STORMWATER MASTER PLAN – PROCESS GUIDELINE

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1 ABSTRACT

The flooding experienced in the Southern Cape region during 2006 and 2007 resulted in significant damage to municipal infrastructure and private property. Rapid urbanisation, as well as the age, condition and capacity of the existing stormwater infrastructure resulted in stormwater run-off from developed areas, negatively impacting on existing municipal infrastructure, private property and river embankments.

To mitigate the impact of possible changing weather patterns and increasing run-off caused by urbanisation, the George Municipality required a single database where all stormwater data could be viewed, queried, stored, added, maintained and expanded. This database would facilitate the compilation of a Stormwater Master Plan, which, in turn, would identify the necessary upgrades to stormwater infrastructure to meet current and future infrastructure needs.

The George Municipality (GM), together with co-funders; the Development Bank of South Africa (DBSA), the Eden District Municipality (EDM) and the Department of Local Government Western Cape (DPLG), undertook the inception phase of the George Stormwater Master Plan. To date, 181 kilometres of network has been topographically surveyed, 151 kilometres hydraulically modelled and 21 kilometres condition assessed. This was a pilot stormwater investigation type project outside the large metros and can therefore be useful to other municipalities with similar needs.

2 DEFINE OBJECTIVE

A project of this nature is a mammoth task and requires proper planning and coordination. As with most projects, the first step is determining the main purpose of the "Stormwater Master Plan".

Typical questions to ask:

- Do you need a drawing book for operational staff for daily maintenance?
- Do you experience structural and operation failures and need to know the actual condition of the network to develop a replacement programme?
- Do you experience stormwater capacity failures and need to know whether the network is undersized or whether the stormwater inlets are inadequate?
- Do you require an asset database to assist with asset management?
- Do you need a fully integrated Stormwater Master Plan?

In an ideal municipal environment, where budget is not a concern, the complete, fully integrated master plan would be first class, but in reality we need to settle for what our budget allows. Despite budgetary restrictions, a fully integrated stormwater master plan can be achieved with smaller, well planned projects.

The first step in estimating the budget required, is to quantify the network length.

3 QUANTIFY NETWORK LENGTH

In general the stormwater network length can be referenced directly to the road network; however, the densities of stormwater networks vary geographically. Adjustments must also be made for rainfall intensities, income demographics and zonings. To illustrate, the stormwater network length in older, central business type areas were found to be double the road network length. This was due to parallel networks that were installed instead of upgrading of the existing networks. The density of structures in central business areas was higher compared to residential areas. The average distance between structures in the George stormwater network was found to be 32 metres.

4 BUDGET REQUIREMENTS

The procurement of services is discussed below. In an open market, prices will vary depending on the geographical location, but the following figures can be used for first order budgets:

Description	Cost
Overall management of stormwater process	R30 000 per month
Topographical survey of as-builts:	R100 – R150 per structure
Capturing of data into database and compilation of drawing book for operational staff	R50 – R100 per structure
Condition assessment of stormwater network – CCTV	R11 000 – R17 000 per km
Modelling of network	R2 500 – R3 000 per km
Plan book	R40 – R60 per km per plan book

Economy of scale affects the prices and a combination of activities will be possible on larger projects. For example, the topographical survey and integration of the data into a database can be done simultaneously. This will be possible if the development of software applications and the procurement of specialised tablet type input equipment is warranted by the establishment cost.

5 PROGRAMME

This is a slow process and adequate provision must be made for the execution of the project. The following timeframes can be used as a guideline:

Description	Timeframe
Topographical survey of as-built	1 km per day per survey team
Compilation of database and drawing book for operational staff	50 km per month
Condition of network – CCTV	0.15 – 0.5 km per day per camera team
Modelling of network	2 km per day
Lidar survey	2 to 6 months
Integrated stormwater master plan	8 to 36 months

The collection of network data for database and modelling purposes were undertaken through topographical surveys, visual inspection and closed circuit video inspection (CCTV) inspections.

6 CCTV

The CCTV is the most expensive activity of the stormwater master planning process, but it is the easiest and most accurate method to determine the location and condition of underground networks.

The technology is constantly improving and a there is a trade-off between cost and value of the inspection. Only 10% of the George stormwater network was CCTV inspected due to the high cost, and it was decided that a topographical survey would be more valuable in the inception phase.

The quality of video, camera deployment and standard specification for assessment are a few of the important factors that require attention.

6.1 Quality of video image and equipment capability

The video quality of the CCTV cameras ranges from standard to high definition, however high definition requires all the editing and storage devices to have high definition capability which makes it very expensive. It is extremely important that the video image must be in focus and have adequate lighting to allow the best image quality. Operators must also have adequate experience to ensure that the camera settings are optimal.

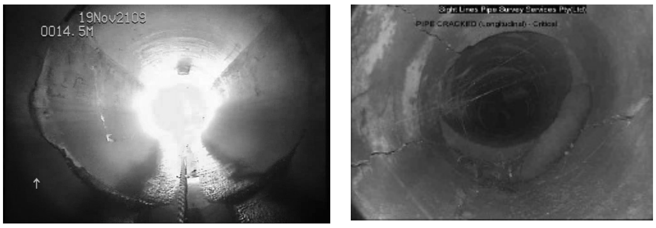

Figure 1: CCTV image quality

Figure 3: Typical structural and operational defects

The camera equipment and hardware can also have the additional capability to produce continuous side view videos, together with the normal front view videos. This enables easier and more accurate assessments and reporting.

6.2 Camera deployment:

The CCTV camera can be deployed manually into the stormwater pipes (conduits) on a wheeled trolley via a fixed line on a spool, or the unit can be self-propelled. A manual unit was used during the George investigations and a line was passed through the conduit either by means of rods for smaller pipes or manually where man-entry could be gained. There are several benefits for the self-propelled unit, but the main benefit is that the operator can stop at any point to view a section of pipe in more detail. Some self-deployed units can be directed into laterals like private connections to determine the source point.

The inspection video includes either the pipe length, or the inspected distance which is used as a reference for condition assessment purposes and corrective maintenance. The geographical coordinates of the start and end manhole can be captured, should the topographical survey information not be available. Another possible feature is an inclinometer that measures the incline of conduits. This is used to verify topographical survey information and can identify faulty slope changes along a conduit.

Figure 2: Typical self-propelled CCTV camera

6.3 Standard specification for assessment

To ensure consistency, the assessment should be based on a specific standard, such as the publication "The Manual of Sewer Condition Classification" (published by the UK Water Research Centre). This standard is compatible with the European Standard for coding of visual inspection data – EN 13508 - 2:2001 (Establishment of the Condition of Drain and Sewer Systems Outside Buildings – Part 2: Visual Inspection Coding System). The scoring system employed by the classification method considers structural and operational defects in manholes and pipes and also provides for threshold values for the computed structural and operational grading scope. Private grading systems do exist and long term consistency must be considered when codes are specified.

The CCTV assessment data is comprehensive and is very useful for specific reference. An interface to access the data should be available to allow users to access the data when required. A summary report consisting of various combinations of the overall results is critical to allow management an overview of the information for planning. The CCTV database must be easily expandable to allow for future CCTV data capturing.

6.4 Problems – blocked pipes

Partly silted conduits can be CCTV inspected to a degree, but the circumference of the conduit below the silt cannot be inspected. As even a partial inspection incurs a CCTV cost, this is not cost effective. Silted conduits have a negative impact on CCTV progress and some CCTV subcontractors may not even CCTV inspect if conduits are not clean, due to low production and potential risk of camera equipment damage.

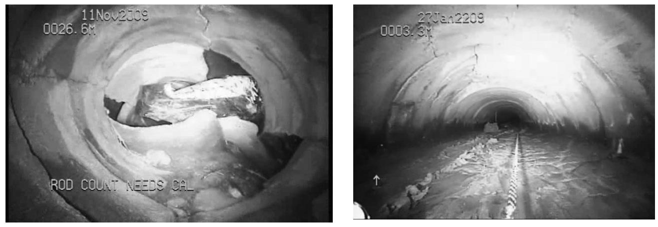

Figure 4: Typical CCTV – problem conduits

It is recommended to include a jetting component in the CCTV contract to ensure all conduits can be jetted if found to be silted. Alternatively, all conduits can be jetted just prior to the CCTV inspection.

Quality control is another benefit of CCTV inspection after a jetting operation, as it will confirm that jetting was executed as specified. If all jetting and CCTV records are captured on a single database, repetitive problem areas can be identified and the source of failures investigated.

7 TOPOGRAPHICAL SURVEY

Topographical survey was used to capture the details of all the structures and interconnecting conduits. To ensure proper integration of the survey data with future modelling, the surveyor was appointed as sub-consultant to the appointed consulting engineers. This ensured that the consulting engineer took ownership of the survey data received, thereby ensuring accurate modelling and preparation of as-built books of drawings.

7.1 Capturing As-builts

It was initially estimated that as-built information from previous developments or municipal projects could be used, but the as-built data was found to be generally inaccurate. It therefore had limited use for modelling purposes, and it was necessary to resurvey. The data could only be used for maintenance purposes or to assist operational staff to locate infrastructure.

It is recommended that municipalities make it compulsory that developers supply accurate as-built data. The most practical option is to specify a development condition that as-built surveys must be executed by registered professional land surveyors. The surveyors' drawings should be supplied by the developer, with the as-built plan, before final development approval is granted.

Institutional knowledge of the network by the municipality's maintenance teams was also not properly recorded. By ensuring regular consultation with the operations and maintenance teams, problem areas prioritised for modelling could be identified. Input from the maintenance teams during the survey period also ensured that all structures and pipelines were surveyed.

7.2 Naming convention

A unique identifier must be assigned to each element in the stormwater network. A 10 digit identifier was used for the George network. This identifier indicates the network and suburb/area to which the element belongs. It also provides a unique sequence number and the type of structure (e.g. pipe, manhole) involved. The conduits inherit their identifier from the upstream structure. The figure below indicates the fields from which the identifiers are compiled.

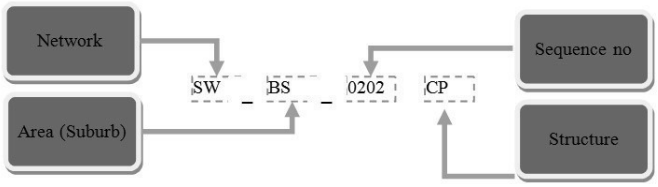

Figure 5: Fields for stormwater element identifier

The various options for the structure type are listed below

Table 1: Structure types

STRUCTURES:	DESCRIPTION:
CP	Catch pit - all stormwater structures with a side inlet
MH	Manhole -stormwater structures that join stormwater pipes
OP	Outlet point - Any structure (except headwall) or position where stormwater exits or enters the network
GR	Grid - grid inlet
HW	Headwall - headwall structures
ND	Nodes - point where pipes intersect without surveyed stormwater structure/no surveyed stormwater structure at beginning or end of pipe
PC	Private connections

The topographical survey was used to determine the position and elevation of all the stormwater structures, including all the connecting conduits to the structures. These details were initially captured in a Microsoft Excel database and then later converted to a full Geographical Information System (GIS) database.

7.3 Information recorded

It is important to capture all the information to maximise modelling and database accuracy.

Table 2 : Survey headings

NAME	DESCRIPTION
Y_CO_ORD	Y coordinate
X_CO_ORD	X coordinate
TYPE	Structure type
CL	Cover level
IL_C	Invert level of structure
RL	Road level - where surveyed
Structure_Number	Name of downstream and upstream structures
IL_A	Invert level of conduit to downstream and upstream structures
Dia_A-Width	Diameter of pipe or width of box culvert to structure A
Dia_A-Height	Height of box culvert to structure A
Barrels_A	Number of conduits of the same dimensions to structure A
Type_A	Material type of conduit to Structure A
CP_INLETW	Catch pit or grid width
CP_INLETH	Catch pit or grid length

7.4 Topographical problems

In a number of cases, problems or inconsistencies were encountered during visual inspection and measurement. The following actions were taken for the various circumstances encountered:

Blocked structures:	Instructions were issued for the cleaning of the manhole, after which the necessary inspection and measurement was undertaken.
Large cover slabs:	Many of the manholes had relatively large cover slabs (1, 5 x 0.55 x 0.125 m thick), which, (at 2 400 kg/m^3) weighed up to 250 kg. It is therefore self-evident that this cannot be lifted manually and, while providing a suitably vandal-proof solution, it hampered inspection and will certainly encumber maintenance. These large covers have to be mechanically lifted. Municipal maintenance teams and later mechanical lifting (i.e. by JCB/TLB) were used to open the structures. The inspection and measurement of the structure would generally have followed immediately after opening the covers due to public health and safety risks.
Additional structures located:	Where additional manholes were located (i.e. had not previously been located during the topographical survey), these would be inspected, measured and recorded for subsequent topographical survey.
Inconsistencies and queries:	Where inconsistencies were noted or queries arose regarding manhole details (e.g. inconsistent levels, irregular or unexpected connectivity), these were recorded and instructions issued for re-survey of the manhole concerned. This included positions where manholes were expected, but had not been recorded in the topographical survey.
Potential structures:	The estimated positions of potential manholes were captured as nodes. The existence of these nodes were then challenged and hopefully confirmed during the CCTV inspections.
Cover slab failures:	The structures are mostly aged and can be damaged when opened. Broken cover slabs must be replaced or temporarily patched to prevent it from being a safety hazard.
Covered structures:	Where structures were covered by either road resurfacing, illegal rubble dumping or paved over in private driveways, the location of the structures were determined using metal detectors and CCTV information. Where practical, the structures were exposed and covers extended to daylight level.
Stormwater network layout:	The layout was not always per current design standards. In some instances the distance between structures was too great to enable CCTV inspection or cleaning of the pipes using jetting equipment. The equipment that was employed in this study could be operated up to a maximum of 140 metres between access points.

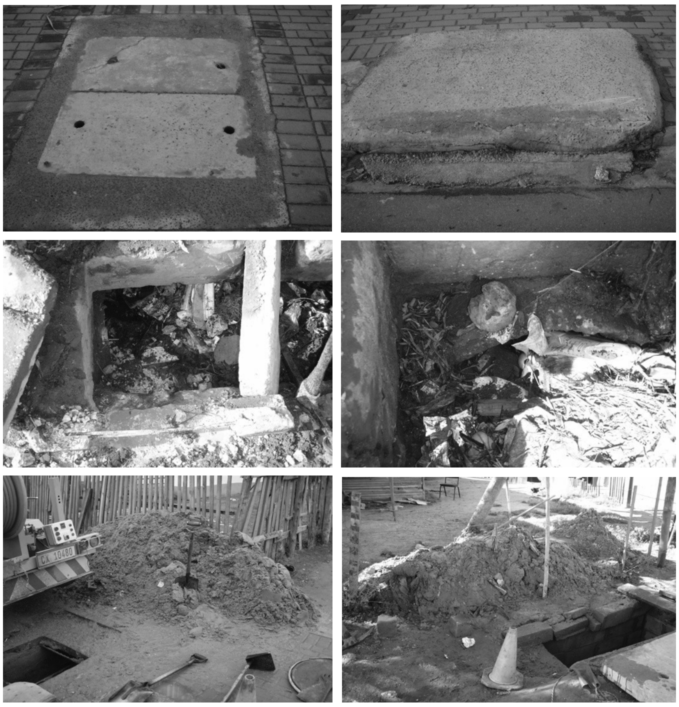

Figure 6: Typical topographical survey problems

It is recommended for future investigations that the following provisions be made to prevent similar delays and problems:

- Include cleaning of manholes as part of the inspection and survey process. Alternatively, the cleaning process should be undertaken prior to the survey exercise.
- Include a service for locating and opening manholes. Ideally this service must be under the control and/or management of the parties responsible for the investigation. Service providers must work in advance of inspection and survey teams to locate and open structures. The teams must be equipped with appropriate tools and mechanical means to lift cover slabs and open manholes and must be available to assist at short notice when structures either cannot be located or are located and cannot be opened. It will be beneficial to have a day work rate for opening of these structures.
- Funding should also be available to replace, or temporarily patch, the aged cover slabs that are damaged during the survey exercise or are already broken.
- Include a provisional sum for the construction of manholes along the lengths of pipes that are too great. The construction itself can be done using the municipal yard tenders or a nominated sub-contractor.

8 STORMWATER SYSTEM ANALYSES (I.E. MODELLING)

Hydrological modelling is the deterministic simulation of the stormwater run-off events and the analysis of the capacity of the stormwater system. The calculations are based on input hydrological data, and the assumptions and correctness of the input data is essential for accuracy of the final results.

8.1 Lidar survey/Contours

The accuracy with which sub-catchments can be determined is an important factor in compiling a high quality stormwater model. The accuracy of the catchment areas is, however, at least partially dependent on the quality of the topographical survey. In addition to assisting in determining catchment areas, a detailed, accurate survey can also be used to determine such factors as temporal storage, thus further influencing the accuracy and dependability of the model.

A number of options exist for obtaining improved survey data:

Topographical survey:	It is a very accurate, but a time consuming and costly exercise that is therefore not feasible.
Airborne laser scanning:	Also known as LiDAR (light detection and ranging), this is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevailing method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal.
Satellite images:	Stereo modelling is capable with today's satellite images from Worldview 2 and GEOEYE 1, with an accuracy of less than 0.5 meters.

8.2 Recurrence interval for stormwater systems

The George Stormwater System is made up of minor, major and secondary infrastructure. In addition, the areas served by the various networks exhibit varying vulnerability to the consequences of flooding. By way of example, parks, residential areas and commercial areas could all be drained by minor infrastructure. The consequences of flooding in residential areas would generally be greater (typically in terms of damage to property) than in parks and greened areas. Similarly, the consequences could be more severe than flooding in commercial areas. The recurrence intervals must take into account this variable. Recurrence intervals selected for the stormwater models were based on the parameters provided in the "Guidelines for Human Settlement Development" (or "Red Book"), as published by CSIR Building and Construction Technology.

The following recurrence intervals have been used.
SWMM stormwater model: 1:5, 1:10 and 1:50 years.
Major canals, channels, rivers and streams: 1:50 and 1:100 years.

8.3 Catchment parameters

The data required for each sub-catchment by the SWMM software included surface area, catchment width, impervious areas as a percentage of total area, slope of the watercourse (as a percentage), rain gauge and catchment outlet.

Catchment area:	Catchment areas (sub-catchments) were grouped around areas of 4 to 20 surface catch-pits and generally have a surface area of less than 0.1 km^2 (10 ha). These catchments are therefore generally defined around minor branches of the stormwater network and a single discharge for the entire catchment is thus calculated for each such minor branch within a catchment The catchment areas were determined (i.e. "traced") manually and captured in the GIS software, from where the surface area (in hectares - ha) was calculated.
Catchment width:	The width was calculated by dividing the catchment area by the overland flow path length which was manually measured using the GIS software.
Impervious areas:	Impervious areas were estimated from the land-use data and from aerial photography.
Watercourse slope:	Watercourse slope was calculated using the 10-85% method over the identified flowpath.
Flowpath:	Flowpaths were determined and entered graphically in the GIS software. The flowpath was selected as the logical path that a drop of rain would follow to a catch-pit (or catchment inlet) closest to the estimated centre of the catchment. Only where such structures were limited to one or two per catchment, would the flowpath to either the most upstream or most downstream catchment inlet be selected.
Junction (structure) data:	Data required for each junction included name (identifier), junction type (e.g. inlet or outfall); invert level (elevation) and depth.

Conduit data:	Network links are either pipes, closed culverts (e.g. rectangular portal culverts) or canals (open culverts). Link data was determined from the network plans and survey data. The data required per network link was link name, from and to junctions, link type (e.g. pipe, canal), length, slope and roughness
Roughness:	Roughness was estimated per pipe material or channel bed condition for both open channels and conduits.

8.4 Catchment properties –land use

Stormwater management planning requires an accurate assessment of current land use/land cover. Remote sensing is a new approach for rapidly documenting watershed characteristics for stormwater management planning and, when combined with GIS, can save labour and reduce time of delivery thereof.

The recent availability of commercial high spatial resolution satellite imagery, offers improved land cover characterisation, digital processing capability and data that is compatible with GIS technologies. The following satellite remote sensed data is suited in terms of spatial, spectral and temporal resolutions to successfully and accurately generate (classify) the land use/cover data required for effective stormwater management:

- Hyperspectral image (<1m spatial resolution)
- Worldview2 image 3
- GeoEye1 image 4
- Ikonos or Quickbird image 5

In all the above mentioned cases, high resolution LiDAR data will improve the classification of land use/cover considerably.

8.5 Hydraulic modelling engine/calculation

The capabilities of the modelling software should be carefully reviewed before modelling large networks. It is important to find a balance between the simplicity of the model for easier modelling and adequate details for accuracy. It is recommended that the modelling software to be used should be specified to allow the municipality easier model integration and further development of the model.

8.6 Stormwater model limitations

The stormwater model was compiled and analysed in PC SWMM 2011. This analysis was intended to provide a "management" model, and was therefore not a design review of the existing stormwater network. In order to achieve such a detailed "review", the topographical detail, subcatchment delineation and model compilation would have to be significantly more extensive.

What the model and the subsequent results, together with the condition assessments do however permit, is an assessment of capacities (and therefore capacity limitations) and identification of problem areas in the networks. As a management tool, this provides the capability to make informed decisions as to where future development can and cannot be accommodated, as well as where maintenance of existing and construction of new infrastructure should be prioritised. The model can be developed further to predict where interventions will be required during future flooding when this occurs.

The model also recommends first order conduit sizes for surcharged sections.

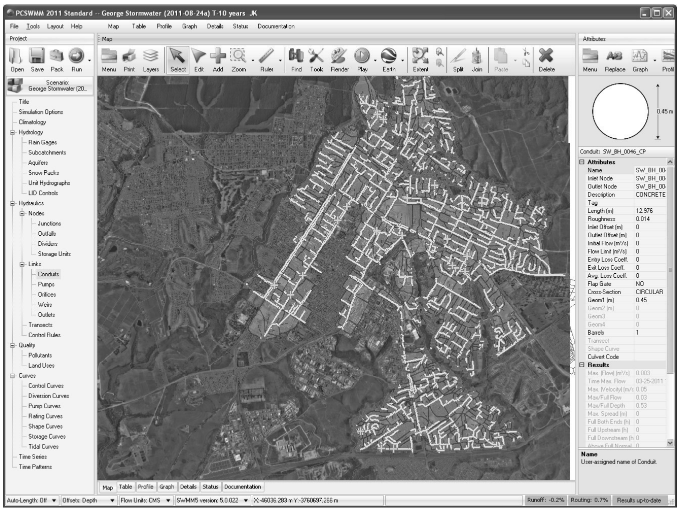

Figure 7: George PCSWMM model

8.7 Pipe flow and overland flow

It should be decided whether to include overland flow modelling in addition to the below ground conduit network. Should it be excluded, assumptions must be made to allow for surcharged network conditions. A very accurate surface survey is essential to allow overland flow routing and is not always feasible.

8.8 River modelling – flood lines

Flood line determination and river modelling was excluded from the investigation as the elevation of rivers in the George stormwater network are relatively lower than the network and have limited back water impact. River levels are more crucial along the larger rivers and in flatter sections of the country and should be dealt with accordingly.

8.9 Linkage to database

The model results should not be a stand-alone data set and should be linked back to the stormwater database for better reporting and ease of reference.

9 REPORTING

Apart from the electronic stormwater database, it is essential to also develop plan books for daily operations and an overall report for more detailed planning.

9.1 Plan book format

The data for the stormwater networks was presented as a series of plans and structured data in a flat-file database format.

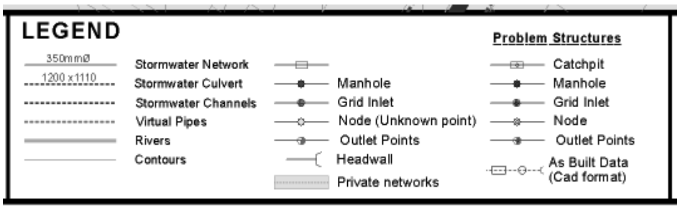

Figure 8 Plan book Legend

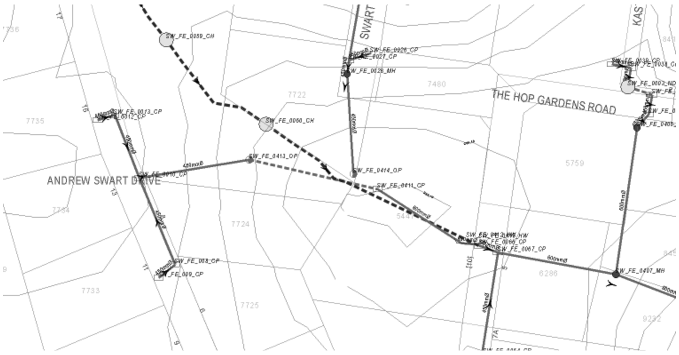

Figure 9 Plan book Snapshot

The plans indicate structure position, structure name and pipe name, while the flat-file database links the surveyed (or observed) properties for each network element to the network plans.

It is important that the plan book is user friendly, therefore an A3 size book with two scales is recommended, namely 1:5000 for overall network layouts and 1:2500 for detail plans.

The sample of a section of the network and features indicated on the George Stormwater plan book is indicated on the figures to the right:

9.2 Report format

In addition to the technical overview of the stormwater master plan, the report should include CCTV and modelling results in tabular and graphical (maps) format. These data set results should also be filtered to allow prioritisation and planning of work. Two important filter permutations of the results that would warrant priority attention are:

- The pipes that were identified during the condition assessment as potential priority replacement, with severe structural defects and conduits that are surcharged; and
- The conduits where flow parameters coincide (e.g. high flow volumes coincides with high velocity and over-capacity) as this may be an indication of potentially high risk conduits.

9.3 Database viewer

The software package that will be used to view, edit and manage the entire database should be specified to prevent end user interface incompatibility problems. Specialised software packages like ArcGIS or IMQS must be procured, or alternatively free GIS viewers can be sourced if not already available.

10 SERVICE PROVIDER PROCUREMENT

The limitations of public procurement regulations are well known and special effort should be made to ensure that a capable service provider is engaged to deliver a good quality product.

10.1 Prequalification

It is recommended that prequalification criteria are developed to suit the project needs. Attention should be given to previous experience, track record, infrastructure levels and the work plan.

10.2 Project scope

The service provider can only price according to the scope of works specified and it should therefore be well defined. The scope should be broken down into the different aspects of the project as explained above to facilitate clear scope and budget control.

The recommended payment items and units are listed below:

Management/ P&G	per month
Topographical survey	per structure
CCTV	per conduit length
Modelling	per conduit length
Plan book	per page
Extras:	
Lifting of heavy structures	per structure cover size
Locating of covered structures	per day
Cleaning of blocked structures	per structure and volume of material
Jetting of conduits	per size and length and size of conduit

11 THE WAY FORWARD FOR GEORGE MUNICIPALITY

The foreseen future items will be to:

- Survey the small remaining sections of stormwater network and capture it on the existing database. Ensure that any changes to the existing network is properly captured and updated. Ensure that updating of the as-built plan book is done.
- Include provision of CCTV camera data to keep record of jetting operations. These visuals can also be used for conditions assessments and can be included in the existing CCTV database.
- Incorporate the development condition that record drawings are to be surveyed by professional surveyors prior to final building/development approvals. Any future developments will then also be captured and added to the network database.
- LiDAR survey the George catchment area to enable accurate catchment delineation.
- Use the stormwater model to determine the effect of future developments on the existing network and develop feasible options. Full impact of new development on the entire network can therefore be determined.
- Use the current model data set and the future data sets for further planning and modelling to determine the external effects of climate change, urban densification and various others. The outcome of these studies can be used to challenge design standards and urban planning.
- Incorporate a clause in the Stormwater bylaw that developments may only be allowed to discharge equivalent flows into the municipal network of that prior to the development. The development must do on-site retention to reduce run-off peak flows.

With the inception phase of this project recently completed, the journey for George Municipality has only just started and continuous improvement and extension of the master plan will be implemented as and when funding is secured. The George Municipality is already experiencing the benefits of this initiative with positive feedback from their operations and maintenance staff, and more accurate resolutions of customer queries and complaints, as well as improved knowledge of the causes of flooding and its related issues and problems.