DRAFT PAPER

HOW TO REDUCE STORMWATER INGRESS INTO SEWERS

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ABSTRACT
It is accepted that the ingress of stormwater occurs in sewers. Design manuals typically recommend an allowance of 15% for stormwater and/or infiltration into sewers, in addition to the Peak Dry Weather Flow (PDWF). However, experience, as documented in reports (Tshwane and Cape Town for instance), and as reported (IMESA 1994), has shown that the ingress often exceeds 100% of the PDWF and that the amount is rainfall dependent.

Excess stormwater has several negative impacts (health due to sewage spillages, pumping and treatment costs, and environmental). Closer examination shows there are four sources of extraneous flows into sewers: infiltration of groundwater, ingress of stormwater, illegal connections and leaks from taps and cisterns.

The paper will examine the legal obligations of municipalities (Water Services Act, National Building Regulations, etc.). It will demonstrate a method of data analysis which reveals whether the extraneous flows are from infiltration, ingress, etc. Lastly, the paper will set out a four stage strategy for reducing the extraneous flows, including the ingress of stormwater, into sewers in a sustainable manner.

The proposed strategy shows that the bulk of the costs, other than the initial investigations, need not be carried by the municipality, but rather by those on whose premises the extraneous flows largely originate.

KEYWORDS
Stormwater ingress, infiltration, extraneous flows, groundwater, illegal connections, legal obligations, leaks from taps and cisterns.

1. WHERE DO WE COME FROM?

It is accepted that the ingress of stormwater occurs in sewers. Design manuals typically recommend an allowance of 15% for stormwater and/or infiltration in sewers, in addition to Peak Dry Weather Flow (PDWF). However, a closer examination shows that there are four sources of extraneous flows into sewers: infiltration of groundwater during dry and wet seasons, increased infiltration during wet seasons, ingress of stormwater and rainwater due to direct discharge into the sewer system and leaks from taps and cisterns.

This paper will deal with all four extraneous flows into sewers [as an aside, this is your first bonus for reading this paper – not just stormwater, but all four elements of extraneous flows are dealt with]. This paper is of course not the first report on the "ingress of stormwater" into sewers.

Previous experiences have been documented in various reports by, for instance:

- City of Tshwane: Negative Effects of Rainwater entering the Sewer System. August 2009.
- Pollet, M. M. L. 1994. Extraneous flow in sewers, The Durbanville Experience. Imiesa, September.
- Impacts of Stormwater and Groundwater Ingress on Municipal Sanitation Services. Stephenson, D & Barta, B.
- Stephenson, D & Barta, B. February 2005. Guidelines on Reduction of the Impact of Water Infiltration into Sewers. WRC TT 239/05.
- Stephenson, D & Barta, B. 1995. Impacts of Stormwater and Groundwater Ingress on Municipal Sanitation Services.

None of these reports other than the one for the City of Cape Town develop the insight that will be shared in this paper or resulted in strategies comparable to those with which this paper will conclude.

2. DOES IT MATTER?

If your municipality has a vision that includes aspects such as sustainable development, a healthy environment, a happy community, being business friendly, etc. it must be realised that this vision is not reachable, if you have an excess of stormwater in your sewers. It is not achievable because of the following impacts:

- Overflows and sewage spills from sewer pipes being filled beyond capacity
- If you have sewage pump stations; spillages from such pump stations and increased electrical power consumption
- Flooding of your wastewater treatment works and the associated risks of upsetting the treatment processes
- Reduction in water quality in stormwater systems, wetlands and rivers
- Increased risks to human and ecological health and knock-on effects such as diseases, loss of biodiversity and increased greenhouse gas emissions.

3. WHERE DO THE EXTRANEOUS FLOWS COME FROM?

It is necessary to look more finely at the mechanisms and types of "stormwater" that enter sewers.

Here are the key components:

- Year round infiltration of groundwater (this is often the base flow in sewers, even in the dry season and in the "dead of night")
- Increased infiltration due to a raised water table during the wet season. This increased flow varies throughout the year and has a relatively slow response time to a particular rainfall event (It is rather a seasonal phenomenon)
- Ingress of stormwater and rainwater directly into the sewer system mainly due to illegal connections such as gulleys, rainwater pipes, swimming pool overflows, etc (in the older literature there is an amazing lack of recognition of this type of extraneous flow – maybe the plumbers of yore were better trained and/or had more scruples)
- Flows from the potable water system, typically from leaking taps and cisterns. Note that this extraneous flow is invariably potable drinking water whereas the previous three inflows are not.

It is not difficult to realise that where infiltration occurs, especially where the infiltration is seasonal, the flow direction may reverse when the water table is below the pipe or the manhole (i.e. during the dry season) and at that time the sewage is likely to leak out of the pipes into the ground.

4. LET'S LOOK AT SOME EXAMPLES

Table 1 shows some records of the dry weather and wet weather flows in some of the wastewater treatment works (WWTW) of the City of Cape Town. The information is only represented to demonstrate the approach. In order to interpret the information, it is essential to understand that the number of hours in which it actually rains, even during the wet months, are relatively few. This means that the contribution of stormwater ingress from illegal connections (i.e. the direct ingress of stormwater and rainwater) is relatively small when seen over a month. Nevertheless the direct ingress of stormwater and rainwater causes high peak flows and this will be explored later in the paper.

As can be seen from Table 1, there are instances where the highest monthly average flow is significantly larger than the average dry weather flow. This implies that during the wet season, there is a significant increase in the flow and hence one is able to conclude from that statistic alone, what the increase in infiltration is (ignoring the relatively minor contribution due to direct ingress). From Table 1 it can also be seen that the highest single day flows are much higher than the highest monthly average flows. In some cases, e.g. Zandvliet, significantly so. This statistic is rather an indication of the contribution of direct ingress of stormwater and rainwater and this invariably occurs on days with peak rainfall events. These relationships are not the same for all catchments. One can therefore calculate the amount of increased infiltration due to raised water tables during the wet season.

In the case of the Cape Flats for example, the increase in infiltration is equal to the highest monthly average flow (240.8) less the average dry weather flow (154.0) that equals 87 Mℓ/d, whereas the amount of ingress will be at least equal to the highest single day flow (257.6) less the highest monthly average flow (240.8) equals 17 Mℓ/d. In the case of Zandvliet, the results are quite different.

From the above analysis we can therefore conclude that the sewer network in the catchment of the Cape Flats WWTW is prone to considerable increases in infiltration during the wet season whereas the sewer network in the catchment of the Zandvliet WWTW is much more prone to ingress of stormwater and rainwater.

So what have we learnt?

In order to determine the degree of increase in infiltration and the degree of ingress all you need are daily flow records. What we have not been able to determine from daily flow records is the following:

- The base flow due to year round infiltration
- The flows due to leaks (imagine what you could learn if you had hourly flow records at your WWTW!)

5. WHAT ABOUT THE SEWER NETWORK?

In the preceding section the use of pretty straightforward information coupled with some insights helps one to understand the increase in infiltration and the ingress of stormwater and rainwater, as experienced at the WWTW. The question may be: What about the sewer network, be it gravity or pumped sewers, where we do not have flow meters, as is often the case at the WWTW? Sewer networks consist mainly of sub-networks of a combination of:

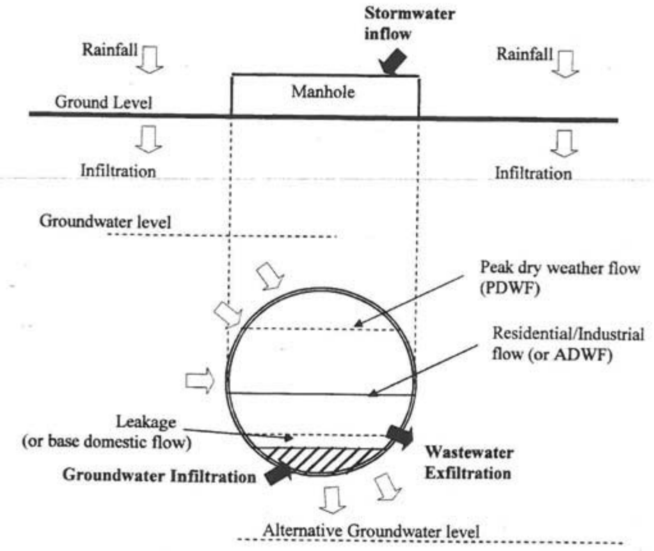
- gravity flow pipes
- pumped sewers (rising mains), and
- sewage pumps.

In gravity sewers, flow/depth readers and loggers can be used but these are relatively costly, not easy to maintain, and at risk of theft and vandalism. In pumped sewers, flow meters with recorders are unusual but fortunately pump stations often have hourly meters on the motors and, sometimes hourly pumping records are available. Herein lies extremely valuable information if you can couple this information to hourly rainfall records.

6. THE KEY INTELLECTUAL INSIGHT

Flow meters with hourly records and loggers in gravity sewers will show you:

- Base flow (long term infiltration plus leaks from taps and cisterns etc.)
- Daily variations in flow
- Increases in infiltration due to raised water table in the wet season
- Ingress due to stormwater and rainfall.



Source: WRC: Report No. 1386/1/05

Figure 1: Generic inflow infiltration/exfiltration

An interpretation of generic inflow infiltration/exfiltration conditions is illustrated in Figure 1.

Table 1: Wet Weather Flows vs. Dry Weather Flows (July 2008 – June 2009)

WET WEATHER FLOWS COMPARED WITH DRY WEATHER FLOWS: JULY 2008 TO JUNE 2009

TREATMENT WORKS	AVERAGE DRY WEATHER FLOW	HIGHEST MONTHLY AVERAGE FLOW		HIGHEST SINGLE DAY FLOW		Highest month less ADWF	Highest day less Highest month
WWTW	Mℓ/d	Mℓ/d	% of ADWF	Mℓ/d	% of ADWF	= infiltration	= Ingress
Athlone	104.1	180.7	174	237.2	228	77	56
Bellville	54.2	73.2	135	111.6	206	19	38
Borchards Quarry	35.1	37.7	107	49.0	140	3	11
Cape Flats	154.0	240.8	156	257.6	167	87	17
Kraaifontein	18.8	28.8	153	40.7	217	10	12
Mitchells Plain	35.7	39.9	112	51.0	143	4	11
Zandvliet	66.8	75.1	112	150.0	225	8	75

6.1 Gravity flow pipes

If the flow measurement is made on an hourly basis for at least 24 hours, you will obtain:

- The daily variations in the flow
- The base flow at that time of the year.

You will not obtain the increase in infiltration or the amount of ingress, unless there was a rain event over the 24 hours. You will also not know how much of the base flow is due to leaks.

If the flow measurement is made from the dry season to the wet season (or the other way around) you will be able to obtain the increase in infiltration due to changes in the water table, as well as the information obtained from a 24 hour period alone. Since this measurement period involves a longer timeframe, one may be tempted to use daily flow records only. In that case, you would not be able to determine the amount of ingress due to stormwater and rainwater and how the system responds to particular rainfall events; therefore hourly readings over relatively long periods are required.

Note: Based on this information alone, one is still not able to determine how much of the base flow is due to leaks in taps, cisterns, etc.

6.2 Pumped sewers

In pumped sewers an analysis of the pumping hours i.e. of the hourly readings of the meters, together with the hourly rainfall figures from a representative weather station provide the key information. [As an aside - the weather station need not be in the actual catchment of the sewer pump station, as the data remains useful as long as the rainfall pattern is representative of the rainfall in the catchment.]

The analysis of the rainfall figures should show that the number of "rainy hours" are surprisingly few and thus one has distinct "dry days" during the rainy season [Again as an aside – if we take July 2009 as an example, it was the wettest month of the year in Cape Town and yet rain only fell during 44 hours (6%) of that month (744 hours in a month, ignoring times when 0,2mm or less fell during that hour]. For October 2009, the second wettest month that year rain only actually fell during 13 hours (2%) of that month. Even though rain only fell during a relatively few hours, it still increases the water table.

The analysis of the hourly pumping records then reveals the following:

The increase in infiltration in the rainy season due to the raised water table – you can obtain this by comparing the base flow in the dry season with the base flow on so called "dry days" in the rainy season. The ingress due to stormwater and rainwater due to direct discharge into the sewer system – you can obtain this by comparing the base flow (dry season or rainy season) with the peak flows following immediately after a rain event.

With a bit more analysis you can determine for each pump station, its response pattern to various rates of rainfall and antecedent conditions. The response pattern is more complex than one would at first expect. It seems that the antecedent conditions are important, that the relationships are not linear and that the percentage increase seems to taper off as the sewer system reaches its capacity (now often flowing as a pressure system and possibly over-topping at manholes).

6.3 Leaks

The insights gained for the determination of the amount of water (potable) in the base flow contributed by leaking taps and cisterns, were developed from a statistical analysis on water meter readings in Khayelitsha.

This analysis showed that over 70% of the flows due to leaks arise from under 30% of the number of consumers. Of the 70%, some 90% of this component is contributed by approximately 2% of all consumers i.e. there are a few really bad guys, a whole lot of fairly naughty ones and a large number of good guys.

For those municipalities where a water network and consumption model exists, such as those developed by GLS Consulting, the forecast water consumption can then be compared with the actual treasury records and this greatly facilitates the analysis to identify the outliers (i.e. the very bad guys).

7. LESSONS FROM CASE STUDIES

7.1 Gravity flow system

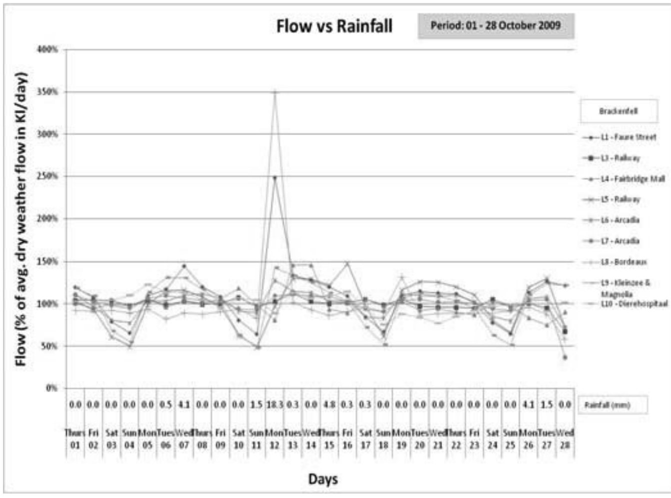


Figure 2: Measured flow in sewers as a % of ADWF vs. Rainfall in days (1 – 28 October 2009)

Figure 2 shows the increase in flow at various locations in the Brackenfell area of Cape Town on Monday 12 October 2009, due to 18,3 mm of rain.

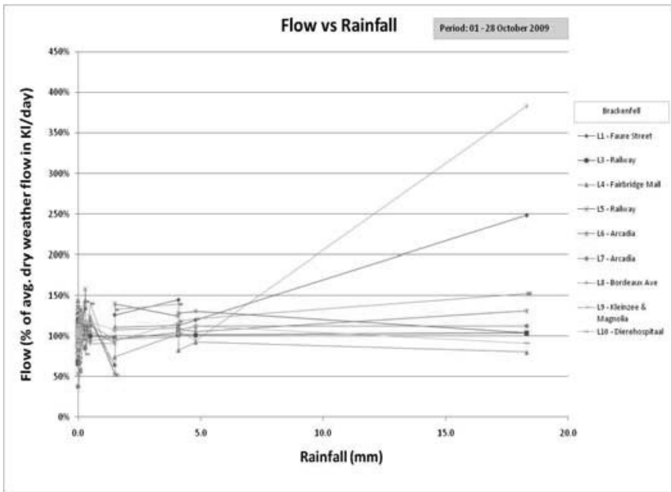
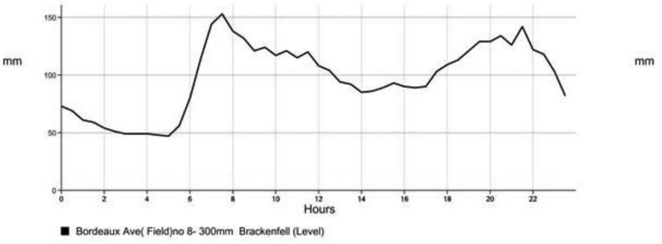


Figure 3: Measured flow in sewers as a % of ADWF vs. Rainfall (1 – 28 October 2009)

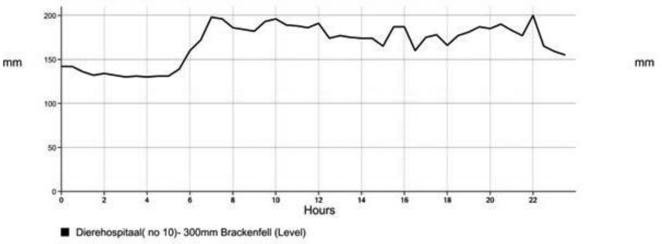
Figure 3 shows the increase in flow due to rain at various locations i.e. the same information plotted differently.

Figure 4 shows that flows follow a typical daily pattern with lower flows during the early morning hours (00:00 to 04:00) with morning and evening peaks (Logger 8). Also noticeable is the sustained high baseflow rate recorded (Logger 10), possibly indicating high levels of infiltration and/or leakages.

Logger 8



Logger 10



Source: My City: Cape Town, Water and Sanitation, WDM Sewage

Figure 4: Measured levels (mm) in sewers for 1 September 2009

8.2 Sewage pumps

At a pump control centre at Blomtuin, Bellville, the City of Cape Town monitors the sump levels and pumping hours of some 70 sewer pump stations, using a telemetry system. An analysis of the pumping hours, in response to rainfall, shows that for some pumps the hours hardly increase whereas for others the increase is quite dramatic. One pump station (Uitkamp) in particular, showed increase of 500% of dry weather flow (DWF) in response to 50mm in rainfall during a 24 hour period.

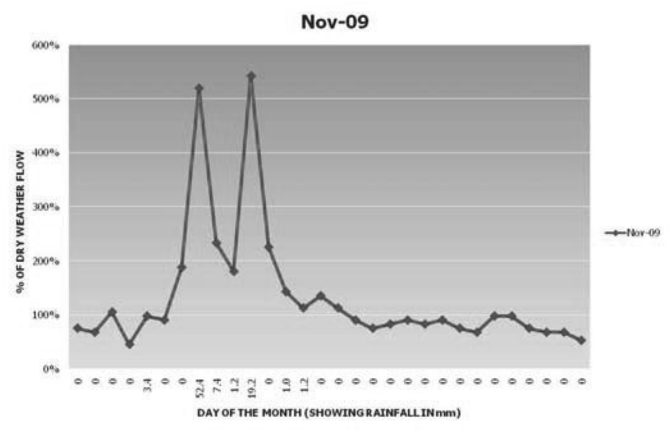


Figure 5: Uitkamp (Durbanville): Flow through pumpstation (7 – 10 November 2009)

The analysis of the rainfall and pumping hours therefore enabled one to conclude:

- From January 2009 to end April 2009 very little rain had fallen and the average number of pumping hours/dry day could be calculated
- From May 2009 to November 2009 (180 days) approximately 500mm of rain fell over 80 days. This is the "wet" period, but it has many dry days, hence the average pumping hours/dry days during the wet period could be calculated. This enables the calculation of the increase in base flow/infiltration due to a rise in the water table.
- For the wet period, from May 2009 to November 2009, the average pumping hours over the wet days were also determined (wet days being days on which at least 5 mm of rain fell). This enables the calculation of the increase in flow due to direct ingress of stormwater or rainwater.

8.3 Leaks

There are a variety of approaches for reducing flow from leaks e.g. pressure management, flow control devices, stepped tariffs, etc. This approach focuses on the identification of the potentially worst cases and deal with these individually rather than a blanket approach, that would affect all consumers. In the case study, information was obtained on an area in Cape Town for which water consumption data from the Treasury Database, for each of the properties, was kindly provided by GLS Consulting. This information could then be grouped into sub catchments aligned with sewer pump stations or loggers so that the information can be correlated.

The analysis was undertaken in each sub catchment and all those consumers where their consumption over the past 12 months was more than 0,1 kℓ/day higher than as modelled/forecast by GLS Consulting, were identified. These high use consumers were then ranked according to their consumption. From these results, the very high use consumers i.e. those whose consumption over the past 12 months was in excess of 2 kℓ/day more than the values used for the modelling, were noted. An example of the analysis is provided in Table 2.

These very high use consumers can then be shown on a map in each of the catchments and can then be visited for inspection and/or investigation for possible leaks. The analysis shows that in some areas most of the high flows are contributed by very few consumers, whereas in some areas, the contribution is very small. In either event, of some 10 000 consumers in the catchment under consideration only approximately 1 800 consumers comprise the high use group and only 80 consumers comprise the very high use consumer group. We would argue that these are manageable numbers of consumers for focussed attentions and inspections.

9. WHO BEARS THE COST?

This paper describes four distinct modes of extraneous flows in the sewer system:

i) Ingress of stormwater and rainfall runoff into the sewer system,
ii) Infiltration of groundwater during dry and wet seasons,
iii) An increase in infiltration during the winter months, presumably due to raised water tables,
iv) An ongoing baseflow caused by leaks from taps and cisterns.

A question is who bears the cost of repairs and corrections?

Table 3 summarises the system response, the impacts, knock-on effects and party to bear the cost.

10. LEGAL SITUATION

The following are the applicable legislative provisions:

- The Water Services Act (Act 108 of 1997) requires water service institutions to take measures to prevent pollution of stormwater (Regulation 509) and take measures to prevent stormwater from entering its sewerage system,
- Regulation 509 of 8 June 2001, in terms of the Water Services Act (WSA), places an obligation on water services institutions to take measures as Section 6(2) reads "a water services institution must take measures to prevent stormwater from entering its sewerage system",
- National Building Regulations and Building Standards Act, Act 103 of 1977, Regulation P3(2) states that "no person shall cause or permit stormwater to enter any drainage installation on any site".

Therefore an action plan is not a "nice to have". It is a legal must.

Table 2: Analysis of actual water consumption exceeding modeling assumption by 0,1 kℓ/day

Logger	No. of consumers with consumption ≥ 0,1 kℓ/day above modelling (High use consumers)	No. of consumers consuming ≥ 0,2 kℓ/day above modelling (Very High use consumers)	Very high use consumers as % of high use consumers	% contribution to high flows by very high use consumers	Comments
1	11	9	82%	97%	Industry, Business & Cluster housing
2	274	10	4%	51%	Cluster housing, Residential, Business, Parks, Industry & Other
3	525	4	1%	12%	Govt., Education, Business, Residential, Industry, Cluster housing & Other
4	4	2	50%	98%	Govt., Parks & Residential
5	24	4	17%	51%	Industry & Residential
6	23	10	43%	81%	Industry
7	14	7	50%	87%	Industry
8	101	1	1%	8%	Residential & Other

Table 3: Summary of system response, impacts and knock-on effects

Phenomenon	System response	Impact	Knock-on effect	Who bears cost of intervention	Cost of intervention	Certainty of improvement
Ingress	Depends on rainfall and is biggest cause of spillages and overflows, except those caused by blockages.	Sewage is spilled at manholes and pumpstations. WWTW are overloaded.	Risks to human health and environmental degradation. Additional operation costs (esp. cleanup, etc.)	Consumer / Household (mainly)	Low	High
Increase in infiltration	During the wetter winter months this may cause overload of WWTW.	Some sewage spillages occur, but the main impact is on the quality of the effluent from WWTW.	Lesser risks to human health an environmental degradation, with some additional costs.	Municipality	Medium to high	Medium
Baseflow due to infiltration	Most systems are designed and operate to accommodate this additional load.	Due to its presence 24/7/365 this causes increased pumping and treatment costs.	Additional costs and overprovision of infrastructure.	Municipality	Medium to high	Medium
Leaks	Most systems are designed and operate to accommodate this additional load.	Due to its presence 24/7/365 this causes increased pumping and treatment costs. Waste of valuable resource (potable water).	Additional costs and overprovision of infrastructure - not just wastewater but also potable water infrastructure.	Consumer / Household (mainly)	Low	Medium

11. ACCESS TO PROPERTIES

There may be a concern that Water Services Authorities (WSAs) may only have limited access to properties and premises (dwellings). The Water Services Act (Act 108 of 1997) makes specific provision for such access:

Section 80 of the WSA makes specific provision for access and reads *"80(1) Any person authorised in writing by the minister, the Province or any water services institution may- At any reasonable time and without prior notice, except in the circumstances set out in subsection (3), enter any property and inspect any water services work in order to ascertain whether this Act or any regulation or directive made under it is being complied with."*

Subsection (3) refers to access to dwellings: *"A dwelling may only be entered: (a) where it is necessary to do so in terms of the Act, (b) on reasonable notice, (c) at a reasonable time."*

From the above, one can conclude that the discharge of stormwater into the sewage system is illegal and that adequate provisions are in place for access to property to inspect any water services in order to ascertain whether these services comply with the Act, regulations and by-laws.

12. GOING FORWARD: STRATEGY OF 4 PARTS

Recognising that the biggest benefit comes from a pro-active, rather than a reactive (after the event) approach, the following four part strategy is recommended:

1. Strategy to reduce ingress (curtailed to point format, due to limitations on page length)
- Communication and education
  - General campaign (internal to municipality, external to builders, plumbers, architects, etc.)
  - Area specific communication (prior to inspections), based on data analysis.
- Inspection of households and businesses

2. Strategy to reduce infiltration (excl. leaks)
- Measure at WWTW (hourly)
- Measure at pumpstations (hourly)
- Measure using loggers (hourly)
- Measure during rainfall (hourly)

3. Strategy to reduce baseflow due to leaks
- Measure flow in sewers in dry season 00:00 – 04:00

• Shut off potential areas
• Inspection of households, etc. based on data analysis

4. Strategy for prevention of ingress (infiltration and leaks)
• Pre-construction/planning stage
• Post-construction stage
• Other measures, incl. "Plumbers Compliance certificate" prior to rates clearance certificate (requires change to by-laws); compile GIS showing record of leaks, spillages, etc.

13. IS IT WORTH THE EFFORT?

Consider the following:
• Cost of pumping additional flow due to ingress
• Cost of pumping additional flow due to increase in infiltration
• Cost of pumping additional flow due to infiltration and leaks
• Additional treatment costs at WWTW
• Additional capital costs

In an example in Cape Town it was found that the effort in preventing and reducing the extraneous flows would be worth the effort, even if these efforts are only 15% effective.

14. CONCLUSION

The following can be concluded:
• There are in essence four types of extraneous flows in sewers
• The key insights in quantifying these flows lie in the fact that:
  • Infiltration consists of two components
  • The actual number of rainy "hours" are remarkably few
  • Hourly pumping records provide a wealth of information, when combined with hourly rainfall readings
• The amount of "ingress" i.e. extraneous flows is much greater (an order of magnitude!!!) than what is commonly assumed.
• There is a legal obligation ("a must") on WSAs to prevent the ingress of stormwater into the sewer system.
• The legislation is in place to enable WSAs to enter properties and dwellings.
• A four part strategy was outlined, which includes preventative measures such as a "Plumbers Compliance Certificate".
• The cost of intervention should generally be worth the effort, as the benefits exceed the costs of intervention.
• There are several unquantified social, environmental and economic benefits, which, if quantified would make the intervention even more desirable.

15. ACKNOWLEDGEMENTS

We gratefully acknowledge the lessons learnt on a project undertaken for the City of Cape Town and the support from Mr Collin Mubadiro and Mr Caashief Adams.

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Therese Luyt

Therese Luyt graduated from Cape Peninsula University of Technology with a BTech Degree in Urban Engineering. She completed a three-month Advanced Management Training & Industrial Placement in Bavaria, Germany, in 2011. Part of the training was a seven-week industrial placement at Finsterwalder Umwelttechnik GmbH. Experience was gained in biogas production from organic waste, co-fermentation of organic liquid waste and sludge at a WWTW and landfill aeration. She is currently employed by PD Naidoo & Associates Consulting Engineers in the Solid Waste Management Division. Her major experience includes Integrated Waste Management Plans and Bulk Infrastructure Master Plans. She is also involved in the design of a waste transfer station in Tygerberg, Cape Town.