that might differ in both cost and degree of performance leads to the application of cost-effective analysis (CEA). The effectiveness of each contemplated alternative is expressed in a standard unit and various options are then compared by an analogous procedure and explained in the following paragraph on benefit-cost analysis.

Cost-effectiveness analysis can be a simple or complex procedure, depending on the number of feasible options in rehabilitation, the size and complexity of the service (study) area, the nature of the I/I condition and future system needs. When peak I/I rates are less than 0,1 ℓ/min/m-dia/m-pipe including service connections, the infiltration/inflow is not usually considered excessive and a cost-effectiveness analysis is not required.

The following information is required to determine the extent of the infiltration/ exfiltration and an evaluation survey program should be conducted if the infiltration/ exfiltration is excessive enabling adequate information to be available for the CEA:

- *Peak inflow rates by sub-drainage area*
- *Average and peak infiltration rates by sub-drainage area*
- *Estimates of flows bypassed from system including locations*
- *Projected peak flows tributary to major transport components*
- *Projected average and peak flow tributary to treatment facilities*
- *Capacities of all major existing transport components and treatment facilities*
- *Estimates of I/I reduction levels and costs by sub-drainage area*

To determine whether the flows are excessive, the capital and operating costs of the facilities are estimated for each I/I reduction level and compared with the costs of eliminating the infiltration/ inflow. For a comprehensive example on a cost-effectiveness analysis of a small municipal wastewater collection system, see Metcalf and Eddy (Edition 1981).

(ii) Ratio of sewer collapse to rehabilitation

The ratio of costs of sewer reinstatement after collapse against the rehabilitation alternatives will indicate the relative appropriateness in decision on rehabilitation programme.

$$\text{Cost of Rehabilitation } (C_{rehab}) < \frac{C_{collapse}}{\left(1+\frac{r}{100}\right)^{t}} \qquad (8.1)$$

Where: $C_{collapse}$ = estimated cost of collapse (i.e. disruption and sewer replacement
r = discount rate (say 6% p.a.)
t = number of years before collapse is predicted to take place

It should be noted that although all inputs to formula (8.1) can be estimated, the exact time of failure and cost of total collapse will be difficult to predict.

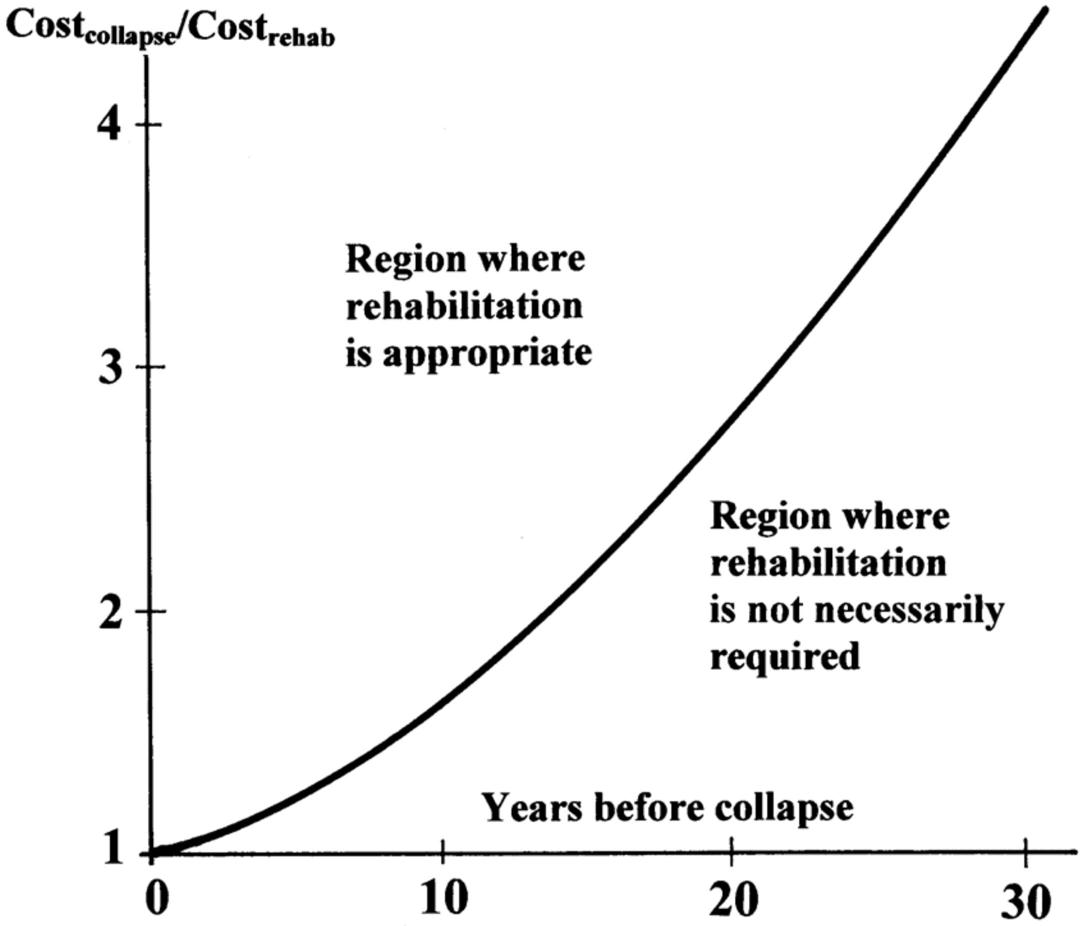


Figure 8.1 Relative costs of rehabilitation and collapse illustrated at 5% discount rate (after Butler and Davis, 2000)

8.1.2 Benefit-cost analysis

(i) Ratio of net benefits to cost (B/C ratio)

The assumption that costs generated and benefits derived from rehabilitation/ replacement of a sewer pipe can be assigned a monetary value allows for a benefit-cost analysis to be conducted.

The technique commonly applied is the ratio of net benefits to costs (B/C ratio). This technique measures the ratio of the present value of future benefits (i.e. at a given discount rate) to the present value of future costs (i.e. discounted at the same rate). The B/C ratio measures the economic efficiency of maximum contribution to the proposed project.

$$\frac{B}{C} = \left[\sum_{t=o}^{T} \frac{B_t}{(1+r)^t} \right] = \left[\sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \right] \tag{8.2}$$

Where: t = an index of time (usually in years)
T = time horizon, the last period for planning

B_t = Total benefits accruing in period t (Rand)
C_t = Total costs accruing in period t (Rand)
r = selected discount rate

If the B/C ratio is >1, then the alternative (project) is economically justified. If B/C ≤1 then the alternative (project) should be rejected or revised.

(ii) Quantification of economic costs and benefits

The benefits derived from any given project are usually more difficult and complicated to value than the costs. All costs and benefits must be valued at economic rates. The gross benefits of new or refurbished water services projects are commonly derived from two key components:

- *increased knowledge about infrastructural assets, and*
- *gradual introduction and upgrading of formal and advanced practices, procedures and systems*

Some of the costs and benefits related to project development will be immediately apparent, others will be more or less unavoidable trade-offs (or externalities). Externalities are costs of benefits generally considered external to direct economic evaluation as they do not benefit or cost the investor directly. They are not easy to quantify in monetary terms and are not commonly included in the calculation of present worth.

The key areas from where benefits for projects can be derived and quantified are related primarily to well-managed infrastructural assets.

(a) *Asset life extension* – based on required levels of service, life span horizon and associated costs.
(b) *Optimized rehabilitation decisions* – knowing rates of decay, current conditions and replacement value of assets.
(c) *Reduced risk control* – knowing impacts of failure and associated risks.
(d) *Appropriate resources management* – cost effective (optimal) maintenance, operations and rehabilitation programmes leading to reduced capital and recurrent costs.
(e) *Improved managerial decision-making and planning* – based on the lowest life cycle costs when considering combinations of conventional and advanced technology.
(f) *Planned preventative maintenance* – introducing a culture of long-term planning and developing strategic plans for rehabilitation, renewal and/or replacement.
(g) *Improved customer service* – reducing exposure to litigation, driving condition programmes, improving customer relations, greater administrative efficiency.

In addition to the above-listed key benefit areas, it is beneficial for WSPs/WSAs to know their external benefits which might amount to the following:

- *minimizing a service gap between supply and demand*
- *minimizing costs*
- *minimizing negative environmental consequences, and*
- *minimizing the economic effect on the regional economy from investment*

The short and long term benefits resulting from implementation of new or rehabilitated projects should be recognized. WSA/WSPs with mature (or old) infrastructural assets can gain some 50 percent in value of medium to long-term benefits if they implement the benefit gain approaches listed in (b), (c) and (e) above.

Water infiltration in sewer pipelines is common and should be included in the peak design flow. A norm of 15% of the dry weather flow allowance for extraneous flows is a generally acceptable standard. The flows exceeding the 15% norm will result in pipe capacity problems and an unnecessary increase in sewer discharge volumes and treatment costs. A reduction in the infiltration/inflow rates will not only save on sewerage treatment costs, but may defer capital expenditure for the upsizing of sewer pipelines and water care works. The decision to solve or ignore an infiltration problem should therefore be based on a benefit-cost analysis.

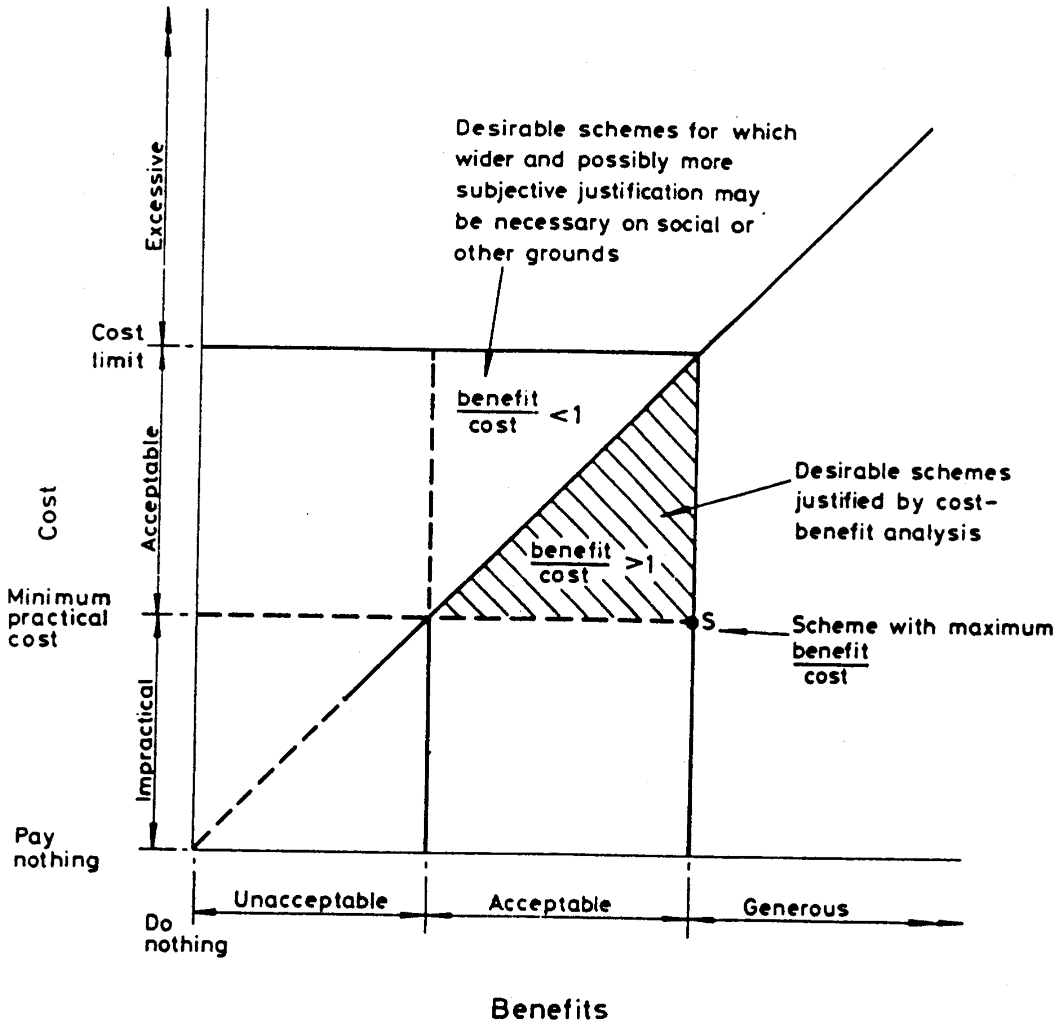


Figure 8.2. Approach to selection of alternatives by cost-benefit analysis (after CIRIA, 1998)

8.2 Benefit-cost-risk analysis

8.2.1 Purpose of benefit-cost-risk analysis

The purpose of benefit-cost-risk analysis is to quantify the costs and benefits of various rehabilitation alternatives with regard to rehabilitation (or sustained integrity) of the overall system. The key objective is to determine the losses associated with various failures and the optimal level of system reliability.

8.2.2 System engineering and economic reliability

(i) Engineering reliability

Engineering reliability of a wastewater system is defined as the reliability specified implicitly or explicitly through standards to which the system must be designed to meet those standards at minimum cost.

(ii) Economic reliability

Economic reliability is defined according to the standards where the system reliability is selected for the system to minimise the total socio-environmental cost. The optimal level of reliability is the value of benefits minus costs (B – C) and depends on the unique situation of each system and the alternative selected.

8.2.3 Quantitative risk analysis

(i) Risk assessment for a sewer system

A risk can be defined as the product of the likelihood of an event and the consequences of that event. The consequences are rather difficult to define and are most commonly attached to the risk to human life. However, to determine the risk associated with the poor condition and performance of a wastewater system would be fare more complex. To assess the risk for such a system, it is necessary to determine individual components of risk and combine them together to obtain the overall risk situation. A risk assessment is either carried out as a quantitative or qualitative analysis.

(ii) Estimation of probability and frequency in qualitative risk analysis

It is essential to consider the combination of events in the assessment of the risk of a system or its vital components. The events are represented by a combination of probabilities and frequencies. This is commonly explained as follows: Two possible events A and B are considered causing C and generating the following probabilities and frequencies:

Probabilities: $P_{A \text{ or } B} = P_A + P_B - P_A P_B$ (8.3)

$P_{A \text{ or } B} = P_A + P_B$, if P_A and P_B are smaller than $P_{A \text{ and } B} = P_A * P_B$ (8.4)

Frequencies: $F_{A \text{ or } B} = F_A + F_B$ (8.5)

$F_{A \text{ or } B} = F_A * F_B * (\tau_A + \tau_B)$ (8.6)

Where: τ_A and τ_B are the duration of the events A and B

Units of frequency are expressed as occasion/year (occ/yr). Frequencies can be multiplied by probabilities.

(iii) Quantifying the risk costs of sewer pipe failure

The cost of risk to the WSA or WSP needs to be assessed for all failures ranging from those needing minor maintenance to major catastrophic structural failures. The reduction or avoidance of risk needs to be quantified as a benefit to the WSA/WSP.

Current Risk Cost (Benefit) = Probability of Failure within next 12 months * cost of the consequence of Failure (8.7)

This approach can assist in the identification of the components that might have a high probability of failure (or highest risk to the WSA/WSP). typical consequences of failure can be listed as follows:

- *Effect on public health (potential loss of life*
- *Damage to private property*
- *Effect on business capacity*
- *Effect on essential services*
- *Disruption to traffic or public transport*
- *Inconvenience to residents (ratepayers) due to repair cost (e.g. digging, access, etc.)*
- *Availability of spare materials*
- *Cost of providing the service during failure*
- *Damage to the environment*
- *Actual cost of the repair*
- *Public image/public relations loss*

(iv) Single/multi-failure state and costs

It should be noted that in some systems, a multitude of failures can take place. The timing of a failure is likely to affect the cost. The cost of failure excludes both the cost of the lost product and the cost of repair (replacement). For fully repairable single failure state system, the following applies:

$$C_{failure} = [(CR + CLP) * u] * SOT \qquad (8.8)$$

Where:
CR = repair cost per hour
CLP = cost of lost production per hour
u = system unavailability (probability of failure)
SOT = system operating hours per annum (i.e. typically 8760 hours)

The following applies for a fully reparable, multi-failure state system:

$$C_{failure} = [(CR_1 + CLP_1) * U_1 + (CR_2 + CLP_2) * U_2] * SOT \qquad (8.9)$$

Where:
CR_1, CR_2 = repair cost per hour for failure state 1 and state 2 respectively
CLP_1, CLP_2 = cost of lost production per hour for failure state 1 and state 2 resp.
U_1, U_2 = system unavailability for failure state 1 and state 2 respectively
SOT = system operating hours per annum (full year = 8760 hours)

The total operating cost (C_{OP}) is the sum of the failure costs, the engineering charge costs (C_{EC}), the fixed maintenance costs (C_{FM}) and the consumable costs (C_{CC}). Since the cost of failure calculation accounts for operating hours in one year, that cost must be multiplied by the anticipated lifetime of the system:

$$C_{OP} = [(C_{EC} + C_{FM} + C_{CC} * C_{failure}) * \text{years of life}] \qquad (8.10)$$

8.3 Requirements and assumptions applied in economic evaluation

8.3.1 Life-cycle costing in economic analysis

(i) Life-cycle cost components

Life-cycle costing is a dynamic approach which deals with changing economic factors by accommodating year-by-year-changes in price inflation, price changes, regulatory requirements and variations in replacement and O & M costs. The method allows for a conversion of changing future costs and benefits to a common time basis by means of a lump sum present worth method. In this way, the total cost of rehabilitation or replacement over the full life span can be determined.

Table 8.1. Life-cycle cost components

LCC component	**Procedure**	**Incremental annual costs**
Interest/opportunity cost	Total capital cost at annual interest rate (%)	C_1
Depreciation of system component	Depreciate costs of components over estimated life span	C_2
Operating costs	Based on labour, plant, materials and energy requirements at unit life	C_3
Maintenance costs	Estimated at proportional percentage of the total capital cost	C_4
Rehabilitation costs	Assumed to be funded from depreciation provision	As per C_2
Decommission/demolition	Estimated value at the end of the life span	C_5
Annual Life Cycle Cost (LCC)		$\mathbf{C_{LCC}}$

(ii) Planned and unplanned life-cycle costs

The estimate of planned and unplanned life-cycle costs provides economic insight into the various cost components of a system and identifies the specific information required to make such estimates into the future.

- *Planned life-cycle costs* – include expenditures and user costs related to the procurement and maintenance phases with regard to the life-span of a system (i.e. capital costs and maintenance.
- *Unplanned life-cycle costs* – cost related to damages which might occur to a system's component(s) primarily due to natural or man-caused hazards.

The total life-cycle cost (TLCC) including planned and unplanned costs is represented as follows:

$$\mathbf{TLCC = CPO + CPU + CUO + CUC} \qquad (8.11)$$

Where: CPO = planned costs incurred to the system owner/developer
CUO = unplanned costs induced upon the owner/developer of a system
CPU and CUC = costs associated with planned and unplanned costs respectively

(iii) Example of life-cycle costing for sewer pumping plant

The following procedure is a recommended guideline in life cycle costing of a sewer pumping plant.

$$LCC = [C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d] \quad (8.12)$$

Where:
- C_{ic} = initial costs, purchase price (pump, system, pipe, auxiliary services)
- C_{in} = installation and commissioning cost (including training)
- C_e = energy costs (predicted cost for system operation, including pump driver, control and any auxiliary services)
- C_o = operating cost (labour cost of normal system supervisor)
- C_m = maintenance and repair cost (routine and predicted repairs)
- C_s = down time and lost of production costs
- C_{env} = environmental cost (contamination from pumped liquid and auxiliary equipment)
- C_d = decommissioning and disposal cost (including restoration of the local environment and disposal of auxiliary services)

Appendix E1 and E2 illustrate the relative costs of various sewage pumping plans and how the distribution costs may vary with pump size and utilization.

8.3.2 Assumptions for a comparative economic evaluation

Illustrative values required for a comparative economic evaluation are listed below:

• *Cost of capital*	*12% per annum*
• *Rate of inflation*	*7% per annum*
• *Capital repayment period*	
Civil work	*30 years*
Electrical/mechanical	*15 years*
• *Composition of cost for new works*	
Civil work	*60%*
Mechanical	*32,5%*
Electrical and instrumentation	*7,5%*
• *Planning horizon (illustrative)*	*21 years*
• *Economy of scale functions for*	*1994*
• *Construction cost escalation*	*8% per annum*
• *Repayment period for capital project of less than R2m*	*5 years*
• *Repayment period for capital project of less than R10m*	*10 years*

An illustration of life-cycle cost optimisation is given in Figure 8.4. This procedure enables the WSAs/WSPs to select the rehabilitation/replacement alternative which will be affordable and suitable to their circumstances.

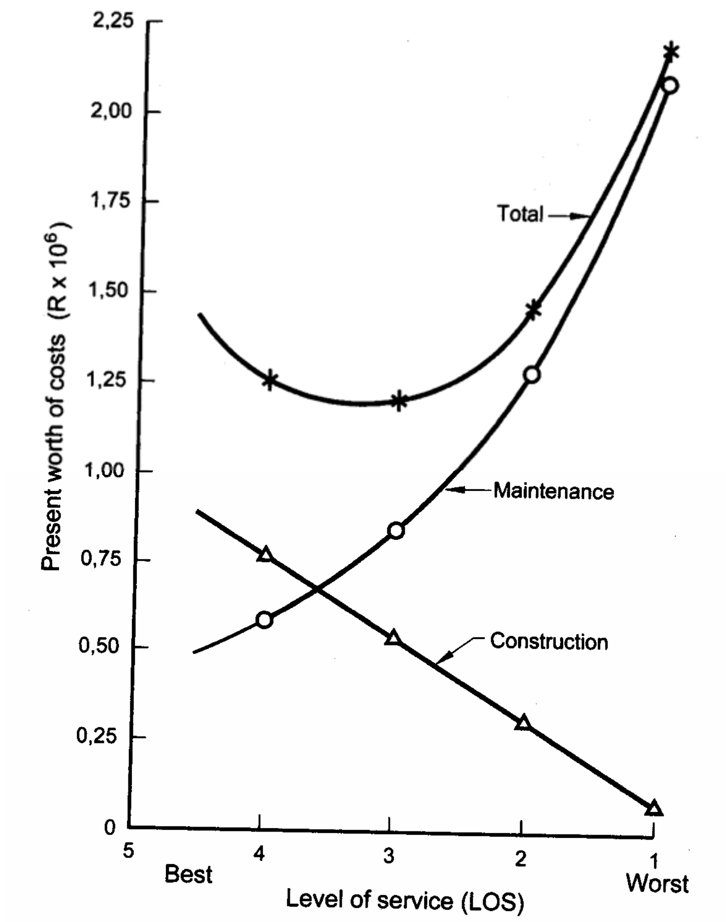


Figure 8.3. Optimization of life cycle costs (after Red Book, 2003)

8.4 Benchmarking in wastewater management

8.4.1 The concept of benchmarking

In principle, benchmarking can be defined as an approach to increase the economic efficiency of a water services utility to sustain quantity and improve quality of water services.

The following are two key methods in benchmarking:

- *Metric benchmarking* – is a quantitative comparative assessment that enables organisations to track internal performance over time and to compare their performance against that of similar organisations.
- *Performance process benchmarking* – involves a process of identifying other organisations that carry out the same activity in a better manner to compare results and ways taken in achieving best methods.

Table 8.2. Benchmarking methods and objectives

Benchmarking method	Objectives	Performance measurements
Metric benchmarking	• To determine factors outside of management control, influencing the apparent poor performance • To confirm improved performance against actions taken	• Performance ratios (e.g. trending charts, league tables, etc.) • Explanatory factors outside of management (e.g. scale of operation, inherited assets, etc.) • Internal data • External data • Additional techniques for data analysis • Key indicators (e.g. cost, efficiency of service indicators, explanatory factors, etc.)
Process (performance) benchmarking	• To make changes that will lead to an improvement • To find best practices and best "bench-marking partners"	• Select benchmarking partners (peer approach) • Determine best practices • Top down approach • Bottom up approach • Multifunctional team • Focus on specific processes

Sources: IWSA (1998) and WRC (2002)

8.4.2 Benchmarking practices in South Africa

WRC (TT168/02) stated that as South Africa is now fully integrated into the world economy, it faces challenges in the water services sector from the effects of globalisation; Consequently, the water services authorities (i.e. municipalities representing local government) will have to ensure acceptable levels of water services to all communities. The expectations of water users will be based on information gathered from their environment, but also from access to international data sources (international review, the Internet, etc.).

Public opinion is gradually being stimulated by the norms and quality of service at international levels and it is envisaged that the situation will become increasingly aligned with these international norms. The same will apply to the water services providers and, in order to keep competitive, they will have to meet international standards of service provision in terms of quality, quantity and cost.

According to IWSA (1998), the methods for benchmarking are recognised internationally as suitable tools for measuring performance and incentives in improving the performance of an organisation. The Institution of Municipal Engineering of Southern Africa (IMESA) together with the National Productivity Institute (NPI) determined the key performance indicators (KPIs) to enable the WSAs and WSPs to implement benchmarking mechanisms at local government level. The KPIs selected in the first round of the benchmarking implementation process are as follows:

- *Water supply* – length of water mains (km), number of pumps, reservoir capacity, number of pipes bursts (p.a.), number of units sewered, informal standpipes, water consumption (p.a.), total staff, staff costs, total costs, total income.
- *Sewerage* – length of sewers (km), pumpstations, capacity of WWTW (Mℓ/d), formal and informal services points, flow of effluent (Mℓ/d), blocked sewers (p.a.), total staff, operating budget, staff costs, total costs, total income.
- *Roads and stormwater* – total length of roads (km), roads area (ha), total length of stormwater pipes (km), number of potholes filled (p.a.), total staff, staff costs, total costs, total income.

REFERENCES

Barta, B. (1999). Guidelines for SWAM consultants for data preparation, Return flows from urban water use. Submission to DWAF.

Barta, B. (2004). *Urban water services system analysis and optimisation*. Draft of PhD thesis, University of the Witwatersrand, Johannesburg.

Butler, D. and Davies, J.W. (2000). *Urban Drainage*. Spoon Press, London, UK.

Chadwick, A. and Morfett, J. (1993). *Hydraulics in Civil and Environmental Engineering*, 2nd Ed, E & F.N. Spon.

Charles, T.A. (1974). *Water Supply*, 2nd Ed, London, E. Arnold.

CIRIA (1998a). *Dry Weather Flow in Sewers*. Report 177, London, UK.

CIRIA (1998b). *Low-cost Options for Prevention of Flooding from Sewers.* Report C506, London.

City of Johannesburg, Wastewater Department (1994). Township sewer design standards/ procedures.

Civil Engineering Reference Book (1995). *Sewage and sewerage disposal*. 4th Ed., Butterworth Heinemann Ltd., UK, pp.29/26.

DWAF (2001). National health threatened by crumbling sewerage systems. *Engineering News*, Johannesburg, July.

DWAF (2003). Sanitation struggle continues. *Engineering News* with R Kasrils, Pretoria, August/ September

Farmer, H. (1975). Sewer system evaluation and rehabilitation cost estimates. *Water and Sewage Works*, April

GHSPD (2000). *Guidelines for Human Settlement Planning and Design*. CSIR Building and Construction Technology, Pretoria, RSA (Red Book).

GHSPD (2003). *Guidelines for Human Settlement Planning and Design*. CSIR Building and Construction Technology, Pretoria, RSA, Revised version, August (New Red Book).

GLS Inc. (1997). Sewerage Master Plan for Moreletaspruit catchment area. Greater Pretoria Metropolitan Council, July.

Godshall, R. (2003). Determining the optimal sewer rehabilitation/repair strategy based on limited pipe condition s information (Internet).

Harman, W.G. (1918). Forecasting sewage in Toledo under dry-weather conditions. *Engineering News Record*, 80, 1233.

Haswell, J. (1999). The pipeline lifecycle. *Pipes & Pipelines International*. Nov/Dec

Hine, A.H. and Stephenson, D. (1985). Sewer flow hydrographs. *IFME IXth Congress*, Brighton, UK.

IAMM (1996). New Zealand Infrastructure Asset Management Manual. November.

IWSA (1998). Use of performance indicators and performance benchmarking in the North American water industry. *Proc. Conf. Master Plans for Water Utilities.* Prague, Czech Rep. June, 19-87.

Metcalf and Eddy Inc. (1981). *Wastewater Engineering*, 2nd ed., New York: McGraw-Hill.

Metcalf and Eddy Inc. (1991). *Wastewater Engineering: Treatment, Disposal and Reuse*, 3rd ed., McGraw-Hill, New York.

National Water Act (1998). Act 36 of 1998, Pretoria, RSA.

Phalafala, M.R. (2003). *Impact of stormwater ingress and groundwater infiltration on municipal sanitation services*. MSc(Eng), University of the Witwatersrand, Johannesburg.

Pollet (1994). Extaneous flows in sewer: the Durbanville experience. *IMIESA*, May.

Qasim, S.R. (1986). *Wastewater Treatment Plants: Planning, Design and Operation*. CBS International Editions.

Rendell, F. (1999). *Water and Wastewater Project Development*. Thomas Telford Publishing, UK.

Reynolds, J.H. (1995). Infiltration: A Case Study of Control, *Municipal Engineer.*

Selva Kumar, A., Clark, R.M. and Sivaganesh, M. (2002). Cost for water supply distribution system rehabilitatio, *Jnl. Water Resources Planning and Management*, July/August.

Stephenson, D. (1981). *Stormwater Hydrology and Drainage.* Developments in Water Science 14, Amsterdam-Oxford-New York, E.lsevier Scientific Publishing Company.

Stephenson, D. (1982). Computer analysis of Johannesburg sewers, *Proc. IMIESA* April, 13-23.

Water Services Act (1997). Act 108 of 1997, Office of the President, No. 1662, Pretoria, RSA.

Wessels, J.W. (2002). Selection and grading of sewers for rehabilitation, Tshwane Metropolitan Municipality, *IMIESA*, May.

APPENDICES

APPENDIX A.

Table A.1. Return ratio in wastewater discharged to water supplied

Item	Zoning/Consumer Group	Measuring unit/day	Water supply	Sewerage outflow	Return ratio
1.	RESIDENTIAL				
1.1	Low cost housing – erf up to 250 m^2	kℓ per erf	0,7	0,6	0,85
1.2	Small sized erf up to 500 m^2	kℓ per erf	1,2	0,7	0,58
1.3	Medium sized erf up to 1000 m^2	kℓ per erf	1,6	0,8	0,50
1.4	Large sized erf up to 1500 m^2	kℓ per erf	2,0	0.8	0,40
1.5	Extra large erf in excess of 1500 m^2	kℓ per erf	2,4	0.8	0,33
1.6	Cluster housing up to 20 units/ha	kℓ per unit	1,2	0,7	0,58
1.7	Cluster housing up to 40 units/ha	kℓ per unit	0,8	0,6	0,75
1.8	Cluster housing up to 60 units/ha	kℓ per unit	0,7	0,6	0,85
1.9	High rise flats (± 50 m^2 per unit)	kℓ per unit every 50 m^2	0.6	0,6	1,00
1.10	Guest and boarding houses, hostels, hotels, retirement centers and villages, orphanages, etc. (with an FSR)	kℓ per 100 m^2 development	0,9	0,9	1,00
1.11	Agricultural holdings (house plus out buildings)	kℓ per holding	4,0	1,4	0,35
2.	BUSINESS DEVELOPMENTS				
2.1	General business with an FSR	kℓ per 100 m^2	0,8	0,8	1,00
2.2	Warehousing (including up to 20% offices)	kℓ per 100 m^2 development	0,6	0,4	0,67
2.3	Industrial (dry)	kℓ per 100 m^2	0,4	0,3	0,75
2.4	Industrial (wet)	kℓ per 100 m^2	specific	specific	specific
2.5	Garage or filling station	kℓ per 100 m^2	1,2	1,0	0,83
2.6	Car wash facility	kℓ per wash bay	10,0	10,0	1,00
3.	GENERAL TYPE OF DEVELOPMENT				
3.1a	Club buildings	kℓ per 100 m^2	0,3	0,3	1,00
3.1b	Club grounds	kℓ per ha	15,0	zero	no return
3.2a	Stadium	kℓ per 1000 people	1,5	1,5	1,00
3.2b	Stadium grounds	kℓ per ha	15,0	zero	no return
3.3a	Park buildings	kℓ per 100 m^2	0,4	0,4	1,00
3.3b	Park grounds	kℓ per ha	15,0	zero	no return
3.4a	Nursery (sales area)	kℓ per 100 m^2	0,8	0,8	1,00
3.4b	Nursery (planting and production area)	kℓ per ha	15,0	zero	no return
3.5a	Hospital buildings	kℓ per 100 m^2	1,2	1,2	,00
3.5b	Hospital grounds	kℓ per ha	15,0	zero	no return
3.6a	Church buildings	kℓ per 100 m^2	0,3	0,3	1,00
3.6b	Church grounds	kℓ per ha	15,0	zero	no return
3.7a	School, crèche, educational buildings	kℓ per 100 m^2	0,6	0,6	1,00
3.7b	School, crèche, educational grounds	kℓ per ha	15,0	zero	no return
3.8	Municipal, governmental developments	kℓ per 100 m^2	0,6	0,6	1,00
3.9	Private open space	kℓ per ha	15,0	zero	no return
3.10	Parking grounds	kℓ per ha	3,0	zero	no return

Source: Adapted and adjusted from Tshwane MM by-laws (revised version, August 2003)

APPENDIX B

Prediction of future reliability of a system

To evaluation and predict future reliability of a water services system (or it subsystems) requires investigating the system complexity, management practices, maintenance programme and costs. A comprehensive programme layout proposed for predicting the reliability of a system is illustrated in Figure B.1 The broad criteria in this assessment approach are compliance, safety, capacity and costs.

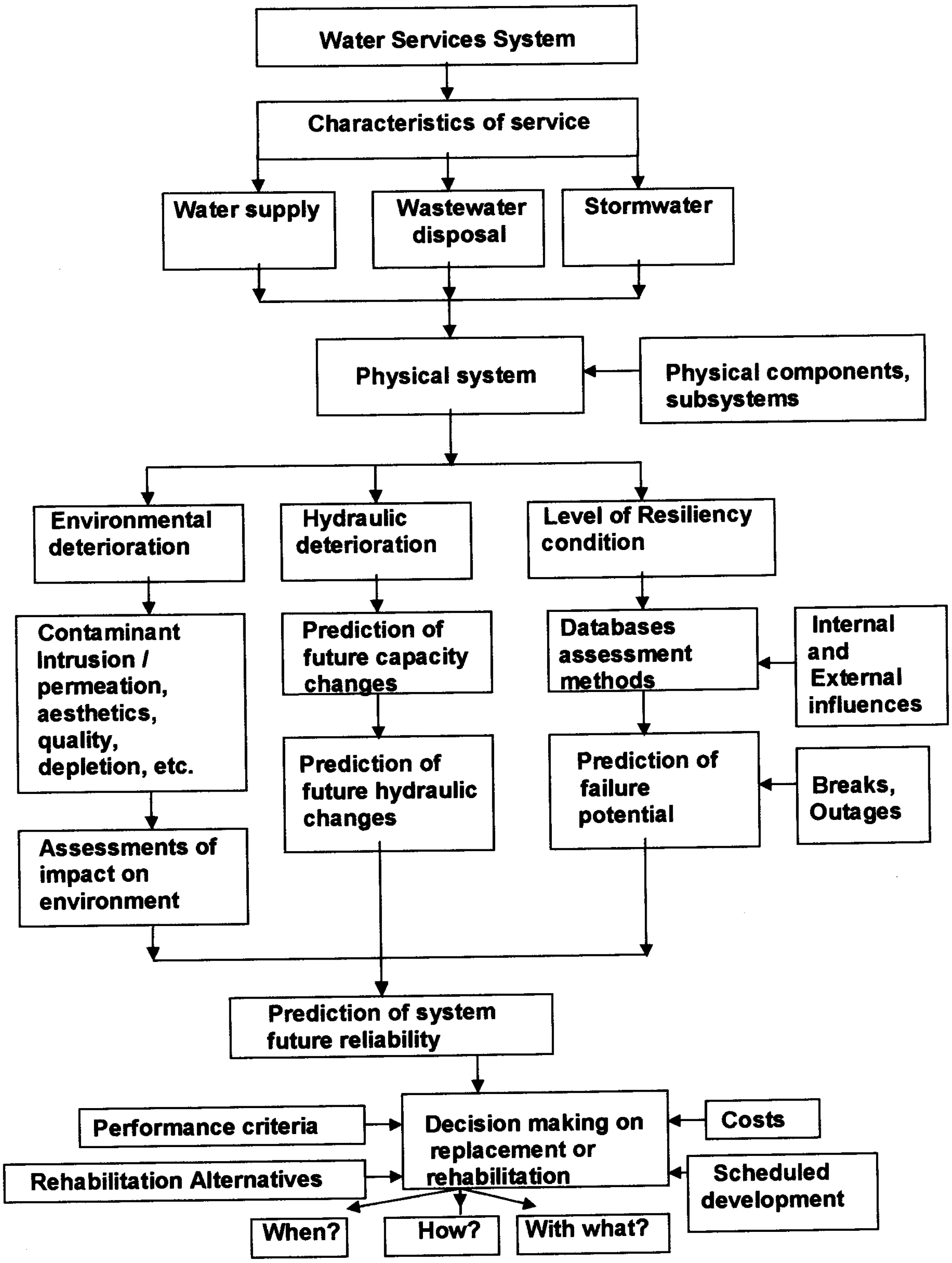


Figure B.1. Programme for predicting future reliability of a system

APPENDIX C

Determining economic life of an existing asset

C.1 Example for determining economic life of an existing asset

The economic life of an infrastructural asset is defined from the so-called "bath tub curve" by various techniques (e.g. age factor or utilisation factor method).

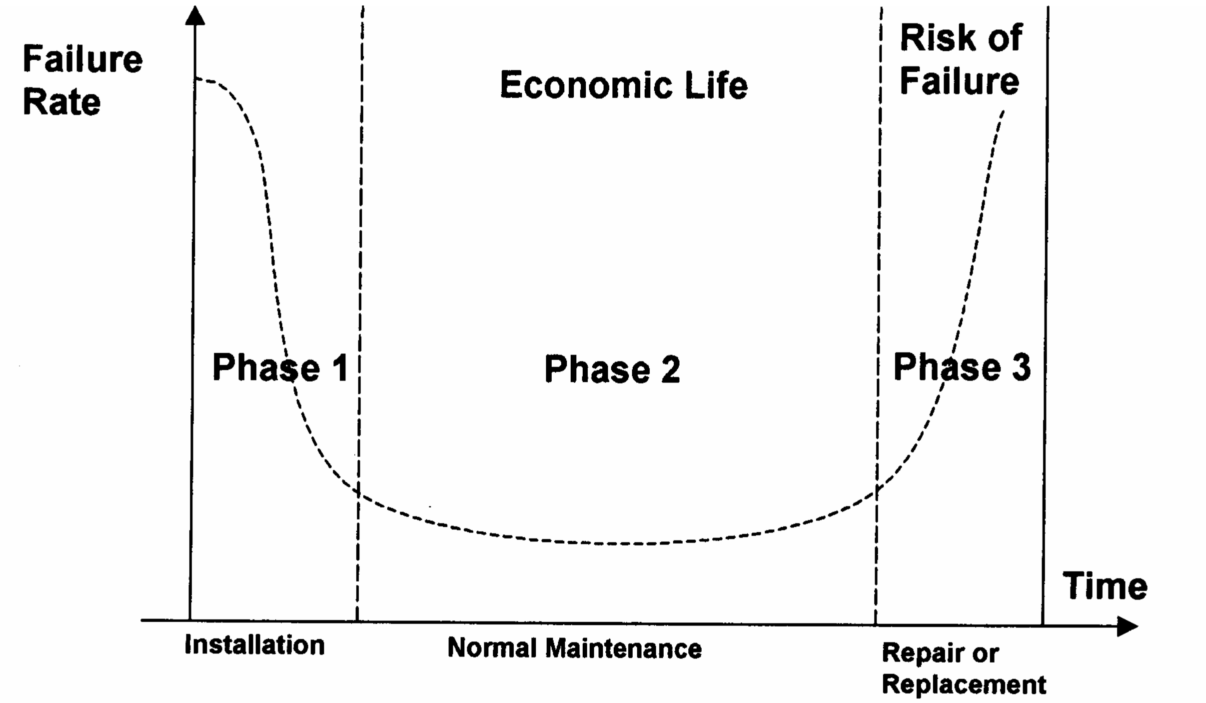


Figure C.1. Representation of reliability by the "bath tub curve"

- *Economic life of an asset using Age Factor technique*

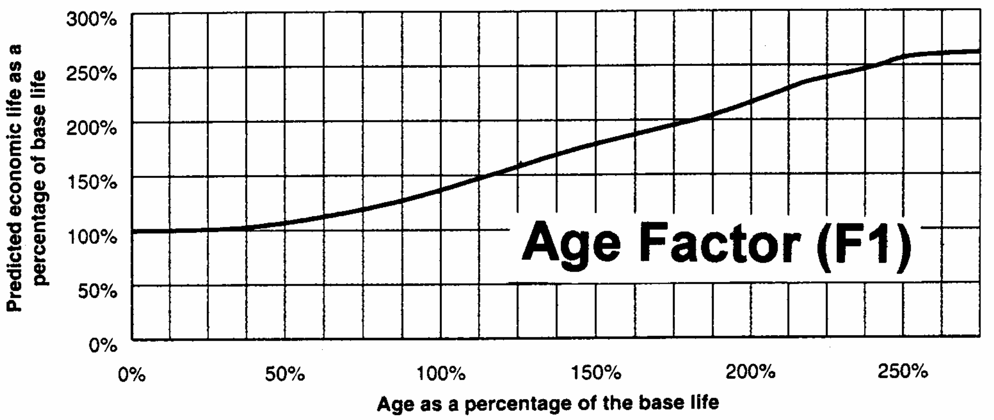


Figure C.2. Prediction of asset economic life using Age Factor (F1)

Example: Asset useful (base) life = 40 years
Asset current age = 25 years

Therefore the age of the asset as a percentage of the estimated service life = 25/40 = 62.5%
Therefore the economic life of the asset as a percentage base life = 110% (from graph)
Therefore the economic life of the asset = 40 x 1.10 (F1) = 44 years
Therefore the remaining economic life of the asset = 44 – 25 = 19 years

C.2 Written down value (WDV)

Using straight line depreciation, the written down value can be determined as follows:

WDV = (effective life – life to date) * replacement value / effective life (C.1)

The values of effective life recommended for various water services infrastructure assets are listed in Table C.1 below. However in South Africa, it is necessary to use the values recommended by GAAP and GAMAP.

Table C.1. Effective life values of wastewater infrastructure assets

Type of asset		**Useful life (years)**
General assets	Buildings	50 – 100
	Houses/toilet blocks	50 – 100
	Access roads:	
	Unsealed surfaces	-
	Wearing surfaces	20
	Bridges	38 – 80
	Culverts	10
Wastewater assets	Reticulation mains	70
	Manholes	20 – 50
	Trunk mains	90 – 100
	Pumping stations: Civil	50
	Mechanical/electrical	15
	Rising mains	
	Treatment plants: Civil	50
	Mechanical/electrical	15 – 25
Written down value (WDV)		

APPENDIX D

Cost comparisons for municipal sewer (Phalafala, 2003)

Example: A sewer pipe at a gradient of 1/300 is designed to take a peak dry weather flow of 1000 ℓ/s over 8 hours a day. Groundwater ingress could amount to 200 ℓ/s and stormwater ingress 600 ℓ/s. Assume the main is 10 km long and the cost of the sewer reticulation is equal to the cost of the sewer main.
Comparison of costs:

(1) Allowing for a total ingress of up to 800 ℓ/s and increasing sewer pipe.
(2) Take preventative measures at design stage to reduce ingress to 300 ℓ/s.
(3) Do rehabilitation at 20 year life by relining to reduce ingress to 300 ℓ/s.
(4) Construct stormwater detention at WWTP.
(5) Enlarge WWTP to take full flow.

Subsequently (1) and (5) should be added.

Using (1):

(a) Cost of sewer to take peak DWF of 1 000 ℓ/s
$D_d = \lambda Q^2/2g(T/4)^2\ S = [0.015 \times 1^2 / (20 \times 0.785^2 \times 1/200)]^{1/5} = 0.754$
Cost $= 0.754 \times$ R2 000/m/m x 10 000 x $2/10^6$ = R30.1 m

(b) To accommodate peak WWF of 1 800 ℓ/s
$D_w = 0.95$, ∴ Cost = R38.1 m

Using (5):

(a) Cost of WWTP to take peak 1 000 ℓ/s = R50 m

(b) Extra cost of pipework to take additional 1 800 ℓ/s = R10 m
larger settling tank and units = R 8 m

Total additional cost to handle WWF = 38.1 – 30.1 + 10 + 8 = R26 m

2. Additional cost of better manholes, jointing, high gulleys, inspections = R12 m
Additional cost of sewers to take 1 200 ℓ/s = R 2 m
Additional cost of WWTP = R 3 m

TOTAL R17 m

3. Rehabilitation cost of 750 mm sewer, etc. = R11 m
Additional cost of WWTP = R20 m

TOTAL R31 m

4. Wet weather storage 0.8 m^3/s x 24 hr x 3600 s = 69 000 m^3
Cost of storage dam = R 3.5 m

Additional cost of WW sewers	=	R 8 m
Additional sewer cost for infiltration	=	R 2 m
TOTAL		R13.5 m

It may be concluded that for this example, case 4 (provision of wet weather storage) is the most economical.

In South Africa as a whole, the cost implication of water ingress is thus estimated to be R600 million spread over existing sewer services with an estimated capital value of R3 billion. By selective management and maintenance, a cost on installations of some 20% could be saved. The biggest cost savings could be on WWTP's and provision of wet weather storage appears the most viable methods of reducing these costs. Rehabilitation costs are high, but it if can avoid increasing WWTP costs.

APPENDIX E

Life-cycle costing of sewage pumps

Table E.1. Distribution of costs over 20 years – 30% utilisation

Pump (Head m)	**A10**	**B10**	**C10**
Q (ℓ/s)	20	150	500
H (m)	10	10	10
Power (kW)	2.6	19.1	61.3
Purchase cost (%)	22	17	16
Energy cost[1] (%)	60	73	73
Maintenance[2] (%)	18	10	11
	100%	100%	100%
Pump	**A20**	**B20**	**C20**
Q (ℓ/s)	20	150	500
H (m)	20	20	20
Power (kW)	6.0	37.0	124.1
Purchase cost (%)	14	12	10
Energy cost[1] (%)	76	81	86
Maintenance[2] (%)	10	7	4
	100%	100%	100%
Pump	**A40**	**B40**	**C40**
Q (ℓ/s)	20	150	500
H (m)	40	40	40
Power (kW)	12.4	77.4	245.1
Purchase cost (%)	13	`0	8
Energy cost[1] (%)	80	84	88
Maintenance[2] (%)	7	6	4
	100%	100%	100%

[1] Energy. Costs based on present prices, no allowance for inflation or loss of efficiency due to blockages or wear during the life time of the pump.

[2] Maintenance costs are for routine maintenance and repairs including spare parts. Excludes unscheduled maintenance such as unblocking pumps.

Table E.2. Effects of sewage pump utilisation on costs

Pump	**A10**			**B10**			**C10**		
Utilisation	5%	30%	60%	5%	30%	60%	5%	30%	60%
Purchase cost %	60	225	12	57	17	9	56	16	8
Energy %	28	60	66	40	73	78	42	73	78
Maintenance %	12	18	22	3	10	24	2	11	14
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pump	**A20**			**B20**			**C20**		
Utilisation	5%	30%	60%	5%	30%	60%	5%	30%	60%
Purchase cost %	48	14	8	47	12	7	41	10	6
Energy %	43	76	81	51	81	85	58	86	89
Maintenance %	9	10	11	2	7	8	1	4	5
	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pump	**A40**			**B40**			**C40**		
Utilisation	5%	30%	60%	5%	30%	60%	5%	30%	60%
Purchase cost %	47	13	7	41	10	5	36	8	4
Energy %	48	80	85	58	84	87	63	88	91
Maintenance %	5	7	8	1	6	8	1	4	5
	100%	100%	100%	100%	100%	100%	100%	100%	100%

A pump with 5% utilisation could be a typical storm pump
A pump with 30% utilisation could be a typical network pumping station
A pump with 60% utilisation could be an inlet or Return Activated Sludge pump

Note: It should also be remembered the percentage of costs attributable to energy will be higher than those shown in Tables E.1 and E.2, if rising energy costs due to inflation and taxes are taken into account. Plus additional energy consumption arising from lower actual efficiency during the life time of the pump and additional energy from running partially blocked sewage pumps

APPENDIX F

Weighting factors for grading inspection of sewers

Backfall	20
Bad bead	5
Blockage	0
Broken pipe	100
Collapsed pipe	100
Crack	25
End bad BT	20
End critical BF	40
End of backfall	20
End of inspection	0
Fatty deposits	0
High flow level	0
Joint shifted	25
Lateral left	0
Lateral right	0
Lateral top	0
Misalignment (down)	10
Misalignment (left)	15
Misalignment (right)	15
Misalignment (up)	25
Misalignment weld	25
Misalignment	20
Obstruction	0
Pipe broken	100
Pipe collapsed	100
Pipe cracked	25
Pipe damaged	50
Pipe deformed	15
Pipe ovality	25
Rocks in pipe	0
Root intrusions (branch)	17
Root intrusions (bush)	17
Root intrusions (fine)	17
Shifted joint	25
Silt deposits	0
Silt	0

Source: Wessels of Tshwane MM (2002)

APPENDIX G

Recommended types of sewer rehabilitation methods

Problem/Requirement	**Rehabilitation Method**
Structural	Excavation and replacement Insertion Speciality concrete
Misaligned piped	Excavation and replacement
Additional capacity needed	Excavation and replacement or duplication
Avoid reduction in capacity	Excavation and replacement
Damaged pipes	Excavation and replacement
High infiltration	Grouting Sliplining
Leaking joints	Grouting Lining
Circumferential cracks	Grouting Lining
Small holes	Grouting Lining
Radial cracks	Grouting
Roots	Sliplining Re-jointing
Corrosion	Sliplining Mortar lining
Broken pipes in busy areas	Cured-in-place lining Sliplining Coating No-dig pipes
Non-circular pipe	Cured-in-place inversion lining
Mild deterioration	Cured-in-place inversion lining
Corrosion	Lining Coating Cured-in-place lining
Corrosion by waste	Sliplining Speciality concrete Lining Coating Cured-in-place inversion lining
Misaligned pipes and bends	Cured-in-place inversion lining

Note: Speciality concrete includes sulphate resistant additives such as potassium silicate and calcium aluminates