SEWER SYSTEM PLANNING MADE SIMPLE – FOR SMALL LOCAL AUTHORITIES

Report to the
Water Research Commission

by

HE Jacobs, K Fair, AH De Klerk and B Bester
on behalf of
Stellenbosch University
Institute for Water and Environmental Engineering

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NOTE

This project consists of 2 products:

1. WRC report No. 1828/1/11.
2. WRC SP 1/10 – Poster: Sewer Infrastructure Estimates 2010. (NOTE: These posters reside with the University of Stellenbosch, Institute for Water and Environmental Engineering. Contact: Dr Heinz Jacobs [hejacobs@sun.ac.za]).

The toolkit devised as part of this project appears in this report as Appendices A-F. For easy reference a separate document of the entire toolkit has been created and placed on the WRC web site (www.wrc.org.za > Knowledge Hub > 1828, scroll down for the report and then the toolkit

EXECUTIVE SUMMARY

Scope of the study

Over the last decade in South Africa there has been a government drive to provide basic services to all residents. This resulted in considerable development in certain areas of the country and particularly in providing new sewer systems.

South African sewer systems and storm drainage systems are designed as separate systems, while the sewer system (SS) is commonly waterborne. Waterborne sewer systems, also called conventional sewer systems, use water as the mode of transport for excrement and other waste. This research project focuses exclusively on separate sewer systems (SSS) and specifically on the planning of waterborne sewer systems. In this context a SS refers to a system of sewer pipes and other infrastructure such as pumps that are needed to transport the sewage from the point of entry to the point of outfall; wastewater treatment is thus excluded by definition.

Key objectives

The terms of reference for this research project described the need for simple tools to assist staff at all levels of local and regional authorities to complete a basic assessment of their sewer systems through compilation of basic inputs and generation of useful outputs. This research also gives structure to the SS planning process (often termed "master planning") and provides a methodology for compilation of a sewer system plan.

The fundamental aim of the project was to develop a product that would be simple with immediate benefits to the local authority, yet would be based on the vast and advanced pool of knowledge available to researchers and specialist consultants. The intention was thus to provide fundamental principles relating to sewer planning and to provide usable tools to the sewer manager and engineer, rather than to structure a comprehensive specification for implementation of proprietary software. In contrast to the advanced software suites available nowadays this study recognised the need for low-technology tools and guidelines to aid relatively small local authorities in moving towards a sewer system plan (SSP), which would ultimately assist in the improvement of planning functions and service delivery.

It is evident from the definitions provided and the knowledge review that sewer planning is inherently complex and that the related planning process is not geared to a low-technology approach. Recognising this complexity while striving towards a low-technology, user-friendly output was the main challenge of this research. The aim of the project was to present a simplified approach to sewer system planning with accompanying tools that could be used directly as a low-technology (non-computer based) method for sewer system planning and to better understand sewer systems and the related planning process. An extensive knowledge review was included in this project.

At this point it should be clear to the reader that the intended use of these tools would be at the level of relatively small (or perhaps poor) local authorities that are hampered by a lack of resources. In many smaller towns computers, and staff with adequate computer knowledge to apply advanced tools, may not always be available at local authority level.

Knowledge review

The knowledge review was extended to also include so-called "grey literature" and key international sources. Consultant's reports were found to provide a large volume of reading matter and data in this regard, in contrast to limited academic publications. A wide search revealed that very few consultants operate specifically in the field of SS planning.

In South Africa sewer systems are designed to convey wastewater flow exclusively. Various design guidelines are available (Little, 2004; City of Tshwane, 2007; CSIR, 2003). Separate stormwater drainage systems exist in parallel for drainage of storm flows, but some groundwater as well as stormwater will ingress the sewer system (Stephenson and Barta, 2005a; Stephenson and Barta, 2005b) and are allowed for partially in SS design criteria. The most recent and arguably the most comprehensive document was produced as an output of WRC project K5-1744 (Van Dijk et al., 2008).

Two pertinent literature references could be traced during the review process addressing SS planning per se in South Africa. The first by Sinske and Zietsman (2001) described the concept of using GIS as a basis for SS planning, while the other by Fair et al. (2008) presents a detailed account of the dynamic planning process. The latter was initiated in view of this research project and aims to describe the comprehensive process in place in large metros.

Three-tiered design philosophy

A three tier philosophy for SS planning in South Africa was proposed as part of this study (Jacobs and Van Dijk, 2009). With due recognition of the complexity of SS planning, both with regards to the system per se and the flow and load transported by it, but also in view of the need for simple procedures which can be used routinely in areas with low service levels, provision is made for the following three-tiered approach:

- The first tier is termed Level 1 and comprises the application of the most basic design rules presented in hard copy format. The Level 1 approach is intended for use in cases where limited technical skill is available, or the scope of work is relatively small with negligible risk. This approach is sufficient only in smaller municipalities and small towns with limited sewer infrastructure. Quite often Level 1 is dominated by minimum requirements for some parameters rather than hydraulic considerations (e.g. the minimum pipe diameter is driven by the required size needed for rodding and to prevent clogging).
- Level 2 entails a more sophisticated approach incorporating design theories that take into account the hydraulics of system elements, requiring a basic analysis of the system or parts thereof. The analysis of a single main sewer, or pump station and rising main are examples of the Level 2 approach. This would typically be the level needed by a medium sized town.
- Level 3 is essential for cities and large metros. Level 3 is the most advanced and requires advanced skill and software tools to conduct planning of extensive sewer systems.

The definition and application of these three tiers could also in future act as a basis for municipalities to describe the level of complexity of work when appointing a consultant to conduct SS planning.

Methodology

The progress of the research moved from assessing existing knowledge to the compilation of draft sewer system planning tools, which were subsequently workshopped in order to gain feedback and improve the concepts to derive tools suitable for practical application. Finally a set of tools were compiled as a project outcome that could be provided to local authorities at ground level. This text provided a detailed account of the process and its outcomes to mainly academic readership. However, feedback obtained during the stakeholder workshops underlined the importance of also making the result available as a wall-mounted poster. A poster-output was subsequently produced as the key application at local authority level. The poster is available separately from the WRC (SP 1/10). The individual tools, components of which have been incorporated on the poster, are included as Appendixes to this report for those requiring more information on any one particular tool.

Workshops

With reference to the initial project proposal for K5-1828 the project team set out to hold workshops with various stakeholders. The idea was to complete workshops with stakeholders in order to establish their needs and interventions and to evaluate the experiences of local authorities in using particular types of tools and planning guidelines. Workshops were hosted by the project team. In order to maximise the impact the workshops intended for this research were combined with other practical training sessions organised for local authorities at different venues in the country, where possible.

The idea was to use these workshops with stakeholders to establish the needs with regards to low-technology tools and guidelines for SS planning. The focus would be on local authorities and other stakeholders involved with SS planning where resources limit the application of expensive high-technology interventions (e.g. specialist consultants or advanced software applications).

Four workshops were held during October and November 2009 at the following locations:

- Cape Town (3 days): collaboration with Institute for Municipal Engineers of South Africa (IMESA) conference, Cape Town International Convention Centre, 28-30 October 2009; all conference break periods were available for workshopping with delegates
- Beaufort West (1 day): site visits to three towns in two Municipalities around Beaufort West on 16 November 2009
- De Aar (1 day): site visits to four towns in three Municipalities in the Pixley Ka Seme region on 17 November 2009
- Worcester (½ day): collaboration with Municipal Infrastructure Grant (MIG) workshop held on 20 November 2009, targeting technical staff of all Municipalities in the Western Cape province.

In addition to the four workshops noted above, a post-project workshop was held at the WISA2010 conference in Durban, 18-22 April 2010, in collaboration with another WRC project team (University of Pretoria; Project K5-1744).

Tools

The eventual tools comprised relatively simple check-lists, tables, graphs and diagrams to aid in the critical steps of the planning process. Despite the availability and application of various propriety software suits for system modelling in South Africa the aim in this research was instead to produce a set of basic hard copy tools. The final toolkit comprised the following components:

- Hydraulic design tool – an aid to understanding the relationships between critical parameters used in basic hydraulics of sewer pipes and a useful way of obtaining a feeling for the required pipe size by means of crude assumptions
- Infrastructure costing tool – a mechanism to estimate the fixed capital cost of sewer infrastructure
- Sewer system planning checklist tool – a method to record progress and guide towards an eventually comprehensive SSP
- Master planning process tool – a schematic description of the SS planning process
- Sewer terms tool – this could be viewed as a sewer terms glossary or mini-sewer-dictionary
- WSDP tool – aimed at simplifying the transfer of information from the SSP to the water services development plan (WSDP).

Hydraulic Tool

The application of the average flow velocity in hydraulics is now accepted to be out-dated and advanced methods are available for determining scouring and sediment transport in sewer pipes (Saatçi, 1990). For the limited application of a simplified tool it was considered necessary to use the average velocity as a means to illustrate some essential relationships, often not understood at the level for which this tool is intended. The hydraulic tool provides graphs to visually illustrate critical relationships between the most notable parameters in sewer flow hydraulics.

Infrastructure Costing Tool

The knowledge review uncovered four types of cost incurred in the installation and operation of a sewer system, namely:

- capital cost (e.g. the cost of constructing new infrastructure)
- operational cost (e.g. electricity for operating pumps, human resources)
- maintenance cost (e.g. repair and refurbishment of ageing infrastructure)
- carbon cost (e.g. the indirect impact on the environment).

Some of these cost types were considered to be set at a technical level higher than what was deemed appropriate for this project. The idea with developing the tool was to start with the most basic cost type (capital) and advance to higher levels of complexity if the need were identified during the workshops. Cost functions would have to be compiled annually by assessing actual costs for various components of sewer construction projects, as per SABS 1200 requirements. These individual costs were integrated to obtain an estimate of what 1 m length of sewer would costs, depending on diameter (in the case of pipes). A similar procedure was followed for pumps, etc. These relatively "fixed" unit values are amenable to amendment at any intermediate stage in the year by increasing the annual base value with a percentage based on the consumer price index (CPI).

Through the workshop-inputs gathered during this study it was found that municipal staff often made their own ad hoc estimates of cost in the absence of better information. In all cases these were based exclusively on capital cost. A clear need for a low-technology tool such as the one presented in this project was noted. The project outcome provides a handy method for estimating sewer infrastructure capital cost.

The infrastructure costing tool was linked to a calendar-format to keep track of the aging information. The poster-calendar would form part of the outcome and would be printed annually, with distribution to stakeholders whose contact details would be maintained by the project team (Stellenbosch University) for the trial period. The project team committed to conduct the administration, poster design, printing and distribution for three years.

Sewer System Planning Checklist Tool

Consultants use in-house checklists to assess the data required during the compilation of a SSP. Two such lists could be obtained as part of this project (from engineering consultants GLS and Aurecon), but in both cases the checklists were not amenable for application at Municipal level. The use of a checklist to describe the particular SSP inputs, and more basically the progression of information from raw data to a final SSP, was considered a convenient tool.

The final checklist was based on a checklist used by GLS Consulting for estimating the workload and cost required to compile a SSP. The checklist was applied in many Municipalities of the Western Cape (as part of non-project related work by GLS Consulting) and the checklist included a few years of development prior to this project.

Master Planning Process Tool

It was considered imperative to include a process description tool in the SSP toolkit. The concept of process description in terms of sewer systems is not new. The knowledge review conducted as part of this study underlined the fact that various authors in the past have presented descriptions of sewer systems and the sewer planning process. None of these specifically attempted to simplify the process in any way, which is the specific focus of this project. It became apparent with progression of the project that a well designed and presented SSP checklist and poster would supersede a mere description of the SS planning process as an independent tool. However, the process description could be used as an aid to understanding the checklist tool.

Sewer Terms Tool

A need was noted to clarify sewer terminology by means of a concise sewer terms list, or sewer terms tool as it was called. The tool would take on the form of a dictionary in mini-booklet form, or at least an extended glossary. The ultimate goal of the terms tool was user education. Understanding the terms often used in this discipline is essential and is considered to be a prerequisite to understanding even the simple low-technology outputs of this project.

The idea was also to set the scene for future compilation of an advanced (and technically speaking correct) document that could find application in academic circles and in the field. For the regions evaluated during this research text in English and/or Afrikaans were desired by small local authorities – a future document in these two languages could be the start to a more advanced document later extended to include other official languages. As part of this project a list with terms and definitions was compiled to meet the initial need, but only in English.

Water services development plan (WSDP) Tool

As part of the project goal to assist local authorities in the improvement of planning functions and service delivery a method was devised to aid with the Water Services Development Planning (WSDP) process. The project team included this tool as a project output although it was not considered to be a key output based on workshop feedback. For this reason it was not incorporated into the poster. The two-page A4 sized WSDP-tool was developed after consultation with KV3 Engineers (Human, 2009), who have been assisting numerous municipalities in the country with developing and updating WSDP's. At the time of investigation KV3 typically made use of specific agenda documentation when initiating a project. The information was kindly provided for perusal to the project team to form the basis for the WSDP-tool.

Sanitown sewer system model as benchmark for application

The development and description of a conceptual, hypothetical hydraulic model for SS analysis was considered useful as part of this project (readers may be au fait with the "Anytown" model used for this purpose for water distribution system analysis). This aspect moves the reader to advance from the focus of this study to more advanced work.

The proposed SS model was called Sanitown, after its brother Anytown. The name is in fact a concatenation of "sanitation" and "town". The Sanitown model was presented at the WISA2010 conference for the first time (De Klerk and Jacobs, 2010). The input parameters and model topology have been carefully selected and refined to include typical yet realistic problems encountered with the hydraulic modelling and planning of sewer systems. The components that were considered notable for inclusion in the model include: the Sanitown model topology, drainage region contours, proposed flow inputs, one future scenario to pose a typical development problem and a few restrictions in terms of system upgrades.

The Sanitown model was also tested as part of this research project by setting up a computer model of Sanitown. With its development the Sanitown sewer model was intended to become a widely used guinea pig for waterborne sewer system analysis, investigation into optimisation techniques and software performance. This type of research is particularly applicable to South Africa with its unique challenges to service delivery demanded by high-level customers at the upper end of the delivery ladder, and those without any service alike.

Conclusion

A key problem in small local authorities – in terms of this research – was that staff at ground level responsible for service delivery were often limited in terms of basic knowledge regarding the sewer system, its operation and planning. The value of the simple tools presented here do not merely lie in their usefulness in sewer system planning, but also in their value as training tools to gain understanding of the sewer system and its planning and to illustrate critical relationships between notable parameters typically used for sewer system planning.

No matter to what extent and how well the simple planning tools provided by this research project are applied in practice, it is imperative that a computer model of the sewer system would ultimately be required. Only by means of an accurate computer model would it be possible to assess the hydraulic capacity of the system. Increasing the level of complexity to a computer model immediately poses a new problem to designers and analysts in that no benchmark model was available to discuss and investigate different approaches to the sewer system design problem.

A hypothetical model for sewer system analysis called Sanitown, a concatenation of "sanitation" and "town", was presented in this text. It included typical yet realistic problems encountered with the hydraulic modelling and planning of sewer systems. The Sanitown model topology, drainage region contours, hypothetical flow inputs, a future scenario and a few restrictions in terms of system upgrades were presented. The Sanitown model was also tested as part of this research project by setting up a computer model of Sanitown, but an example was also provided where the low-technology tools were applied to one of the hypothetical Sanitown developments. With its development the Sanitown sewer model was intended to become a widely used guinea pig for waterborne sewer system analysis, investigation into optimisation techniques and software performance.

The outcomes of this project would aid a Municipality to better understand the working, modelling and planning of a sewer system and its optimisation in terms of hydraulics and cost. The sewer system planning checklist tool in particular would aid staff to record and prepare the required and desired information, ultimately needed to compile a computer model, in a useful format. In doing so an understanding would be gained of both the sewer system and the sewer system planning process.

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The Reference Group responsible for this project consisted of the following persons:

Dr V Naidoo	Water Research Commission (Chair)
Prof N Armitage	University of Cape Town
Prof A Burger	Stellenbosch University (SU)
Mr A Goyns	Pipeline Installation & Professional Engineering Services (PIPES) cc
Mrs M Griffioen	University of Johannesburg
Mr JL Harrison	eThekwini Water and Sanitation
Mr P Reddy	Dept of Water Affairs & Forestry, DWAF (Durban)
Mr M Van Dijk	University of Pretoria

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ABBREVIATIONS AND ACCRONYMS

AADD	-	Average annual daily (water) demand
AC	-	Asbestos cement
AMDD	-	Average monthly daily water demand wastewater flow (l/d/du)
AMDF	-	Average monthly daily wastewater flow (l/d/du)
CEN	-	European Committee for Standardization
CPI	-	Consumer price index
CSIR	-	Council for Scientific and Industrial Research
CSO	-	Combined sewer overflow
CSS	-	Combined sewer system
d	-	day
DB	-	Drainage basin
DIN	-	Deutsche Institut fur Normung
du	-	dwelling unit (the equivalent term "stand" is also used in literature)
DWAF	-	Department of Water Affairs and Forestry
EPISTEL	-	Environment, Political, Informatic, Social, Technological, Economic and Legal
FTP	-	File transfer protocol
GIS	-	Geographic information system
HI	-	high-income (household)
IDP	-	Integrated development plan
IMESA	-	Institute of Municipal Engineering of South Africa
IMQS	-	A commercial software product (www.imqs.co.za)
KSA	-	Key strategic area (WRC)
LA	-	Local authority
LCA	-	Life cycle analysis

LI	-	low-income (household)
MI	-	middle-income (household)
MIG	-	Municipal Infrastructure grant (a local funding programme)
MoDeCo	-	Model based Design and Control
NE	-	north-east
NW	-	north-west
O&M	-	Operations and maintenance
PEST	-	Political, Economic, Social, and Technological
POS	-	Public open space
PT	-	Project team (WRC)
PVC	-	Polyvinyl Chloride
RDP	-	Reconstruction and development programme
RG	-	Reference group (relating to the WRC project)
SABS	-	South African Bureau of Standards
SDF	-	Spatial development framework
SEWSAN	-	A commercial software product (www.gls.co.za)
SS	-	Sewer system
SSP	-	Sewer system plan (also sewer master plan)
SSS	-	Separate sewer system
STEER	-	Socio-cultural, Technological, Economic, Ecological, and Regulatory factors
SU	-	Stellenbosch University
SWIFT	-	A commercial software product (www.gls.co.za)
SWOT	-	Strengths, Weaknesses, Opportunities, and Threats
TOR	-	Terms of reference
u	-	Wastewater return flow factor

UH	-	Unit hydrograph
uPVC	-	Unplasticized Polyvinyl Chloride
VSD	-	Variable speed drive (pumps)
WRC	-	Water Research Commission
WSDP	-	Water services development plan
WWTW	-	Wastewater treatment works

1. INTRODUCTION

1.1 Setting the scene

1.1.1 Sewer planning in context

Maslow's well-known hierarchy of needs is a theory in psychology, proposed in 1943 (Maslow, 1943). The hierarchy of human needs is often portrayed in the shape of a pyramid, with the largest and lowest levels of needs at the bottom, and the need for self-actualization at the top. The provision of water relates to the most basic level of the pyramid (physiological needs) and sanitation to the second level (safety needs, including health and well-being). Both these are what were termed "deficiency needs" or "d-needs". Communities need water and sanitation services as part of their basic needs and local authorities are tasked with the huge responsibility of providing these services to urban and rural dwellers.

In contrast to the advanced software suites available nowadays, this WRC-funded study recognised the need for low-technology tools (or guidelines) to aid relatively small local authorities in moving towards a sewer system plan (SSP), which would ultimately assist in the improvement of planning functions and service delivery. Lawless (Lawless, 2007) underlined the scope of the problems in terms of staff capacity at local authorities in the country. These limitations are the main driver behind this research into simple methods for SS planning. The terms of reference (TOR) for this research project described the need for simple tools to assist staff at all levels of local and regional authorities to complete a basic assessment of their sewer systems through compilation of basic inputs and generation of useful outputs. This research would also give structure to the SS planning process and would provide a methodology for compilation of such a plan.

The intention here was to create an ethos of compliance and improvement by providing useful tools. This could not be achieved unless the product would be simple with immediate benefits to the user. The intention was thus to provide fundamental principles relating to sewer planning and to provide usable tools to the sewer manager/engineer, rather than to structure a comprehensive specification for implementation of proprietary software.

At this point is should be clear to the reader that the intended use of these tools would be at the level of relatively small (or perhaps poor) local authorities that are hampered by a lack of resources. In many smaller towns computers and/or staff with adequate computer knowledge to apply advanced tools were not available at local authority level.

1.1.2 Definitions of key terms

A few key terms that are used regularly in this report are briefly defined in this section with the idea of subsequently providing a clear description of this research project and its outcomes:

- sanitation: generally speaking the term refers to public health and would thus include the provision of waterborne sewer as a service in the wider definition – this research does not directly address sanitation issues and alternative sanitation systems

- sewer: the term is defined as "an underground conduit for carrying of drainage water and waste matter" (Oxford English Dictionary, 2006); however, this definition is technically incorrect in instances such as South Africa where waste matter (e.g. sewage) and drainage water (e.g. storm water) are typically conveyed in separate conduit systems; the term "sewer" is used in the remainder of this report as it pertains to conduits conveying sewage.

- sewage: the term is defined as "wastewater and excrement conveyed in sewers" (Oxford English Dictionary, 2006).

- sewer system (SS): a system of sewer pipes and other infrastructure (e.g. pumps) needed to transport the sewage from the point of entry to the point of outfall

- waterborne sewer system (or conventional sewer system): sewer systems that use water as the mode of transport for excrement and other waste

- plan: a detailed proposal for doing or achieving something – and in terms of this research project it would be sustained and improved service delivery in terms of sewer systems

- Strategic planning: the commonly accepted definition of strategic planning of an organization is its process of defining its strategy, or direction, and making decisions on allocating its resources to pursue this strategy, including its capital and people (Wikipedia, 2009). Various business analysis techniques can be used in strategic planning, including SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats), PEST analysis (Political, Economic, Social, and Technological), STEER analysis (Socio-cultural, Technological, Economic, Ecological, and Regulatory factors), and EPISTEL (Environment, Political, Informatics, Social, Technological, Economic and Legal). Strategic planning is the formal consideration of an organization's future course. All strategic planning deals with at least one of three key questions: "What do we do?", "For whom do we do it?", "How do we excel?" In line with this, urban planning (also town planning) integrates land use planning and transport planning to improve the built, economic and social environments of communities. The strategic plan would thus include all aspects of the urban plan and other engineering infrastructure (e.g. electricity supply, water distribution systems, stormwater- and sewer systems). With this background it is clear that a local authority's SS plan would form part of the more holistic strategic plan.

- SS planning (SS planning), also termed master planning: the systematic process of evaluating an existing sewer network in terms of hydraulic and operational performance while subjecting it to existing and potential future development loading scenarios to determine whether the system has sufficient capacity; the main purpose of SS planning is the identification and quantification of the most economical infrastructure interventions to ensure that uninterrupted development can proceed without sacrificing a predefined level of service or risking damage to the environment.

Classical theory distinguishes between true separate sewer systems (SSS) and combined sewer systems (CSS) that transport both sewerage and stormwater in one system. CSS are not typical in South Africa. South African sewer systems and storm drainage systems are designed as separate systems.

This research project focuses exclusively on SSS and specifically on SS planning, with due respect to the integrated nature of all engineering systems in view of strategic planning at a higher level.

1.1.3 Expected outcomes of this research project

It is evident from the definition and purpose that sewer planning is inherently complex and that the related SS planning process is not geared to a low-technology approach. Recognising this complexity of SS planning while striving towards a low-technology, user-friendly output was the main challenge of this research.

As part of the project, various aspects were addressed that were considered essential in view of providing a good foundation for the final product, but both these components of the work would not necessarily be considered "low-tech".

The main outcomes of this project would comprise two components, each with a different target audience, as briefly outlined below:

- this research report aimed mainly at academic readership was the first research output; it could also interest higher level technical staff in local authorities and engineering consulting firms; it captures all aspects of the knowledge review, the project, progress, and outcomes.

- the second output comprised tools intended for use at local authority level and would include a "one-stop-shop" poster-format product aimed at providing the key outcomes to ground staff at small local authorities (and their engineering consultants), plus additional tools in the form of compact yet simple, stand-alone, information sheets on topics that were identified during this project. The word "tool" is used often in this text, with the intended meaning "a thing used to help perform a job" (Oxford Dictionary, 2006); in this sense the tools would refer to the second type of outcome.

The project also had outcomes in the form of peer reviewed academic publications and conference proceedings. Although these are referenced and addressed in this text, they are not considered to form the core of the outputs in terms of the project aims.

1.2 Background and rationale

This research output emanates from a solicited WRC Project to address a pressing issue in the field of sewer systems, namely a lack of available knowledge with regards to low-technology tools and guidelines for SS planning. The project was funded under Key strategic area (KSA) 3 and Thrust 3 addressing wastewater and effluent treatment technology.

The WRC recently completed a national audit of sewer reticulation issues in South Africa (De Swart and Barta, 2008), which included a series of workshops with various local authorities to establish needs concerning sewerage within the sector. In many smaller authorities the primary focus is on the day-to-day operation of the system, and due to existing resource and funding constraints the planning functions have been neglected. This has in some cases resulted in unplanned or ad-hoc maintenance and upgrading which is often financially prohibitive.

It is therefore imperative to assess the existing system and provide a methodology to plan future interventions. The manager/engineer of the under resourced local authority must be provided with tools to better understand the SS planning process, to report and make decisions regarding the sewer reticulation based on a low-technology process and accepted methodology. Simply the concept of SS planning alone was poorly defined prior to this study and the related terminology was often misused in the past.

The idea of this project was to establish design tools and guidelines aimed at the eventual compilation of comprehensive SS plans for local authorities which would ultimately assist in the improvement of planning functions, service delivery and inputs to the Water Services Development Planning (WSDP) process through enhanced methods, practices and interventions. The outputs would give structure to the SS planning process and include a methodology for compilation of such a plan.

The intention of the initial project proposal was to create an ethos of compliance and improvement with the final product of this study. This can not be achieved unless the product would be simple with immediate benefits to the user. The intention was thus not to structure a comprehensive method statement or specification for implementation of proprietary software, but rather to provide fundamental principles in developing a SSP and provide usable tools to the sewer manager/engineer. Although cognisance is taken of other infrastructure (e.g. roads, water and electricity) required to meet community needs – and even to sustain the provision of sewer services – addressing these other elements were considered to be beyond the scope of this study. This project focuses exclusively on waterborne sewers.

1.3 Need for low-technology tools

The reasoning behind low-technology tools for SS planning becomes clear when case studies of SSP in small local municipalities are conducted. In these instances the practical application of scientific knowledge is not always straight forward. The intricate application of SSP in six scattered, small, arid South African towns located in two adjacent, poor municipalities was investigated as part of a case study conducted during the duration of this project. These towns were typified by an acute lack of information and prior planning in the water and sanitation sectors at the onset of this project early in 2008. The research team set out to conduct comprehensive SS planning of the sewer infrastructure in these six towns while monitoring progress. The hydraulic analyses and cost optimisation did not form part of this project, but the knowledge gained in doing so was incorporated here.

After the first site visit it became clear that the conventional SSP process, leaning strongly on pillars of spatially based hydraulic modelling and capital cost optimisation, is not amenable to application in these cases. The team was faced with a lack of basic information such as system layout, connectivity, background ortho-photos, contours, base maps and sewer flow records. Also, a basic lack of understanding was noted at ground level with regards to both the SS and its operation as well as the SSP process.

The need for a set of novel low-technology tools, particularly useful for planning sewer systems in small local authorities, was clearly identified by the team. The approach followed was one of starting small and successively adding complexity. The results were expected to be particularly applicable to third world communities where the level of service is poor and technical levels of staff are limited, often accompanied by limited access to a computer.

1.4 Sewer system design philosophy

South African sewers can be classified as separate sewer systems (SSS), in contrast to some international sewers that are combined sewer systems (CSS) conveying both sewerage and stormwater in the same reticulation system. This study focuses exclusively on SSS and does not address systems that are intentionally designed to convey stormwater as well (stormwater also unintentionally ingresses a SSS).

A parallel WRC-project managed by the University of Pretoria presents an extensive survey of South African guidelines for SS design and analysis and identifies the regional nature of existing guidelines. Their survey results highlight the ad hoc nature of current practice.

A three tier philosophy for SS planning in South Africa was proposed as part of this study. The philosophy originates from the field of transport engineering where three different "solution levels for design procedures" are documented in the South African code of practice for the design of highway bridges and culverts. This concept was adopted for the planning of sewer systems and led to three technical tiers of SS planning, described in more detail by Jacobs and Van Dijk (2009).

With due recognition of the complexity of SS planning, both with regards to the system per se and the flow and load transported by it, but also in view of the need for simple procedures which can be used routinely in areas with low service levels, provision is made for the following three-tiered approach:

- The first tier is termed Level 1 and comprises the application of the most basic design rules presented in hard copy format. The Level 1 approach is intended for use in cases where limited technical skill is available, or the scope of work is relatively small with negligible risk. This approach is sufficient only in smaller municipalities and small towns with limited sewer infrastructure. Quite often Level 1 is dominated by minimum requirements for some parameters rather than hydraulic considerations (e.g. the minimum pipe diameter is driven by the required size needed for rodding and to prevent clogging).

- Level 2 entails a more sophisticated approach incorporating design theories that take into account the hydraulics of system elements, requiring a basic analysis of the system or parts thereof. The analysis of a single main sewer, or pump station and rising main are examples of the Level 2 approach. This would typically be the level needed by a medium sized town.

- Level 3 is essential for cities and large metros. Level 3 is the most advanced and requires advanced skill and software tools to conduct planning of extensive sewer systems.

The definition and application of these three tiers could also in future act as a basis for municipalities to describe the level of complexity of work when appointing a consultant to conduct SS planning.

1.5 Key Objectives

The aim of the project was to present a simplified approach to SSP with accompanying tools and guidelines that could be used directly as a low-technology (non-computer based) tool for SSP and to better understand the SSP process. In view of the key objectives listed in the project proposal, the following were accomplished in this regard:

1. Assess existing knowledge regarding SS planning tools

2. Describe a SS and the planning process generically

3. Analyse existing SS plans and the planning process

4. Organise four stakeholder workshops to gain input and test draft tools

5. Develop a low technology, user friendly SS planning toolkit

6. Prepare a final project report.

1.6 Structure of Report

This report was intended to provide a thorough knowledge review and technical background. The report also includes a description of the stakeholder workshops and related outcomes. This text is thus not to be used as a SSP tool per se, but was intended to provide background to interested readers with the main focus being academic and technical reference.

A low-tech toolkit was presented separately, comprising loose-standing documents (tools). Each of these was included as appendixes to this report. That output was intended for distribution independently of this document, for use at local authorities. The tools included an A1-sized poster and six A4-sized mini booklets, as discussed in this text.

2. BACKGROUND AND KNOWLEDGE REVIEW

2.1 Overview

2.1.1 Previous knowledge reviews and focus of this review

The fact that the area of need for research into SSP was identified by the WRC (De Swart and Barta, 2008) as a priority indicates that there is a lack of published literature in this field. In addition, an extensive data base of literature relating to "sewer" topics is included in the above deliverable in a very useful MS Excel spreadsheet. Those who would like to read wider on the topic are referred to the literature summary presented by De Swart and Barta (ibid.).

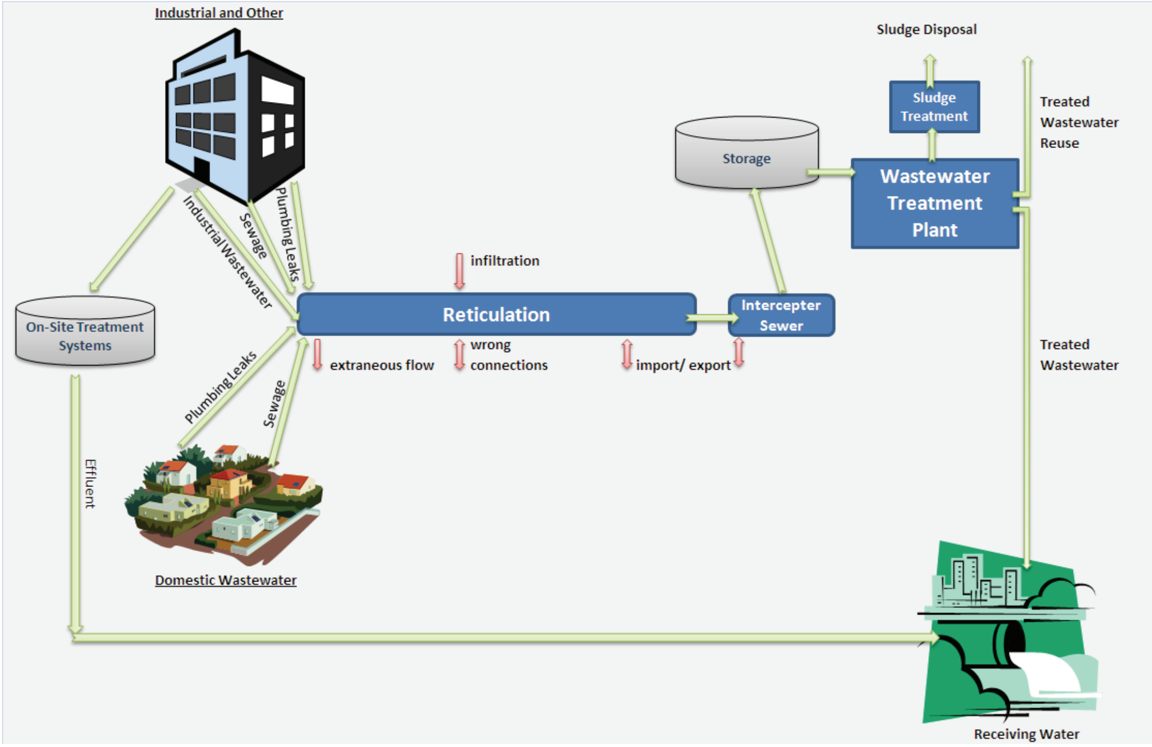
In this research project the project team (PT) focused exclusively on SS planning in the knowledge review and on the application in Southern Africa. Very few literature references could be identified and the work was therefore extended to also include so-called "grey literature" and key international sources. Consultant's reports were found to provide a large volume of reading matter and data in this regard. A wide search revealed that very few consultants operate specifically in the field of SS planning.

2.1.2 System description

In order to produce the desired outcomes of this research it is essential to describe a "generic" sewer system, based on a schematic diagram. A typical example of this is given by Butler and Memon (2006) where a schematic presentation of a CSS is presented – that is where sewage and stormwater are conveyed in the same system. A SSS is when sewage (and "unwanted" extraneous flow) and stormwater flow into separate piped systems, as presented schematically in Figure 2-1.

Published work with regards to system description in practice locally is limited and knowledge could be gained mainly from grey literature and prior experience. Without exception the reports include reference to the lack of information available at smaller LA-level. Physical surveys are often too expensive to perform, or solutions are based on very crude assumptions.

Figure 2-1. Schematic representation of a separate SS



Experience by the project team is that not only is information limited as it pertains to the systems, but basic information such as background orthophotos, contours, and base maps are often not available in these instances (e.g. no 1:10 000 orthophotos have ever been produced for large areas of the country, for example all three towns in Renosterberg Municipality are not covered by the maps).

2.2 Background to South African practice

In South Africa sewer systems are designed to convey wastewater flow exclusively. Various design guidelines are available (Little, 2004; City of Tshwane, 2007; CSIR, 2003). Separate stormwater drainage systems exist in parallel for drainage of storm flows, but some groundwater as well as stormwater will ingress the sewer system (Stephenson and Barta, 2005a; Stephenson and Barta, 2005b) and are allowed for partially in design criteria. The most recent and arguably the most comprehensive document was produced as an output of WRC project K5-1744 (Van Dijk et al., 2008).

The peak dry weather flow is used in South Africa for system modelling and an allowance of spare capacity is then stipulated to accommodate stormwater ingress during wet weather flow (Little, 2004). Butler and Graham (1995) present a detailed discussion on modelling dry weather sewer flows. Sewer flows in most local SS plans are based on monthly water consumption data of individual consumers. The latter water use information is readily available from the South African National Water Consumption Archive (Van Zyl and Geustyn, 2007) and is often reported as an annual average daily water demand (AADD). Detailed sewer flow monitoring is conducted in the field at strategic points in the system for pre-determined time periods prior to hydraulic modelling. In conjunction with "typical" diurnal flow patterns, compiled by the project team over many years the sewer flow for each land use type in the area to be modelled is obtained by calibrating the modelled flows to measured flows at strategic points. In other words, the sewer flows are calculated as a percentage of the AADD linked to a manhole and distributed over a 24 hour period according to the hydrographs applicable for the relevant land use categories. Infiltration into the system is also included in this procedure. This process is more complex and is considered to be more accurate than guidelines suggesting mere estimates for sewer flow (say based on a per capita flow).

After a SS plan item, such as a new pipe segment or pump, has been identified it is (hopefully) addressed by the service provider. A detailed design is made and the work is put out for tender. Construction of the infrastructure element follows during which time construction drawings are available. Once construction is complete a final set of drawings are compiled by the Consulting Engineer. These drawings are commonly called "as-builts" in South Africa and are considered to be the most accurate representation of what was constructed, although they might not be that accurate at all. Unfortunately some system elements are very old and it is often hard to obtain the original as-built drawings. With new developments as-built information is readily available.

2.3 Background to sewer system planning

Only two literature references could be traced during the review process addressing SS planning per se in South Africa. The first by Sinske and Zietsman (2001) described the concept of using GIS as a basis for SS planning, while the other by Fair et al. (2008) presents a detailed account of the dynamic planning process. The latter was initiated in view of this research project and aims to describe the comprehensive process in place in large metros. Working back from it the final low-tech tool should incorporate this "higher level" knowledge.

As noted briefly earlier in this report SSP could be regarded as the systematic process of evaluating an existing sewer network in terms of hydraulic and operational performance and using existing and potential future development loading scenarios to determine whether the system has sufficient hydraulic capacity. The main purpose of SS planning is the identification and quantification of the most economical infrastructure interventions to ensure that uninterrupted development of urban areas can proceed without sacrificing a predefined level of service or risking damage to the environment.

The literature review indicated that SS planning is not clearly defined. It is apparent that local SS plans are based mainly on hydraulic analyses that optimise capital cost. However, various other costs are also incurred by the LA operating a SS – these include for example operation and maintenance costs and even so-called carbon cost (these types of costs are discussed later in this document). In some specialised cases system reliability may be included in the planning process (e.g. Port Elizabeth). For the purpose of consistency the following terms are defined for use in this and later documents pertaining to SS planning:

- Conventional SS planning – planning based on hydraulic capacity (that may include some allowance for extraneous flows such as stormwater ingress and groundwater infiltration) optimised for capital cost only.

- Dynamic SS planning – the term is adopted from a paper compiled as part of this research (Fair et al., 2008) and describes conventional SS planning when it is repeatedly conducted at regular intervals (say quarterly) to keep the plan "up to date".

- Reliability based planning – such conventional SS planning incorporate some form of reliability- or risk-based approach (risk is defined as reliability times consequence of failure) to extend the optimisation to a level where the failure of system elements could for example be assessed.

- Financial SS planning – any of the above SS plans incorporating at least capital-, operational- and maintenance costs over the life cycle of the particular element.

The low-tech approach used in this research implies that the focus is on conventional SS planning instead of on the more advanced types of SS planning. The conventional SS planning process can be divided into the following three steps:

- Construct and evaluate an existing sewer network model

- Identify and evaluate potential future developments within the scope area
- Construct and evaluate a future sewer network model incorporating future developments and proposed changes to the system

These steps will be discussed in more detail within the following paragraphs. In order to clearly understand the planning process it is necessary to include a description of the hydraulic modelling used as a basis in all types of SS planning.

This text is taken mainly from Fair et al. (2008), a paper prepared and presented as part of this project. It provides a generic description of the dynamic SS planning process. The focus in this section is on the dynamic nature of the SS planning process.

In South Africa, water and SS planning has taken the form of establishing a model of existing infrastructure followed by the preparation of a SSP defining future improvements to the system to meet the requirements for expected developments. The SSP typically includes a capital expenditure programme that is used for budget purposes and project prioritisation by the service provider. Traditionally the process is repeated and updated every two to five years, depending on the rate of development in the study area.

Over the last decade in South Africa there has been a government drive to provide basic services to all residents. This has resulted in considerable development within certain areas of the country. As part of this text reference is made to the SSP of the City of Tshwane (previously known as Greater Pretoria). The City of Tshwane has a population of approximately 2.2 million people and covers an area of 2350 km^2. Unless newly constructed infrastructure elements are captured electronically on a regular basis, the SS model of the "existing system" soon becomes outdated. There is a continuing interest in development, which includes extension to the sewer system. For example, approximately 300 applications for new development have been made since 2004, signifying a dire need to systematically process these applications and their impact on the SSP process.

Not only are the number of applications significant but it has recently been experienced that the number of units and associated theoretically calculated sewer flow for which applications are made, exceed that used in the initial SS planning studies. Land use densification leads to increased sewer service densities that need to be considered during planning. Once verified and accepted, the trends should be accommodated in future planning, with corresponding adjustments to the capacities of the planned infrastructure.

The challenge has been to develop a strategy to manage, capture and utilise information, to keep the models up to date, to plan for the future and revise the planning given new information. Up to date information should be available from the model at any time to facilitate decision making for both the existing and future systems, allowing for prompt and accurate responses to queries and applications for new developments.

2.4 Challenges of planning for smaller municipalities

2.4.1 Key issues

Compiling a basic SSP, let alone the dynamic SS planning, is a challenge for most municipalities. This challenge however increases substantially at the level of smaller municipalities owing to some of the following key issues:

- Shortage of technical staff
- Lack of knowledge in terms of existing infrastructure typically pertaining to the availability of accurate plans showing the existing network, network topology and hydraulic capacity (many older knowledgeable technical staff have retired or passed away).
- Lack of topographic information for example contour data owing to the fact that many of the smaller municipalities are located in rural areas where surveyor data is not readily available.
- Limited or no technical skills to capture, populate and evaluate hydraulic models, or even a limited understanding of SSPs compiled by others (consultants, etc.).
- Limited or no technical skills to capture and maintain GIS information which is essential to the success of SS planning.
- Access to computer hardware and software to capture, analyse and store data and models are limited or nonexistent
- Financial resources are usually very limited and owing to the predominantly rural nature of the smaller municipalities the use of consultants to aid the process is severely constrained by travelling expenses in terms of fuel and time.

- The conventional SS planning process is often too involved for the needs of the smaller municipalities thus in many instances only consuming precious funds and leaving many basic questions unanswered.

It is clear that although SS planning is essential to the successful functioning of any municipality a simplified approach tailored to the needs of smaller municipalities is required to ensure that funds are effectively utilized and critical questions are answered. A possible solution to this challenge is to provide a simple SS planning process.

2.4.2 Simple sewer system planning process

The concept of the simple SS planning process is the crux of this research. It consists of the same three steps as the conventional SS planning process, but the complexity is greatly reduced allowing it to be used effectively on smaller sewer networks without the aid of computer hardware and software. The process focuses on analysing critical infrastructure only, thereby reducing the amount of resources required for analysis and potential for errors that may occur.

As a first step the LA could be guided by tools/guidelines (prepared as part of this research) to understand what level of planning is actually necessary. The simple sewer system planning process would thus ultimately include a tool to aid LA's in the management of sewer infrastructure. Application thereof would also place the LA in a position to establish whether in-house capacity exists to complete certain activities, or whether activities need to be outsourced.

2.4.3 Design philosophy and levels of technical advancement

Baars et al. (2008) report on a different approach to sewer management as it pertains to Amsterdam. The service provider, Waternet, is responsible for the SS of Amsterdam (3700 km of main sewers). A special circumstance is that the soil in Amsterdam is relatively weak. Therefore, the most important sewers, the transportation sewers, are founded on driven piles. Collection sewers are not founded at all. In the past 15-20 years Amsterdam has refined the integrated SS management as described in the code of practice (BS EN, 1998) to suit their needs.

At a regular interval all sewers are cleaned and inspected. After an assessment of the results a plan for structural rehabilitation is made. In general a distinction is made between two types of management of infrastructure: prevention of failures and corrective action afterwards. The work by Baars et al. (ibid.) focuses on the preventative approach where all efforts are put into taking action before failure occurs. A further distinction in preventive action can be made based on the usage of the system and based on the actual condition of the system. To be able to prevent failure and take appropriate measures it is necessary to understand the mechanisms leading to failure. The efforts needed to collect and assess data of the actual condition must be in balance with the actual damage and effects of failure. If the efforts outweigh the advantages a preventive approach based on the usage of the system is a logical choice. The effects of failure and especially the high costs of restoring failures have lead to the choice of a preventive strategy in sewer management in their case.

Benchmarking made clear that Waternet invests more effort in investigation/inspection when compared to other municipalities. Waternet addressed what was considered to be the basic question of sewer management: "What do we have to know to determine which sewers have to be repaired, renovated or replaced?" This question has lead to a new approach to sewer management.

The new approach presented by Baars et al. (ibid.) distinguishes three levels of assessment.

1) City level (system concept): define or re-define the handling of rainwater in relation with the soil conditions and receiving surface water and address environmental issues for each area. Does it make sense to continue using combined sewer systems (CSS) where these are in use and is treatment capacity sufficient?

2) Sewer systems level: can the functional requirements such as stipulated combined sewer overflow (CSO) spill frequency, street inundation, and environmental impact of overflows during rainfall, be met? Can transport of wastewater to a wastewater treatment works (WWTW) be guaranteed?

3) Object level: can the water tightness and structural integrity of the pipe system be guaranteed? Is the level of cleaning sufficient?

The developed three-level approach is very different from the present approach of sewer management in the Netherlands. The new approach focuses on the relation between different levels of research and assessment. The application of the result to planning is more direct. The efficiency of the sewer management process is placed before the efficiency of the different tasks. This departs radically from local practice, where sewer management often pertains to provision of new infrastructure to service new developments or improve service levels. In this hydraulic modelling of sewer systems becomes particularly relevant, especially integrated GIS-based modelling. The experience from central Europe in the field of integrated modelling of urban wastewater systems is described by Muschalla et al. (2008), while Mitchell (2006) presents a case for Australia, but this is not particularly relevant to local practice.

The inherited concept of steady state design of urban wastewater systems is challenged by Vélez et al. (2008) who present an innovative approach named Model based Design and Control (MoDeCo) is proposed. This implies the development and use of integrated modelling tools in a dynamic way and the development of optimisation routines that cope with multi-objective requirements of modern urban wastewater systems.

The combination of effective design and optimal control bring benefits through the reduction in the pollution impacts and the reduction in the total capital invested. The level of complexity, however, surpasses the level of technology justified by the scope of this current project.

A three tier design philosophy was identified from the field of transport engineering, where three different "solution levels for design procedures" are documented in the code of practice for the design of highway bridges and culverts (TMH 7, 1986). Adopting the same concept for the planning of sewer systems leads to the following new concept of three technical tiers for SS planning:

With due recognition of the complexity of SS planning, both with regards to the system per se and the flow transported by it, but also in view of the need for simple procedures which can be used routinely, provision is made for a three-tier approach in this study as described in more detail by Jacobs and Van Dijk (2009):

1. The application of the most basic design rules presented in hard copy format (e.g. tables and graphs) and based on more advanced theory / methods. No analysis is needed to apply the Level 1 approach. The Level 1 approach is intended for use in cases where limited technical skill is available and the scope of work is relatively small with negligible risk. This approach is sufficient only in smaller LA's and small towns with limited sewer infrastructure.

2. A more sophisticated approach incorporating design theories that take into account the hydraulics of system elements, requiring a basic analysis of the system or parts thereof. The analysis of a single main sewer, or pump station and rising main are examples of the Level 2 approach.

3. The most advanced level of planning activity, requiring advanced skill and software tools to conduct planning of extensive sewer systems. This approach is essential for cities and large metros.

The focus of this project is on producing a Level 1 product, but it is essential to present and understand the theory of Level 2 and even Level 3 prior to producing a Level 1 outcome. The following knowledge review is the first step in this regard.

2.5 Components of dynamic sewer system planning

The various components of the system are listed and described below. Their inter-relationships are shown in the schematic flow chart presented in Figure 2.1 that was presented by Fair et al. (2008). The discussion on dynamic sewer system planning presented in the following sections was mainly adopted from the work by Fair et al. (2008).

2.5.1 Existing system model

The "existing" system model could be considered to represent the hydraulic model of the sewer system at the time of conducting the planning study. It would contain all information required for accurate hydraulic simulation of the "existing" system. The model is then populated with topological and hydraulic information captured from as-built drawings, typically at 3 monthly intervals.

The model flows would typically be populated on a monthly basis with water consumption and land use information obtained from the municipal billing systems combined with a return fraction to describe the average sewer flow entering each manhole modelled in the system. Two development scenarios would be maintained for the model of the existing sewer system:

- An operational flow scenario to simulate the existing sewer flow in the system. This model would be used for verification and calibration purposes
- A fully developed model populated according to land use or zoning. The model would represent the system as if all of the existing yet vacant stands would be occupied.

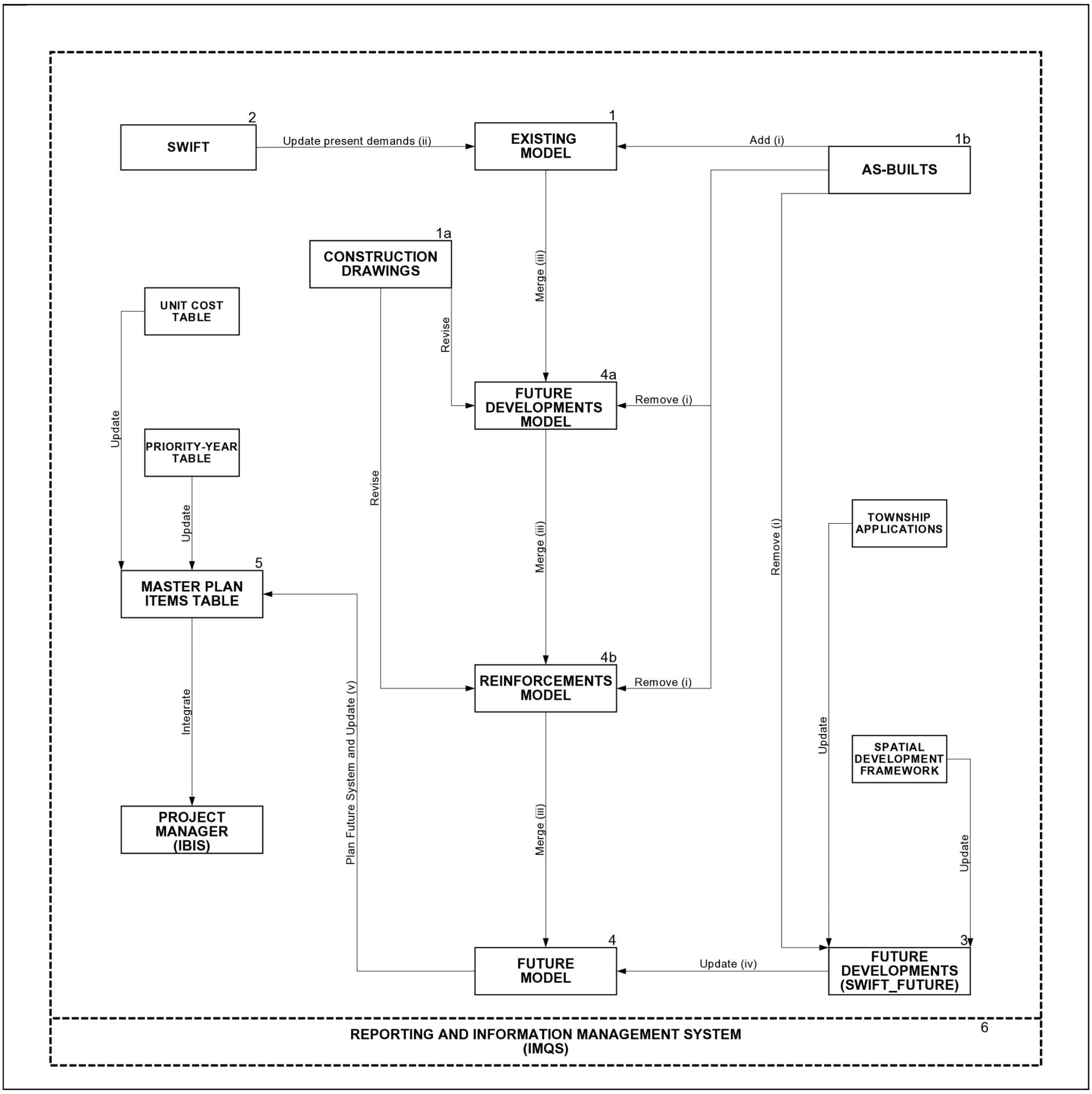


Figure 2-2. The Dynamic Master Planning Process (Fair et al., 2008)

2.5.2 Existing land use and billing data analysis

In order to conduct this research it was necessary to assess the type of land use for particular properties. A commercially available software programme (Swift®) was used to obtain information from water sales records held in municipal billing systems, which could be linked to sewer flow by means of a return flow fraction. Swift was used to, inter alia, populate sewer models with accurate flow and land use information.

2.5.3 Future land use and flow data

Research initially reported on by Sinske and Zietsman (2001) led to a GIS-based approach to SS planning and reporting that was also implemented by the project team in this research. The spatial development framework (SDF), compiled by town planners, formed the main input to this component. Shape files defining the future development areas were linked to a database of expected land use, densities and unit water demands. From this information the expected number of units expected to be developed and their combined sewer flow were determined. The information was then used to populate the future development model with theoretically estimated future sewer flows. At the most detailed level this could include individual end-uses in homes and the volume and salinity contribution by each end-use (Jacobs and Haarhoff, 2004c).

2.5.4 The ultimate future model

This hydraulic model would represent the system topology required to meet the ultimate future flow scenario, with all future areas fully developed and with every existing land occupied and where applicable, sub-divided or re-zoned. The ultimate future model (refer to block number 4 in Figure 2-2; other numbers given in brackets below also refer back to this figure) would comprise the following components:

- The existing system network representing pipes and SS components as they currently exist (1), with sewer flow and land use information for the two flow scenarios discussed in section 2.5.1
- The schematic pipes which represent the proposed exertions of the SS to service the future development areas (4a)
- Reinforcements to the existing system and major works which will be required to upgrade the existing system to handle the ultimate future flow scenario (4b).

2.5.5 Master plan details

The improvements to the existing system that are included in the ultimate future model are labelled with unique SSP item numbers – these items are often termed "master plan items". The sewer modelling software uses this information and user defined cost functions – discussed later in this text – to estimate the cost of each planning item. A SSP table would then be generated to provide a summary, description of the work required and the expected cost. Each item could be linked to a SSP project number in project management software. In this way modifications to the SSP items are implemented and accounted for in the project management software. Recent advances also link the process to asset management (the output from this research into simple sewer planning would however not extend to this level of detail and would not provide such a component).

2.5.6 Additional data

Other important information noted to be critical during planning would include: cadastral shape files, aerial photographs and digital terrain models. All these would require regular updating. Additional output typically provided as part of a dynamic master plan would include plan books (drawings) of the system layout, GIS shape files of the drainage areas and related information such as sewer flow and land use.

2.6 Procedures for sewer system planning

2.6.1 As-built information

As-built information would be received on a regular basis via courier, e-mail, file transfer protocol (FTP) or via communication through GIS based reporting software (e.g. IMQS). The data would then be checked by the capturing team for completeness and against existing data. The data would be further categorised according to whether:

- it is a new network in a new development or
- whether it pertains to the replacement or reinforcement of existing network elements.

Pertinent data which would need to be captured for the sewer systems includes:

- Pipe layouts with diameters, materials and manholes
- Pipe vertical alignment, e.g. inverts or slopes
- Additional information including material, nominal and inside diameters
- Special elements e.g. pumps, siphons, bridges
- Connections to stands or land parcels.

Unfortunately no standard or norms regarding the format of as-built data was found to be in place (and if it were it would probably not be used), with the result that as-built information was found to be supplied in various formats including electronic drawings (*.dwg/*.dxf), GIS shape files, PDF documents or hard copy paper drawings.

Various functions have been developed in software products to facilitate the conversion of electronic drawings to hydraulic models by for example importing text semi-automatically into the model space, rather than manually entering the information. The authors have found that a GIS representation of pipe layout is seldom at the same standard as that required for a hydraulic model. Once a particular set of as-builts has been captured it would be merged with other similar as-built model elements. The as-built model continues to grow until it would be joined to the existing system model.

2.6.2 Population of existing system model

At this stage the existing system model would be complete, with hydraulic information required for simulation. The next step would be to populate it with updated flow and land use information from the billing system

2.6.3 Merging model components

At this stage each of the sections of the model would be completely populated with the topology and slope information. These would then be merged together to form the fully populated future model. During the merging process the future development model and reinforcement model must be merged to the existing elements with proper connectivity being established and elements which are to be decommissioned must be removed from the model.

2.6.4 Population of future development model

The future development areas in the future development shape file would then be updated. The shapes must be either removed or adjusted where the development is complete and the as-built information has been captured and merged to the existing model. Changes to the SDF would be implemented in the future demand model. Once the areas, densities, dominant land use and unit water demand have been updated, the new sewer flows would be calculated for each development area and these "new flows" would then be applied to the future model.

2.6.5 Future planning

At this stage the fully populated model of the future system would be established, the flows simulated and additional reinforcements identified. Once the future model has been optimised to effectively meet the hydraulic design criteria, the table of SSP items would be compiled (or updated) and the project information would be linked to other sources such as project management software.

2.7 Sewage flow

2.7.1 Sewer flow

Whether a SS is planned by means of an advanced dynamic process as described earlier, or by means of a more basic approach, two crucial components could be identified that are needed to develop a SSP:

- sewer system – knowledge about the sewer system, as described earlier in this chapter
- sewage flow – information regarding existing and future flows.

In contrast to the description of sewer systems literature abounds with reports on sewer flows. Butler and Memon (2006) provide useful insight and include various references for further reading in this regard. However, no reports in peer reviewed journals of sewer loads and their impact on the planning process could be found to date during this study.

As mentioned earlier, there is a strong link between water usage and wastewater disposal, with relatively little supplied water being consumed or taken out of the system. Adopting the notation of Jacobs and Haarhoff (2004a), the monthly average relationship could be expressed as:

$$AMDF = u(AMDD)$$

Where,
AMDF is the average monthly daily wastewater flow (l/d/du)
AMDD is the average monthly daily water demand (l/d/du)
u is the wastewater return flow factor.

Water use exceeds wastewater flow, especially in the early evening when gardens are being watered. At night this situation is reversed due to sewer infiltration flows.

Exfiltration is the opposite of infiltration. Under certain circumstances, wastewater (or stormwater) is able to leak out of the sewer into the surrounding soil and groundwater. This creates the potential for groundwater contamination.

Factors affecting the likelihood of exfiltration are similar to those discussed for infiltration. Fuller details of the causes, costs, control and implications of exfiltration can be found in Anderson et al. (1995) and Ellis et al. (2004).

In order to design sewer pipes or evaluate existing systems the flow in the pipes has to be determined. Use patterns within individual households vary and when moving down the system there is a point where the combined flow components result in continuous flows at some times during the day. Even further down the system there is continuous flow throughout the day. Variation of water use throughout the day causes this diurnal variation. The peaks are generated by patterns of water use. The trough occurs in the early hours when the majority of people are asleep and the flow is made up almost entirely of base flow (from infiltration).

Butler and Memon (2006) note that the peaks are relatively larger at the periphery of the sewage system than at its outlet. There are two reasons for this: firstly due to the effect of attenuation of the individual waves discharged form appliances; secondly due to the effect of timing differences in travel from the many different properties served by the system.

Much has been reported on what is entrenched in the sewerage, with a neat summary by Butler and Memon (ibid.). The load typically includes dissolved and solid organic and inorganic matter from domestic, industrial and commercial stands. The dissolved matter and fine suspended particles are readily conveyed through the sewage system by the water. The same authors note that the conveyance of the gross solids is more complex and depends on the relationship between the specific gravity of the particulate, the size and quantity of the particulate and the quantity and the velocity of the water available for transport. In addition solids may catch on the features within the sewer. The detail of sediment transport and what is transported (and what not) falls beyond the scope of this study, suffice it to say that this field underlies the hydraulic analyses of sewers required for SS planning. Master planning in South Africa is based on the basic assumption that the sewer flow has similar characteristics to raw water to simplify the hydraulic analysis.

2.7.2 Point of entry for flow component into sewer

Local inflow is the sewer flow contributed by the land parcels serviced by a pipe. The inflow contributed by each of the land parcels along the pipe is assumed to enter the pipe at its upstream manhole. Leakage from the plumbing system, such as leaking cisterns and dripping taps, also contributes to the inflow into the sewer system. Leakage is generally regarded as being a constant flow over 24 hours a day throughout the year and the quantity is associated with a land use type. Stephenson and Barta (2005b:31) suggests a rate of 0,15 l/min/land parcel, which can be increased for older and larger type properties. This rate of infiltration is the only published value for local inflow that could be identified during the knowledge review.

2.7.3 Review of available flow theory

Three methods for calculating the local inflow to a pipe are generally used in local SSPs:

- Hydro-dynamic modelling
- The unit hydrograph peak inflow calculation method
- The AADD inflow calculation method

Hydro-dynamic modelling entails finding a solution to the full set of Saint Venant equations and is particularly well suited to combined sewer systems. Building an accurate model and finding correct solutions is often complex and time consuming; optimising problems based on this approach are considered impractical for relatively large systems restricted by limited resources. For this reason most SSPs compiled locally are based on one of the less advanced approaches.

The unit hydrograph peak method uses the expected peak flows associated with the land use types and expected flow patterns to calculate the volume of the input hydrograph, whereas the AADD method bases the volume of inflow to a manhole on the fraction of the AADD returned to the sewer (for the land parcels linked to the particular model node) and some estimate of the peak flow. This method can be used when the water consumption, or AADD, for the land parcels is known. The sewer flow for a stand is then determined as a percentage of the AADD. The percentage of the AADD which is used is generally related to the land use of the land parcel. In this method the composite hydrograph is scaled so that the area under the hydrograph is equal to the percentage of the AADD.

The peak flow could of course be accessed directly. Fixed peak flows for three different land uses are, for example, provided by the CISR (2003) and are combined in that publication with attenuation in peaks with increased area serviced.

Sewer flow is one input required to conduct planning of a sewer system. Contributor hydrograph theory was considered to provide the most basic and reasonably accurate method to assess sewer flow. The method was originally developed by Shaw (Shaw, 1963) and it is used widely to determine sewer flow for design. The concept is very similar to using unit hydrographs for stormwater system design. Each contributory unit (normally a single pipe in the sewer network) "contributes" a 24-hour sewer flow hydrograph to the system. The hydrograph that has been determined it is routed downstream through the SS and accumulated with hydrographs from other pipes at each confluence.

The flow was noted to be expensive to monitor. For this reason theoretical estimates of sewer flows were often found to be used in practice and were addressed as part of this project in order to arrive at "typical" values for different land use scenarios. The contributor hydrograph could be considered to consist of the following four components:

- Local Inflow from the land parcels serviced by the pipe
- Leakage from plumbing into the system
- Ground water infiltration into the system
- Stormwater ingress into the system

2.7.4 User-induced sewer flow hydrographs

The 24 hour sewage flow pattern for a certain type of land use could be described by a dimensionless unit hydrograph. The unit hydrograph covers the full 24 hour period, with user defined ordinates which usually correspond to the simulation time step. The peak of the unit hydrograph is unity, hence the name unit hydrograph.

Typical unit hydrographs obtained from analysis of measured data are shown in Figure 2-3. These hydrographs relate to flows in Gauteng, but were considered to be typical of other regions. No publication could be located during the knowledge review where hydrographs for sewer flow from different land uses were presented. This pointed to an acute lack of knowledge regarding an aspect that was deemed an essential input for SS planning.

In order to determine the flow pattern at the manhole a composite hydrograph would be calculated for the manhole. The land parcels draining to a manhole would then be categorised according to their land uses and the number of land parcels per category would be counted. The flow pattern for each land use is then described by a unit hydrograph. The 24 hour flow pattern is determined by combining the unit hydrographs pro rata to the number of land parcel units associated with each land use.

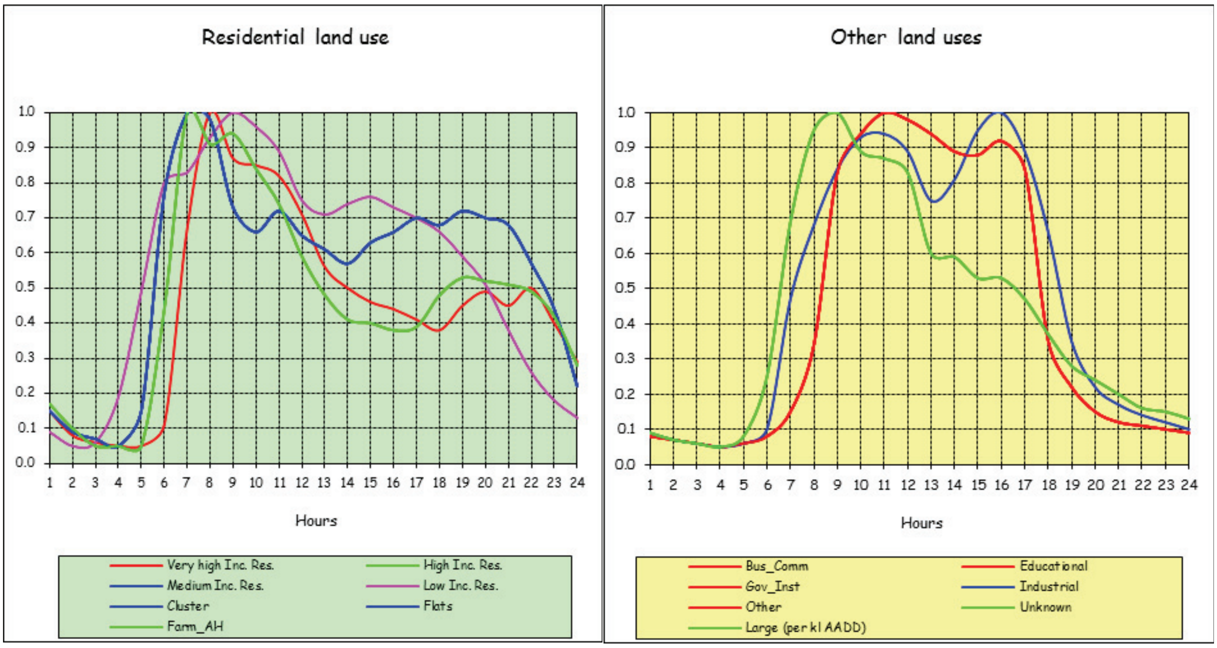


Figure 2.3. Typical unit hydrographs for user-induced flow (Stellenbosch University, 2009b)

2.8 Extraneous sewer flow components

2.8.1 Stormwater ingress

Despite being designed and designated as SSS, stormwater ingresses sewers. During storms, rainwater enters the system, causing a notable peak on a sewer flow hydrograph as the storm event progresses through the system. Some of the points of entry for stormwater may be "intentional" (e.g. downpipes from roofs connected to sewer system/plumbing gulleys on individual properties), while others may simply be a result of some system failure (e.g. a river level rising during flood to a point above the sewer manhole cover levels).

The amount of ingress in each pipe is a percentage of precipitation on an effective contributing area along the length of the pipe. Parameters to be specified include the hydrograph describing the storm, the contributing area and the percentage of ingress into the storm. This percentage will vary widely depending on the methods of controlling stormwater into gullies.

The most convenient way to address stormwater ingress is to simply allow some type of "spare capacity" in the pipe (and pump) design to accommodate a "reasonable amount" of stormwater ingress. Experience seems to point to 30% spare capacity to compensate for storm water.

2.8.2 Infiltration

This component is the direct result of infiltration of groundwater into the system through joints and connections at manholes and land parcels. As such it is a constant flow and a function of sewer length and diameter. A rate of 0,15 l/metre pipe/metre diameter has been suggested by Stephenson and Barta (2005b:31) and is widely used locally. Future research should evaluate the validity of this value, particularly since it is not linked to the type of pipe material or jointing method.

2.8.3 Plumbing leaks

Plumbing leaks on residential properties have been noted to be very common. Faustin et al. (2008) concluded in a recent study that significant losses of water do occur on-site and found that 60 % of the stands in the study area have some type of water leak. The average leakage rate was found to be 34 l/ property/h, which would be equivalent to 295 m^3/property/year. The reasons for the on-site leakage were not determined in that study and necessitated further investigation. However, whatever the reason may be for the relatively high leakage rates, an (unknown) fraction of the water is bound to return to the sewer system. Leaks typically produce a flat hydrograph due to the constant flow rate.

A large fraction of the base flow recorded in sewer studies may be due to these leaks rather than infiltration. Assessing plumbing leaks in a study area is particularly arduous and, due to the highly variable nature of this flow component, it is often used to "calibrate" the hydraulic model (as described below) of a SS to measured flow, given fixed values for the other components.

2.9 Extensive review of South African sewer system plans

Numerous SS plans for various clients have been compiled by the project team in recent years. The comprehensive list of projects is included in the Bibliography of this report. The list includes all Municipalities in the Western Cape, all large metros in Gauteng as well as Buffalo City and also some Municipalities in the Northern Cape district of Pixley ka Seme. The project team were also aware of a SSP compiled for Port Elizabeth by Aurecon (Stellenbosch University, 2008), but the report was not available and thus not included in this review.

As part of this research the SSP documents were located – as hard copies or in PDF format. The SSP documents typically comprised a text document, a set of figures and tables. The tables and figures were stored independently in e-format. Table 2-1 summarises the SSP components that could be traced during this investigation (in this text and the sewer models referred to, "Pretoria" represents one part of the sewer system in Tshwane; in other words, the sewer systems of Pretoria, Atteridgeville, Centurion etc. all form various sub-components of the larger Tshwane metro sewer system – understanding this relationship is not critical to understanding this text, but it would leave the knowledgeable reader at ease that the old and new names of this city have not been used in vain).

Table 2-1 Sewer system master plans (compiled by GLS Consulting)

Town or Municipality	Year of project	SMP files included		
		Text	Figures	Tables
Bonnievale	2006	pdf	pdf	pdf
Cederberg (Draft)	2006	word	pdf	excel
Drakenstein (South rural paarl)	2005	pdf	pdf	pdf
Ekurhuleni				
Alberton	2007	pdf	pdf	pdf
Benoni	2007	pdf	pdf	pdf
Boksburg	2008	word	pdf	pdf
Brakpan	2006	word	pdf	excel
Edenvale	2007	pdf	pdf	pdf
Germiston	2007	pdf	pdf	pdf
Kempton	2007	pdf	pdf	pdf
Nigel	2008	word	pdf	excel
Springs	2006	word	pdf	excel
George	2006	pdf	pdf	pdf
Hessequa	2006	pdf	pdf	pdf
JHB				
Driefontein	2006	pdf	pdf	pdf
Western Klein Jukskei	2006	pdf	pdf	pdf
Matzikama	2005	pdf	pdf	pdf
Oudtshoorn	2004	word	pdf	excel
Overstrand	2008	pdf	pdf	pdf
Saldanha Bay	2007	word	pdf	excel
Sedibeng				
Emfuleni	2006	pdf	pdf	pdf
Midvaal	2005	pdf	pdf	pdf
Stellenbosch Municipality	2008	pdf	pdf	pdf
Swartland	2008	pdf	pdf	pdf
Theewaterskloof	2006	pdf		pdf
Tshwane				
Atteridgeville	2002	pdf	pdf	pdf
Centurion	2004	pdf	pdf	pdf
Mamelodi	2002	pdf	pdf	pdf
N-Tshwane	2005	pdf	pdf	pdf
Pretoria	2004	pdf	pdf	pdf
Witzenberg	2005	pdf	pdf	pdf

2.10 Calibration of models to measured flow

The measurement of flow at a gauging station (preferably logged at regular intervals) could be used to calibrate any SS model. Useful information could be derived from flow measurements, which could be used to assess model parameters such as unit hydrographs and leakage/infiltration. If a rainstorm were encountered during the period of measurement (logging) it would also aid in the assessment of stormwater ingress.

Given a good set of data from a logger an analyst could compare the modelled flow pattern and flow rate at the flow measurement point to flow rates within the context of uncertainties related to sewer flow depth measurement, the slope of the pipe at the location of measurement and subsequent conversion.

Two points are of particular interest to this project, focusing on low-level tools to aid SS planning:

- a flow record at any point in the system over a relatively long period of time is extremely valuable prior to SS planning; such a record could typically be kept up to date for large drainage basins (or entire systems) by recording flow readings, or depths, at measuring flumes near the exit point of the system (e.g. at the WWTW)
- flow logging at (say) 15 minute intervals for a limited period of at least one week at a strategic point in the system could be valuable in view of system calibration in terms of peak flows.

The team noted a particular concern when comparing logged flow measurements to modelled flows in that cognisance should be taken of the upstream flow pattern: discontinuous flow from pumps versus continuous flow from infiltration and large gravity fed drainage basins, should be correctly included in the analysis. This highlights the need for a basic understanding of the entire upstream sewer system prior to modelling or planning, even at a low-technology level.

3. PROJECT METHODOLOGY

3.1 Procedure followed

3.1.1 Overview

The methodology followed in this research is briefly reviewed in this chapter. The progress of the research moved from assessing existing knowledge to the compilation of draft sewer system planning tools, which were subsequently workshopped in order to gain feedback and improve those tools that were found to be suitable for practical application. Finally a set of tools were compiled as a project outcome that could be provided to local authorities at ground level. This text provided a detailed account of the process and its outcomes to mainly academic readership.

3.1.2 Outcomes

The final product of this research was a user friendly low-technology toolkit, comprising a few individual tools to assist local authorities with SS planning. The toolkit would aid local authorities in accessing basic information regarding the sewer systems and the setting of planning strategies. The toolkit could be viewed as a guideline. The decision was made early on in the project to limit the outcome of the research to a non-software tool, thus implying a low-technology (e.g. hard copy) product.

Workshops with stakeholders were considered integral to the process in order to establish their needs and interventions and to evaluate the experiences of local authorities in using particular types of tools and planning guidelines. Workshopping the draft format of the guideline tools developed as part of this project, prior to final completion, would help the project team to provide a useful output.

3.1.3 Approach

The project team set out to review available literature and also to evaluate and report on the status quo of existing SS planning tools used by South African local authorities and their consultants. The focus was on small local authorities. The team identified specific consultants who specialised in SS modelling and planning, briefly assessing commercial and non-commercial software products for hydraulic analysis and asset management in the review. It was hoped that some software "help files" could provide additional knowledge at the early stages of the project.

An overview of the existing knowledge that was available to South African local authorities (and their consultants) for SS modelling and planning, was compiled.

In view of estimating asset value, updated SS infrastructure cost functions based on actual construction costs and previous planning studies were compiled. The functions were drawn up for different types of sewer infrastructure considered to be “typical” to most systems. Various parameters were included to assess the results on an area-wide scale.

3.2 Simple sewer system

In order to limit the technology needed and technical background required to understand/use the tools presented in this report, it was considered necessary to limit the tool in terms of its functionality (e.g. hydraulic capabilities). Whether SS evaluation is based on simplified tools, or the most complex software suits, it is considered necessary to describe a generic SS by using text, tables and schematic drawings.

It would be convenient to base comparison of different methods and techniques on some "standard" sewer system. The water distribution analysis fraternity is au fait with the Anytown water model, which is used regularly to assess all aspects of water distribution system modelling. No such model was available for sewer studies at the time of this research and for this reason it was considered an advantage to describe such a system for future reference and comparison as part of this work.

The idea was to present a basic SS and corresponding sewer flows. The system would include all the typical system elements and would pose some "real life" problems to the analyst. The need for a user friendly, low technology tool necessitated various limitations in view of SS description. This SS description would highlight exactly which components were noted to be critical for inclusion and which aspects could be neglected to achieve the project goal of a "low technology" tool.

3.3 Estimating hydraulic aspects and asset value

A user-friendly method for estimating the hydraulic capacity and asset value of SS components were developed by using text, tables and schematic drawings. The SS dynamic planning process was described by Fair et al. (2008) as part of this work – explaining the complexities inherent in an advanced SSP. The focus of this project was on the low-technological requirement. It was envisaged that an area-based schematic approach would be useful in order to boldly describe a local authority's sewer system, but this approach was not considered feasible as the work progressed. A hydraulic tool, based on fundamental theory, was linked to assumptions regarding sewer flows in order to illustrate some basic relationships between parameters involved in SS planning. In addition a tool was developed to estimate the asset value of various infrastructure components (i.e. it would not be, or incorporate, a hydraulic model of the sewer system).

3.4 Review completed sewer system plans

The team reviewed as many existing (completed) SS plans as practical within budget constraints and conducted empirical analyses on selected parameters in each SSP in order to apply the results to the tool being developed. One example was to obtain an estimate for the total length of small diameter sewer pipes in an area in relation to the number of upstream service connections.

This approach to review completed SSPs and the corresponding SS models showed how simple methods compared to theoretical estimates. An empirical study of existing SS plans and system models was conducted by analysing data of completed hydraulic models. The outputs enabled the researchers to gain knowledge of the sewer pipe sizes and lengths in relation to known inputs such as the number of connections. The analysis was useful in that it showed the spread of data – a wide scatter was noted and served as a warning of applying a simple approach for design purposes (for which it is not intended).

3.5 Method of development

3.5.1 Progressive development of tools with stakeholder workshops

Four workshops were held as part of this project to gain input in terms of the needs and requirements to shape the outcomes of this research project. The four stakeholder workshops are discussed in the following chapter of this report and are not elaborated on here, bar a short review that is needed to understand the development process.

The different workshops were earmarked to gain different inputs. The reason for this was that the tools were being developed, and adjusted, during the process. In other words, inputs from one workshop would be added to the toolkit (or adjusted) prior to the next visit. In some cases simply a "concept" was initially tested rather than a useable tool. The first workshop was selected to have a rather broad based approach, in line with the attendance. Eventually a practical, usable tool was on the table to workshop with technical staff at ground level.

3.5.2 Development of the SSP-Tools

A list of SSP-tools were initially conceptualised by the project team and systematically developed during the early stages of this project (e.g. during the knowledge review) for possible inclusion in the toolkit. The different concepts were brought together by the project team to form 11 individually identifiable components for evaluation at the first workshop. The questionnaire used during that workshop session addressed each of these tools and also explored wider needs.

The project team attempted to learn more of the need for each tool at this first workshop. It quickly became clear at the particular workshop that one-on-one discussions with key individuals ("champions", or helpful people directly involved in the line of SS planning) provided much more valuable input than the mass of data obtained from questionnaires based on inputs by a large number of conference delegates.

The initially envisaged SSP-tools were categorised into three broad groups. The three groups are listed below, despite the categories later being discarded:

- General management and training
- Meeting government requirements
- Hydraulics and SS planning

After the first round workshop and input by key Municipal staff the project team decided to focus on a few particular SSP-guideline tools which drew much of the initial interest and attention. Most of these were eventually included in the final toolkit, discussed later in this report.

3.5.3 Reporting and recording development

It was of course essential that the whole process of data collection, model compilation, calibration, analysis and evaluation be properly documented by means of electronic and hard copy documentation. An implementation proposal on how the knowledge would be disseminated after completion of this research was also presented and is included in the final section of this report.

4. STAKEHOLDER WORKSHOPS

4.1 Workshops as a project deliverable

4.1.1 Approach and initial proposed venues

With reference to the initial project proposal for K5-1828 the project team set out to hold workshops with various stakeholders. The idea was to complete workshops with stakeholders in order to establish their needs and interventions and to evaluate the experiences of local authorities in using particular types of tools and planning guidelines. Workshops were hosted by the project team. In order to maximise the impact the workshops intended for this research were combined with other practical training sessions organised for local authorities at different venues in the country, where possible. Four workshops were eventually held.

The idea was to use these workshops with stakeholders to establish the needs with regards to low-technology tools and guidelines for SS planning. The focus would be on local authorities and other stakeholders involved with SS planning where resources limit the application of expensive high-technology interventions (e.g. specialist consultants or advanced software applications).

In addition, the draft version of the tools and guidelines developed as part of this project would be presented as a trial at each workshop in order to assess the usefulness of each tool in the toolkit. The experiences of local authorities in using particular types of tools and planning guidelines could thus be evaluated. This would also be useful in assessing the level of technology needed in the field so that the project team could pitch the final result at the right level of technological advancement.

4.1.2 Approach and initial proposed venues

The proposal initially indicated that GLS Consulting engineers, who have a dedicated team experienced in organising and running workshops, would organise these meetings. In order to maximise the impact the workshops intended for this research would ideally be combined with other practical training sessions or events, organised for local authorities at different venues in the country.

The proposal set out to include four workshops in the budget and time frame. Four possible venues listed in the proposal were Stellenbosch, Johannesburg, Pretoria (Tshwane) and the Southern Cape (George) or Eastern Cape (Buffalo City). However, it was clear that detail regarding venues and scheduling would be determined at a later stage by the WRC Project Reference Group (RG).

4.1.3 Capacity and competency development

As part of capacity and competency development in this project it was envisaged that students from the project team would be involved in the stakeholder workshops, feedback analysis, and the subsequent integration with SS planning tools. This would of course lead to capacity building and community development. Such interaction would encourage direct involvement in the project by these less experienced students and would lead to a better understanding of the authorities' and communities' needs by all those involved in the development process.

4.1.4 Time frames and budget

The proposal indicated that these workshops would be held relatively late in the project schedule so as to allow for the tools and guidelines to progress to a certain level of completion prior to the workshops. For this reason the intended workshop period was foreseen to be during October and November 2009.

The total budget for the planning the workshops, including post-processing of the data and compilation of the subsequent report (Deliverable 3) was R70 000, including all fees and expenses. This relatively low budget was based on the understanding that the workshops would be integrated with other events where possible so as to reduce planning time, that the contact time with stakeholders would be limited to allow for short, focused discussions only and that this report presenting the findings would be a relatively uncomplicated document presenting only the key findings.

4.2 Stakeholder workshop – site selection

4.2.1 Amended approach for hosting workshops

During the WRC Reference Group meeting on 19 June 2009 a few amendments were made to the initial proposal, based on the understanding that the budget and time frame of Deliverable 3 would not be affected. The key considerations and inputs from the RG are outlined below:

- The IMESA conference in Cape Town was identified as a possible avenue to gain knowledge and input regarding the project

- The RG proposed the following as potential venues for workshops: (i) Pietermaritzburg or Durban, (ii) Stellenbosch, (iii) the Northern Cape and (iv) a suitable town in the Southern Cape region.
- In the case of poorer Municipalities, mainly in the northern and southern Cape, it was agreed that it would make more sense to visit the Municipalities (towns) on a one-by-one basis, rather than to organise a gathering at a central venue, which may be poorly attended due to the large distances involved and limited travel budgets in these areas
- The idea was mentioned to organise a post-project workshop at the WISA2010 conference in Durban to gain input from specialists and academics attending the conference. The target audience would clearly not be at a low-technology level, but such a workshop would be valuable in view of knowledge dissemination.

4.2.2 Final considerations and limitations

Four workshops were eventually held, based on the above amendments. However, considering the limitations of the project budget and time frame the venues were adjusted slightly. Practical implications for setting up workshops with stakeholders in the proposed locations and/or collaboration with other events led to some final adjustments in terms of the exact locations eventually selected.

In two cases the project team collaborated with other event organisers, while the other two workshops in the Karoo region entailed one-by-one visits to targeted Municipalities in this sparsely populated region. The key aim of all the workshops was to ensure that valuable input could be gained for the research into low-technology SS planning tools – this also led to the final selection of venues.

4.3 Final venues and dates of stakeholder workshops

4.3.1 Final workshop venues and schedule

Four workshops were held during October and November 2009 at the following locations:

- Cape Town (3 days): collaboration with Institute for Municipal Engineers of South Africa (IMESA) conference, Cape Town International Convention Centre, 28-30 October 2009; all conference break periods were available for workshop sessions

- Beaufort West (1 day): site visits to three towns/two Municipalities around Beaufort West on 16 November 2009
- De Aar (1 day): site visits to four towns/three Municipalities in the Pixley Ka Seme region on 17 November 2009
- Worcester (½ day): collaboration with Municipal Infrastructure Grant (MIG) workshop held on 20 November 2009
- In addition to the four workshops noted above, a post-project workshop was held on 18 April 2010 at the WISA2010 conference in Durban, 18-22 April 2010, in collaboration with another WRC project team (University of Pretoria; Project K5-1744).

The time frames above were short in order to interrogate the relatively large number of towns, allowing only for an hour or two at each town. Within the time frame and budget of this project this short time was all that was available. It was considered more valuable to visit the towns (relatively many, but short visits) than to arrange fewer, larger, longer workshops at central locations. The focus with the field visits was thus on targeting specific individuals by arranging the workshops and attendance in advance. This paid off with good feedback received in each case.

4.3.2 Workshop content

At each workshop the possible application and usefulness of each SSP tool, at the corresponding stage of development corresponding to the workshop date, were assessed. Initially the idea was to identify the need of tools relative to others in order to select which tools needed to be developed further, and which could be put aside. In addition to this initial goal, the project team used the workshops to assess the level of technology available and whether that of the intended tool matched what was required. The two workshops conducted during the road trip made it possible to identify the need and usefulness of the draft SSP tools at ground level with notes on possible improvements during the final stages of this project and also possible future needs.

The presentation method of the low-technology SSP tools was initially not a key consideration, but during the workshops it became clear that the method of presenting the information was as important to the intended users as the information contained. The project team's initial idea was to present the tools as a single "one-stop" document comprising independent components (e.g. chapters) written at a low-technology level. It soon became clear that a poster, that could be placed on the wall of a Municipal staff member's office or communal work-area, was considered by most to be more useful than (just another) report/document on a shelf or pile of papers. For this reason the different tools workshopped were also presented in different formats during the last three workshops in order to assess the method of presentation as well.

A possible method for dissemination of the final low-tech tool to the various potential users at local authority level was also evaluated during the workshop process.

4.3.3 Workshop organisation and student involvement

The project team organised the workshops and/or their involvement in the workshops. The project team arranged for collaboration where appropriate and organised for the relevant contributions in each case. In two instances collaboration with others was needed (IMESA and Worcester/MIG) while the other two workshops were organised solely by the project team.

Two Master's students were involved throughout the process and physically attended each workshop, with two other students taking turns to assist. An international exchange student from the University of Kessel (Germany), Matthias Kompfe, who was visiting SU at the time, also attended all four workshops and assisted where possible.

4.4 Low-technology sewer planning tools

4.4.1 Progressive development of tools with workshops

The different workshops were earmarked to gain different inputs. The reason for this was that the tools were being developed and adjusted during the process. In other words, inputs from one workshop would be added to the toolkit (or adjusted) prior to the next visit. This was particularly true for inputs that were considered valuable based on subjective judgement by the project team. For this reason the first workshop was selected to have a rather broad based approach, in line with the attendance. At the outset as many potential low-technology tools were included as possible, with each tool having a very low level of development. In some cases simply a "concept" was tested rather than a useable tool. Eventually a practical, usable tool was on the table to workshop with technical staff at ground level (during the MIG workshop in Worcester). In so doing the final product(s) would thus be achieved by starting on a low level of detail and successively adding complexity until a few useful tools had been put in place. The refinement implied that some tools would be rejected completely during the workshop progress to arrive at a final set of useful tools. Others, perhaps, would be identified that would require further research to develop to a useful user-friendly low-technology level.

4.4.2 The sewer system planning tools

A list of SS planning tools were initially conceptualised by the project team and systematically developed during the early stages of this project (e.g. during the knowledge review) for possible inclusion in the toolkit. The different concepts were brought together by the project team to form 11 individually identifiable components for evaluation at the first Workshop. The questionnaire used during that IMESA workshop sessions addressed each of these with a single question. The project team attempted to learn more of the need for each tool at this first workshop. It quickly became clear at the particular workshop that one-on-one discussions with focus groups ("champions" – helpful people directly involved in the line of SS planning) provided much more valuable input than the mass of data obtained from questionnaires – based on inputs by a large number of conference delegates.

The initially envisaged tools were categorised into three broad groups. The three groups are listed below, despite the categories later being discarded:

- General management and training
- Meeting government requirements
- Hydraulics and SS planning

These groups were eventually discarded due to the fact that they did not prove useful in categorising the different tools. After the first round workshop the project team decided to focus on a few particular areas which drew much of the initial interest and attention. Most of these eventually survived all stages of the process to be included in the final toolkit:

- Infrastructure Costing Tool – a mechanism to estimate the fixed capital cost of sewer infrastructure
- Hydraulic Design Tool – an aid to understanding the relationships between critical parameters used in basic hydraulics of sewer pipes and a useful way of estimating required infrastructure size by means of very crude assumptions
- SS planning Checklist Tool – a method to record progress and guide towards an eventually comprehensive SSP
- Master Planning Process Tool – a general description of the SS planning process

- Sewer Terms Tool – this could be viewed as a sewer terms glossary or mini-sewer-dictionary.

- WSDP Tool – aimed at simplifying the transfer of information from the SSP to the water services development plan (WSDP).

4.5 Review of Workshop 1 (IMESA Conference, Cape Town)

Three post graduate students from Stellenbosch University (SU), Civil Engineering Department (Institute for Water and Environmental Engineering), were granted the opportunity to conduct a workshop during the IMESA conference, which was held at the Cape Town International Convention Centre from the 28-30 October 2009.

A total of 620 delegates from consulting and contracting firms, material and product suppliers, as well as the municipal delegates attended the three day seminar. The conference Expo comprised 150 stands from consultants, contractors, suppliers and certain municipalities.

The firm responsible for organising the IMESA conference was Paragon-Conventions and contact with the organisers was established via the shared GLS-stall in the Expo area at the conference. Unfortunately the maximum limit of people at the particular stall had already been exceeded and it was not possible to host the project team and/or students at the stall within the allowable staff limit.

This entailed additional negotiations between the project team and conference organisers. The project team eventually gained permission to workshop the SSP tools at IMESA from the organising committee and the organisers, Paragon-Conventions. This was achieved after various discussions and finally a formal request describing the aim of the involvement. The particular involvement allowed for workshop sessions on a one-to-one basis during each and every break. In addition, questionnaires were distributed to all delegates during the main conference function and the project team was afforded the opportunity to include a short description of the project to the entire group via the speaker at the function.

The sessions thus entailed gathering information for further development of the low tech tools and guidelines for SS planning. This was done during the tea and lunch times of the three days by discussing tools with interested delegates and filling questionnaires, either individually, or in small groups. Workshops at the IMESA conference thus comprised roaming project team members organising ad hoc mini-workshop groups during conference break times.

Questionnaires were also distributed in the seminar hall and the main dinner event, and could be completed during the course of the seminar by passers-by (many of these were later discarded as discussed below due to inaccurate information and/or irrelevant background of the respondent). It was soon decided to limit the involvement to those persons particularly involved in sewer systems to achieve better inputs.

A total number of 151 questionnaires were completed on hard copies (each being a single A4 page) by individual respondents. After applying a filter to include only accurately completed and legible responses where some involvement in SS planning was noted, a total of 129 good responses were captured electronically. The feedback included representatives of 56 different Municipalities, 43 engineering consulting firms, 18 equipment or product suppliers and 7 from other types of institutions (e.g. government or institutional). When posed with a question to test whether the individual respondents were directly involved in SS planning and design, only 47 responded positively. Of these, some were prepared to provide a lengthy discourse to the project team about what they deemed to be valuable in terms of simple tools.

Of the tools finally selected, only the WSDP-tool was not particularly highly rated based on the initial workshop feedback. However, the project team considered the WSDP as a crucial component of a Municipality's planning process and opted to include the tool nevertheless.

One need that was noted during the workshop by various Municipalities, but was considered to fall beyond the scope of this research project, was for in-house training of staff at ground level. As an example, some respondents specifically asked to have "some knowledgeable person/s" visit the Municipality to provide training and guide staff through a practical design exercise. This need is in line with a report by Lawless (2007) underlining the urgent need for technically skilled personnel at relatively small local authorities.

4.6 Review of Workshops 2 & 3 (Karoo road trip)

4.6.1 Description

The Karoo road trip entailed two workshops held on 16 and 17 November, with a total distance of almost 2000 km covered. Feedback gained during these "ground level" workshops was particularly useful. Selection of the particular towns and Municipalities as well as municipal staff members involved was based on the following:

- target areas of the country as per WRC Reference Group meeting (discussed earlier)

- towns situated far from large metros and the many engineering consultants they offer
- locations were preferred where the project team had known contacts (in these target regions); it was noted that a few of these "known contacts" had moved on since last contact and the replacement staff member then became the target!
- availability of key Municipal staff to attend on dates suitable for the workshop/s
- availability of the project team members in view of other commitments
- budget constraints implied that two suitable consecutive days had to be found within logical geographical constraints and travel time/s between the towns selected.

Although various towns were eventually visited, two central (somewhat larger) towns were considered the base of each day's events:

- Beaufort West (1 day): site visits to three towns/two Municipalities around Beaufort West on 16 November 2009
- De Aar (1 day): site visits to four towns/three Municipalities in the Pixley Ka Seme region on 17 November 2009

The full list of Municipalities visited is given in Table 4-1.

Table 4-1. Workshop summary – Municipalities and contact details

	Municipality / Town	Contact Person	Contact Number
1	Beaufort West (Beaufort West Municipality)	Louw Smit	
2	Richmond (Ubuntu Municipality)	Antonie Sesman	
3	Phillipstown (Renosterberg Municipality)	Elias Hugo	
4	VanderKloof (Renosterberg Municipality)	Patricia Mqokoza	
5	Petrusville (Renosterberg Municipality)	Patricia Mqokoza	
6	De Aar (Pixley Ka Seme District Municipality)	Hendrik du Plessis	
7	De Aar (Emthanjeni Municipality)	Chris Hendriks*	
8	Hanover (Emthanjeni Municipality)	Chris Hendriks*	
9	Victoria West (Ubuntu Municipality)	Fanie Dignon	

* Involvement cancelled on the day due to unforeseen urgent repair/maintenance work

Seven towns in 5 Municipal regions in the central parts of the country were visited on the 16th and 17th November 2009 to gather inputs on the development of low tech tools/guidelines to assist municipal workers in regards with sewer infrastructure projects and management (note that the table correctly includes nine entries, but two are for De Aar and one visit was cancelled).

During the first workshop and a subsequent project team meeting the team attempted to identify the most useful tools, while keeping a simple and uncomplicated end product in mind. The decision was taken to focus on as few target areas as possible (the aim was set to include only 5), while remaining flexible and open to change during the workshop session. The 5 most notable key points would then be developed to a set of 5 tools. The key points were selected by means of subjective judgement by the project team, keeping in mind the project TOR, the WRC Reference Group comments, the large number of returned questionnaires and also the specific and very useful inputs received from key role players during the workshop. The main reason for rejecting the other concepts tested at the first workshop includes the fact that they were misunderstood by some respondents, or that the need was not particularly well defined.

Six tools were eventually included. As part of the further development a description of the project, SS planning and the initial ideas in developing these tools were presented in each case to stakeholders. The background was discussed before moving on to workshopping the following 6 tools, based on the level of evolution when presented in mid-November:

- Infrastructure Costing Tool
- Hydraulic Design Tool
- SS planning Checklist Tool
- Master Planning Process Tool
- Sewer Terms Tool
- WSDP-Tool

The specific comments and recommendations were recorded for each tool listed above. These were grouped in order to add value and improve each tool. The comments are presented below.

4.6.2 Feedback on Infrastructure Costing Tool

The tool was well received and in some cases respondents indicated that they had devised in-house methods for estimating the cost of infrastructure based on prior experience and recorded project costs in the past. The most notable comments regarding the costing tool could be grouped as follows:

- the response received on this tool was generally positive, with all the participants confirming a definite need for such a tool
- concerns were raised regarding the method of updating the tool; how could it be kept up to date and applicable.
- differentiation between the three different types of cover for pipe laying (roads, road reserves, or open spaces) were noted to be valuable, but some concerns were noted in areas where tough excavation conditions were common; one idea was to include a price factor to compensate for hard soil or rock, despite the pipe being placed in an "open space".
- A few concerns were raised to also include costs incurred during operation and maintenance of pumps, but such costs were considered to be at a more advanced level than the outcome strived for in this project. The limited responses in favour of such an O&M costs were dwarfed by the response to maintain a tool that is easy to understand and use that would be based on capital cost only.

4.6.3 Feedback on Hydraulic Design Tool

The following feedback was received on the hydraulic design tool:

- a definite need was noted, but it was noted by some to be only a "nice-to-have" and thus less critical than some other tools
- the output should be durable, possibly printed with a hardcover or as a poster
- a need was noted for post-project training on-site
- municipal workers had a need to gain knowledge on products and equipment, rather than the hydraulic theory (e.g. increased frequency of visits by equipment suppliers' marketing staff)

- some municipalities have already developed similar tools thus underlining the need for such a tool

In addition to the comments given above, particular concerns were raised by some stakeholders as to the need for a tool to select appropriate pump technology. Minimization of sewer pumps should possibly be considered a priority when designing sewer systems to alleviate the numerous reported operations and maintenance problems associated with this infrastructure element.

4.6.4 Feedback on SSP Checklist Tool

The following provides a summary of the feedback on the SS planning checklist tool:

- the main purpose of the tool was noted to be gaining knowledge about available information regarding the local authority's sewer infrastructure
- The added value in terms of asset management was noted
- the tool would be needed in digital format for those with computers to access and update it easily in electronic format (this was the only tool noted to have a particular use in electronic format during the workshops)
- it would be valuable to include the state of the specific section of the system in the checklist, together with the estimated life and/or remaining life (in view of asset management).

An interesting use for the checklist tool was noted to be an easy method to record information (on SSP progress) in clear and standard format. This record of information would then aid other staff, consultants, and possibly future staff members, to quickly assess how far the particular town had progressed with its SSP. A particular use was noted in one case where sudden and unexpected staff turnover meant that the knowledge of previous SSP could easily be lost with such a staff member moving away. A new employee may thus be left duly unaware of the former progress, if not for such a checklist tool. It was thus apparent that the tool would have to be provided to Municipalities as a wall chart of some sort, rather than a document or small checklist-sheet.

4.6.5 Feedback on SS planning process Tool

For the SS planning process tool it was found that in all the municipalities a consultant would simply be appointed for such instances. It was clear that Municipal staff were not keen or interested to even understand the process of SSP and would prefer to simply appoint a consultant, who was perceived to understand the work.

4.6.6 Feedback on Sewer Terms Tool

A neat and compact booklet of sewer terms, or mini-sewer dictionary, would clearly find a home with most of the workshop delegates. The notable feedback could be grouped as follows:

- it is definitely needed
- it should include terms that are commonly used by the lower level of the municipality's workforce, including perhaps lay and slang terms (sometimes these terms are region specific that significantly complicates the problem to produce a single project output)
- of all the municipalities visited Afrikaans and English were the only languages used at the time of the study.

4.6.7 Feedback on Sewer WSDP-Tool

Despite the fact that the WSDP is a legal requirement, few of the stakeholders seemed to appreciate a tool to aid in compilation of the necessary information in the required format of the WSDP. This was mainly attributed to three reasons:

- firstly, the WSDP format provided by DWAF is regularly changed and updated, thus creating the perception that any SSP-tool aiding the municipality towards the WSDP would soon be out-dated
- secondly, it was apparent that municipalities prefer using an engineering consultant to assist with WSDP-compilation
- and thirdly, the WSDP encompasses all water infrastructure as well as socio-political and general non-technical information; sewer is only a small input to the process and a tool aiding in (only) sewer-related aspects would be deemed insignificantly useful when compared to the compilation of the complete WSDP.

4.7 Review of Workshop 4 (MIG Western Cape, Worcester)

4.7.1 Description

Collaborating with the MIG workshop in Worcester proved to be a particularly valuable method of meeting with a very large number of Municipalities and related civil technical staff. The workshop was organised by Aurecon and after some negotiations it was agreed that the project team would obtain a short turn to present their case before the entire group of delegates, and were then allowed to workshop the SSP tools during the break time. The workshop chairman was Mr Leon Eksteen, and the organising chief was Mr Charl Nieuwoudt (Aurecon Technical Director: Project Management – based in Century City office, Cape Town). In excess of 100 Individuals, from 43 different institutions/Municipalities in the Western Cape Province attended the MIG workshop (a signed attendance register is available).

Due to the nature of the MIG workshop, the tight schedule and the large number of diverse individuals attending with the aim MIG-funding, it was not considered appropriate to formally include a workshop slot in the MIG workshop programme to test the SSP tools with the whole group. Interested individuals were invited to partake during break time. Those individuals who approached the project team, after the presentation on SSP tools to the whole group, were those particularly interested in the project and the low-technology SSP tools.

4.7.2 Municipalities represented

The following 27 different Municipalities were represented at the MIG workshop. In about 80% of the cases the representatives were civil technical staff:

Beaufort West Municipality
Bergrivier Municipality
Bitou Municipality
Breede Valley Municipality
Cape Agulhas Municipality
Cape Winelands District Municipality
Cederberg Municipality
Central Karoo District Municipality
Eden District Municipality
George Municipality
Hessequa Municipality
Kannaland Municipality
Knysna Municipality
Laingsburg Municipality
Langeberg Municipality

Matzikama Municipality
Mossel Bay Municipality
Oudtshoorn Municipality
Overberg District Municipality
Overstrand Municipality
Prince Albert Municipality
Saldanha Bay Municipality
Stellenbosch Municipality
Swartland Municipality
Theewaterskloof Municipality
West Coast District Municipality
Witzenberg Municipality

It is apparent that some of the individuals and/or Municipalities involved in the other three workshops (IMESA and the road trip) were again targeted here; this was not considered a problem.

4.7.3 Feedback

Very positive feedback was received on all the SSP tools at the level of completion presented at the workshop. The following specific points were noted by stakeholders and recorded by the project team:

- Presentation format: The one tool presented as an example in poster-format was well-received and the poster-format was clearly more sought after than say, an A4 mini-report or booklet.

- Pumps and pump stations: pumping installations were noted as a particular concern in view of effective design and operations/maintenance. Some stakeholders noted a need for development of a tool (beyond the scope of this study) at a higher level of technology that would assist in selection of appropriate pumps and related technologies for small-scale installations.

- Cost-functions: in many instances stakeholders noted that less accurate and less user-friendly "thumb-suck" methods were in place to estimate cost of infrastructure. None of these alternative methods had been recorded or reported for reference. Contradictory comments were made by stakeholders with regards to the cost-functions. Firstly, the fact that the cost was presented as an actual "Rand value" was noted to be essential, because many intended users of the cost-tool would – with due respect – not understand a more complicated presentation of the cost/value (say as a normalised value); secondly, the tool would need to be regularly updated in order for it to be useful. The project team opted to maintain the actual Rand-value, despite some concerns noted in this regard by the WRC reference group. Instead, a workable solution based mainly on stakeholder feedback, was presented by the project team for the costs to be regularly updated. Two noteworthy suggestions in this regard include presenting it on a web-interface for download by senior staff (with access to a computer with internet) on say an annual basis and/or presenting it to registered users on an annual basis in poster format, with the last update year displayed in a large font in the title (update would work in a similar manner as obtaining a new TELKOM phone directory, except that users would be "registered").

- The hydraulic design tool was noted to have value as an aid in education and training of Municipal staff involved with sewer systems. The relationships between different variables, presenting in this relatively simple manner and in different ways, clearly had an advantage. However, few stakeholders would ever use the tool to move any further than education/training or possible concept design (it was noted that consultants would be appointed to conduct the design and hydraulic analysis). From an academic perspective the hydraulic design tool has an added value since it could be applied to illustrate basic principles on under-graduate level.

- The Sewer terms tool should in fact be included in a more comprehensive dictionary for local water terms in (say) English and Afrikaans (these languages were reported to predominate in the local authorities visited during this project). The workshop project team learned of various "dictionary" booklets and these are reported on later in this document.

- Most of the Municipalities at the MIG workshop were aware of the SS planning process due to previous presentations by GLS Consulting (in collaboration with Aurecon) at former MIG workshops and/or SSPs conducted in the past. For this reason the SSP checklist tool seemed to be taken for granted and the impression was that the Municipal staff would expect the consultant to use and update the checklist as the SS planning process evolves with time. This aspect does not nullify its use, but clearly highlights the fact that tools with a clear and direct value for in-house education and training on Municipal level were noted to be more useful than those without.

5. HYDRAULIC DESIGN TOOL

5.1 The Basics – How does a sewer system work?

Some detailed documents are available for the design and construction of sewer systems (e.g. ASCE, 1982), but few provide a good background of a sewer system and its functioning for a wider readership, say at local authority level. It was noted during the stakeholder workshops that a basic description of the operation of a SS is often needed, i.e. a short description of the most basic aspects of SS operation. Such a short description would also set the scene for application of a somewhat more advanced hydraulic design tool. The presentation would be a text file with illustrations where appropriate.

In future the work around this topic should preferably be extended to a video (movie). The movie would be similar in nature to one produced in the late 1980's by Johannesburg Water (Nay, 2009). It was used for basic education of visiting school and student groups at Goudkoppies sewer treatment works. Although the correct contact person who was involved at the time could be traced during this study, no copy of the video could be found.

5.2 History of basic pipe flow hydraulics

In considering a simple tool for sewer planning hydraulics it would make sense to go back to the historical methods used for hydraulic analysis prior to the computer-era. Even the most basic of those methods attempting to present solutions to hydraulic head loss equations, such as the "HRS-charts" still presented in some hydraulic text books to this day (Chadwick et al., 2004), were found to be too complex in the light of local authority needs. This is in line with findings regarding the relatively low technical skill level and human resources available at many small local authorities in South Africa (Lawless, 2007).

Also, the application of the average flow velocity in hydraulics is now accepted to be out-dated and other methods are available for determining scouring and sediment transport in sewer pipes (Saatçi, 1990). For the limited application of a simplified tool it was considered necessary to use the average velocity as a means to illustrate some essential relationships, often not understood at the level for which this tool is intended.

In South Africa the "Red Book" in its various forms from first publication (CSIR, 1983) to the most recent (CSIR, 2003) provides existing guidelines, with a strong focus on practical design matters. Chapter 10 of the most recent edition deals with Sanitation, and Appendix C of that chapter provides a design guide for waterborne sanitation systems. The latter includes very limited information on hydraulic design, but is not suitable for use as a simple tool. Appendix C of the Red Book document relates well to another WRC-funded project currently under way (Van Dijk et al., 2008) that addresses design of sewer systems.

This chapter describes the development of components of this project where hydraulic matters are considered relatively easy to portray in the form of graphs. Graphs were found to be easy to understand and useful to describe the relationship between different variables. Guided by the intensive workshop exercise forming part of this project (discussed earlier) the final aim was to limit tables or graphs to single-variable relations as far as possible. It is obvious that limitations would be inherent in these simple relations, presented as graphs or tables in this Chapter of the text. Despite advances in technology over the years similar methods are still used in practice to this day and are often useful in a very crude and somewhat non-scientific way.

The development and background of these "hydraulic graphs" are presented in this chapter. Some of these tools are presented in earlier literature, when their use was encouraged due to the lack of computers – a particular point of interest during this research. In some cases presentation of graphs in other literature sources were used as a basis and subsequently amended with a focus on SS planning.

It was considered appropriate to use Manning's equation to evaluate the relationship between pipe diameter, slope and velocity for pipes flowing full (as is the case during a typical design) where necessary. This produced, for example, a graph presenting the relationship between pipe diameter and required slope. It was learned during the stakeholder workshops that the pipe diameter was easily accessed and understood, while the slope was considered a critical parameter in understanding the operation of a gravity sewer system. The intention of the project outcome, to be applied at ground level in local authorities, was not to tell anything of the way in which the "simple tool" was developed, but rather to present the outcome without any need for hydraulic knowledge (e.g. Manning's equation and parameter values are not even mentioned in the outcome/s).

Figure 5.1 and Table 5.1 shows the slope required to sustain the three most typical minimum velocities in various sized pipes. Pipe slope is expressed in all cases as metre per kilometre (m/1000 m) as this was found to be the most basic and understandable unit to present pipe slope in practice.

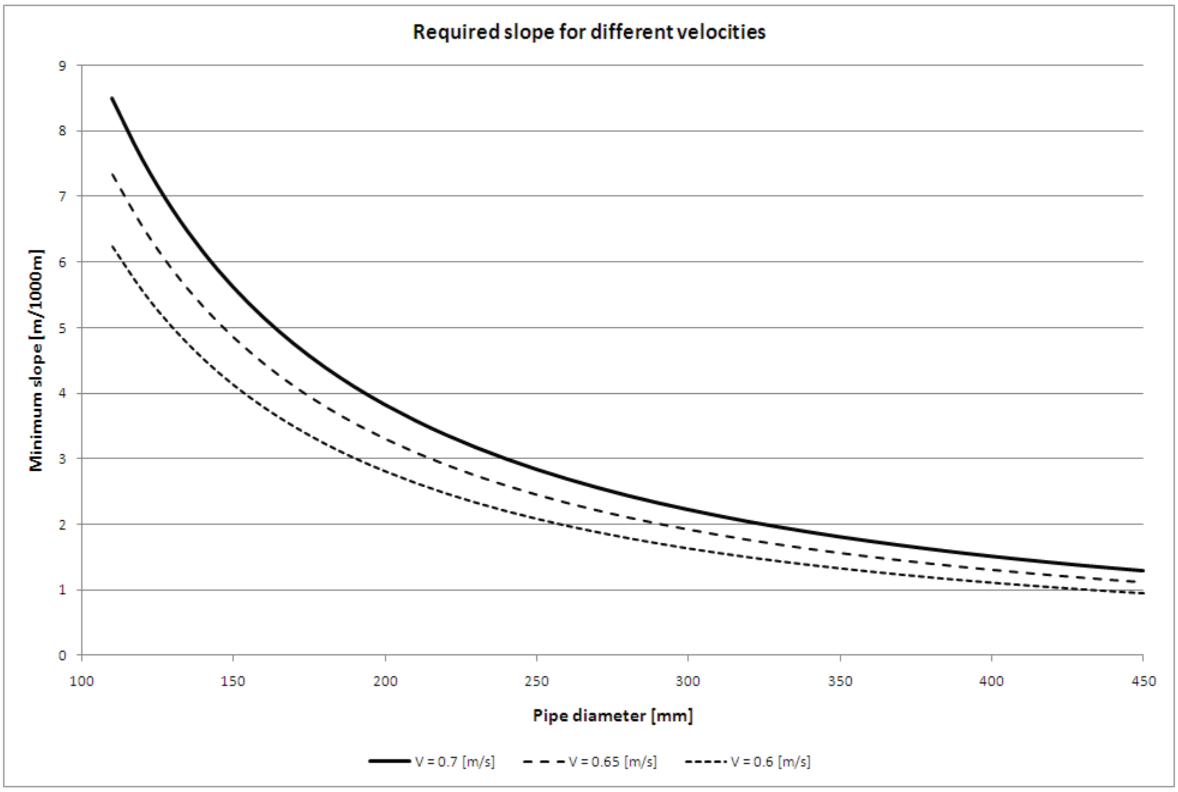


Figure 5.1: Pipe diameter, slope and different average velocities for pipes flowing full

5.3 Basic sediment transport and particle settlement

It is common for the minimum flow velocity and/or pipe slope to be used as criteria for system design, as was also apparent from another ongoing WRC study by the University of Pretoria (Van Dijk et al., 2008). However, it is in fact the movement and settlement of particles in the sewage that demands this minimum velocity and thus minimum slope. The literature is rife with reports on the transport of particles, varying in detail from the most basic to extremely advanced and complex (e.g. Jacobs and Crombie, 2009).

The use of graphical methods to illustrate the relationship between the related variables in this regard proved to be particularly interesting and useful during stakeholder workshops and it was found particularly useful to plot other findings from literature. In an example of work by Walski et al. (2004) the slope required to transport particles of a given size was investigated. Their results are shown in Figure 5.2 and were based on pre-defined particle sizes injected into the flow. Figure 5.3 shows the superposition of the lines in Figure 5.1 and Figure 5.2 on the same axes. The superimposed lines show that a relatively small particle of 0.5 mm would settle if the velocity were to drop under 0.6 m/s for a Ø150 mm pipe and 0.7 m/s for a Ø450 mm pipe. Particles entrained in sewage are typically of this order of magnitude (although reports of objects like bricks, engine blocks, bodies and tyres blocking sewer pipes have been recorded during this study!). This explains in part why the minimum flow velocity is typically prescribed to be between 0.6 m/s and 0.7 m/s.

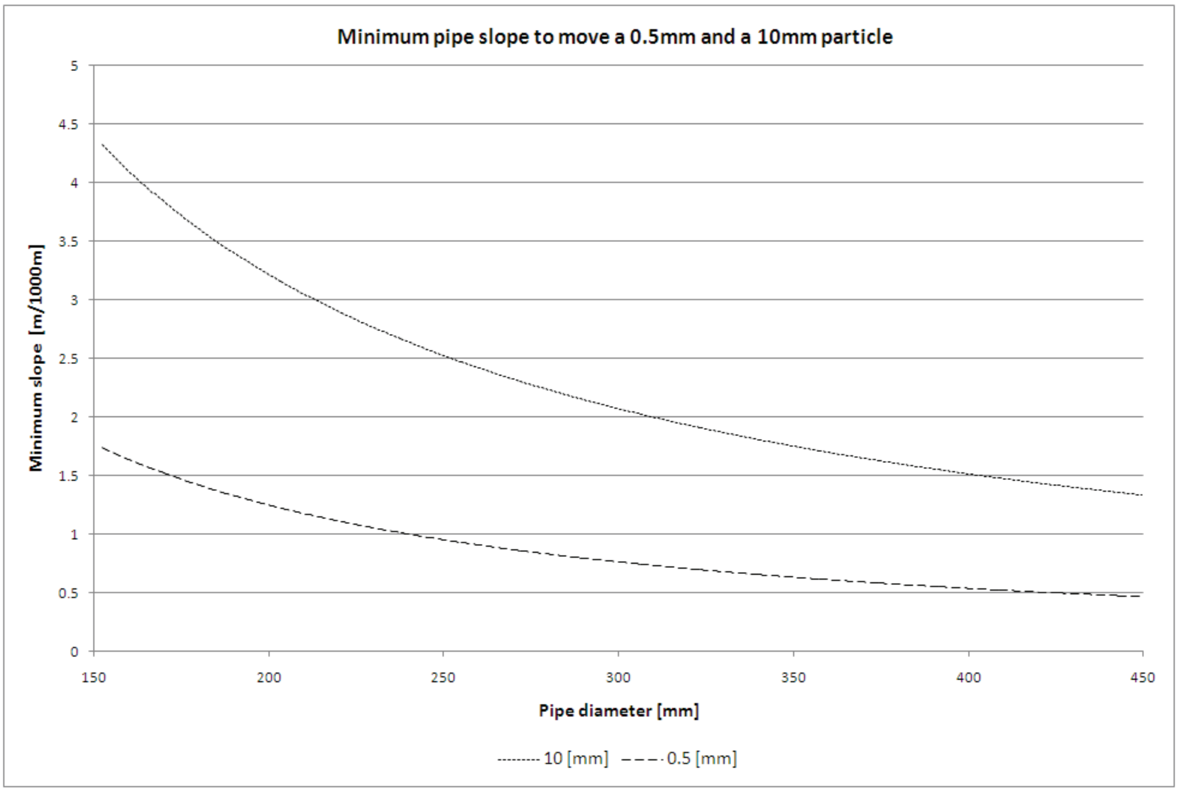


Figure 5.2: Particle settling for different pipe diameters and slopes (Walski et al., 2004)

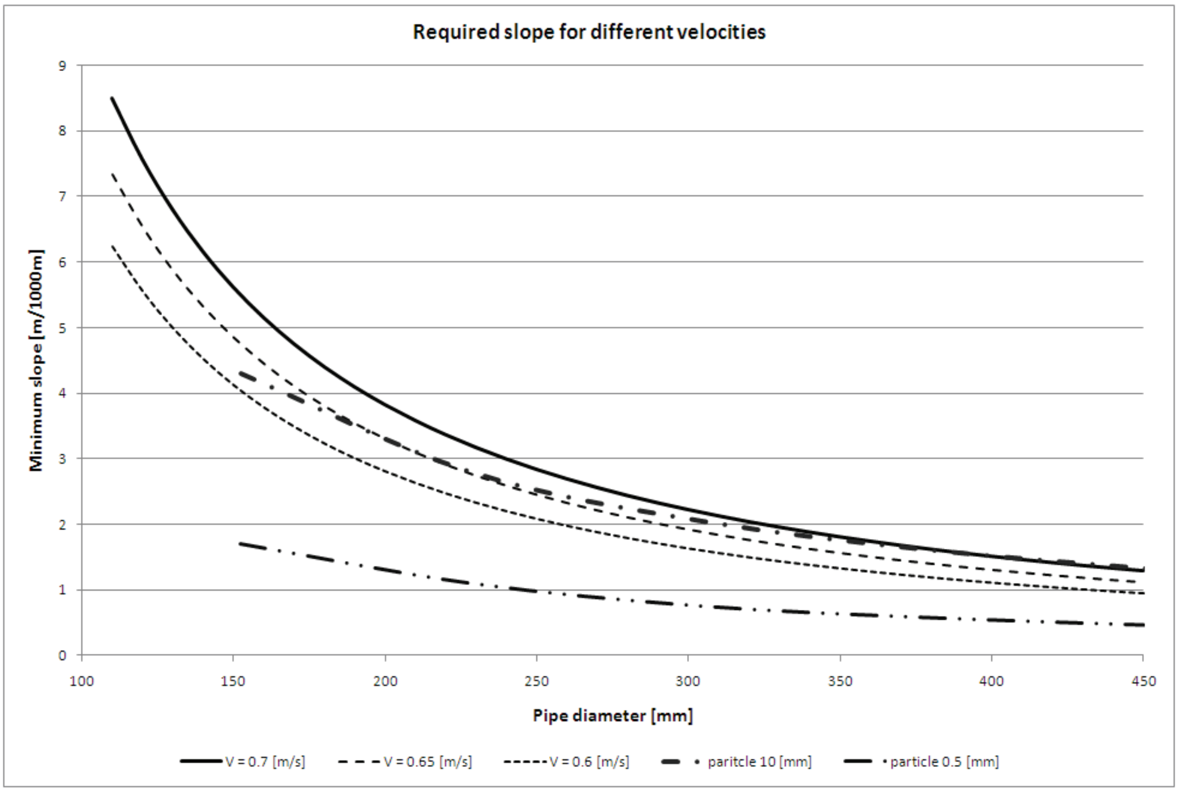


Figure 5.3: Particle settling (Fig.5.2) superimposed on different average velocities (Fig.5.1).

5.4 Linking the number of RDP-homes to hydraulic characteristics

The first stakeholder workshop suggested that the hydraulic tool above, per se, would be limited to some extent unless it could be extended to assess the scope of future development serviced by the pipe/s in one way or the other.

For this reason one type of typical development that Municipalities are often faced with was identified, namely residential properties. The number of units (houses) was then linked to the hydraulic characteristics based on some estimates described below. The result was a very crude yet very user-friendly way of showing the relationship between the number of homes to be services and the sewer pipe size and slope that is likely to be required. The intention is not for this tool (or any other presented here) to replace the need for a qualified engineer to design the system. It should merely give an idea of the impact that any development idea may have on the system. It would then be easy to extend the estimated infrastructure intervention to a financial implication by applying the cost tool also presented as part of this study. The fact that the tool is not in fact intended to serve a design purpose led the team to limit the tool to one type of land use only instead of extending it to also include non-residential land uses.

The construction of low-income, high density homes such as those initially constructed as part of the Reconstruction and Development Programme (called RDP-homes in this text after the initial drive to provide this type of housing) was noted to be a particular homogeneous type of development that these poorer Municipalities are faced with. However, similar results were also produced for middle and higher income properties.

The idea was to estimate the sewer flow from a house and development, then link the flow to the hydraulics presented earlier. The calculations were based on the following values reported elsewhere, and assumptions:

- The average sewage flow for the lower, middle and higher income groups as per the CSIR (2003) guideline are 500-, 750- and 1000 litres per dwelling unit (du) per day.

- The peak flow is based on a peak factor of 2.5 times the average flow (CSIR, 2003), plus 15% of the peak flow allowed for extraneous flows – as also discussed below in more detail. The peak flows for the low, middle and higher income groups are 0.0167-, 0.025- and 0.0333 l/s/du respectively. It is interesting to also note that Stephenson and Barta (2005a) reported residential wastewater outflows to range between 0.01- and 1.20 l/min/household (equivalent to 0 ~ 0.02 l/s/du) plus water leakages into municipal waterborne sewers of between 0.06 and 0.20 l/min/household. It appears that the CSIR (2003) estimates are relatively high and thus that, in using them, the outcome would be relatively conservative. Based on the crude result developed here such conservatism is justified.

- It is assumed that peaks from homes correspond in time, thus conservatively neglecting the effect of the total sewer hydrographs attenuation as it moves down the system, once again remaining conservative.

- An allowance is made for infiltration (groundwater etc.) on the basis of 15% of the dry weather flow, as this is the generally acceptable standard allowance for extraneous flows; this is in line with practical experience by the project team as well as Stephenson and Barta (2005a) who reported that groundwater ingress amounts to up to 15% of sewer capacity and that the groundwater infiltration into municipal sewers ranges between 0,01 and 0,50 l/min per metre diameter per metre pipe length (it should be noted that those authors recommended to consider groundwater infiltration exceeding 0,10 /min/m-dia/m-pipe as being excessive for all sewer pipe materials)

- Although the hydraulically derived full flow capacity of pipes was based on full flow of the sewer, all sewers were assumed to flow only 60% full based on their flow rate ratio. The 60% capacity value was based on the most conservative reports found during the knowledge review (Stephenson and Barta (2005a). The remaining spare capacity of 40% would thus be available to convey undesired stormwater ingress. Despite the reports by Stephenson and Barta (2005a) that stormwater inflows could amount to up to 40% of sewer capacity, 30% was actually found to be commonly used in SS designs in the country.

- Manning's n-value was taken as 0.015 for all calculations. This assumption is crude; most literature sources suggest n-values of between 0.012 and 0.015 for typical sewers – and 0.015 being the most conservative of these. To underline the complexity of this aspect, one study (Guzman et al., 2007) on the impact of biofilms in sewers and entrained sand particles in sewage on the n-value showed that n could easily vary from 0.010 to 0.045 in a specific Ø200 mm pipe under various flow conditions (varying flow depth over diameter ratios and variation in biofilm presence and entrained sand). However, further elaboration on values of n and their variation was not justified here.

The calculated results were termed the "hydraulic tool" and are presented in a number of graphs, presented in the following figures:

- Figure 5-4 shows flow rate versus pipe diameter for a few selected pipe slopes (limited to small diameter pipes under 200 mm diameter)

- Figure 5-5 shows the flow rate versus pipe diameter as before for larger diameter pipes up to 450 mm

- Figure 5-6a and Figure 5-6b links the flow to the number of low-income (LI) homes for the smaller and larger pipe sizes mentioned above respectively

- Figure 5-7a and Figure 5-7b links the flow to the number of medium-income (MI) homes for the smaller and larger pipe sizes mentioned above respectively

- Figure 5-8a and Figure 5-8b links the flow to the number of high-income (HI) homes for the smaller and larger pipe sizes mentioned above respectively.

This tool makes it possible to quickly, easily, crudely and conservatively assess the number of homes that could be serviced by different pipe sizes at different slopes. The slope would be determined by the given site under consideration and could be determined for a given development. It goes without saying that this tool provides merely a crude estimate and is intended to be used to illustrate the link between the increasing number of homes and increasing pipe size required. A conceptual and later detail design by an engineer would of course be needed to select the pipe sizes required to service the given development when a project is given the green light.

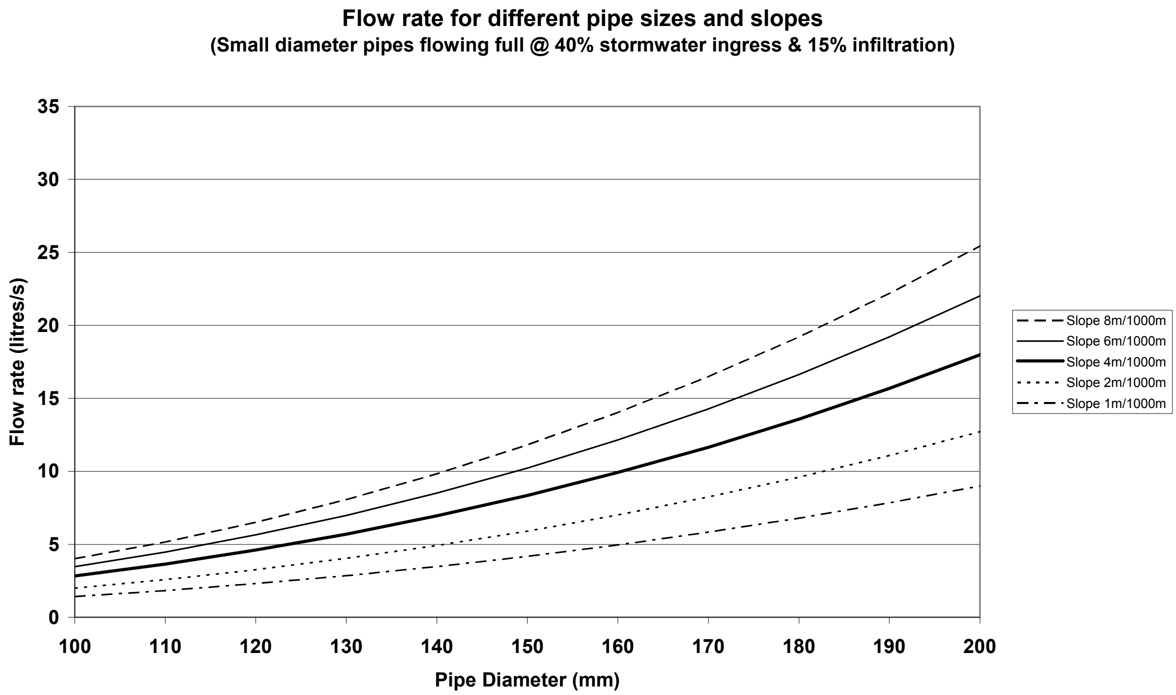


Figure 5.4: Flow rate for different pipe diameters and slopes (D<Ø200 mm)

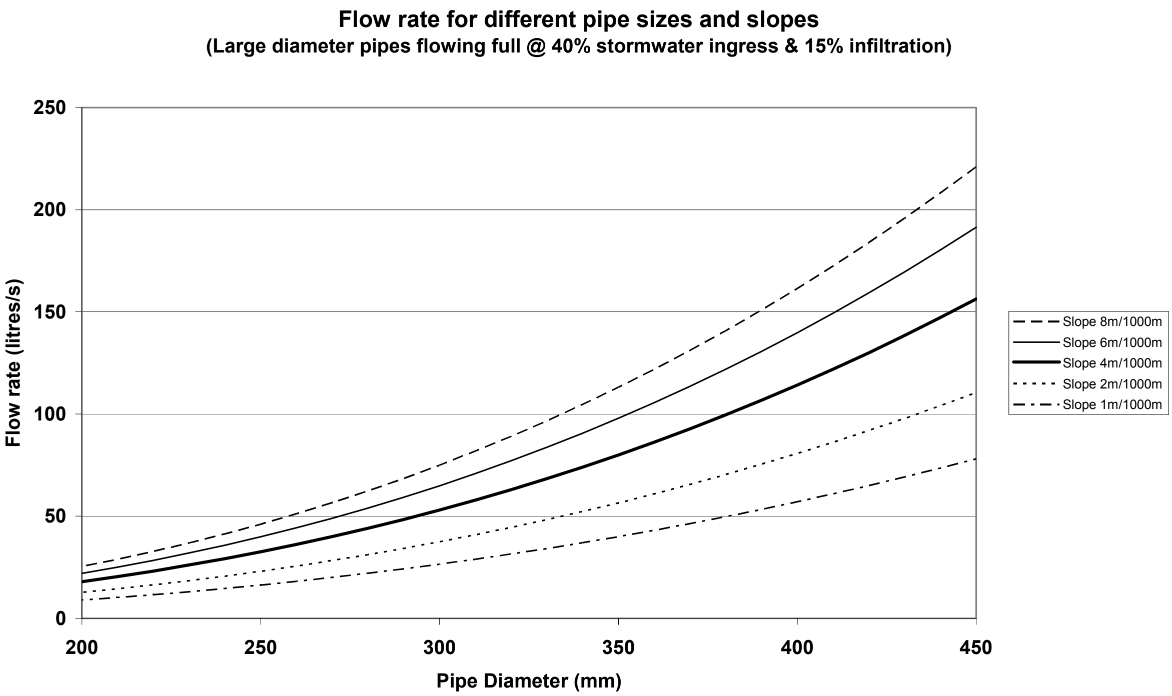


Figure 5.5: Flow rate for different pipe diameters and slopes (D>Ø200 mm)

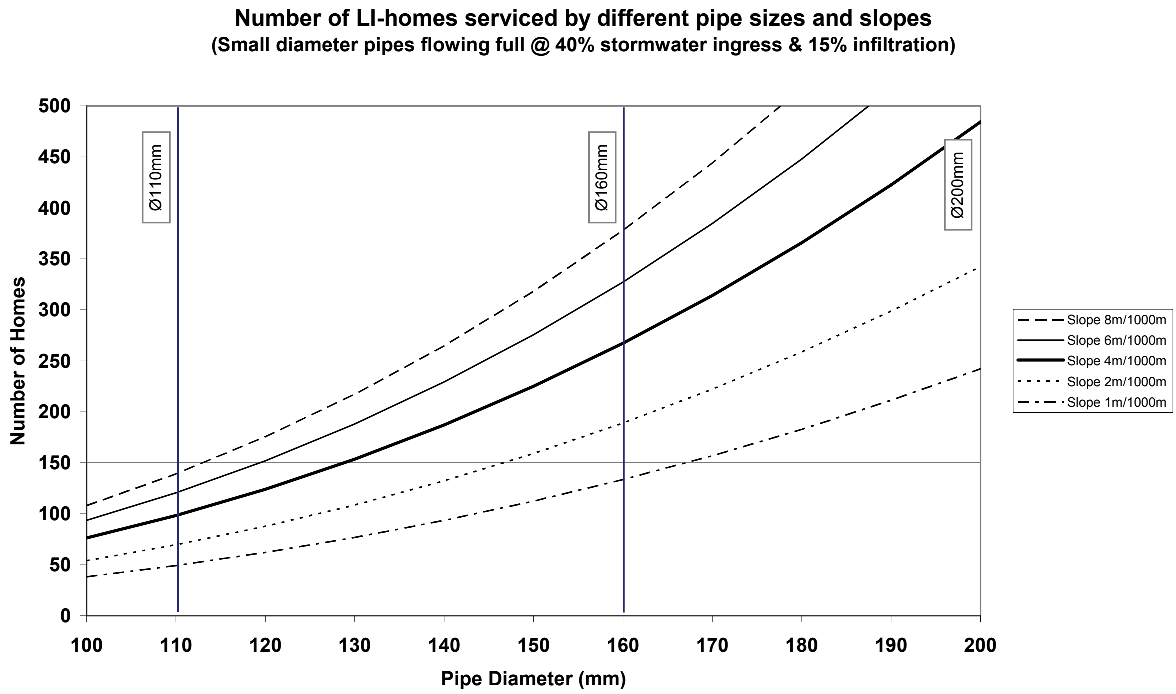


Figure 5.6a: Relationship between number of LI-homes, pipe diameter and slope (D<Ø200 mm)

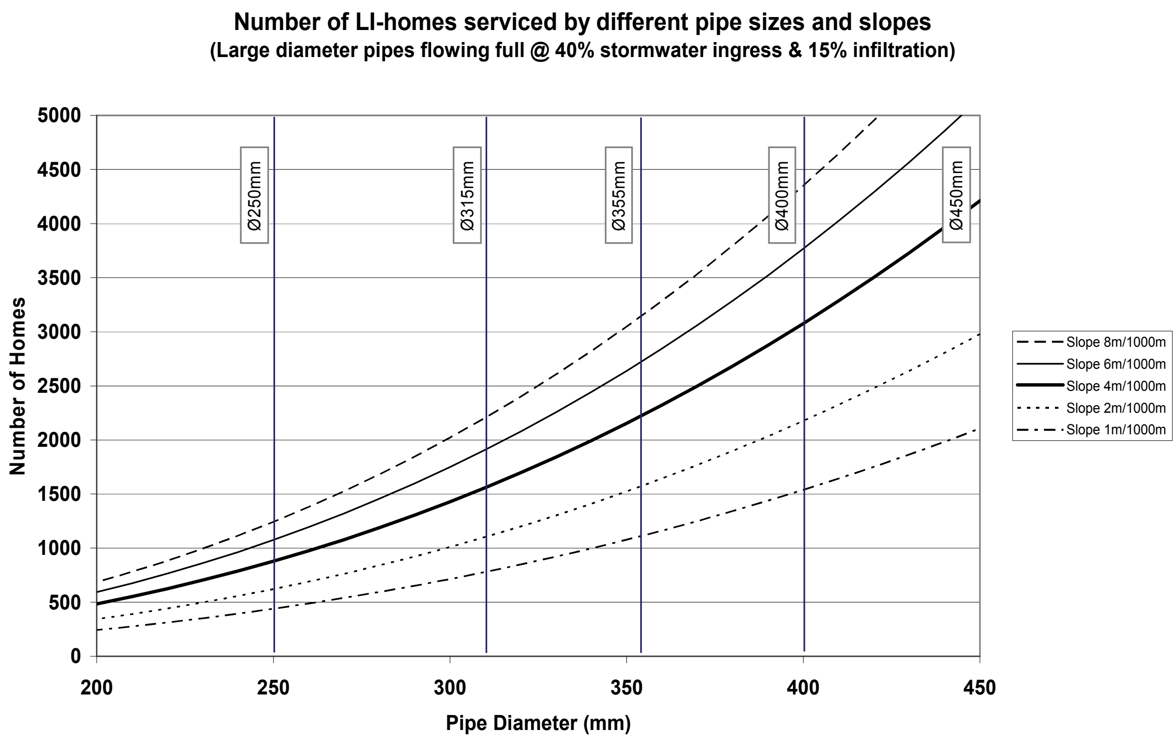


Figure 5.6b: Relationship between number of LI-homes, pipe diameter and slope (D>Ø200 mm)

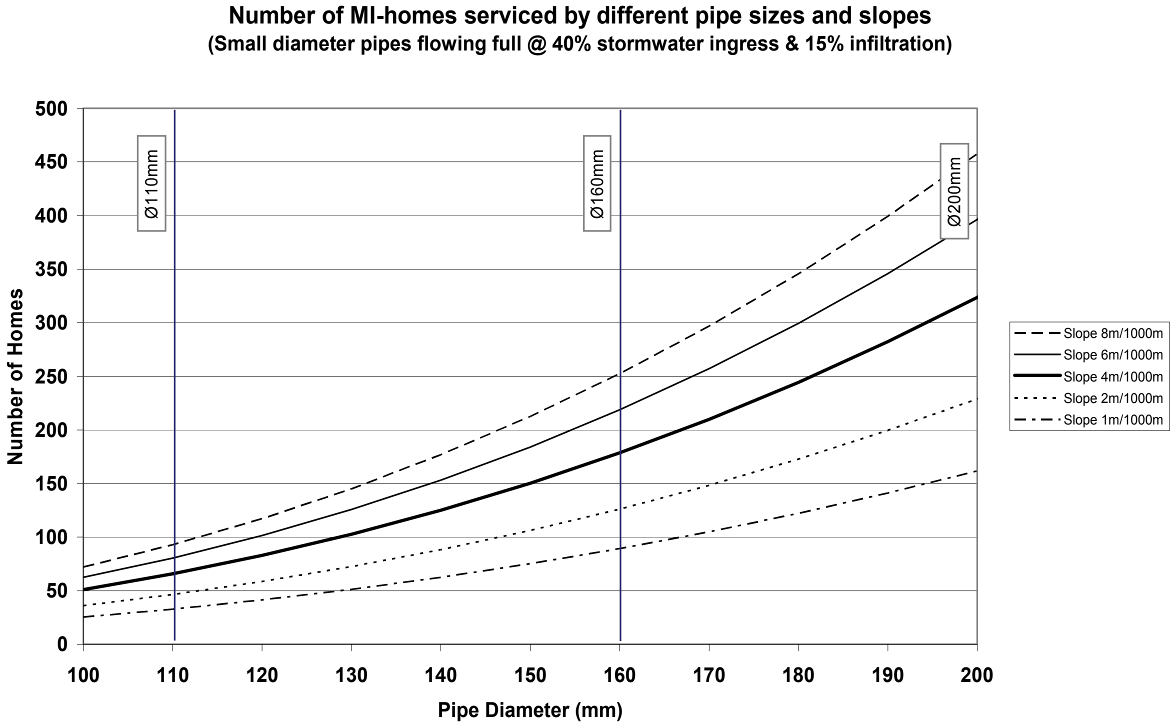


Figure 5.7a: Relationship between number of MI-homes, pipe diameter and slope (D<Ø200 mm)

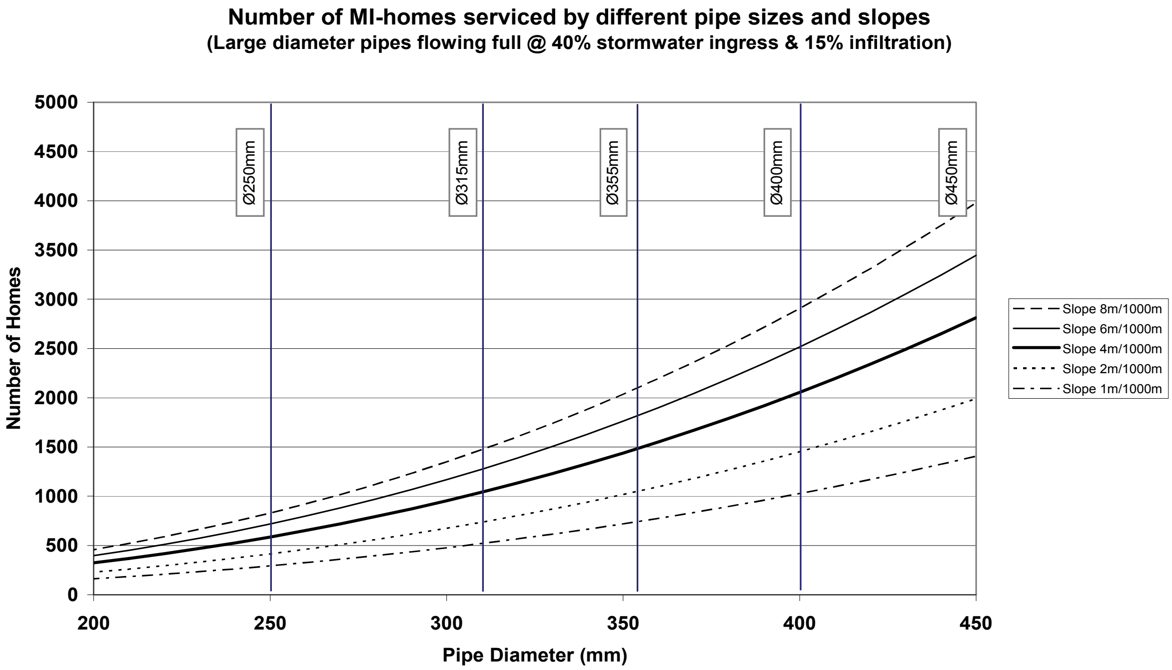


Figure 5.7b: Relationship between number of MI-homes, pipe diameter and slope (D>Ø200 mm)

Figure 5.8a: Relationship between number of HI-homes, pipe diameter and slope (D<Ø200 mm)

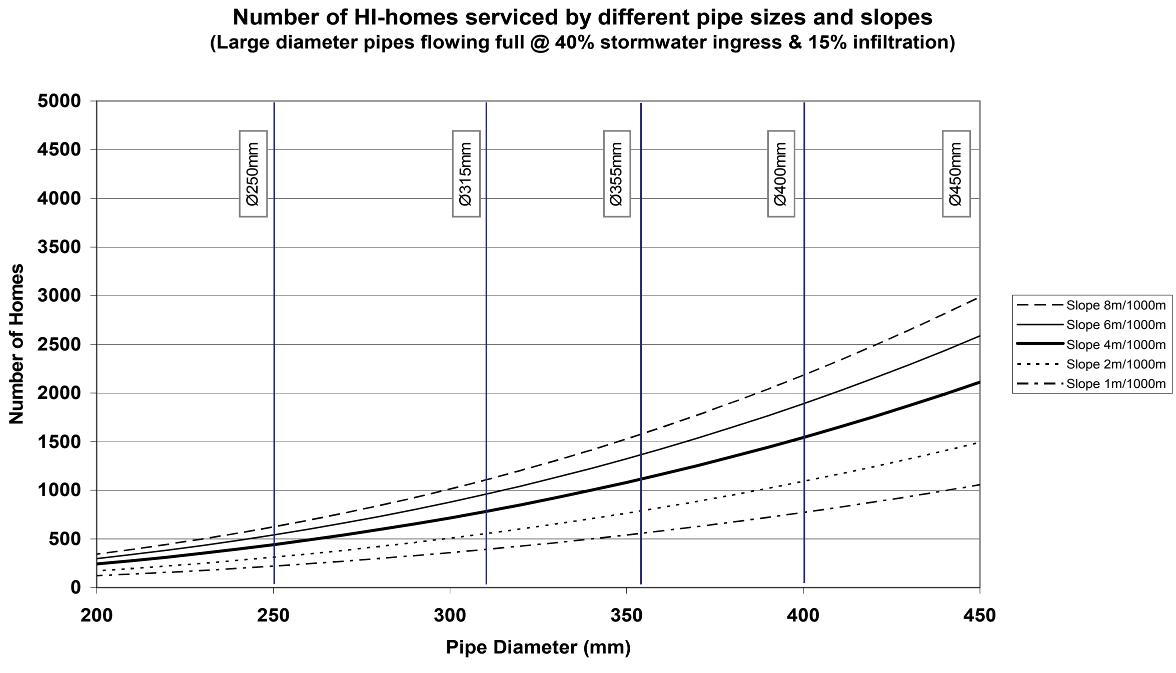


Figure 5.8b: Relationship between number of HI-homes, pipe diameter and slope (D>Ø200 mm)

5.5 Empirical analysis of completed SSP results

5.5.1 Evaluating the amount of scatter

In addition to the theoretically-derived graphs presented earlier in this chapter, the project team also conducted a detailed review of actual completed SSPs and the hydraulic models of the corresponding sewer systems. The intention with this step was to assess the relationship between some selected parameters and to evaluate the scatter of data experienced in practice.

The first step towards analysis of completed SSPs was to obtain the report (documents) and hydraulic models of each SSP to be analysed. The project team compiled a table summarising the available SSP documents. After gaining various systems models the team continued to identify those portions of the models that were deemed to be sufficiently accurate (e.g. pipe sections that had been surveyed as part of previous work). Various design parameters (e.g. pipe diameter) were subsequently gained and tested against those that were considered to be "easy to ascertain" in any SS design (e.g. number of properties to be serviced). The idea of testing those parameters that are "easy to ascertain" was in line with the low-technology nature of the SSP tools in this project.

Graphs of some selected variables (e.g. diameter, upstream erven and length of upstream gravity pipes) could then be established for each of the drainage basins. This information at hand enabled the team to investigate possible trends or relationships between the variables and to assess the scatter and spread of data.

5.5.2 Investigating the link between pipe diameter and user connections

The reason for this exercise was to investigate the relationship between the number of upstream erven (land parcels or properties) and the diameter of the sewer pipe at any particular point in the system. This could be presented in a user friendly manner graphically to form part of the tool presented as final deliverable of this project if the result was considered suitable for this purpose. Such a tool would provide an idea of the pipe size required for a certain size of development (based on number of properties), which would empower the decision makers to have more reliable data with which to scrutinise recommendations or tenders from engineering companies.

Say, for example, that a new development calls for the installation of 400 low income housing units and the tenders indicate that a 300 mm pipe would be required to manage the sewage. The results of this analysis could then be used for quick reference to assess the likelihood that such a pipe size might indeed be needed and the scatter around the given data point. As this study focuses on smaller municipalities, it was decided to gather information for sub-catchments containing no more than 2000 erven in any one drainage basin.

To gather the data needed for the inspection, Sewsan was used together with models which had high integrity levels and were already introduced to GIS-based management software (IMQS) as part of previous projects. The models chosen were those of George and Tshwane. The Tshwane model included the drainage basins of Akasia, Centurion, Mamelodi, Pretoria, Atteridgeville, Rietgat, Sandspruit, Klipgat and Temba. The information that was required was mainly that of the upstream erven that was serviced by a particular pipe size. Sewsan has a query function giving a summary of the information linked to the upstream part of the model from a selected structure.

The required information had to be extracted on a one-by-one basis from these summaries per drainage basin. The information extracted included the number of upstream erven (land parcels) and the length of gravity pipe upstream of the structure. The size of the pipe at the manhole structure under consideration was used to indicate the diameter which would be needed to service the indicated number of erven. The data was extracted from the SS model (SEWSAN software tool) and was subsequently analysed with the aid of MS Excel.

The results from the individual areas indicated that the minimum pipe size of 150 mm is by far the most commonly encountered for drainage basin sizes of up to 500 erven. It was found that less than 18% of the pipes (from all the data collected) were larger than 160 mm for a drainage basin of up to 500 erven in size. The results are presented in Figure 5-8. Given that sufficient data points are available in selected ranges (classes) of the x-axis values (number of properties in drainage basin) it would be possible to construct reliability bounds for each of these ranges, but extension of the analysis in that regard was considered to be beyond the scope of this study.

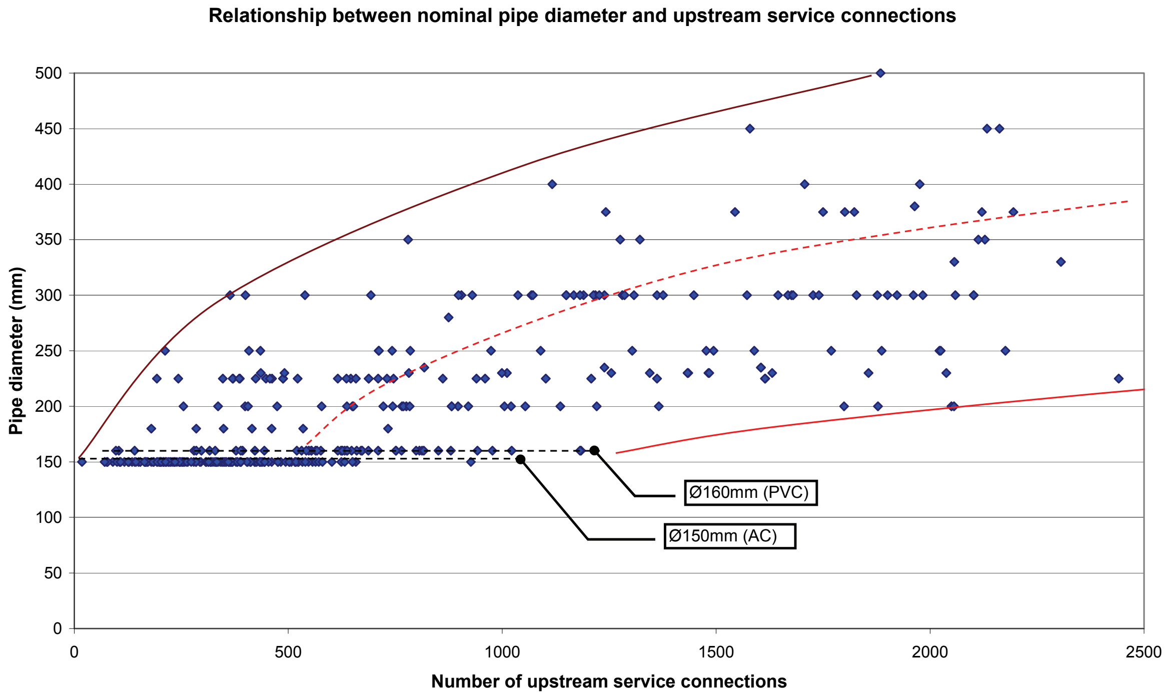


Figure 5-9: Plot (i) of data from existing SS models showing range of scatter

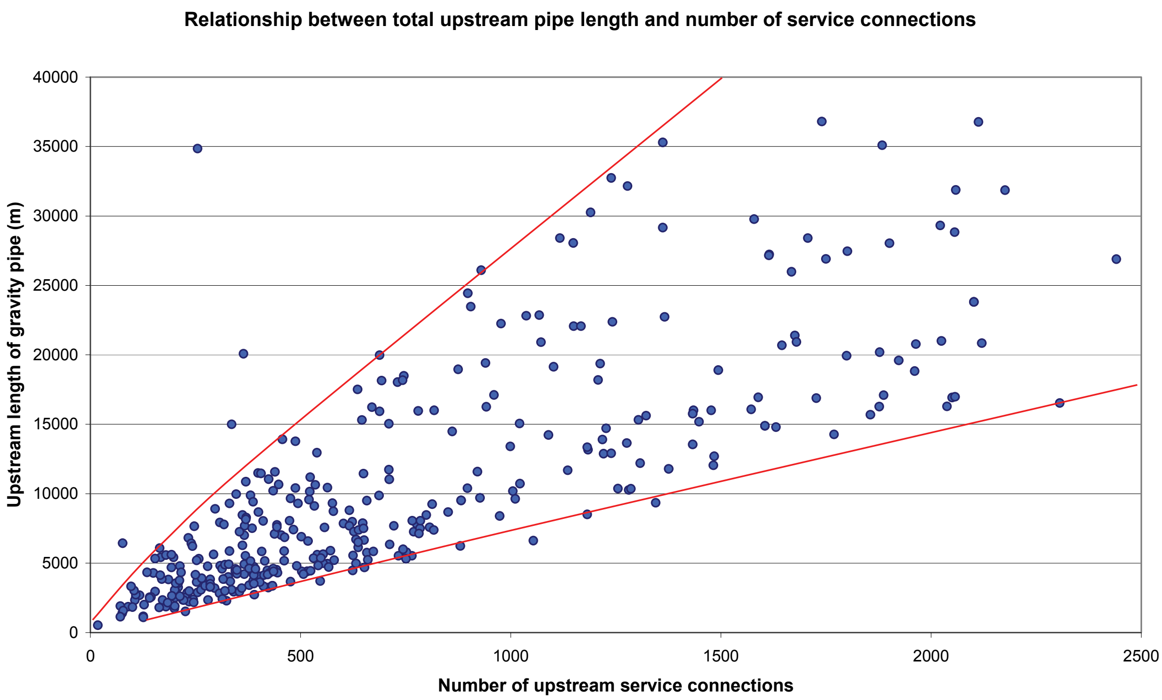


Figure 5-10: Plot (ii) of data from existing SS models showing range of scatter

The grouping of data along horizontal lines in Figure 5-9 is a direct result, of course, of the fact that pipes are manufactured in certain diameters only. Inspection of Figure 5-9 shows a large amount of scatter and thus suggests that the exact choice of the diameter type to plot as ordinate is not critical – the graph is only included in this text to illustrate the scatter and not to prepare a mathematical or statistical fit to the data. The nominal diameter was selected for this purpose to illustrate the difference between the older asbestos cement (AC) pipes that were typically provided in 150 mm sizes and PVC pipes with a nominal diameter of Ø160 mm in this size range. The large number of data points plotting along the 150 mm/160 mm diameter pipe size is clearly visible and confirms 150 mm as the typical minimum pipe diameter for all sewers in the data set. However, it should be noted that the project team are aware of some systems where Ø110 mm PVC pipe was used for gravity sewers – mainly by smaller local authorities and their consultants.

It should be remembered that many factors contribute to the size of the pipe needed to service an area, with slope probably being the most influential factor not addressed above. Therefore, these graphs should only be used to give an indication of the necessary pipe size and scatter that might be encountered in practice. The result was never intended as a tool for design purposes, but rather as a warning to show the amount of scatter and relatively wide ranges that could occur.

5.5.3 Investigating the link between pipeline length and user connections

By following a similar procedure the number of service connections upstream of any particular node (manhole) could also be plotted against the total upstream length of pipe in the system. The result shown in Figure 5-10 also shows notable scatter, but clearly suggests linear trends for the upper and lower bounds of the data with an increasing range between these bounds as the number of connections increases. The graph was included primarily to illustrate the relationship between increasing length of gravity pipe (and thus system cost) required to service an increasing number of properties. The result also underlines the relatively wide range of values between the upper and lower bounds. The results are intended to serve as an indication of the relationship between the variables tested and should not be viewed as having use in terms of a detail design tool.

5.6 Extension of the tool to address pumps

A method to assess pump technology was considered to be unsuitable to the low-technology nature of this research project. For this reason it was put forward as a separate proposal to the WRC during the final stages of this work. The proposal was accepted by the WRC and a 3-year project with the title "Investigation into pumps and pressurised flow in separate sewer systems" was initiated in March 2010.

6. INFRASTRUCTURE COSTING TOOL

6.1 Review of infrastructure cost for SSP

6.1.1 Types of cost

It was noted by De Swart and Barta (2008) that various costs are incurred when a certain technology or system is implemented and that it is important to understand the initial capital cost as well as the operational and maintenance cost. Combining these would give a life cycle cost, which is needed for life cycle analysis (LCA). This knowledge review report confirms previous findings by De Swart and Barta (ibid.) that planning in South Africa typically includes only the former – capital cost.

International trends are to include a so-called "carbon cost" to assess the actual impact of the particular technology on the environment, from its production to destruction. In summary, the following costs are incurred in the installation and operation of a sewer system:

- capital cost (e.g. the cost of constructing new infrastructure)
- operational cost (e.g. electricity for operating pumps, human resources)
- maintenance cost (e.g. repair and refurbishment of ageing infrastructure)
- carbon cost (e.g. the indirect impact on the environment)

6.1.2 Cost functions for SS planning

Conventional SS planning locally is based on optimising the capital cost only. In this case cost functions are needed by any software tool to conduct such an optimisation exercise. In this project, where the focus is on a low-technology tool, it is considered essential to limit Level 1 tools to this most basic level of SS planning. Subsequently it is essential to have accurate input data with regards to capital cost of sewers. LA's need to understand the implications of this approach and may want to extent the analysis to Level 2 in cases where (say) relatively larger pump stations or bulk sewers are considered.

A table with cost functions was presented in the Knowledge Review Report (Annexure C) and is included here again (as Annexure C) without amendment. The estimates were derived directly from work by GLS Engineers and was updated with the latest costs for inclusion in that document. This chapter directly pertains to the cost functions mentioned above.

The cost of civil engineering infrastructure is often volatile and subject to the economical climate. For this reason the project team built in additional functionality to update these cost functions. A detailed description of the basis and compilation of the cost functions is presented in this chapter. This text continues to describe how these cost functions are constructed and how the input parameters could be amended.

6.1.3 Compilation of cost functions – general description

The cost functions used by GLS for SS planning are compiled annually by assessing actual costs for various detail components of sewer construction projects, as per SABS 1200 requirements. These individual costs are integrated to obtain an estimate of what 1 m length of sewer would costs, depending on diameter (in the case of pipes). A similar procedure is followed when it comes to pumps, etc. These relatively "fixed" unit values can be amended at any stage in the year by increasing the annual base value with a percentage based on the consumer price index (CPI), as described shortly.

According to SABS 1200, works concern all the relevant exertions needed to complete a full installation of a sewer pipe project. Every aspect or stage of the construction phase of the pipe has a certain cost, or a certain amount of resources need to be exerted to facilitate the execution of the job at hand (i.e. the construction of the sewer line). These costs and expenditures include the price of the pipe *per se* and the resources utilised to ultimately get a commissioned SS installed. The secondary costs (excluding only the cost of the pipe, for this price is set by the specific pipe manufacturer as will be discussed later in the chapter) includes the earthworks for trenches for all types and sizes of pipes. It covers the excavation, the preparation of the trench bottom, backfilling and reinstatement of surfaces.

The administration and general preliminary costs for a project are not included in the calculations, as these values are project particular (as a rule of thumb, some consultants typically add 40% for these so-called preliminary and general items, or P&G's).

The intention of the cost functions are to give a quick and easy means to assess any project cost by inputting the specific parameters for the design of a sewer line and obtain an estimate for the costs based on the cost functions. For ease of use the values are given as Rand per meter value for the certain type and size of pipe (i.e. uPVC, concrete, or steel) and in which area of the landscape, or land use type, it needs to be constructed (i.e. public open space, road reserve, or in the road).

6.1.4 Deriving costs as per metre values

The cost functions were created by using actual values for sewer tender items, as given in tender documents submitted by various arbitrarily selected civil construction companies (those that were readily available at the time of study). The values that cover the excavation, the preparation of the trench bottom, backfilling and reinstatement of surfaces were averaged across tenders from a wide assortment of civil construction companies. These values are obtained and analysed once a year to determine the unit base price.

For the computation of quantities the excavation is measured considering vertical sides in the excavation as a first order estimate, regardless of whether the excavation has sloping sides or not. The measurement of, and payment for, earthworks for a pipe trench stipulates that the rates tendered shall cover the cost of the removal and the re-use of the excavated material for backfilling and disposal of any surplus material along the route of the pipeline.

The rate for the preparation of the trench bottom (bedding cradle and specific fill blanket) is to cover the cost of the handling, placing, and the compaction of the bedding materials in addition to any other cost associated with the laying of the pipeline. The cost of the reinstatement of surfaces is subjected to the type of surface that was previously instated.

For all surface types the length used to estimate the total cost of the sewer in question is the total length of the pipeline. The cost for every aspect of the project was computed from the cost of completed constructed sewer projects, and all items were added together to determine the overall cost of the sewer for the specific length of that project. The total cost was then divided by the length to obtain a cost per metre length. The values were determined for the each of the three types of surface cover that were previously mentioned, and in so doing the cost functions could be compiled.

6.1.5 Pipe material costs

The rates (cost) for pipes are determined by the specific manufacturer and pipe material and are not influenced by the contractor for any particular project, therefore the costs were derived from each supplier and inputted into the cost function directly – to be added to the above cost for constructing the pipe.

Provision is made for the following types of pipe material:

- Unplasticized Polyvinyl Chloride (uPVC)
- Concrete
- Steel

The choice of pipe is normally determined by the hydraulic requirements (flow and pressure) and external forces (e.g. loads imposed by soil, etc) on the pipe. Discussion regarding material – which is best or better in certain applications – is beyond the scope of this project, but a brief description is included below in view of cost functions.

Unplasticized Polyvinyl Chloride (uPVC) Pipes

The uPVC pipes that are described comply with the relevant requirements and have suitable flexible joints as per SABS 1200LD.

The cost rates for the different diameters uPVC pipes were collected from Petzetakis Africa (Pty) Ltd, a firm established in June 2001 in South Africa, formerly known as Main Pipe Systems (Pty) Ltd. (Visit www.petzetakis.co.za). The prices were considered to be typical of other plastic pipe manufacturers, which are vulnerable to fluctuations in oil price.

Concrete Pipes

Reinforced concrete pipes that are described comply with the applicable requirements and have been manufactured from dolomitic aggregate. Joints are rubber rings or other approved flexible joints, as per SABS 1200LD.

The cost rates for the different diameters concrete pipes were collected from Rocla (Pty) Ltd, Southern Africa's leading manufacturer of precast concrete products. (Visit www.rocla.co.za).

Steel Pipes

Steel pipes may be used for pump / pressure pipe segments in SS design. The rates for the different diameter steel pipes were collected from Hall Longmore (Pty) Ltd. The company began manufacturing welded steel pipes in 1924 (visit www.hall-longmore.co.za) and the prices obtained were considered to be typical for steel pipes. Other materials used in industry (ductile iron, GRP and vitreous clay) were not included due to the fact that limited information was available.

6.1.6 Normalising the Rand value

Based on inputs by the WRC reference group (RG) it was considered necessary to normalise the Rand value presented in the infrastructure costing tool. However, after various workshops with Municipalities and other stakeholders involved in SS planning in smaller Municipalities, the project team opted to maintain a more basic approach in presenting the values of infrastructure in 2010 Rand-terms. Values could be escalated in future to obtain estimates of future years' values.

This is, of course, a limitation in that the value would become out-dated with time. In view of the low-technology application of these cost functions in this study it was considered essential to provide an output that would be useful – even if it were to become out-dated – rather than to provide a clinically correct approach that would be too complex from a viewpoint of application at the required low-technology level. In other words, it was considered inappropriate to derive cost-functions based on some normalised value that would in turn simply be converted back to Rands for the sake of practical application by a senior staff member with the required knowledge. The output would again be subjected to the problem of becoming out-dated after "conversion" to a Rand-value. It was thus considered far more useful to provide the output in Rand-terms and subsequently to address the problem of keeping the tool up-to-date at the grass-root level.

Some stakeholders at the workshops indicated that they made use of their own – very crude – methods to estimate infrastructure cost. These were based on actual Rand value, underlining that this was the method preferred by potential users of the tools.

6.1.7 Limiting the tool to capital cost

Based on information gained during the knowledge review and the stakeholder workshops it was considered an essential simplification to limit the infrastructure costing tool to capital cost. The project team and WRC reference group members noted concerns initially that operations and maintenance (O&M) costs were also needed to ensure comprehensive SS planning.

With the introduction of O&M costs come significant complexity, moving beyond a low-technology hard-copy tool. Researchers have reported in the past – and still do – that planning should not be based on capital cost only due to, for example, the notable running cost of pump installations. These reports refer to the highest level of technical advancement and to what could be viewed as an "ideal" (or perfect) SSP. What this research set out to address was the other extreme, namely those Municipalities with very limited or absolutely no capacity to compile a SSP and/or very limited knowledge in this regard. The golden rule in this study could simply be stated as, "first things first". In other words, moving too fast towards an "ideal" SSP would arguably derail the process.

A first step is needed where no planning is in place. SSP studies based on capital cost only was found to be a typical first step towards SSP in many Municipalities locally. Three consultants approached during this study (including GLS engineering) independently confirmed that capital cost is used in SSP studies in all instances as a first step, where no prior work in this regard has been conducted and budgets are limited.

As a result of the simplistic nature of the product sought, the cost functions presented in the infrastructure costing tool are based purely on capital cost. O&M costs are not included in order to sustain the low-technology and user-friendly level of the product. This could be viewed as a limitation in that these functions cannot be applied to optimise total cost during SS planning, which is considered by the project team as a positive point – more advanced studies need more advanced tools and probably specialist consultants to obtain the required inputs and conduct the highly-technical analyses involved. Thus, when a local authority reaches the point in time (and advancement of the SSP process) where such optimisation is needed a specialist consultant is arguably needed to conduct a more detailed analysis.

The functions based on capital cost are for example handy to provide estimates of sewer infrastructure replacement value and could also act as a method to verify budgets and estimated tender prices – typically provided by Engineering consultants – for the construction of new infrastructure. Anything more complex would move beyond the aim of this study and the low-technology outputs required.

6.1.8 Operations and maintenance cost and advanced techniques

In the process of cost optimisation by capital cost only the operation and maintenance (O&M) costs are not needed. However, from time to time it may be necessary to assess these costs on an ad hoc basis, or as part of more advanced optimisation techniques. Approximate values for O&M costs in the planning and design of systems (as noted in grey literature during this project) is typically presented as a percentage of the capital cost. The values vary from source to source and are not accurate enough to be relied upon in general without further investigation.

Inclusion of total cost (capital and O&M) in the optimisation routines of SSP studies and also analysis by means of advanced risk based techniques to assess probability and consequence of failure are considered essential in cases where planning has advanced to the next level (increased technical complexity). Examples of the latter include large metros, but exclude the smaller municipalities in almost all instances evaluated during this study. Only one example (Overstrand Municipality SSP, 2003; GLS Consulting) could be found where a risk-based approach had been employed as part of SSP in a non-metro area. The specific study was driven by special circumstances and was considered to be atypical.

A future research need originating from this work is to assess O&M cost at a higher-technology level than that intended for this project.

6.2 Cost influencing factors

For pipes, the main cost influencing factors in this study are considered to be the pipe diameter and the type of surface to be reinstated. Construction in roads is more expensive than that in the road reserve (the side of the road), while construction in an open space is relatively cheap compared to the others.

An interesting result, in agreement with practice, is that gravity sewers are generally more expensive than rising mains of the same diameter, despite the fact that the pressure class and cost of the pipe itself is higher for the rising main than the gravity sewer (due to the thicker pipe wall). The two reasons for the higher cost of gravity sewers are the deeper trenches needed to maintain a suitable gradient (and miss other services along the way) and also the presence of manholes at regular intervals. It is also possible to use a smaller diameter pipe on a rising main, than required for gravity pipes.

Cost influencing factors for pumps are much more complex and typically would involve O&M costs in a detailed planning study, system optimisation or design. In the case of pumps the capital costs for civil works, mechanical and electrical works are addressed separately in this study, arriving at an estimate for the pump station cost based on the total installed capacity (in kW).

Estimates for cost of wastewater treatment works (WWTW) are crude and based simply on hydraulic capacity required. Assessment of the type of works required and the complex nature of the cost influencing factors at any level of detail are beyond the scope of this study.

6.3 System cost estimation model

6.3.1 Development and methodology

Four workshops were held with various Municipalities in the Western Cape and Central Karoo during November 2009 as part of this project to test the possible application of the cost functions as a low technology tool. The target municipalities were the smaller and in effect, poorer municipalities that did not necessarily have the knowledge base or even access to computers to do accurate costing. In some cases comprehensive SSPs had been compiled by specialist consultants, but the application and usefulness of the cost functions were tested nonetheless for in-house use.

A clear need was identified for a tool such as the one presented here, particularly since it could be presented in hard copy format (e.g. as a poster) which would be easy to use. The fact that a Rand-value was presented was noted to be particularly handy and easy to understand. Stakeholders were specifically asked to comment on methods (like a normalised value) that would prevent the tool from becoming dated. The idea was not well received. In contrast, various options to keep the cost functions up to date were presented instead during these workshop sessions. For ease of use purposes the values were thus finally given as a Rand per meter value for the certain type and size of pipe (i.e. uPVC, concrete, or steel) with categories for the type of land coverage in which the pipe would be constructed (i.e. public open space, road reserve, or in the road).

The model was developed by using actual values given in tender documents submitted by civil construction companies. The values that cover the excavation, the preparation of the trench bottom, backfilling and reinstatement of surfaces were averaged across tenders from a wide assortment of civil construction companies to obtain the first-order estimate of the cost.

For the computation of quantities the excavation is measured as if taken out with vertical sides, regardless of whether the sides are sloping. The measurement of and payment for earthworks for a pipe trench is that the rates which were tendered shall cover the cost of the evacuation and the re-use of the excavated material for backfilling and disposal of any surplus material along the route of the pipeline. The rate for the preparation of the trench bottom (bedding cradle and specific fill blanket) shall cover the cost of the handling, placing, and the compaction of the bedding materials in addition to any other cost associated with the laying of the pipeline. The cost of the reinstatement of surfaces is subjected to the type of surface that was previously in place – prior to construction.

Provision is made for pipeline construction cost underneath different land surface types. The cost functions provide for the following three surface types:

- Public Open space (POS) – Due to the fact that public open spaces are normally covered in either dirt or grass it is relative inexpensive to reinstate the ground cover to its former condition. The materials removed can be salvaged through the excavation period and replaced after backfilling has occurred.
- Road reserves – most urban sewer pipes of relatively small diameter are normally constructed in the road reserve. The reserve is that portion of vacant land adjacent to the road surface, within the jurisdiction of the local authority. Construction along this surface type is more expensive than a POS, because a large number of existing services are often encountered in the reserve. These services need to be crossed and, particularly with a sewer, this could become a challenge during design and even more so during construction. However, it is not necessary to damage the road surface, or repair it, during construction.
- Roads – in some cases it is necessary to cross existing roads by either exposed trenches or tunneling/pipe jacking when excavation for a pipeline is needed on a road or a segment of a road the contractor faces higher costs for reinstatement of the road after excavation is completed. The higher costs are due to additional compaction effort required and of the additional selection of material to be used to comply with the requirements of the areas subjected to road traffic loads. The cost for pipe jacking is relatively high and is justified in some cases where need arises, say to cross a freeway. When estimating costs pipe jacking was treated as a special case (by obtaining a quote for the project considered) and it is not included in the cost functions; the cost for construction along a road surface is based on the assumption that an open trench will be constructed where after the road surface would be repaired.

The cost for every aspect of the system is then computed and added together to determine the overall cost of the infrastructure element. The total cost is then divided by the length in meters to determine the value of the pipe per meter length. These are the average value per meter length for a certain size and type of pipe. The values were determined for the each of three types of surface cover that were previously mentioned.

The cost of the construction of pump stations were developed similarly to the development of the cost functions for sewer mains, i.e. by averaging the cost of actual accepted tenders. The value derived was for the pump operating at 60% efficiency.

The same principle was also applied to obtain estimates for the cost of a WWTW. An equation was derived based on the total volume of sewage (in Ml/day) for an activated sludge treatment facility. In this study only hydraulic load was considered. Future research should address the matter of organic load in combination to hydraulic load in the cost estimation process.

In the set-up of the unit costs the administration and general preliminary costs for a project are not included in the calculations, as these values are project particular.

6.3.2 Gravity pipes

In instances where the water is driven along only by gravitational forces, the most commonly used pipe material is either uPVC or concrete. The model is based on the assumption that for diameters from 100 mm to 450 mm uPVC pipes will be used, and for diameters from 450 mm up to 1.8 m concrete will be utilised.

The rates for the different diameters uPVC pipes were collected from Petzetakis Africa (Pty) Ltd., established in June 2001 in South Africa, formerly known as Main Pipe Systems (Pty) Ltd. (www.petzetakis.co.za).

Reinforced concrete pipes that are described comply with the applicable requirements and are manufactured from dolomitic aggregate. The rates for the different diameters concrete pipes were collected from Rocla (Pty) Ltd. (www.rocla.co.za).

The graph in Figure 6-1 depicts the different diameters available in the model, with the corresponding Rand per meter value for the three different types of cover conditions.

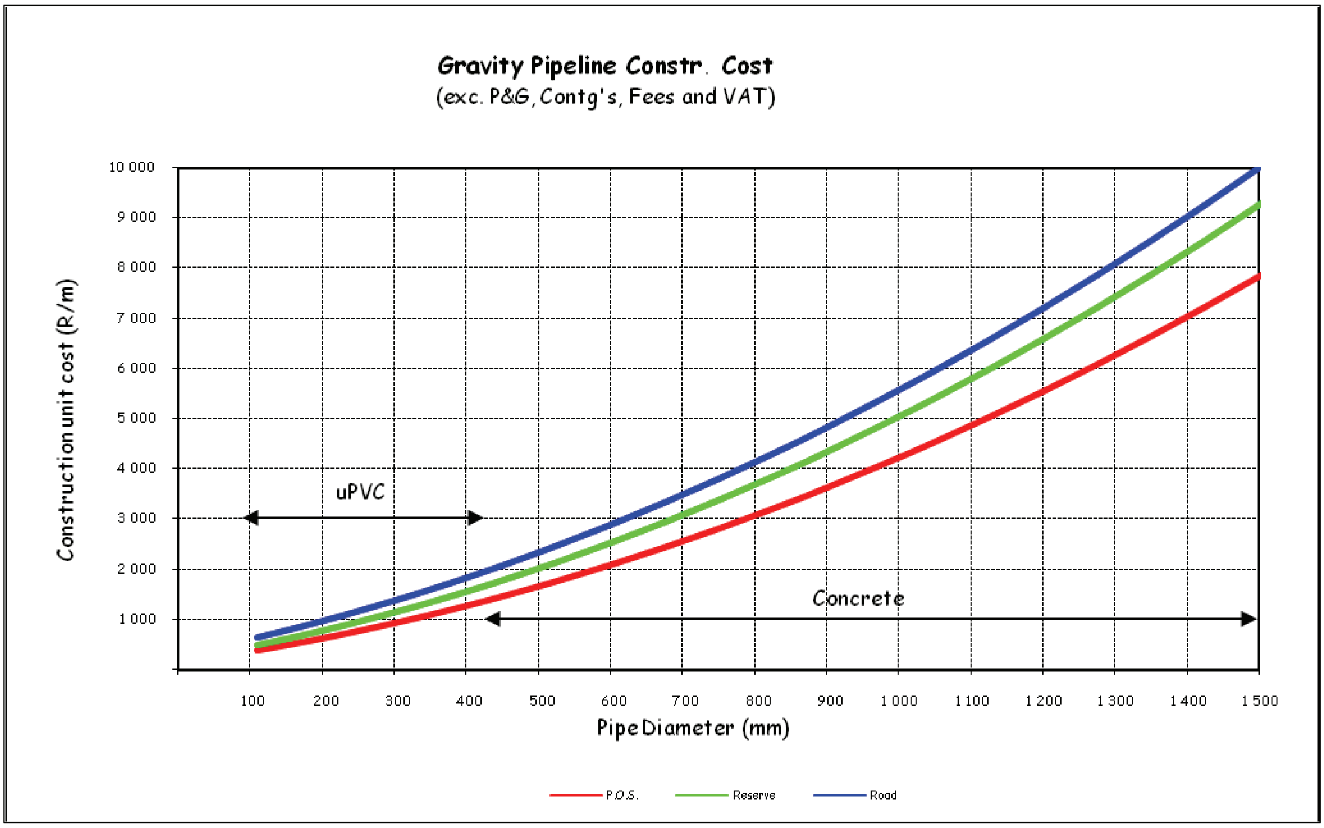


Figure 6-1: Gravity sewer construction cost (includes pipe and installation)

The data plotted in Figure 6-1 was used to compile three different equations for the different types of land cover:

For Public Open Space areas:

$$Cost = L * (0.0024D^2 + 2.8788D + 300) \quad [1]$$

For Reserve areas:

$$Cost = L * (0.0024D^2 + 2.4544D + 190) \quad [2]$$

For Road areas:

$$Cost = L * (0.0021D^2 + 1.9783D + 154) \quad [3]$$

where: $Cost$ is the value in Rand

L is the total length of pipeline (in meters)

D is the nominal pipe diameter (in millimetres)

This means that the comparative costing of the construction of a pipeline in a road reserve area will be about 20% higher than for public open spaces, and in the road about 13% higher than in a road reserve area.

6.3.3 Rising (pumping) mains

In some instances the water needs to be pumped to a higher level, thus requiring a rising main pipe. In such cases two types of pipe materials are commonly used, i.e. uPVC or steel. The model is based on the assumption that for diameters from 100 mm to 450 mm uPVC pipes will be used, and for diameters from 450 mm up to 1.0 m steel will be utilised.

The rates for the different diameters steel pipes were collected from Hall Longmore (Pty) Ltd. (www.hall-longmore.co.za).

The graph in Figure 6-2 depicts the different diameters available in the model, with their corresponding Rand per meter value for the three different types of land cover conditions.

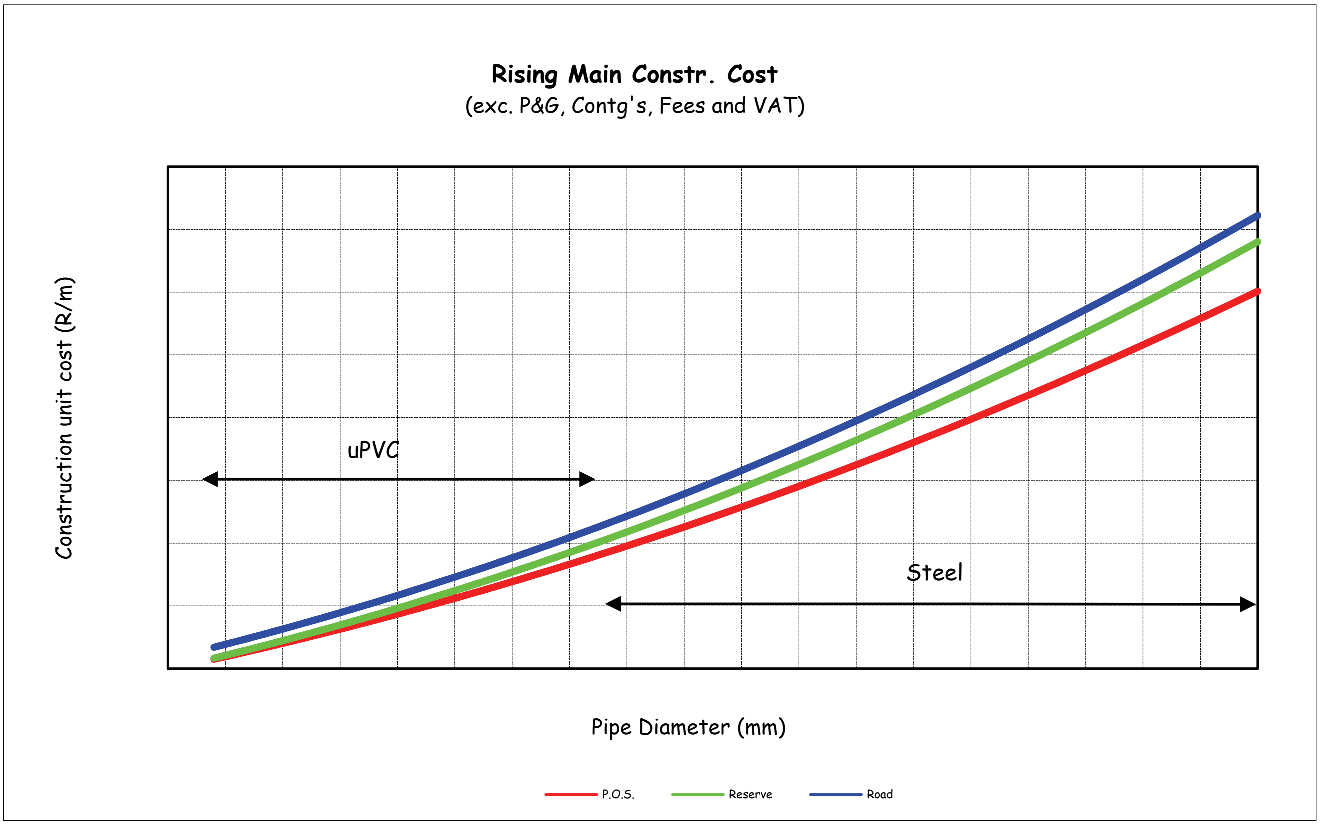


Figure 6-2: Sewer rising main construction cost (includes pipe and installation)

The data plotted in Figure 6-2 was used to compile three different equations for the different types of land cover:

- For Public Open Space areas:

$$Cost = L * (0.0032D^2 + 4.0755D - 52) \qquad [4]$$

- For Reserve areas:

$$Cost = L * (0.0031D^2 + 3.1947D - 211) \quad [5]$$

- For Road areas:

$$Cost = L * (0.0026D^2 + 2.8788D - 198) \quad [6]$$

where the parameters have the same meaning as before.

This means that the comparative costing of the construction of a pipeline in a road reserve area will be about 10% higher than for public open spaces, and in the road about 9% higher than in a road reserve area.

6.3.4 Pumps

Three major cost influencing factors in the construction of a pump stations were noted. These include:

- The cost of civil works to erect the building to house the pumps; these normally include the covering structure of the pumps, the supply sumps, and the inlet structure.
- The cost of the intricate pipe networks leading the water to and from the pumps to the main line, together with the various necessary valves and auxiliary equipment.
- The cost of the mechanical and electrical components of the pump station. These include the pumps, the control and monitoring equipment, flow meters, and measurement devices.

Pumps also impose a relatively large operational and maintenance cost in addition to the capital cost of the pump and rising main. Optimisation of the total cost is what should be strived for, thus including capital cost of the pump station and rising main pipe as well as the running cost of the pump. The most basic example of such optimisation is a single pump and single pipe system, as described in detail by Chadwich et al. (2004:420). Unfortunately pump and pipe systems interact so as to provide a unique duty point matching the two specific systems (pump and pipe). In addition, the optimum is a function of the energy unit cost which in turn is often a function of the time of operation (hour of the day, day of the week, etc). In South Africa various structures are offered to encourage off-peak energy use and it could be necessary to conduct a detail analysis of an existing pump-pipe system simply to determine the most suitable energy tariff scheme on offer for a particular situation.

It would only make sense to optimise a particular system, and the result would only be valid for the applicable energy tariff scheme. This research project is aimed at providing a simple approach, which could lead the reader to believe that pumps should be excluded completely from the text. However, it was considered essential to include at least the capital cost of pumps in the costing tool presented here, since this cost could be generically described without moving to more complex matters.

The graph in Figure 6-3 portrays the three different costs involved in the construction of a complete pump station, proportionately. The total cost for the pump station is shown, of the pumps operating at 60% efficiency, with a total head value of up to 40 meters.

The total cost for a pump station could be described by the formula:

$$Cost \ = 91169 * PC^{0.5444} \qquad [7]$$

where $Cost$ has the same meaning as before, and PC represents the total volume of water that can be pumped (l/s)

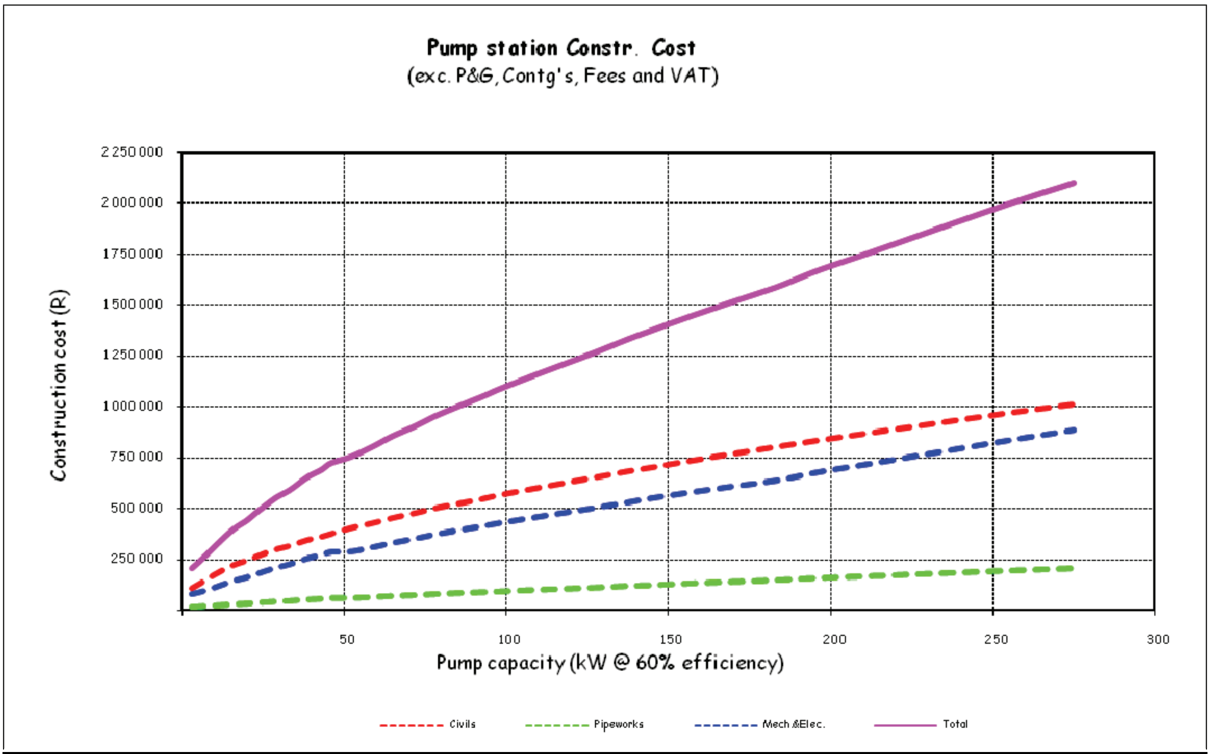


Figure 6-3: Pump station construction cost

6.4 Discussion and further work

Through the various workshops presented and inputs gathered during this study it was found that municipal staff often made their own ad hoc estimates of cost based simply on experience. A clear need for a low-technology tool such as the one presented in this paper was noted.

These “self-developed” models were noted to be inaccurate and often outdated. This project strived to provide an outcome that would be able to convey the knowledge gained here to municipal staff at ground-level, or even to a newly appointed person with limited background to sewers. The idea was that such an individual would somehow be concerned with the costing of the sewer system, or part thereof. The project outcome provided a relatively easy way of estimating sewer infrastructure cost, which is easily updatable, and (hopefully) understandable.

The infrastructure costing tool would be kept up to date by linking the cost functions to a calendar-format. The calendar would form part of the outcome and would be printed annually, with distribution to stakeholders whose contact details would be maintained by the project team (Stellenbosch University) for a trial period. The project team committed to conduct the administration, poster design, printing and distribution for three years. The printing cost would be covered by Stellenbosch University and GLS Consulting Engineers (limited to a maximum of 50 posters per year), with limited space for promotion on the poster in exchange.

7. SEWER SYSTEM PLAN CHECKLIST TOOL

7.1 Concept

7.1.1 SSP data input requirements

Development of a SSP could be viewed as a progression from basic raw input data, or even in extreme cases a substantial lack thereof, to a final product. The final product would include for example the organised data, a hydraulic model of the existing system, a spatial development plan and an ultimate future hydraulic model designed to provide services to the intended developments. The final SSP would present a comprehensive list of SSP items, each identifying a particular infrastructure upgrade (project) that needs to be put in place.

Various methods exist to analyse the data, but in all instances a basic set of raw data is needed prior to embarking on the process. This raw data could be viewed as an essential input requirement to any SSP process. Where it is not available it would have to be obtained.

A detailed session on data capture, cleanup and verification with regards to sewer assets and hydraulic model creation in the Eastern Cape was presented by K Simon (Aurecon, Port Elizabeth) at a post-graduate course offered at Stellenbosch University (SU, 2008). The following topics were discussed in that work as critical in view of data collection:

- Fundamental GIS features
- Sources of information
- Positioning information
- Data types to be captured
- Data capture presentation and methods
- Typical errors and corrections required
- Data cleanup and field verification
- Other pertinent information

The following specific information was considered critical in that course in view of building a hydraulic model of the system and subsequently a SSP:

- Manhole cover levels
- Pipe invert levels (at each manhole entry or exit point)
- Depths
- Gradients (could be obtained from invert levels)
- Pipe sizes
- Pipe materials
- Installation dates
- Filing / cabinet reference details, consultant details and drawing number

GLS Consulting also have a list of information required to compile a comprehensive SSP. The list was simplified and incorporated into the project poster presented as part of this project, but was also presented as one of the output tools.

7.1.2 Describing the SSP input requirements with a checklist

Consultants use in-house checklists to assess the data required during the compilation of a SSP. Two such lists could be obtained as part of this project (GLS and Aurecon), but in both cases the checklists were not amenable for application at Municipal level. The use of a checklist to describe the particular SSP inputs, and more basically the progression of information from raw data to a final SSP, was considered a convenient tool for a few reasons:

- the list shows, at first glance, what data exactly is needed prior to compilation of a SSP, thus enabling the Municipality to demand and gather any missing data from others as time passes and new projects are put in place in view of compiling a SSP at some stage afterwards
- a checklist enables the user to record and progressively update the availability of the necessary input data required to initiate and complete the SSP process

- a checklist could be used by other stakeholders to quickly and easily assess the progression towards a complete and up-to-date SSP in a particular town (or for a particular system); this is also true in those instances where staff turnover may otherwise lead to a loss of valuable knowledge with regards to the process and/or available information.

- the checklist could be used by the Municipality's consultants to assess the amount of work required to compile a SSP in the specific instance, based on a knowledge of the available data (as per the checklist).

7.1.3 Presentation format

Stakeholder workshops underlined the importance of making the result available as a wall-mounted poster. A poster was compiled for this purpose prior to the final 3 workshops, but it was rudimentary and lacked "finishing". Despite these lacks the poster format of the checklist was well-received. Ideally it would be handy to provide a poster finish surface on which the required tick marks could even be added, then erased again and updated as time passes. This would be possible by either laminating the poster and using a non-permanent coki, or by means of magnet-tags (or other non-permanent adhesive such as Velcro) that enables the marker to be moved from one block to the next as the particular item is updated. The most basic approach would be to use sticky plastic tags that could be moved for each item along as the process evolves.

It was considered essential to also add some type of information sheet to provide more detail on the particular item to be assessed, say as a small booklet or brochure included in a add-in-pocket on the rear of the poster. The project team was of the opinion that such a booklet or information sheet would soon go missing and the recommendation was that a web-site address (e.g. www.gls.co.za) be added to the poster, where more information could be obtained on using the checklist and on obtaining professional input to compile a SSP.

7.1.4 Assessing completeness

The checklist would entail various rows (top down) listing the specific information required or SSP component, with a few categories included to assess the availability of information and thus progression towards a complete SSP. The latter was best achieved by including the following 5 categories as individual columns to the right, where each component (row) could be updated:

- No, the information is not available

- I do not know (whether the information is available or not)
- Yes, but it is available from a consultant (not the Municipality)
- Yes it is available from the Municipality, but it is out-dated or incomplete
- Yes (it is available from the Municipality and is up-to-to-date and complete).

7.2 Description

The final checklist was based on a checklist used by GLS Consulting for estimating the workload and cost required to compile a SSP. The checklist was applied in many Municipalities of the Western Cape (as part of non-project related planning projects by GLS Consulting), including a few years of development prior to this project.

The former knowledge and inputs from stakeholders led to the following 10 main sections to finally be selected for the checklist:

- Basic information and data integrity
- Hydraulic computer model of existing system
- Plan books and wall maps (drawings)
- Water balance and sewer flow estimates
- Link between flow data and model topology
- Hydraulic calibration of model
- Evaluation of existing system
- Future land use and sewer flow analysis
- Master plan for sewer system
- Reports and documents

7.3 Application

The SSP checklist was specifically developed as a non-PC-based tool for application in those areas where computers are not available. The low-technology checklist was also designed to be relatively user-friendly, thus aimed at use in municipalities where the skill level of technical staff and/or IT-related resources limit more advanced methods of use, such as web-based application. However, the added advantage of the latter would be that Municipal managers responsible for different towns in a sparsely populated region could easily and quickly assess the progression of SSP by viewing the checklist for each town on a central computer via an internet-based link. In this project, however, application was considered limited to application in hard copy format only at ground-level.

In addition to application by Municipal staff, the SSP checklist is used by some specialist consultants to assess the workload needed to compile a SSP. Application in this manner would imply that the checklist becomes the basis of estimating the cost for compiling a complete SSP in a format that would be understandable to the local Municipality who would then be au fait with the checklist tool. Thus, it is a handy tool not only at Municipal level, but also for the Municipality's consultants to clearly and easily describe the cost estimates for compiling a SSP.

8. SEWER SYSTEM PLANNING PROCESS TOOL

8.1 The sewer system planning process

8.1.1 Process description

Description of the SS planning process per se seems like the first obvious step when addressing any technical issue. For this reason it was considered imperative to include a process description tool in the SSP toolkit. The concept of process description in terms of sewer systems is not new. The knowledge review conducted as part of this study underlined the fact that various authors in the past have presented descriptions of sewer systems and the sewer planning process. None of these specifically attempt to simplify the process, which is the specific focus of this text.

The SS planning process was included in the toolkit, but it later became apparent that a well designed and presented SSP checklist (discussed earlier in this report) would in fact supersede a description of the SS planning process as an independent tool. The process description could be used as an aid in understanding the checklist tool.

8.1.2 Master planning process description

All recorded descriptions of the SS planning process locally are by members of the project team. The first report where planning was linked to spatial development locally was by Sinske and Zietsman (2001), but it does not address the planning process per se. The first report that could be viewed as some sort of useful "tool" in this regard was by Geustyn (Stellenbosch University, 2008b) during a post-graduate course presented at Stellenbosch University where the critical steps in the comprehensive process for water and sewer system planning were identified and listed and were outlined schematically in Figure 8-1.

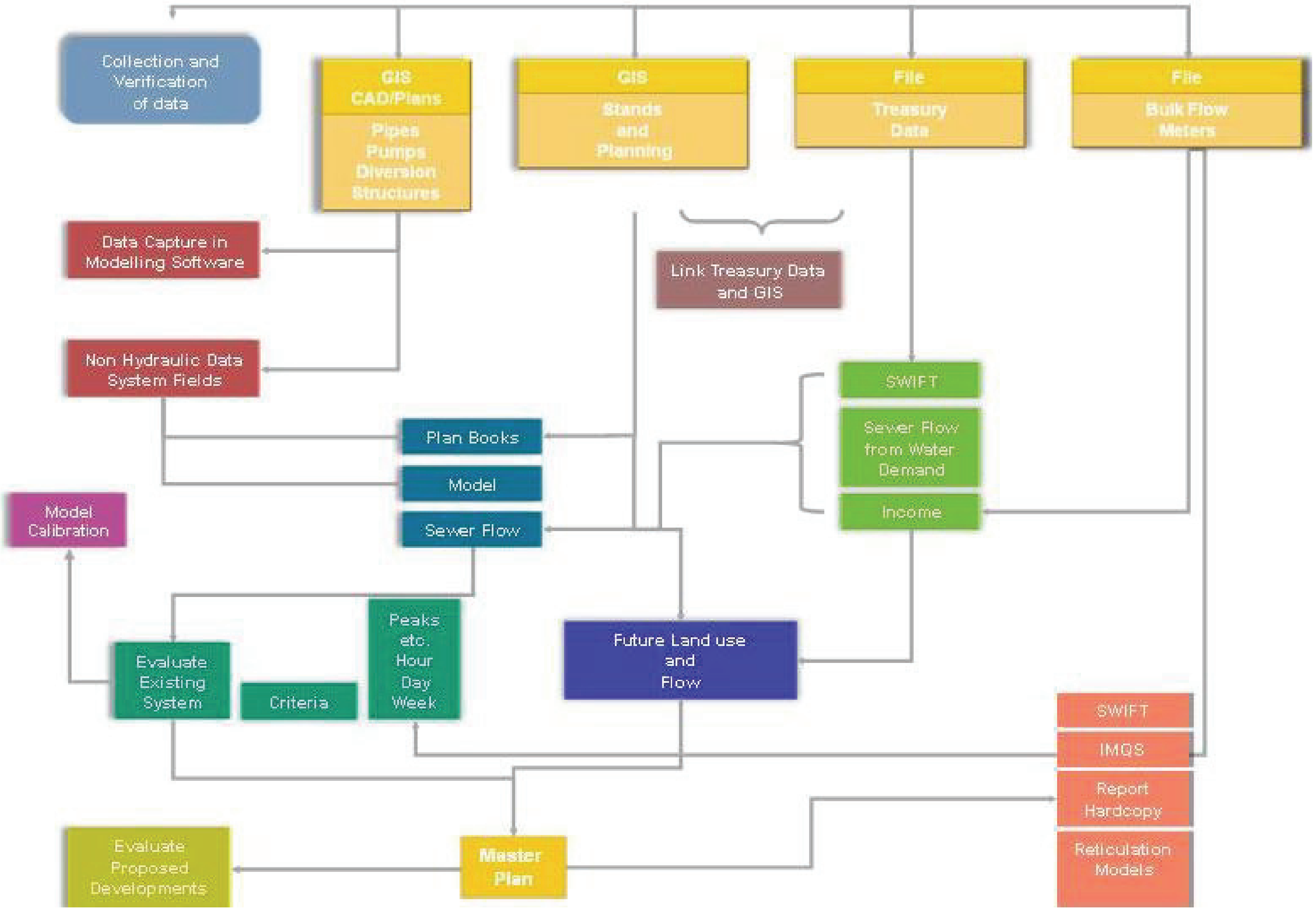


Figure 8-1: Flow chart of comprehensive sewer planning process

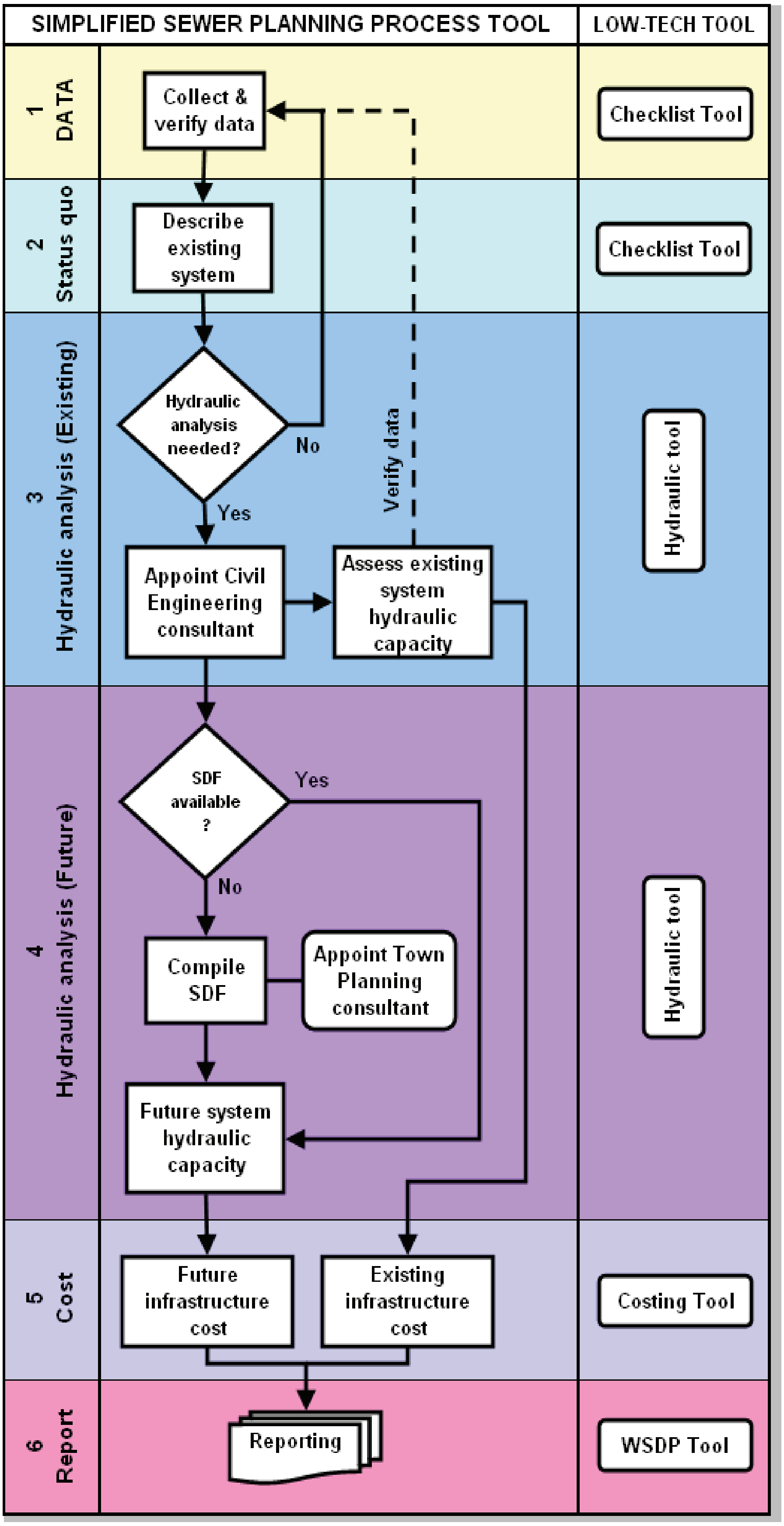
The flow diagram could be simplified substantially by considered only key steps in the process. The 6 key steps were considered to be:

- Collection and verification of data
- Establish sewer system status quo – building an accurate existing system model
- Establish system capacity – hydraulic modelling of existing system
- SDF integration and required future system capacity – incorporate future planning
- Estimate infrastructure cost by considering individual elements – first for the existing and then the future elements of the system
- Reporting

A brief description of each step as it relates to the simple sewer system planning approach and some specific problems to look out for in each case are presented in Table 8-1. The corresponding schematic flow chart of the process is presented in Figure 8-2.

Table 8-1 Descriptive summary of the simple sewer system planning process

Process description		Checklist section no.	Description of tasks relating to simple sewer system planning	Check for the following problems
No	Short title			
1	Data collection	1	Collect and verify data "by hand" so that combined pipe layout logically overlays cadastral map of serviced area; draw arrows with flow direction at each manhole and check in the field; find the following: IL of each pipe, cover level of each manhole and ground level at each manhole; internal diameter of each pipe segment, sewer flow records (even monthly volumes) and pump logs.	Start at each point of entry and work downstream: - all pipes should connect (no "gaps") - only one pipe should lead away from each manhole (else confirm that it is a diversion structure) - at each bend there should be a manhole - IL should decrease between manholes (increase in IL implies that there is a pump?)
2	Existing system	2, 3	This step requires a computer and appropriate software	N/a
3	Existing system capacity	4, 5, 6, 7	This step requires a computer and appropriate software; results produced by others could be compared to findings presented in the hydraulic tool to assess whether the results make sense	Excessive pipe diameters
4	Future system planning	8	Find: SDF and records of any other possible future land developments	Unrealistic growth in SDF
5	Infrastructure cost	9	A crude estimate of the replacement value of some components in the existing system could be obtained with the infrastructure costing tool, based on the status quo of the existing system; the same could be done for the future planning items (master plan items)	- Out-dated cost functions (i.e. more than a year old) - Inaccurate data in the model (incorrect pipe sizes, missing pumps, etc.)
6	Reporting	10	A report is typically compiled at the end of a planning study	N/a


SIMPLIFIED SEWER PLANNING PROCESS TOOL
LOW-TECH TOOL
1 DATA
Collect & verify data
Checklist Tool
2 Status quo
Describe existing system
Checklist Tool
3 Hydraulic analysis (Existing)
Hydraulic analysis needed?
No
Yes
Verify data
Appoint Civil Engineering consultant
Assess existing system hydraulic capacity
Hydraulic tool
4 Hydraulic analysis (Future)
SDF available ?
Yes
No
Compile SDF
Appoint Town Planning consultant
Future system hydraulic capacity
Hydraulic tool
5 Cost
Future infrastructure cost
Existing infrastructure cost
Costing Tool
6 Report
Reporting
WSDP Tool

In presenting this description it is of course essential for the stakeholder involved to:

- initiate and perform the planning process with an understanding of the general philosophy and objectives
- acknowledge and understand the effect of uncertainties and inaccuracies related to components of the process
- establish thorough procedures for continuous updating and evaluation of the SSP and its building blocks, preferably by applying the most advanced techniques that could be afforded in view of various constraints.

8.2 Information gathering

Information gathering is the first step in the SSP process. Planning for acceptable service levels requires information. The information needs to gather in line with the expected outcomes. For example, more information at a higher level of accuracy would be required for a very detailed study than that needed to compile a preliminary or basic SSP.

It is thus necessary to define what is acceptable by considering for example:

- Customer needs: level of service, availability etc.
- Service provider needs: redundancy, environment etc.

Subsequently it is necessary to establish standards and criteria for a SSP. This is even more important when compiling multiple SSP's over a period of time for different Municipalities to allow for accurate comparison and fair and equitable service delivery in different study areas. In establishing these standards and criteria the following should be considered:

- Previous knowledge (e.g. reports such as the output from WRC Project K5-1744)
- Uniform rules: unit flows, pumps, storage, spare capacity etc.
- Deterministic and probabilistic rules

Modelling could be performed at different levels of accuracy. The tools from this report are not suitable for hydraulic modelling, but even in this case some assumptions were needed to provide the outputs in the hydraulic design tool. In setting realistic accuracy levels the following needs to be considered:

- Defining tolerance on outputs or results (e.g. spare capacity in pipes)
- Acknowledging uncertainties in input parameters (e.g. component information; metered data; effect of interventions such as WDM; uncertainties in spatial planning information on which the SSP is based)
- Cost (for basic studies capital cost is used with no consideration for phasing of projects, while advanced studies allow for the former complexities)

8.3 Data integrity and verification

The second step of the SS planning process concerns data integrity and verification. The data that requires specific attention during this step of the process could be grouped into different classes, each briefly listed as bullets below the appropriate headings (note that some of the information is repeated, because under each heading the information would be different:

8.3.1 Background data

- Data sources
- Cadastral information: Age, Projection, Layout, Layers, Numbering
- Topographical data and aerial photography: Age, Resolution, Coverage

8.3.2 Existing system data

- Data sources
- System components with attributes: Age and version, Coverage
- Operational information: Static and dynamic

8.3.3 Temporary meter data

This is where sewer flow was logged for a period of time at a special strategic location:

- Meter age/calibration

- Continuity
- Time coverage
- Conversion of information from recorded (e.g. logger to water surface distance) to flow rate

8.3.4 Consumer information

- Meter age/calibration
- Meter reading reliability
- Consumer attributes accuracy: Land use, Stand size, etc.

8.4 Model calibration

The third step of the SSP is probably the first where the low-technology user would not be able to assist further with the process. Nonetheless, the brief explanation is included here for those instances where the tool would be used for in-house training and education of staff with regards to SSP.

Hydraulic model calibration is a special step whereby the modelled flow is compared to recorded flow at select locations. In doing this, the analyst needs to consider the following steps.

- Allocation of flow hydrograph per consumer unit in accordance with land use type
- Allocation of flow rate per consumer unit as a function of actual water consumption
- Flow measurements
- Field inspections and observations
- Adjustment of flow characteristics: Hydrograph, Infiltration, leakage, ingress.

8.5 Spatial development framework Integration

The fourth step of the SS planning process is where town planners and engineers meet (or are supposed to meet!): SDF Integration. Not only is spatial planning considered to be an essential step towards strategic projects (Albrechts, 2006), but spatial description of the system by means of GIS is also linked to rehabilitation of sewer systems (Burkhard and Gonzalez-Lakehal, 2006) and system planning in general (Emrani, 2006).

The spatial development framework is the key input in moving from the existing system to a future model and accurate SSP. It is necessary to:

- Establish future development areas: Define urban edge, Determine land use, Determine development density, Define phasing
- Define densification policy: Allocate areas, Determine ultimate development density, Define phasing
- Migration: Determine existing informal/unserviced areas, Define backlog eradication policy, Allocate land for development, Define phasing of migration.

8.6 Master plan items (projects)

Given all the above inputs, the infrastructure reinforcements, or SSP items, could be identified. In doing so it is often necessary to revisit one or more of the former steps in the process. The four key components of this step in the process are:

- Establish the sewer system plan items
- Confirm the practicality
- Consider time related phasing
- Costing.

8.7 Continuous updating

Continuous updating of the SSP is a dynamic process and moves beyond this low-technology approach. Fair et al. (2008) provide a detailed description of the dynamic SS planning process and the reader is referred to that text for more information on the topic.

8.8 Format of tool

The process tool was the only of the tools to be included as a presentation in MS PowerPoint format during the workshop phase, but the team learned early on that the presentation format was not well received. During the stakeholder workshops this format was subsequently changed and the slides were instead printed as individual, full-colour, A4 size pages for distribution and workshopping as an A4-size mini booklet. Even this was found to be a complicated method of conveying the information and the final product presented was a flow chart, combined with other relevant outputs as a single poster format.

9. SEWER TERMS TOOL

9.1 Sewer terminology

9.1.1 Motivation for a sewer terms tool

The project team initially noted that some terms used in sewer-circles were interpreted differently, depending on the individual and/or region. Discussions with the project team of another project into sewer systems (Van DIjk et al., 2008) underlined that the same problem was noted in that study. There is a clear need to clarify the terminology by means of a concise sewer terms list, or sewer terms tool as it was called in this study. The tool would take on the form of a dictionary in mini-booklet form, or at least an extended glossary.

The main challenge was to provide terms and definitions that would make sense locally, but would also align with academic use – also internationally. It was soon accepted that no terms list would satisfy all stakeholders.

9.1.2 Stakeholder workshop input

A few key points that were underlined time and again by stakeholders in the workshops were outlined below:

- there was a need to include English and Afrikaans words; these were the only two languages that were noted by stakeholders to be used regularly in small local authorities taking part in the survey; for the purpose of the sewer terms tool English was selected, with cognisance of the fact that other languages may be used as well in different geographical regions of the country
- some stakeholders noted a need to marry slang terminology that was commonly used at ground level by Municipal staff to the technically correct terms; it was however agreed during the progression of this research that the slang terms were region-specific and use thereof was considered to be undesirable – the technically correct terms should rather be promoted and only these were subsequently included
- a hard copy format of the final tool would be essential (to be used like a dictionary)
- a terminology list should not be long and winding; it should be concise and should preferably include short descriptions of each term

- the list should extend beyond the sewer system to also include terms relating to water distribution systems, water quality, water treatment and wastewater treatment and even stormwater and general planning matters (this of course contradicts the point noted just before it!).
- not a single stakeholder taking part in this project was even aware that a document of this nature actually existed (findings by the project team are discussed below)
- the need was not only to understand the terms, but also to translate the terms (between Afrikaans and English in the area studied during this project); chances are that similar needs for translation between other languages and English would be found elsewhere in the country.

Based on the inputs from the stakeholder workshop it was agreed that the sewer terms tool would take on the form of a mini-dictionary, but that it would be presented in English only and would include sewer-related terms only.

9.1.3 First reported material

The Association of the British Institute of Sewage Purification was locally established in 1937. In 1967 the name changed to the Institute of Water Pollution Control (IWPC). Upon the disbandment of the IWPC the Water Institute of Southern Africa (WISA) was formed in 1987. This background is needed to understand the origin of the first work into sewer terminology in South Africa.

The first local report of a water and sewer terms list was reportedly presented (but never published) by Mr PR Krige and Mr PBB Vosloo as representatives of the IWPC in about 1967 – the year in which the name also changed to IWPC. The list was in Afrikaans and was developed by the language bureau of the "SA Akademie vir Wetenskap en Kuns", who eventually published a dictionary of water and sewage works terms – in Afrikaans only (SAAWK, 1970). Unfortunately the publication is out dated and no record of an updated version could be found during this review. No English version could be traced (although the project team remain subjectively convinced that an English version would have been available at the time).

Some text books (Butler and Davies, 2009; Brière, 1999) provide glossaries of terms, but have an international flavour and often lead to confusion when presented locally due to the common presence of combined sewer systems in other countries.

9.1.4 Other published glossaries

One specific international document that was particularly relevant to this study was a German national standard on wastewater treatment vocabulary (CEN, 2007). It is a 76-page long A4 sized document, printed in landscape format that presents a trilingual dictionary in German, English and French – three languages commonly used in Germany for technical purposes. Each language is presented in a column across the page. Each term is then listed with the corresponding three definitions given in line (horizontally across the page). A final fourth column is included to give the SI unit of measurement where appropriate.

Terms are classified in the DIN-document according to 9 categories. Each term is numbered, with the number corresponding to various categories (e.g. numbers 1000 to 1999 are reserved for what is termed "General definitions", and so forth). The nine categories are listed below and underline that the document basically addressed aspect pertaining to wastewater treatment:

- General definitions (numbers from 1000 to 1999 reserved for this category)
- Types of wastewater and wastewater collection (2000+)
- Wastewater quantity and quality (3000+)
- Methods, characteristics and impact on the environment (4000+)
- Preliminary and primary treatment (5000+)
- Fixed film treatment (6000+)
- Activated sludge treatment (7000+)
- Other wastewater treatment (8000+)
- Sludge treatment (9000+)

The document also includes a table of contents and three comprehensive alphabetical indices, in the three languages mentioned earlier. Compilation of such an extensive vocabulary document was beyond the scope of this study. Such a document would be widely used locally if one were prepared, based on the stakeholder input received during this study. This is a key area for future research, or perhaps simply a task left to a keen author!

9.1.5 Unpublished glossaries

No attempt was made during this study to assess the numerous unpublished glossaries and informal literature available on the internet with regards to sewer terms.

9.2 Development of a sewer terms tool

In collaboration with another WRC project on sewer systems (Van Dijk et al., 2008) a list was compiled of the most essential sewer terms during this research. The initial intention was to come up with a relatively comprehensive list including most terms pertaining to sewer systems. However, "discovery" of both the old South African "dictionary" and the DIN-document (elaborated on earlier) led the team to realise that each term has to be clearly and carefully considered prior to publication in such a document. For this reason it was decided to limit the output of this research in terms of the sewer terms tool to non-technical users, i.e. those that the study outputs were intended for. An academic discourse on the terms and their meanings could derail the process and was beyond the scope of this research proposal.

9.3 Ultimate goal

The ultimate goal of the terms tool was user education. Understanding the terms often used in this discipline is essential and is considered to be a prerequisite to understanding even the simple low-technology outputs of this project.

The idea was also to set the scene for compilation of an advanced (and technically speaking correct) document that could find application in academic circles and in the field. The DIN-vocabulary was considered to be the best reference in this regard and it could be used as a starting point, with many of the definitions also applicable locally.

For the regions evaluated during this research English and Afrikaans were exclusively desired by small local authorities – a future document in these two languages could be the start to a more advanced document later extended to include all 9 South African official languages, although that would be quite a challenge!

9.4 Presentation format

As part of this project a list with terms and definitions was compiled to meet the initial need, but it was clear from the stakeholder workshops that a more detailed booklet, such as the German

CEN-standard, would be of more value particularly as it would also be used to translate terms. The sewer terms tool is included in Appendix E.

10. SEWER WSDP TOOL

10.1 Development and origin

Compilation of a Water Services Development Plan (WSDP) is a legal requirement for each local authority. The WSDP-tool was not particularly highly rated during the initial workshop sessions and could arguably have been discarded. The project team included this tool as a project output in the Appendixes of this report for future reference, but the information was not included in the project poster as it was not considered to be a key output.

The two-page A4 sized WSDP-tool developed for the first workshop was developed after consultation with KV3 Engineers (Human, 2009), who have been assisting numerous municipalities in the country with developing and updating WSDP's for the past 10+ years. At the time of investigation KV3 typically made use of specific agenda documentation when initiating a project. The information was kindly provided for perusal to the project team.

The KV3-agenda information was filtered to exclude all non-sewer related information and the remaining sewer-based requirements of the WSDP were organised and presented in a user-friendly tabular format.

The tool did not draw notable positive feedback from Municipalities, probably for the following reasons:

- the WSDP format provided by DWAF is regularly changed and updated creating the perception that a SSP-tool aiding the municipality towards the WSDP would soon be out-dated
- it was apparent that municipalities prefer using an engineering consultant to assist with WSDP-compilation instead of doing the work in-house
- the WSDP encompasses all water infrastructure as well as socio-political and general non-technical information; with sewer being only a small input to the process the tool was often thought to be of limited value during compilation of the complete WSDP.

10.2 Presentation format

The WSDP tool was presented as an A3 sized mini-poster. After the relatively poor feedback with regards to the practical application of the WSDP-tool the format was not developed further.

10.3 Relationship between WSDP and other documents

The WSDP relies on the fact that a local authority has a sewer master plan in place, since many outputs of the SS plan are required as inputs to the WSDP. These particular items could arguably be obtained by compiling an ad hoc plan for sewer infrastructure, but this approach would prove to be a problem when the subsequent WSDP has to be compiled (2 years later) and then needs to relate service levels back to previous targets. The SSP thus feeds valuable information to the WSDP, albeit only relating to one component of the latter document which encompasses all water services.

From another viewpoint the WSDP needs to be founded on the general strategy set in the authority's Integrated Development Plan (IDP). The spatial development framework (SDF), a document typically set by town planners, records the developments set out in the IDP spatially. The WSDP needs to report on the status quo of water infrastructure and needs to clearly stipulate how the service provider intends on meeting the service levels demanded by the IDP.

11. SANITOWN – A BENCHMARK FOR APPLICATION

11.1 Limited application of simple sewer planning tools

11.1.1 How far can simple tools go?

No matter to what extent and how well the simple planning tools provided by this research project are applied in practice, it is imperative that a computer model of the SS would be required at one stage or another – as soon as resources allow for it – in order to accurately assess the hydraulic capacity. The sooner this is done, the better. Increasing the level of complexity in this manner immediately poses a new problem to designers and analysts.

In a developing country such as South Africa the continual provision of adequate sanitation becomes difficult with urbanization and the resulting growing communities which need these services. It has been noted by Fair et al. (2008) that planning of an area needs to be updated on a regular basis to ensure that future developments will not exceed the current capacity of the systems that are in place, or the planned future capacity that needs to be designed for. For this reason planning is often conducted by applying advanced software suits incorporating spatial attributes in geographical information systems (Sinske and Zietsman, 2001). Investigation into aapproaches and software tools used for sewer system analysis has remained limited, but not so when it comes to water distribution system modelling. In that field researchers have spent a few decades developing handy techniques to evaluate software products and to compare methods of analysis.

11.1.2 Anytown benchmark model for water distribution system modelling

As one example, a hypothetical water network model, known as the "Anytown" model, was developed as a benchmark for hydraulic analysis and cost optimisation of water distribution systems. The publication of the famous Anytown benchmark problem for water distribution systems (Walski et al., 1987) set the scene for researchers to discuss and investigate different approaches to the water network design problem. However, no similar hypothetical sewer model was available for this purpose prior to this research. The Anytown model has been widely cited over the years and was still used at the time of this study as a guinea pig for water network analysis optimisation techniques and software performance (it was for example cited recently by Herstein and Filion, 2008).

The process of planning is essential to ensure effective service delivery, viable asset management, timely upgrading and optimisation of capital expenditure. Therefore a benchmark model for comparative hydraulic analysis is needed for testing procedures and optimisation techniques – also for sewer systems.

11.2 Sanitown sewer model concept

The aim of this chapter is to present a conceptual description of a hypothetical model for SS analysis similar to the one available for water networks. The contents of this chapter move the reader to advance from the focus of this study – simple sewer planning – to a foundation for more advanced work in future.

The model was called Sanitown, after its brother Anytown. The name is in fact a concatenation of "sanitation" and "town". The Sanitown model presented in this chapter is currently being tested as part of ongoing research and software development. However, the presented input parameters and model topology have been carefully selected and refined to include typical yet realistic problems encountered with the hydraulic modelling and planning of sewer systems. The components that were considered notable for inclusion in the model include: the Sanitown model topology, drainage region contours, proposed flow inputs, one future scenario to pose a typical development problem and a few restrictions in terms of system upgrades.

11.3 Sanitown sewer system components

11.3.1 Component symbols

The SS components and corresponding symbols presented in Figure 11-1 were used in this text to describe the Sanitown system (the project team were also aware of various other symbols used in other texts, mainly for pumps, but decided to use the symbols presented as a matter of illustration).

Component	Symbol
Diversion structure	
Manhole	
Pipe	
Pump	
Rising main	
WWTP	

Figure 11-1: System components and symbols (as used in this text)

11.3.2 Gravity pipes

Gravity pipes are certainly the most common element in a SS and are probably the most important part of any waterborne sewer system. Some sewer systems investigated as part of this research (e.g. the town of Caledon and large drainage basins in Soweto, Johannesburg) operate exclusively by means of gravity sewers. Gravity pipes were described by characteristics such as pipe diameter, slope and the friction coefficient describing pipe roughness. Manholes are considered integral to pipes in a sense, in that a manhole is located at each node in the model. The pipe slope is either specified or calculated by the difference in the invert levels divided by the length of the pipe section. A common unit of measurement for slope is percentage (%), but locally other units of measurement are more common in practice. One convenient way to express slope is as a metre vertical drop per 1000 m distance (m/km).

The friction factor is dependent on the type of pipe material. These roughness values are typically available from literature sources (Brière, 1999:25; Butler and Davies, 2009:146) and also from some pipe manufacturers and software suites.

The relative spare capacity of each pipe can be calculated from the difference in the peak flow in the pipe and theoretical full flow in terms of the pipe characteristics. The relative spare capacity within the pipe can be used as a first order estimate of the hydraulic load on a pipe and subsequent need for upgrade.

Another factor that should be considered is the flow velocity in the pipe. The CSIR (2003) suggests that sewers may follow the general slope of the ground, provided that a minimum full-bore velocity of 0,7 m/s is maintained. Brière (1999:223) suggests a minimum flow velocity for sanitary sewers of between 0.6 m/s and 0.75 m/s. The purpose of the predetermined minimum velocity is to ensure self-cleansing of the pipe. It should be noted that sediment transport is not directly related to flow velocity.

On the other hand the maximum allowable velocity of about 3.0 m/s (Brière, 1999:245) should not be exceeded; local consultants often use 2.5 m/s as a maximum value. Minimum pipe slopes, which correspond to the minimum allowable velocities, could be applied where inverts or specified slopes are not available during model building.

Infiltration into sewers is a reality and has been studied in the past (Stephenson and Barta, 2005a). An infiltration rate of 0,15 l/metre pipe/metre diameter has been suggested (Stephenson and Barta, 2005b) and is often used locally in SS planning to estimate infiltration rates. This rate could be applied to all gravity pipes in the model presented here in addition to the flow induced by users.

11.3.3 Manholes

This component constitutes a node in computer modelling and is also the point of flow calculation between the two ends of the pipe. Manholes are installed where pipes either have an angle, slope or diameter change or to restrict the pipe segment length to less than about 100 m for maintenance purposes.

11.3.4 Diversion structures

Diversion structures allow the flow or part thereof to be diverted to an alternate route or parallel pipeline to relieve capacity problems that may occur. The method for modelling such structures is dependent on the software product employed. The input parameters could range from specifying percentage of diversion between pipes for certain flow intensities, to manual diversion, which would mean multiple analyses of the same model.

11.3.5 Pumps

This component is installed where either the flow can no longer be transported by means of gravity or where it would be more economical to install a pump and rising main than excavating very deep trenches. Pumps are often needed for the latter reason in flat regions. Variable speed drive (VSD) pumps would result in transfer of flow from the pumping structure to the discharge manhole at a variable rate aiming to achieve a pump rate equal to the incoming sewer flow, which could assist in pump design. VSD pumps have some limitations, for example that lower revolutions may result in more blockage. In any case an existing pump could be modelled in the most simplistic way on the basis of continuous flow by entering the duty point flow as a constant value. This approach is valid in most cases, because of the pump-sump configuration the duty flow could occur at any time of the day and therefore should be allowed for at all times in a conservative hydraulic analysis.

11.3.6 Rising mains (pumping mains)

Rising mains are pipes that deliver the sewage from the pumping structure to a discharge manhole at the specified pump flow rate.

11.3.7 Wastewater treatment works

The WWTW is the point of treatment and falls beyond the scope of this study. It is included here because some "end point" is needed to define the SS (e.g. in hydraulic models).

11.4 Model flow inputs

Wastewater production and hence the sewer flow that is produced is largely dependent on the type of users. These points of entry induce a load on the system. This load is best described by a unit hydrograph. A unique unit hydrograph (UH) can be assigned to each user group, i.e. residential, which is based on the land use of a property, which allows for different sewer production trends throughout the day. For instance, a residential UH would have a peak in the morning and a peak in the evening, while a commercial or industrial UH would have a sustained "peak" located during office hours. A peak flow factor may then be applied to account for the sewer flow that is produced. Another way of finding the sewer flow is by applying a percentage of “return flow” to the expected water usage of the user group.

Each user has a unique diurnal wastewater production hydrograph that would also be unique for any given day. However, this complex nature of flow from different users is often simplified in modelling by considering a unique diurnal hydrograph for each user type. In contrast to the application of simple peak or average flows at a node, the resultant time lag routed flow of these hydrographs describes the flow along a pipeline as it moves downstream. This provides a much better representation of sewer flow.

The unit hydrographs shown in Figure 2-3 have been in use for SS planning by specialist consultants GLS (www.gls.co.za) since about 1995 and were updated in 2002 to include the latest calibration to various recorded sewer flows in the Tshwane (Pretoria) sewer system. A flow factor was applied to each UH type and multiplied by the number of users corresponding to that type of land use. These flows are then summed to calculate the total sewer flow from the users.

11.5 Detail description of Sanitown sewer system model

11.5.1 Basis for development

Due to the fact that the concept of the Sanitown model is based on that of the Anytown water model, the Anytown model was used as a starting point for the development of Sanitown. The Anytown model is a simplistic representation of an hypothetical water network which has an existing scenario and planning is needed to satisfy the future scenario. In other words, an "existing system" is presented with a problem posed that needs to be resolved. A similar approach is presented here with Sanitown, where a final result was achieved by starting small and successively adding complexity to a point where the most notable system elements were all included and typical modelling challenges could be included. A comprehensive discussion about the reasoning behind the particular final selection of elements and their connectivity, as presented in this paper, is beyond the scope of this text. The end result is a hypothetical system (or town for that matter) that looks nothing like the Anytown model, but is based on the same concept.

11.5.2 Topology and drainage basins

A 100 km² area was selected to establish the model in order to allow for satisfactory time lag characteristics while representing a realistic "town" with its typical modelling challenges. Two WWTW's, one diversion structure and one pump station were eventually included.

As conventional waterborne sewer systems are heavily influenced by the surrounding topology and mainly designed to gravitate as far as possible, contours were needed to justify the path of the gravity pipes. The Sanitown system comprises four drainage basins. Figure 11-2 is a schematic representation of the hypothetical existing Sanitown model, showing contour elevations in metres above sea level. North is considered to be to the top of each figure (the arrow is shown only in Figure 11-2).

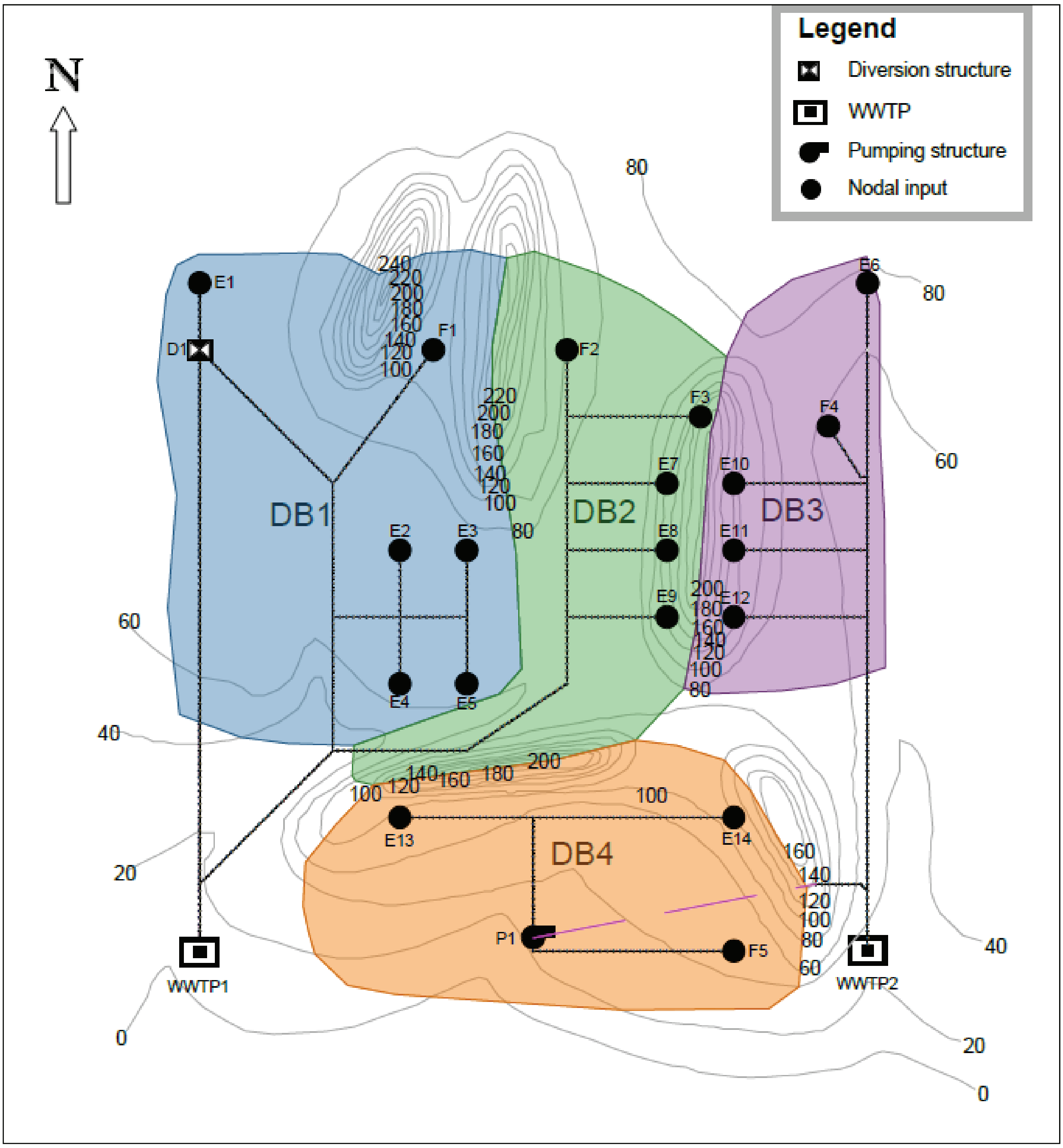


Figure 11-2: Sanitown existing scenario with contours

Each drainage basin (DB) is shown in a different shaded colour in Figure 11-2. The model has four drainage basins, numbered DB1 to DB4 in the same figure. Of these, DB1 and DB2 gravitate towards the south-west (SW) to WWTW1, while DB3 gravitates to the south-east (SE) to WWTW2. A south-fronting basin, DB4 drains away from both treatment facilities to a low lying area, from where the sewerage is subsequently pumped via a rising main to WWTW2. Various flow input nodes, comprising different land use types are available as described shortly. E1 through E14 denote existing scenario flow inputs while F1 through F5 denote inputs for the future planning scenario.

11.5.3 External flow inputs

Two potential external inputs E1 and E6 – that could be user defined in addition to the sewer flows to these nodes – are allowed for at the north-western (NW) and north-eastern (NE) corners of DB1 and DB3 respectively. Both these nodes are however also used as drainage points for users in the system.

11.5.4 Capacity of treatment works

In order to introduce a problem at one of the two WWTWs a capacity restriction was imposed on WWTW1 – thus preventing it from being further upgraded. Reasons for such a restriction might be a limitation to physical space for upgrading or that WWTW1 is situated in a sensitive environmental region that would not accommodate further extension of the facility at that location. Therefore, if the flow towards WWTW1 would exceed its capacity in the future, some of the flow would need to be diverted to WWTW2. A possible solution comprising such a diversion is presented later in this paper.

11.5.5 Pipe diameters

Figure 11-3 is another schematic representation of the proposed Sanitown model, but shows the nominal pipe diameters only. Five different diameters are used and coloured according to the diameter sizes. The rising main is a Ø90 mm pipe, with gravity pipe diameters of Ø110 mm, Ø160 mm, Ø200 mm and Ø315 mm used to allow for realistic (or "desired") flow velocities.

11.5.6 Future development areas

A proposed future scenario is presented in Figure 11-4, based on a mock spatial development framework. Sufficient flow should reach WWTW1 for its operation to be economical and a future diversion, D2, and pump-rising main at P2, should therefore allow enough flow to drain to

WWTW1 to continue operation at maximum capacity while introducing an increased flow to WWTW2.

The above planning scenario will allow for the upgrading of existing gravity pipes, an existing pump and the possibility of a rising main upgrade as well as the expansion of a WWTW. The design of a new pump and rising main is also present in this model.

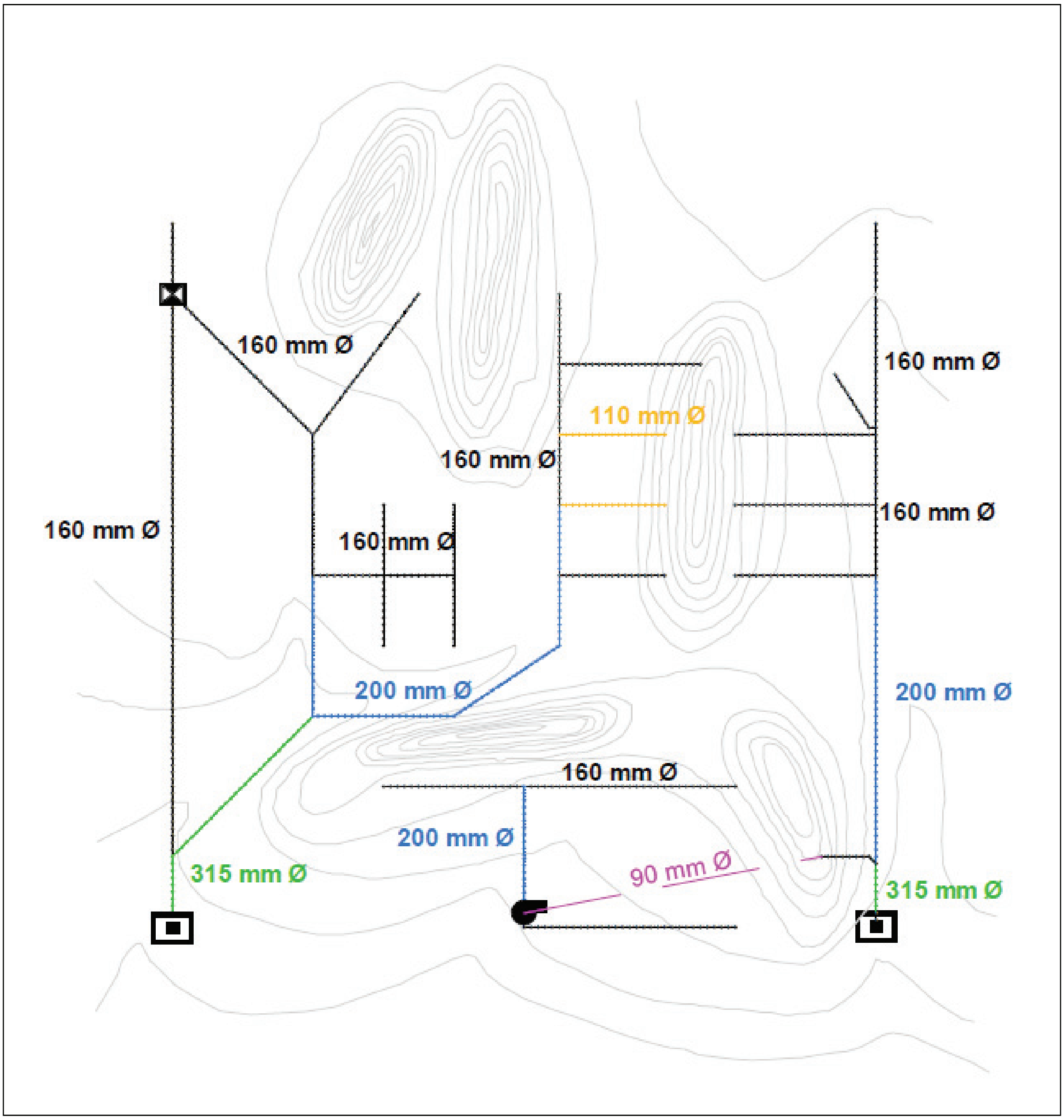


Figure 11-3: Sanitown existing scenario with pipe diameters

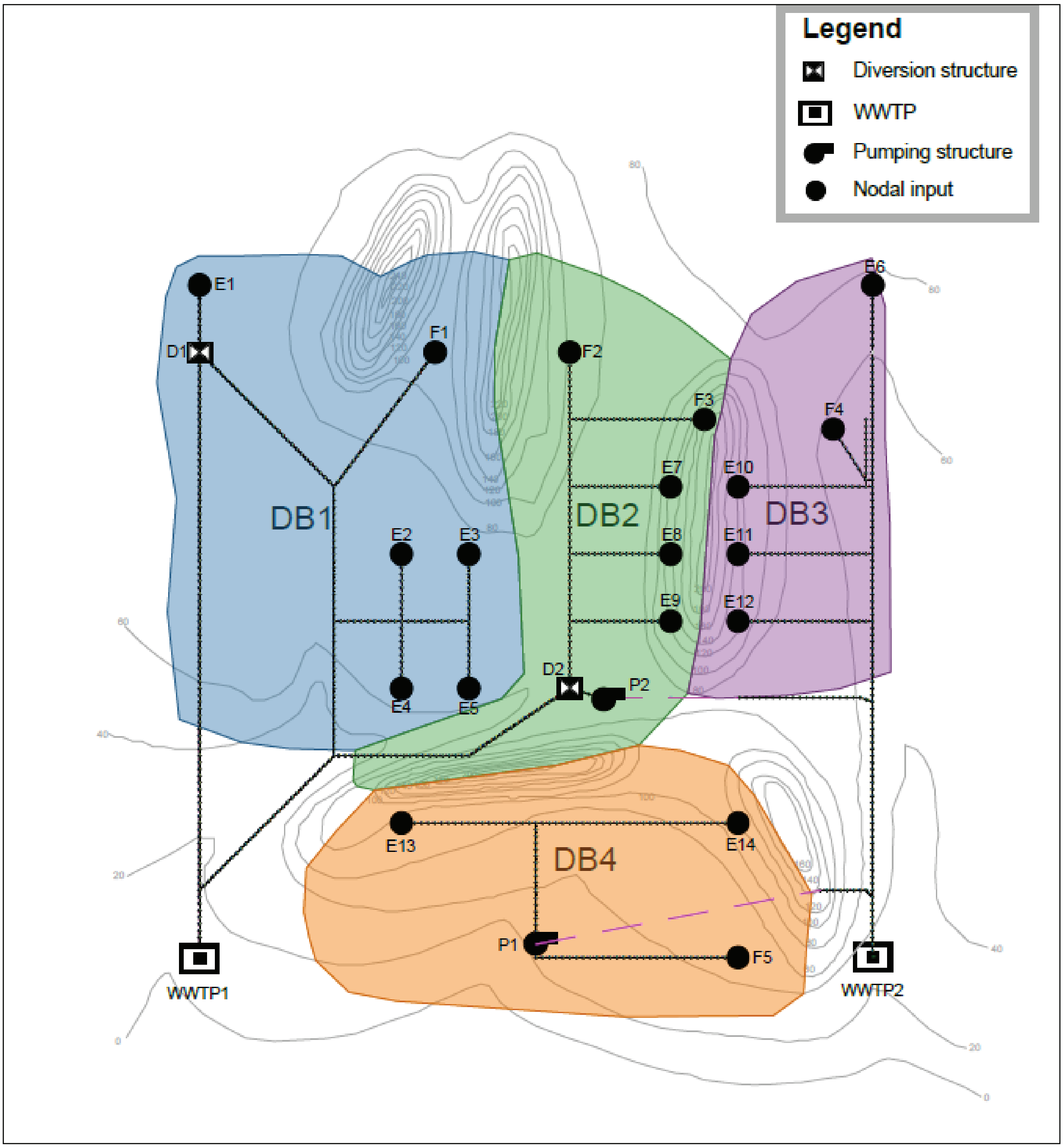


Figure 11-4: Sanitown showing development areas in the future scenario

11.6 Sanitown model additional input parameter values

The following tables present the detail of additional input parameter values required to model the system. The inputs pertain mainly to the various nodes in the model, with each table presenting the inputs for the following types of nodes:

- Table 11-1 gives the nodal flow input (land use type, hydrograph, number of homogeneous land parcel units and the resulting total flow to the particular model node)
- Diversion structures are summarised in Table 11-2
- Table 11-3 presents the pump structure information
- Ditto in Table 11-4 for the two wastewater treatment works.

Table 11-1 Hydrographs and flow inputs

Node	Land Use	Unit Hydrograph	Units	kℓ/unit/d
E1	Residential: High Income	UH2	300	0.999
E2	Residential: Medium Income	UH3	500	0.78
E3	Flats	UH6	100	0.492
E4	Educational	UH8	2	6.109
E5	Government/Institutional	UH9	20	2.382
E6	Cluster	UH5	500	0.495
E7	Residential: Medium Income	UH3	200	0.78
E8	Industrial	UH10	150	2.988
E9	Large	UH15	1	500
E10	Residential: Low Income	UH4	200	0.385
E11	Flats	UH6	150	0.492
E12	Business/Commercial	UH7	30	3.025
E13	Farm/AH	UH12	50	0.611
E14	Other	UH11	200	2.156
F1	Residential: Very High Income	UH1	50	1.464
F2	Flats	UH6	200	0.492
F3	Residential: Medium Income	UH3	100	0.78
F4	Educational	UH8	2	6.109
F5	Residential: Low Income	UH4	500	0.96

Table 11-2 Diversion structures

Node	Initial diversion %
D1	40/60
D2	50/50

Table 11-3 Pump structures

Node	Duty Flow (ℓ/s)
P1	7
P2	5

Table 11-4 Wastewater treatment works

Node	Capacity (kℓ/d)
WWTW1	1200
WWTW2	unlimited

11.7 Application and further development

11.7.1 Practical application of simple tools to Sanitown

The Sanitown model presented in this chapter could be used to illustrate the application of the simple tools presented in this report. Some of the tools are amenable to application only at ground level in a local authority, e.g. to complete the check list. As a matter of illustration the hydraulic design tool was applied to development F5 (refer to Table 11-1) as briefly presented in example below.

Consider development F5, a future low-income development of 500 homes impacting on the system and serviced by a single Ø160 mm pipe, a pump and rising main. From Chapter 5 we learn that the peak flow for a single LI-home is 0.0167 l/s/du, suggesting a total peak flow of around 8 l/s, excluding any allowance for extraneous flows. Figure 11-2 shows that the pipe connecting

F5 to the system is about 3.5 km long and drops with a steady slope from about 50 m at point of origin to 20 m at the pump. The slope is thus (50-20)/3.5 = 8.5 m/1 km, or approximately 8 m/1000 m. From Figure 5-3 we note that a Ø160 mm pipe at this slope should deliver about 14 l/s and that it would suffice.

Now considering Figure 6a, the Ø160 mm pipe diameter at the given slope would only service about 400 homes – this is due to the allowance for extraneous flows. This could serve as a warning that the Ø160 mm gravity pipe may be too small based on the conservative criteria used for setting up these tools. Finally, with reference to Figure 9 a vertical line drawn from 500 homes up would typically point to a pipe size of about Ø160 mm.

As a matter of further investigation, the total length of upstream pipe could be assessed by referring to Figure 5-10, suggesting that 3500 m is on the lower limit of the pipe length expected to service 500 homes. This is explained by the fact that the single pipe used in Sanitown is simply the bulk connection shown schematically by a single line and that part of the system probably does not include the various less significant (but equally large) pipes servicing the individual properties. Thus, basing an estimate for cost simply on the 3500 m length of pipe would probably result in an under-estimate for cost to service these properties.

This section was intended as an illustration only and was included mainly to underline the value of the Sanitown baseline sewer model for future research into sewer system modelling – even at a relatively low-technology level.

11.7.2 Further development

The Sanitown model was also tested as part of this research project by setting up a computer model of Sanitown. With its development the Sanitown sewer model was intended to become a widely used guinea pig for waterborne sewer system analysis, investigation into optimisation techniques and software performance. This type of research is particularly true for South Africa with its unique challenges to service delivery demanded by high-level customers at the upper end of the delivery ladder, and those without any service alike.

Sanitown is the first hypothetical model for sewer system analysis, complete with contours, input parameters and model topology that were carefully selected and refined to include typical yet realistic problems encountered with hydraulic modelling and planning of sewer systems. An "existing" scenario of the Sanitown model was presented, followed by a problem posed to address a future development scenario. The Sanitown system comprises four drainage basins covering a 100 km² area allowing for satisfactory time lag characteristics, while representing a realistic town size with typical modelling challenges. Two WWTW's, one diversion structure and one pump station were eventually included.

The final result was achieved by starting small and successively adding complexity to a point where the most notable system elements were all included and typical modelling challenges were allowed for. The end result is a hypothetical system (or town for that matter) that looks nothing like the Anytown water model, but is based on the same concept. It was hoped that the inclusion of the Sanitown model description as part of this research output would lead to further work in this regard – also possibly by future researchers suggesting amendments or improvements to the model after initial trials.

12. CONCLUSION

12.1 Discussion

In contrast to the advanced software suites available nowadays, this WRC-funded study recognised the need for low-technology tools to aid relatively small local authorities in moving towards a sewer system plan, which would ultimately assist in the improvement of planning functions and service delivery. It is evident from the definitions provided and the knowledge review that sewer planning is inherently complex and that the related planning process is not geared to a low-technology approach. Recognising this complexity while striving towards a low-technology, user-friendly output was the main challenge of this research. The aim of the project was to present a simplified approach to sewer system planning with accompanying tools that could be used directly as a low-technology (non-computer based) method for sewer system planning and to better understand the planning process.

An extensive knowledge review was included in this project. Despite valuable knowledge identified in grey literature and informal sources, the project team noticed an acute lack of peer reviewed journal publications pertaining to sewer systems and their planning, particularly with reference to local work and local systems. The knowledge review covered sewer system planning, local practice, key issues pertaining to small local authorities, design philosophies, the dynamic planning process, sewer flow and flow components, as well as an extensive review of completed South African sewer system (master) plans. The knowledge review set the scene for development of low-technology tools that could aid staff in small local authorities.

12.2 Project outcomes

The eventual tools comprised relatively simple check-lists, tables, graphs and diagrams to aid in the critical steps of the planning process. Despite the availability and application of various propriety software suits for system modelling in South Africa the aim in this research was instead to produce a set of basic hard copy tools. The results were aimed at third world communities where the level of service is poor and technical skill levels of staff were limited, often accompanied by limited access to a computer.

The low-technology toolkit was presented separately, comprising the following six loose-standing documents (these were termed tools):

- Hydraulic design tool – an aid to understanding the relationships between critical parameters used in basic hydraulics of sewer pipes and a useful way of estimating required infrastructure size by means of very crude assumptions
- Infrastructure costing tool – a mechanism to estimate the fixed capital cost of sewer infrastructure
- Sewer system planning checklist – a method to record progress and guide towards an eventually comprehensive SSP
- Sewer system planning process tool – a general description of the SS planning process
- Sewer terms tool – this could be viewed as a sewer terms glossary or mini-sewer-dictionary
- WSDP tool – aimed at simplifying the transfer of information from the SSP to the WSDP.

Each of these was included as appendices to this report. Each was also intended for distribution independently of this document and independently of the others, for use at local authorities. The tools were prepared as individual A4-sized mini-booklets. Some aspects of the tools were combined to form a single overview presented as an A1-sized poster that could be viewed as a one-stop-shop intended for wall mounting in a distant Municipal office.

12.3 Stakeholder input

The project team held workshops at four venues in the country. The idea was to complete workshops with stakeholders in order to establish their needs and interventions and to evaluate the experiences of local authorities in using particular types of tools and planning guidelines. The stakeholder input was considered crucial in that tools were developed and adjusted during the process.

Four workshops were held during October and November 2009 at the following locations:

(i) Cape Town, in collaboration with IMESA conference where 151 completed questionnaires were received;

(ii) Beaufort West, with site visits to three towns/two Municipalities in the region;

(iii) De Aar, with site visits to four towns/three Municipalities in the Pixley Ka Seme region;

(iv) Worcester, in collaboration with the MIG-working group, where technical staff of 27 different Municipalities provided feedback to the project team.

In addition to the four workshops noted above, a post-project workshop was held at the WISA2010 conference in Durban on 18 April 2010 in collaboration with another WRC project team (Van Dijk et al., 2008). The aim of the WISA workshop, presented to approximately 50 attendees, was to disseminate knowledge and provide reviews of the two parallel WRC-funded projects.

In conclusion it could be stated that the stakeholder input was a valuable aspect in finally shaping the outcome of this project.

12.4 Addressing the need for knowledge

A key problem in small local authorities – in terms of this research – was that staff at ground level responsible for service delivery were often limited in terms of basic knowledge regarding the sewer system, its operation and planning. The value of the simple tools presented here do not merely lie in their usefulness in sewer system planning, but rather in their value as training tools to gain understanding of the sewer system and its planning and to illustrate critical relationships between notable parameters typically used for sewer system planning.

No matter to what extent and how well the simple planning tools provided by this research project are applied in practice, it is imperative that a computer model of the sewer system would ultimately be required. Only by means of an accurate computer model would it be possible to assess the hydraulic capacity of the system. Increasing the level of complexity to a computer model immediately poses a new problem to designers and analysts in that no benchmark model was available to discuss and investigate different approaches to the sewer system design problem.

A hypothetical model for sewer system analysis called Sanitown, a concatenation of "sanitation" and "town", was presented in this text. It included typical yet realistic problems encountered with the hydraulic modelling and planning of sewer systems. The Sanitown model topology, drainage region contours, hypothetical flow inputs, a future scenario and a few restrictions in terms of system upgrades were presented. The Sanitown model was also tested as part of this research project by setting up a computer model of Sanitown, but an example was also provided where the low-technology tools were applied to one of the hypothetical Sanitown developments. With its development the Sanitown sewer model was intended to become a widely used guinea pig for waterborne sewer system analysis, investigation into optimisation techniques and software performance.

The outcomes of this project would aid a Municipality to better understand the working, modelling and planning of a sewer system and its optimisation in terms of hydraulics and cost. The sewer system planning checklist tool in particular would aid staff to record and prepare the required and desired information, ultimately needed to compile a computer model, in a useful format. In doing so an understanding would be gained of both the sewer system and the sewer system planning process.

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APPENDIX A: Tool 1 – Hydraulic Design Tool

WATER RESEARCH COMMISION SEWER MASTER PLANNING TOOLKIT

Hydraulic Tool

A Project by Stellenbosch University in Collaboration GLS Consulting

waternetworks@sun.ac.za

2010

WATER RESEARCH COMMISION

Note to the user

Average flow velocity

The application of the average flow velocity in hydraulics is now accepted to be out-dated and other more advanced methods are available for determining scouring and sediment transport in sewer pipes. Contrary to the theory presented here, sewers often do not flow full. Sewers typically have a free surface flow that is subject to complex phenomenon (like hydraulic jumps) that could not be addressed in a simplified manner here. For the limited application of this simplified tool it was considered necessary to use the average velocity and the assumption of pipes flowing full as a means to illustrate some essential concepts in pipe flow hydraulics.

Simplified approach versus computer modelling

Sewer system design and planning is nowadays conducted by means of computer models. The hard-copy graphs presented here should not be used for design, but could aid the user in better understanding the typical values that could be expected when an Engineer finally conducts a design.

Format of this tool

This A4 format of the tool includes 9 pages showing various graphs. Each figure number corresponds to a Water Research Commission Report from which these were drawn (www.wrc.org.za). A larger poster-format for wall mounting was also developed during this project and includes some selected graphs of the Hydraulic Tool. The following figures are included here:

- Flow rate for different pipe diameters and slopes
- The relationship between pipe diameter and minimum slope
- Relationship between number of low-income (LI) homes, pipe diameter and slope
- Relationship between number of middle-income (MI) homes, pipe diameter and slope
- Relationship between number of high-income (HI) homes, pipe diameter and slope

Warning with regards to scatter

To illustrate the amount of scatter that is found when analysing actual existing sewer systems, two additional graphs were also included in the Hydraulic Tool:

- A scatter plot showing the large variation in pipe diameter with increasing number of upstream service connections
- A scatter plot showing the large variation in total gravity pipe length with increasing number of upstream service connections.

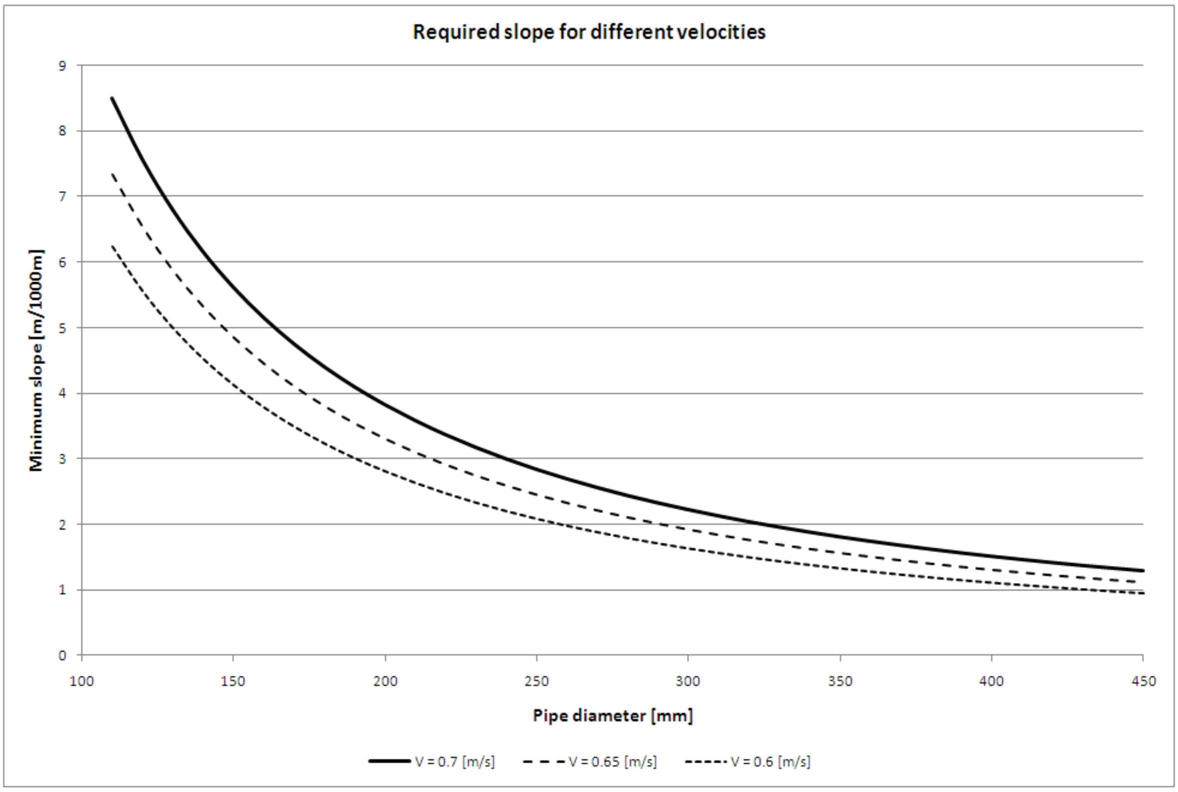


Figure 5.1: Pipe diameter, slope and different average velocities for pipes flowing full

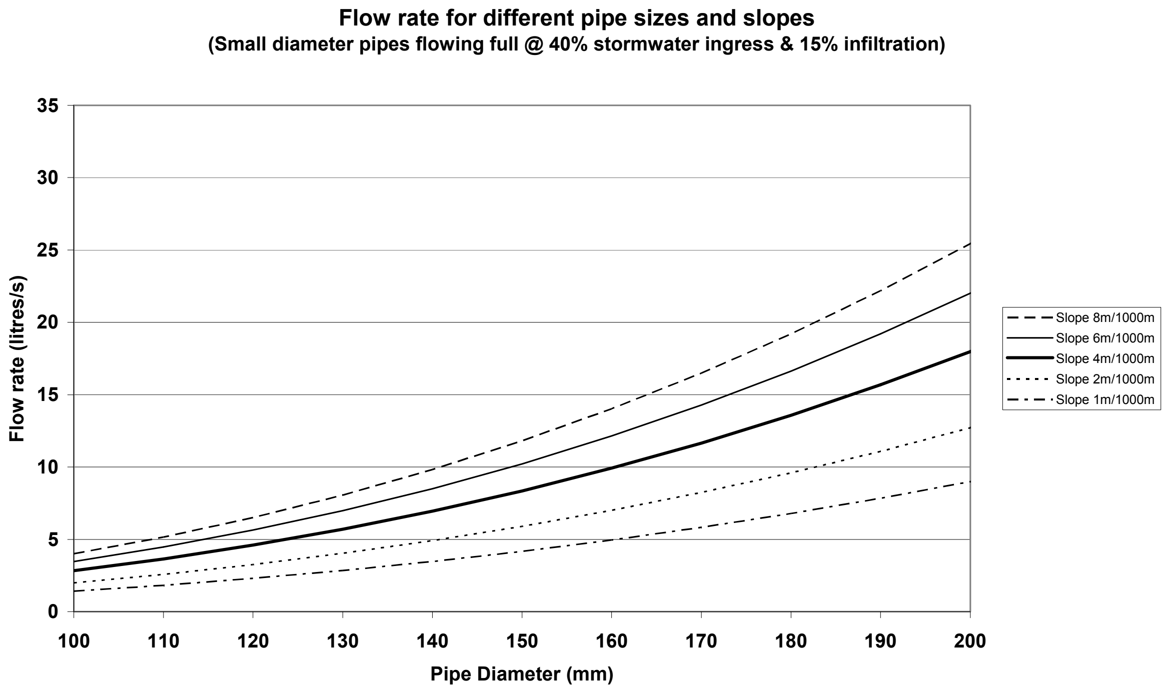


Figure 5.4: Flow rate for different pipe diameters and slopes (D<Ø200 mm)

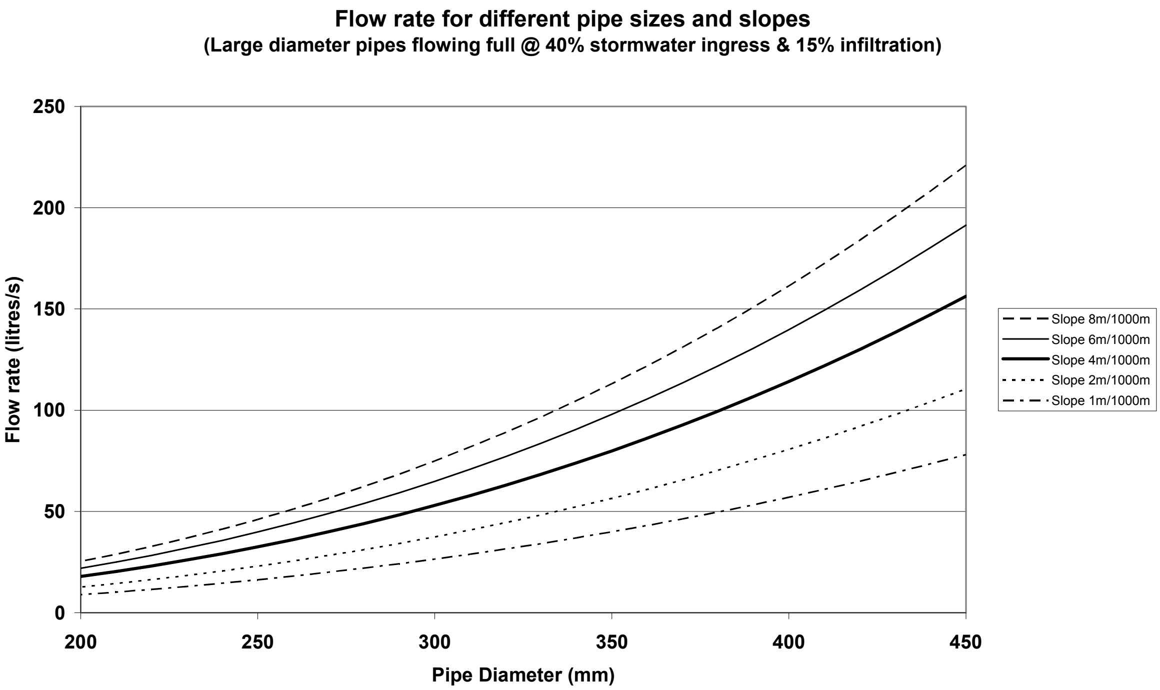


Figure 5.5: Flow rate for different pipe diameters and slopes (D>Ø200 mm)

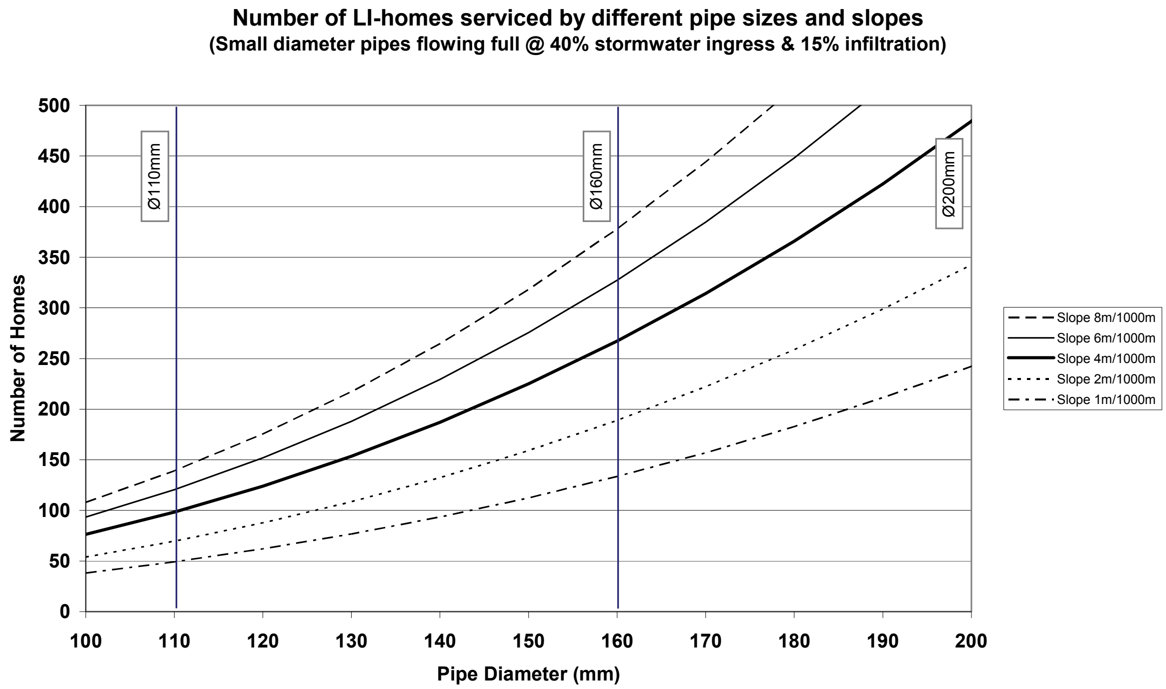


Figure 5.6a: Relationship between number of LI-homes, pipe diameter and slope (D<Ø200 mm)

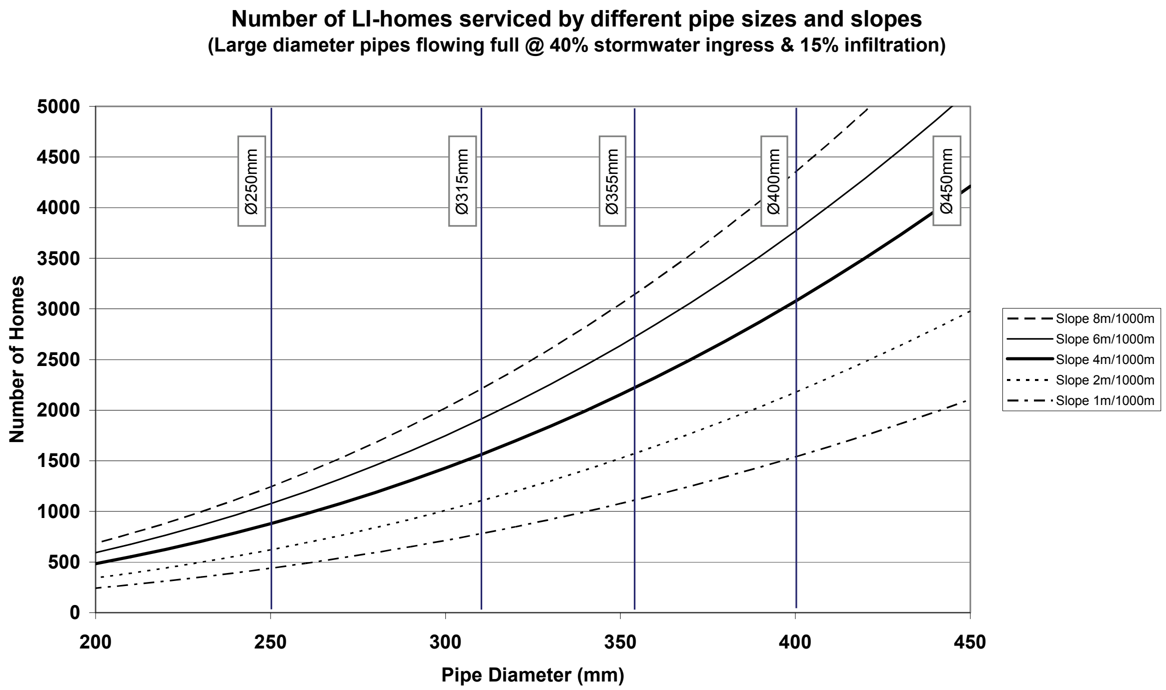


Figure 5.6b: Relationship between number of LI-homes, pipe diameter and slope (D>Ø200 mm)

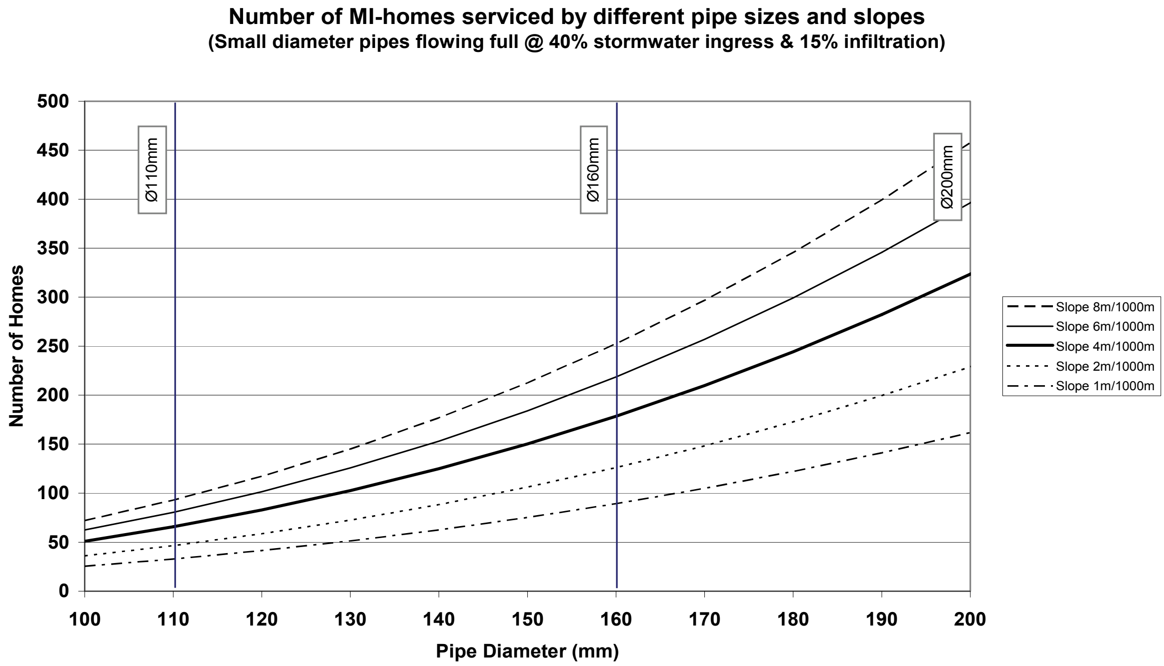


Figure 5.7a: Relationship between number of MI-homes, pipe diameter and slope (D<Ø200 mm)

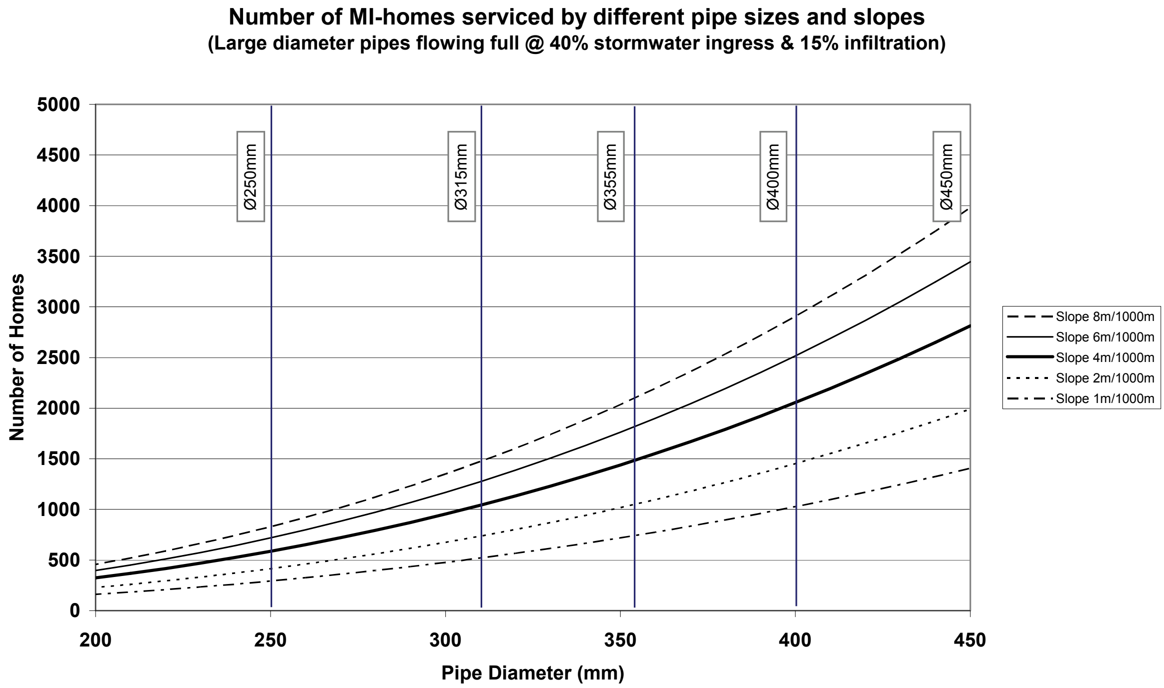


Figure 5.7b: Relationship between number of MI-homes, pipe diameter and slope (D>Ø200 mm)

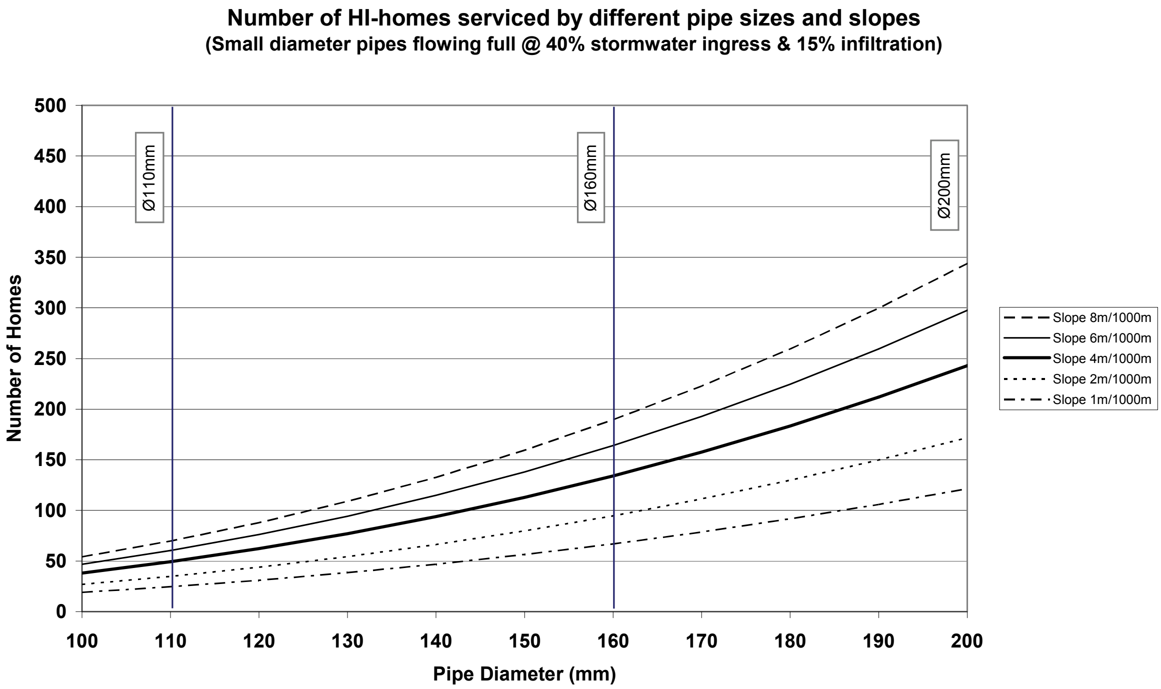


Figure 5.8a: Relationship between number of HI-homes, pipe diameter and slope (D<Ø200 mm)

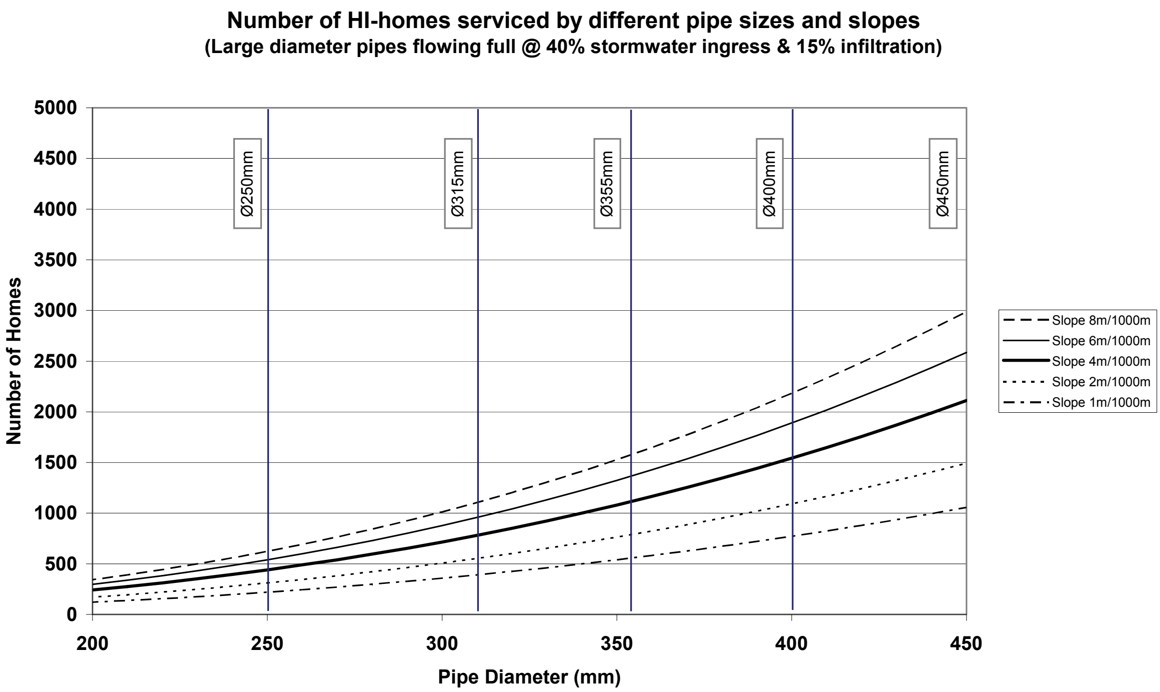


Figure 5.8b: Relationship between number of HI-homes, pipe diameter and slope (D>Ø200 mm)

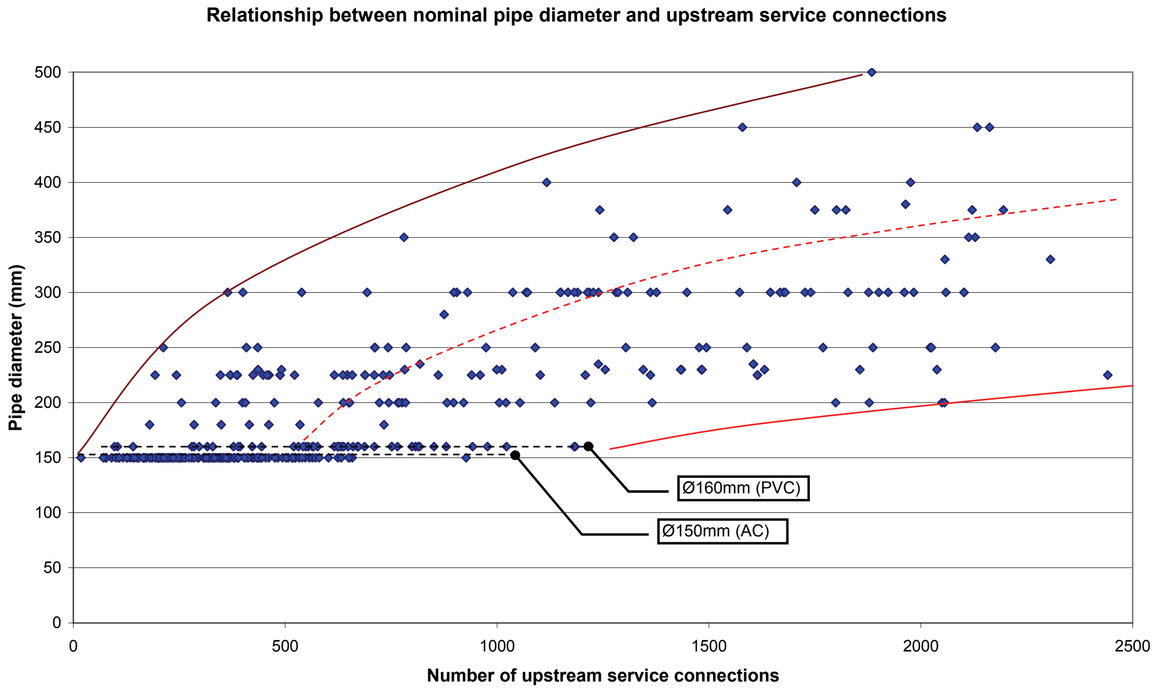


Figure 5-9: Plot of data from existing sewer system models showing range of scatter

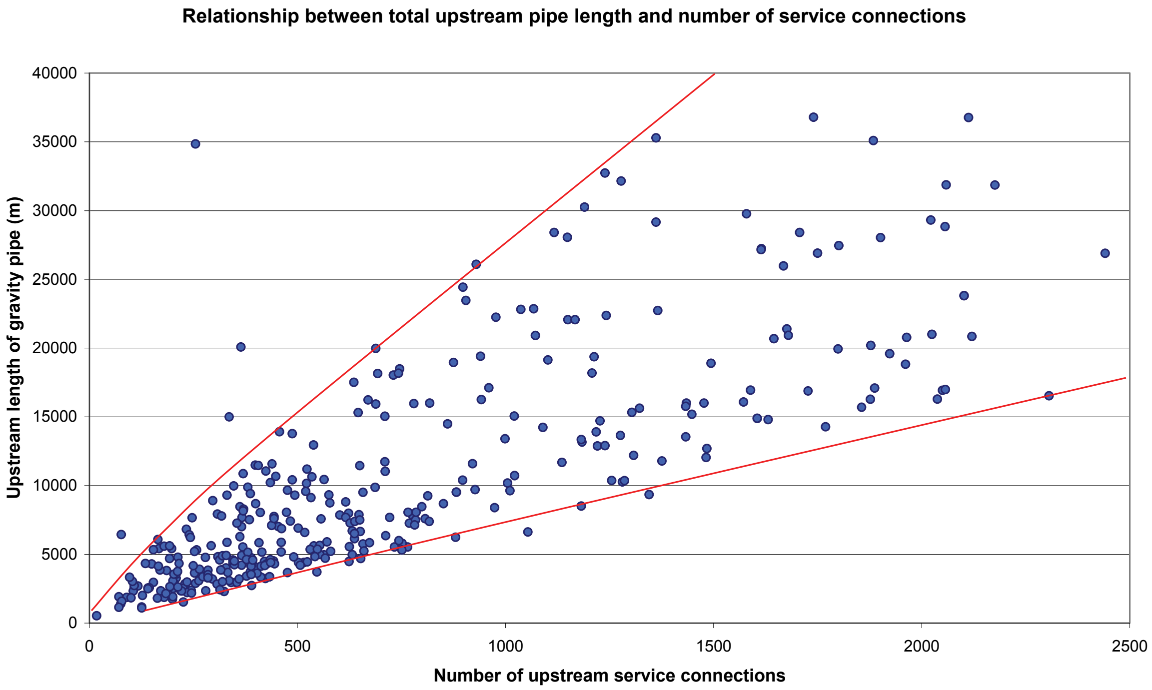


Figure 5-10: Plot of data from existing sewer system models showing range of scatter

APPENDIX B: Tool 2 – Infrastructure Costing Tool

WATER RESEARCH COMMISION SEWER MASTER PLANNING TOOLKIT

Infrastructure Cost Tool

A Project by Stellenbosch University in Collaboration GLS Consulting

waternetworks@sun.ac.za

2010

WATER RESEARCH COMMISION

Note to the user

Format of this tool

This tool was developed as an A1 size poster-format for wall mounting, with graphs drawn from a Water Research Commission Report (www.wrc.org.za). A publication with detail on this topic was presented at the WISA2010 conference and the full paper, including all graphs, is available for free download via the internet from www.ewisa.co.za.

Simplified approach versus computer modelling

Sewer system design and planning is nowadays conducted by means of computer models. The hard-copy graphs presented in the poster should not be used for design, but could aid the user in better understanding the typical values that could be expected when a detailed costing of the system is done by an expert.

Warning with regards to types of cost

Capital cost is the only type of cost that is amenable to simplified hard-copy presentation, and it is relatively easy to understand. Operations and maintenance costs vary greatly from one installation to the next and are a function of various complex parameters. The cost functions are useful for estimating existing system replacement value, but have limited application when it comes to optimising pump and rising main costs for future developments

APPENDIX C: Tool 3 – Checklist Tool

WATER RESEARCH COMMISION SEWER MASTER PLANNING TOOLKIT

Sewer System Planning Checklist Tool

A Project by Stellenbosch University in Collaboration GLS Consulting

waternetworks@sun.ac.za

2010

WATER RESEARCH COMMISION

Note to the user

Format of this tool

This tool was developed as an A1 size poster-format for wall mounting, with the information contained drawn from a Water Research Commission Report (www.wrc.org.za). A reduced single-page A4 version of the poster is included here for optional printing and use in cases where this text is available, but the A1 project poster was not accessible.

Simplified approach versus computer modelling

Sewer system design and planning is nowadays conducted by means of computer models. The hard-copy checklist presented in the poster is an ideal method to record the type and level of information that would be needed by an expert to conduct a detailed planning study by means of computer.

Use of the Checklist Tool

The idea is to mark (e.g. tick with a pen) each level of completeness for each step in the progress (each row down the table). The levels of completeness, in increasing order of desirability, are:

- "No / Not available" = the person completing the checklist knows that the information is not available or has not been recorded
- "I do not know" = the person completing the checklist is not sure whether the information is available or not
- "Available from consultant" = the information is available, but not from the Municipality; it could for example be obtained by contacting the Municipality's engineering consultant/s
- "At Municipality, but out-dated or incomplete" = the information (say a CAD drawing) is available in the Municipal office, but the recorded data is either incomplete or out-dated.

"At Municipality – Yes" = the information is available in the Municipal office.

SEWER MASTER PLANNING

PROGRESS CHECKLIST TOOL

SEWER SYSTEM PLANNING PROGRESS

Completeness →

	Item	No / Not available	I don't know	Available from Consultant	At Municipality: Out-dated / Incomplete	At Municipality: Yes
1	**Basic information and data integrity**					
1.1	As-built drawings of sewer system					
1.2	Site survey data of manhole positions (x,y,z - coordinates)					
1.3	CCTV-survey or other accurate GIS information of manholes					
1.4	Pump station location and capacity					
1.5	Existing hydraulic model(s) of the sewer system					
1.6	Drainage zone information (drainage basin boundaries etc)					
1.7	Cadastral and land use (GIS; number of properties etc)					
1.8	Basic flow measurements at treatment plant (e.g. monthly)					
1.9	General sewer flow logging and/or daily measurements					
2	**Hydraulic (computer) model of existing system**					
2.1	Data capturing from CAD/GIS/Existing models					
2.2	Electronic survey data of manholes					
2.3	Detailed modelling of pump stations, diversions, etc.					
2.4	Non-hydraulic info, e.g. pipe material/installation year					
2.5	Discrepancies/field inspections					
3	**Plan books or wall maps**					
3.1	Title blocks and grids established					
3.2	Background drawings, images and text					
3.3	Printed maps/plan books of sewer system					
4	**Water balance and sewer flow estimates**					
4.1	Bulk sewer flow measurements (e.g. at WCW's)					
4.2	Water demand records per property (AADD)					
4.3	Sewer flow measurements at pump stations					
4.4	Unit hydrographs and estimates of sewer flows					
5	**Link between flow data and model topology**					
5.1	Detail drawings and knowledge of sewer connections					
5.2	Property to manhole cross referencing (in model)					
5.3	Drainage zone-by-zone sewer flow profile (in model)					
6	**Hydraulic calibration of model**					
6.1	Flow logging at selected manholes and rainfall data					
6.2	Records of monthly rainfall					
6.3	Analysis of flow measurement data (infiltration/ingress)					
6.4	Discrepancies and topological corrections					
6.5	Field records and inspections (e.g. record of sewer spills)					
6.6	Adjustments (pipe roughness coefficients, etc)					
7	**Evaluation of existing system**					
7.1	Design criteria (minimum slopes/velocities, etc.)					
7.2	Groundwater infiltration/stormwater ingress analysis					
7.3	Existing system hydraulic analysis					
7.4	Existing system interpretation of results					
7.5	Identification of problems based on modelled results					
8	**Future land use and sewer flow analysis**					
8.1	Spatial Development Framework (SDF)					
8.2	Future occupation of vacant land / densification					
8.3	Re-zoning of existing developments					
8.4	Potential upgrading of service levels					
8.5	Growth scenario and planning horizon					
9	**Master plan for sewer system**					
9.1	Extend model to cover future land developments					
9.2	Modelling of future sewer flows					
9.3	Plan future system (size future infrastructure)					
9.4	Phasing in of future master plan items					
9.5	Cost estimates for future capital projects					
9.6	Optimise cost to identify best solutions					
9.7	Capital budget summary (prioritised project list)					
9.8	Software purchase or contract					
10	**Reports / Documents**					
10.1	Existing system status quo					
10.2	Spatial Development Framework (SDF)					
10.3	Sewer Master Plan (SMP)					
10.3	SMP results incorporated in WSDP					

APPENDIX D: Tool 4 – SS Planning Process Description Tool

WATER RESEARCH COMMISION SEWER MASTER PLANNING TOOLKIT

Sewer System Planning Process Tool

A Project by Stellenbosch University in Collaboration GLS Consulting

waternetworks@sun.ac.za

2010

WATER RESEARCH COMMISION

Note to the user

Format of this tool

This tool comprises a flow chart that describes the sewer system planning process in two levels of detail:

- first a reduced level of complexity as a schematic diagram of the simplified approach; it also includes a column on the right showing the link between each sewer system planning tool and the corresponding step in the process
- a more comprehensive viewpoint of the process.

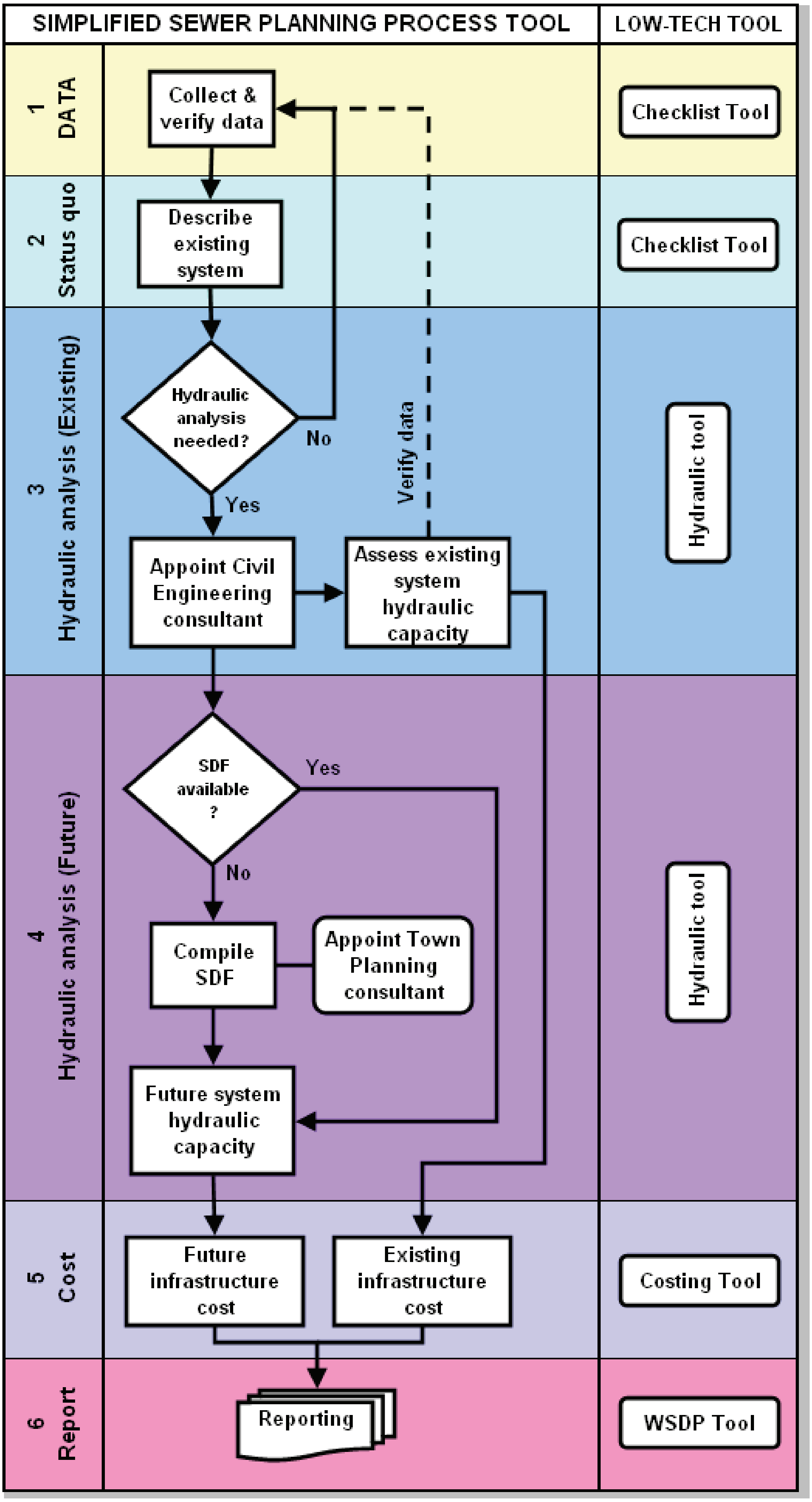
This tool was developed to fit on an A4 size page and the flow was included in the project poster-format for wall mounting, where it is linked to other tools. The information contained was drawn from a Water Research Commission Report (www.wrc.org.za).

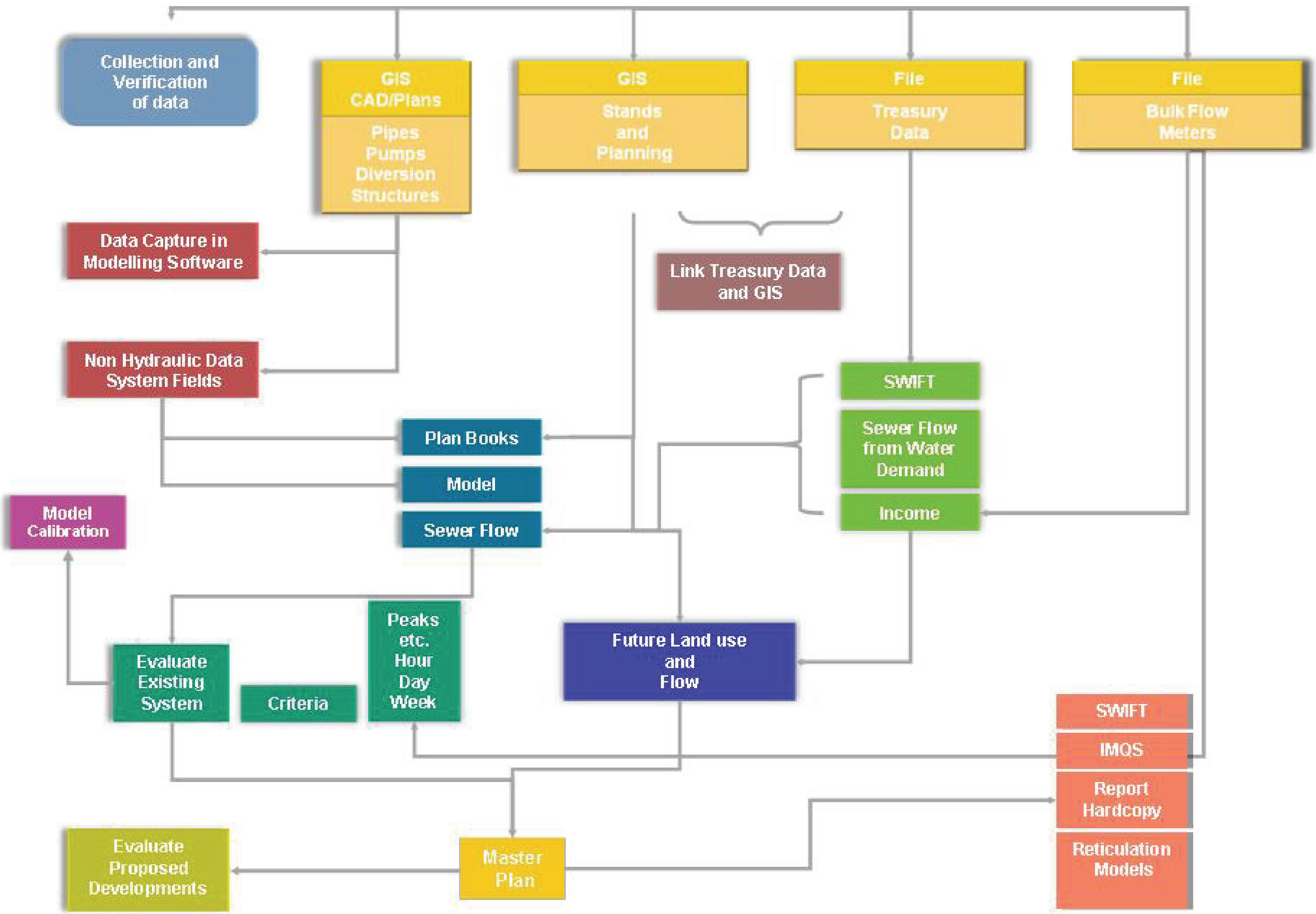
Simplified approach versus computer modelling

Sewer system design and planning is nowadays conducted by means of computer models. The checklist presented here is aimed at explaining the relatively simple approach of sewer system planning. A more comprehensive description is available to describe the dynamic sewer master planning process and how it integrates to the water master plan; that work is not included here.

Use of the Process Tool

The idea of this tool is to illustrate the process by means of a simple flow chart, with actions and warnings where appropriate as they relate to each step.


SIMPLIFIED SEWER PLANNING PROCESS TOOL
LOW-TECH TOOL
1 DATA
2 Status quo
3 Hydraulic analysis (Existing)
4 Hydraulic analysis (Future)
5 Cost
6 Report
Collect & verify data
Describe existing system
Hydraulic analysis needed?
No
Yes
Verify data
Appoint Civil Engineering consultant
Assess existing system hydraulic capacity
SDF available ?
Yes
No
Compile SDF
Appoint Town Planning consultant
Future system hydraulic capacity
Future infrastructure cost
Existing infrastructure cost
Reporting
Checklist Tool
Checklist Tool
Hydraulic tool
Hydraulic tool
Costing Tool
WSDP Tool



Collection and Verification of data
GIS CAD/Plans
Pipes Pumps Diversion Structures
GIS
Stands and Planning
File
Treasury Data
File
Bulk Flow Meters
Data Capture in Modelling Software
Link Treasury Data and GIS
Non Hydraulic Data System Fields
SWIFT
Sewer Flow from Water Demand
Income
Plan Books
Model
Sewer Flow
Model Calibration
Peaks etc. Hour Day Week
Future Land use and Flow
Evaluate Existing System
Criteria
SWIFT
IMQS
Report Hardcopy
Reticulation Models
Evaluate Proposed Developments
Master Plan

APPENDIX E: Tool 5 – Sewer Terms Tool

WATER RESEARCH COMMISION SEWER MASTER PLANNING TOOLKIT

Sewer Terms Tool

A Project by Stellenbosch University in Collaboration GLS Consulting

waternetworks@sun.ac.za

2010

WATER RESEARCH COMMISION

PART A. SEWER SPECIFIC- The following list of definitions and terms relate to sewers.

Attenuation
The reduction in magnitude/intensity/concentration of a substance dispersed in a liquid medium.

Average dry weather flow
The average non-storm flow over 24 hours during the dry months of the year. It is composed of the average sewage flow and the average dry weather inflow/infiltration.

Average wet weather flow
The average flow over 24 hours during the wet months of the year on days when no rainfall occurred on that or the preceding day.

Base flow
That portion of the wastewater flow, including inflow and infiltration, that corresponds to the minimum flow recorded in a sewer. It typically equates to the "minimum night flow" concept in water distribution systems.

Bulk main
See Collector main.

Blockage
A deposit in a sewer resulting in restriction or stopping of flow.

Cesspool
A covered watertight tank used for receiving and storing sewage from premises which cannot be connected to the public sewer and where conditions prevent the use of a small sewage treatment works, including a septic tank.

Cleaning eye
An access opening to the interior of the discharge pipe or of a trap, provided for the purpose of internal cleaning, and which remains permanently accessible after completion of the drainage installation.

Collector main
In collection systems, this is a larger pipe in which smaller branch and sub main sewers are connected.

Collector sewer
The intermediate sized pipelines that convey the effluent from the reticulation to the main outfall sewers. These are usually in sizes ranging from 150 to 450 mm in diameter (Goyns, 2007).

Collection system
In a wastewater system, a collection system is a system of pipes which receives and conveys sewage and/or storm water.

Combined sewer system
A wastewater collection and treatment system where domestic and industrial wastewater is combined with storm runoff.

Combined sewers
A sewer that carries both sewage and stormwater runoff.

Conservancy tank
A covered tank that is used for the reception and temporary retention of sewage and that requires emptying at intervals.

Conventional sewer system
Refer to waterborne sewer system

Detention
The process of collecting and holding back stormwater or combined sewage for delayed release to receiving waters.

Discharge
The release of wastewater or contaminants to the environment. A direct discharge of wastewater flows from a land surface directly into surface waters, while an indirect discharge of wastewater flows into surface waters by way of a wastewater treatment system.

Diversion structure
A type of regulator that diverts flow from one pipe to another.

Drain
A pipeline, generally underground, designed to carry wastewater and/or surface water from a source to a sewer; the drain is the plumbing within the boundary of the water consumer (it could also be interpreted as a pipeline carrying land drainage flow or surface water from roads, Stephenson and Barta, 2005).

Domestic wastewater
Human-generated sewage that flows from homes and businesses.

Effluent
Treated water, wastewater or other liquid flowing out of a treatment facility.

Extraneous flow
Water entering the sewer from sources other than intended water used and wasted, or leaking, at source (e.g. stormwater and groundwater infiltration). Extraneous flows make up most of the base flow in most sewers.

French drain
A conventional absorption field that comprises a trench that is filled with suitable material and that is used for the disposal of liquid effluent from a septic tank or waste water.

Grease trap
A device that is designed to cool down incoming hot waste water to below 30^0C, to enable grease and fat to separate from the water and to solidify at the surface level of the waste water, and that prevents grease and fat from entering the sewer (also referred to as a grease interceptor).

Greywater
Wastewater from the bath, shower and possibly the washing machine that is "less polluted" than waste from the other sources (e.g. the toilet and kitchen sink).

Groundwater infiltration
Infiltration of groundwater (that typically enters the sewer system through pipe defects located below the normal groundwater table).

Gully
A pipe fitting that incorporates a trap into which waste water is discharged and that is normally connected to a drain.

Infiltration
The ingress of water into a drain or sewer through defects in pipes, joints or manholes (Stephenson and Barta, 2005).

Inflow
Flows of extraneous water into a wastewater conveyance system from sources other than a sanitary sewer connections, such as roof leaders, basement drains, manhole covers, and cross-connections from storm sewers.

Influent
Water, wastewater or other liquid flowing into a reservoir, basin or treatment plant.

Influent pump station
A pump station that pumps flow from an interceptor sewer into a treatment plant.

Inspection chamber
A chamber not deeper than 1 m and of such dimensions that permanent access may be obtained to a drain without a person being required to enter into such a chamber.

Invert
The bottom of the inside of a pipe.

Lateral sewer
A sewer that discharges into a branch or other sewer and has no other common sewer tributary to it.

Lag
An interval of time before additional flow enters the system.

Load
Any matter transported by the flow in sewers (typically this would be sewage).

Main sewer
This is a relatively larger pipe into which smaller branch and submain sewers are connected. It may also be called a trunk sewer.

Manhole
Chamber of depth exceeding 750 mm and of such dimensions that a person can enter such chamber to obtain access to a drain.

Network pipe
See reticulation pipe.

Nonpoint source pollution
Pollution that enters water from dispersed and uncontrolled sources (such as surface runoff) rather than through pipes. Nonpoint sources (for example, stormwater runoff from agricultural or forest operations, on-site sewage disposal systems, and discharge from boats) may contribute pathogens, suspended solids, and toxicants.

Outfall
The point, location, or structure where wastewater or drainage discharges from a sewer, drain or other conduit.

Outfall sewer
A sewer that receives wastewater from a collecting system or from a treatment plant and carries it to a point of final discharge. These are usually from 450 mm in diameter and larger.

Peak dry weather flow (PDWF)
The peak non-storm flow during the dry months of the year. It is composed of the peak sewage flow and the peak dry weather inflow/infiltration.

Peak wet weather flow (PWWF)
The peak flow during the wet months of the year on days when no rainfall occurred on that preceding day.

Plumbing
The system of pipes and fittings required for the sanitation of a building (to the stand boundary where the plumbing joins the sewer).

Pump station (also pumping station)
A pump station comprises at least a motor, pump and some type of sump. A pump station may contain more than one of the former elements. This is usually an underground structure that the sewage is discharges into. The types vary but in smaller systems these comprise of a wet well, into which the sewage is discharged, and the wet well also houses submersible pumps which pump the sewage to its destination via a rising main (pipe). In a larger pump stations there may be a separate dry well, adjacent to the wet well, where the pumps are housed. On some pump stations the pumps may be housed above ground near the wet well.

Raw sewage
Untreated waste water.

Regulator
A structure that controls the flow of wastewater from two or more input pipes (trunk lines) to a single output (usually a larger interceptor line). Regulators can be used to restrict or halt flow, thus causing wastewater to be stored in the conveyance system until it can be handled by the treatment plant.

Relief sewer
A sewer built to carry flows in excess of the capacity of an existing sewer.

Reticulation pipe
Also called a network pipe. This is the smallest element of a sanitation system and consists of the small diameter pipelines that convey the effluent from the individual properties and along streets. They are usually in sizes ranging from 110 to 225 mm in diameter (Goyns, 2007).

Rising main
A pipeline leading from a pump station that transports wastewater under pressure to its destination at higher elevation.

Runoff
That part of precipitation, snow melt, or irrigation water that runs off of the land surface into streams or other surface water instead of infiltrating the land surface. Runoff could infiltrate sewers.

Rodding eye
A permanent access opening to the interior of a drainage installation that permits full-bore access to the interior of a drain for internal cleaning, but does not include an inspection eye or manhole.

Sand trap
A large construction (typically of concrete) to trap load in sewage. To be completed.

Sanitation
Conditions relating to public health. The term would thus include the provision of waterborne sewerage as a service in the wider definition

Sanitation system
N/a

Screen
A large sieve used for the purpose of trapping the load in sewage.

Secondary treatment
Biochemical treatment of wastewater after the primary stage, using bacteria to consume the organic wastes. The secondary treatment step includes aeration, settling, disinfection and discharge through an outfall. Secondary treatment in conjunction with primary treatment removes about 85 to 90 percent of suspended solids in wastewater.

Sediment
Once-suspended material which has settled to the bottom of a liquid, such as the sand and mud.

Sedimentation tanks
Tanks or tunnels for holding wastewater where floating wastes are skimmed off and solids settle by gravity. Settled solids, called "sludge," are pumped out for further treatment. Sedimentation tanks are also referred to as clarifiers.

Septic tank
An underground tank used for the deposition of domestic wastes. Bacteria in the wastes decompose the organic matter, and the sludge settles to the bottom. The effluent flows through drains into the ground. Sludge is pumped out at regular intervals.

Sewage
Wastewater and excrement conveyed in sewers. It could include infiltrated soil water, industrial effluent and other liquid waste, either separately or in combination, but excludes stormwater by design. Sewage is usually classified as wastewater derived from human communities – toilet, bathroom, laundry and kitchen waste.

Sewer
A pipe or conduit used for the conveyance of sewage (the sewer is typically the property of the local authority and excludes on-site plumbing and drains). The term is often defined in dictionaries as "an underground conduit for carrying of drainage water and waste matter", but this definition is technically incorrect in instances such as South Africa where waste matter (e.g. sewage) and drainage water (e.g. storm water) are typically conveyed in separate conduit systems; the term "sewer" is used in this study as it pertains to conduits conveying wastewater.

Sewerage
The provision of drainage by sewers.

Sewer system
A system of sewer pipes and other infrastructure (e.g. pumps) needed to transport the sewage from the point of entry to the point of outfall. It includes wastewater pipes, pumping stations, treatment plants, etc. A sewer system may also be called a sewerage system, sanitation system or wastewater system, but these terms are not used in this study.

Sludge
The suspended matter in industrial effluent or sewage remaining after partial drying.

Sludge removal
This is the process of removing sludge from treatment systems or tanks and can be carried out manually or automatically.

Soffit
The top of the inside of a pipe.

Storage
A method for controlling combined sewer overflows by storing the combined sewage until the rainstorm subsides, then releasing it back into the conveyance system to be treated at the usual treatment plant.

Storm drain
A system of gutters, pipes, or ditches used to collect and carry stormwater from buildings or land surfaces to streams, lakes, or other receiving waters. In practice storm drains carry a variety of substances such as sediments, metals, bacteria, oil, and antifreeze which enter the system through runoff, deliberate dumping, or spills. This term also refers to the end of the pipe where the stormwater is discharged.

Storm sewer
A system of pipes (separate from sanitary sewers) that carry only water runoff from building and land surfaces.

Stormwater
Water that is generated by rainfall and is often routed into drain systems in order to prevent flooding.

Sullage
See greywater.

Suspended solids
Small particles of organic or inorganic materials that float on the surface of, or are suspended in, sewage or other liquids and which cloud the water. The term may include sand, mud, and clay particles as well as waste materials.

Treatment
Chemical, biological, or mechanical procedures applied to industrial or municipal wastewater or to other sources of contamination to remove, reduce, or neutralize contaminants.

Trunk main
See collector main.

Trunk sewer
See main sewer.

Wastewater flow
Total flow within a sewer system. In separated systems, it includes sewage and infiltration/inflow (thus unintended storm water ingress would be included). In combined systems, it also includes stormwater.

Wastewater system
See sewer system.

Waterborne
Transported by water.

Waterborne sewer system
A sewer system that uses water as the mode of transport for excrement and other waste.

APPENDIX F: Tool 6 – WSDP Tool

WATER RESEARCH COMMISION SEWER MASTER PLANNING TOOLKIT

WSDP Tool

A Project by Stellenbosch University in Collaboration GLS Consulting

waternetworks@sun.ac.za

2010

WATER RESEARCH COMMISION

Sewer Master Planning – WSDP TOOL

SEWER-RELATED INFORMATION REQUIRED FOR WSDP INPUT

Based mainly on KV3 Engineers Agenda Documentation (www.kv3.co.za)

4.1	**GENERAL**	
	List of Towns and water balance models (see Sewer Master Plan Tool)	
	Integrated Development Plan (IDP)	
	Spatial Development Framework (SDF)	
	Operational and Capital Budgets for previous two financial years	
	Key Performance Management System and KPIs	
4.2	**ADMINISTRATION**	
4.2.1	Verify WSDP Drafting Team	
4.2.2	2008/2009 Process Plan (IDP program)	
4.2.3	Sanitation Service Level Policies	
4.2.4	Community Participation Plan for selection of service levels	
4.3	**IDP AND WSDP GOALS**	
4.3.1	Priority ward needs	
4.3.2	Vision / Targets / Goals / Strategies	
4.3.3	Identify sanitation sub-goals	
4.4	**PHYSICAL AND SOCIO ECONOMIC PROFILE**	
4.4.1	Population and growth rates (Census / IDP / SDF)	
4.4.2	Age and gender, household income (Census / IDP / SDF)	
4.4.3	Consumer units and their categories (HH, dry&wet industries, commercial) – Financial System	
4.4.4	Migration information	
4.4.5	Health information	
4.4.6	Poor household definition	
4.4.7	Economic Information (LED Strategy)	
4.5	**SERVICE LEVEL PROFILE**	
4.5.1	Service levels for each system (town)	
	Sanitation: None or inadequate, bucket, on site dry, wet, intermediate or full waterborne.	
4.5.2	Grey water management / pit emptying and sludge disposal / Types of sanitation technology options	
4.5.3	Detail on any "Wet industries"	
4.5.5	Industrial consumer units (Monthly sewage & waste water) and permitted effluent releases	

4.6 WATER RESOURCE PROFILE 4.6.1 Water Balances 4.6.4 Water returned to resources (Flow from waste water treatment works) 4.6.5 Quality of water taken from source and returned to the source (WQ & treated effluent monitoring, test results) 4.6.6 Pollution Contingency measures	
4.7 WC/WDM This section is not directly applicable to sewer	
4.8 WATER SERVICES INFRASTRUCTURE PROFILE 4.8.1 Existing groundwater and surface water infrastructure 4.8.2 Existing WTWs 4.8.3 Existing pump stations 4.8.4 Existing bulk pipelines 4.8.5 Existing reservoirs 4.8.6 Existing reticulation 4.8.7 Existing WWTWs 4.8.8 Asset Register and AMPs (Assessments) 4.8.9 Sewer Master Plans	
4.9 WATER BALANCE 4.9.1 Commercial, industrial and residential sales, raw water and treated water meter readings, treated effluent and recycled.	
4.10 WATER SERVICES INSTITUTIONAL ARRANGEMENTS PROFILE 4.10.1 WSA Capacity development program 4.10.2 Organogram 4.10.3 Water Services By-laws 4.10.4 Water services providers (Water & Sanitation, current + over 5 years) 4.10.5 Water services providers (Bulk water & sanitation, current + over 5 years) 4.10.6 Sanitation promotion agent (Current + over 5 years) 4.10.7 Support service contract	
4.11 CUSTOMER SERVICES PROFILE 4.11.1 Number of queries/complaints, % responded to within 24hours, number of leaks and blockages, number of tanks, number of calls received for emptying (Also emergency). 4.11.2 Health and Hygiene education 4.11.3 Water education 4.11.4 Pollution awareness program	

4.12 FINANCIAL PROFILE	
4.12.1 Capital and Operational budgets (Sources of funding)	
4.12.2 % Equitable share allocated to basic water and sanitation services	
4.12.3 Non payment per residential, commercial and industrial category	
4.12.4 Tariffs for current and two previous financial years	
4.12.5 Subsidy targeting approach for free basic water	
4.12.6 Water metering and billing (No of meter installations, meters tested and replaced)	
4.12.7 Free basic sanitation	
4.12.8 Credit Control and Debt Collection Policy, Indigent Policy	
4.12.9 Typical bill	
4.13 LIST OF PROJECTS (SMP MASTER PLAN ITEMS)	

APPENDIX G: Project poster

Refer to the project poster (WRC order No SP 1/10).