EFFECTS OF REDUCTION OF WASTEWATER VOLUMES ON SEWERAGE SYSTEMS AND WASTEWATER TREATMENT PLANTS

Report to the

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by

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TABLE OF CONTENTS

LIST OF TABLES

1 Introduction

This study aimed to assess and quantify the extent of negative impacts on the proper functionality of sewerage systems (collection and conveyance systems) and wastewater treatment works (WWTW) resulting from drought and water conservation and demand management measures such as reduced wastewater influent flows and quality, and to identify mitigation measures to minimise these impacts.

A review of the impacts and mitigation measures employed during reduced wastewater flow conditions in international case studies was conducted, as well as a local case study on the City of Cape Town (CoCT). The CoCT has experienced the most severe drought conditions of any Metro in the country with respect to the recent drought, with water restrictions reaching Level 5 in September 2017. The findings of the international literature review revealed that the conditions such as climate, integration of storm water with sewerage and the disposal of garbage, such as kitchen waste to the sewer, differed from the South African conditions. It was also noted that in most cases, the per capita consumption during water conserving conditions, was significantly higher than the local average normal water consumption of 235 l/cap.d. While wastewater flow reduction as a result of drought conditions or demand management in South Africa resulted in many of the impacts described in the international case studies, the different conditions highlighted the need for the development of a guideline document that also draws from local observations and experiences.

This guideline has thus been compiled from the findings of both the international studies and the local contextualisation of this information, to provide practical and applicable adaptive interventions for negative impact mitigation within the framework of the South African best practices and operational requirements. Municipal officials can make use of this guideline to not only educate on the expected impacts of drought conditions on sewage conveyance and plant infrastructure and performance, but also to assist with planning and implementation of mitigation measures.

The target audience of this guide is municipalities with established wastewater conveyance and treatment infrastructure, but the design guidelines can also be applied to un-developed and rural municipalities where such systems are planned.

The following sections describe the expected impacts of reduced wastewater flows on raw wastewater quality, conveyance infrastructure, wastewater treatment works and final effluent quality, as well as potential mitigating adaptive responses.

2 Expected changes to raw incoming effluent

It is expected that the percentage increase of pollutants in the waste water would be proportional to the decrease in wastewater flow. In reality, while concentrations of soluble components such as ammonia may increase proportionally to the decrease in flow, the conditions in the conveyance system will have an impact on the quality of the wastewater that ultimately reaches the WWTW. Where the flow is low enough to result in the deposition of grit, the TSS concentration reaching the plant is expected to be lower than under normal flow conditions. Where septic conditions occur, the breakdown of organic material may result in a reduction in the concentration of biodegradable organic material available to the downstream processes. The decomposition of organic material under anaerobic conditions is also likely to increase the concentration of ammonia in the raw effluent above a proportional concentration increase.

3 Adaptive interventions to handle reduced wastewater flow in conveyance infrastructure

Sewers are generally designed so as to meet several criteria including physical gradients such that a free atmospheric surface is maintained while at the same time sufficient depth and velocity are maintained in order to mobilise and transport the silt and grit which finds its way into those sewers. These systems normally function with constant velocity, regardless of the discharge, with little effect on the residence time of the sewage in the reticulation system as opposed to systems with pump stations. Another, sometimes competing, constraint is the provision of the smallest and therefore lowest cost pipe which will accommodate the design flow.

It is possible that beyond some point, a reduction in flow would produce enough of an increase in the detention time that septic conditions would develop in the collection system. This negative impact would result in the production of hydrogen sulphide gas and difficult treatment conditions as a result of the anaerobic breakdown of readily biodegradable organic material. Another potential impact of reduced flows might be the deposition of suspended material in the sewers, which during higher flows would be re-suspended and delivered to the plant as a slug. Such an erratic regime of sediment delivery is difficult for most conventionally designed grit removal processes to accommodate. On the contrary, if sewers are running near to capacity or there are significant problems with excessive inflow and infiltration, a reduction in flow due to water conservation could be welcome.

Adaptive interventions to mitigate the impacts of reduced wastewater flow in conveyance infrastructure are presented in Table 1 and Table 2. Table 1 details the interventions for existing infrastructure, and Table 2 lists considerations for future planning to assist municipalities to plan future expansions in the context of potential lower flow conditions, such as when the municipality has plans to enforce demand management, is investigating re-use or is in a high-risk region for low rainfall in future, based on its hydroclimatic region.

Table 1 Expected impacts and proposed adaptation interventions for low wastewater flows in existing conveyance infrastructure

Impact	Interventions
Sedimentation of solids due to reduced flow (flow reductions greater than 20% from normal dry weather flow). Blockages as a result of sand, faecal solids and industrial fat deposition.	Clean lines more often. Hydraulic flushing of pipes under high pressure with water from tank trucks.
Blockages resulting from invasion of tree roots in search of water through cracked or damaged pipes. Pipes are more prone to cracking under drought conditions when soils contract.	Root removal by physical, mechanical or chemical means: Physical control • Pipe replacement: Digging up defective sewage lines and replacing with new ones. New pipes must have airtight joints to prevent root infestation. This is the costliest option but if the pipe risks failing and collapsing then replacement is the recommended course of action. • Pipe relining: Sewage lines can be refurbished by pulling a seamless pipe through the existing pipe - this is called “slip-lining”. A technology called “Cured-in-Place” lining inflates and cures a softcore plastic tube that fits the shape of the pipe. • Tree removal: If blockages are repetitive, removing the offending tree may be the best solution. The tree stump must be removed as well and the roots must be treated chemically with basal application herbicide. Mechanical control The use of tools and devices that can cut and remove the roots in sewer lines. The major advantage is that a blocked line is relieved immediately. Chemicals can be dangerous and ineffective when dealing with roots. A blocked sewer is typically a municipal emergency that requires a mechanical device to alleviate the clog or blockage. The major disadvantage of mechanical control is its lack of long-term effectiveness and roots may grow back more heavily after cutting. This method is best used in combination with chemical control • Smaller diameter pipes, such as from homes to the main sewer line: Drilling and rodding machines that use flexible steel rods with rotating augers, corkscrews or blade cutters. • Large diameter main sewer lines: hydraulic sewer cleaners (high pressure water pumps) with water propelled root cutters. Chemical control

	Most root control products, as most chemicals used to kill plants, are herbicides. Herbicides destroy plants by systemic or contact action. • Systemic herbicide is absorbed by roots that carry the agent through the plant over two weeks or more to be effective. • Contact herbicides cause quick death and a localized effect at the point of contact of the plant. Closed circuit television inspection (CCTV) provides the most positive and reliable information on the internal condition of a small- or large-diameter sewer line. Use of such technology can assist the municipality to monitor the development of blockages and attend to them before they cause significant problems. Breaks, leaks, protruding laterals, root intrusion and other blockages can all be located by means of CCTV. Visual and CCTV inspections will provide verification that manholes and cleanouts are on the proper level and accessible in future.
Anaerobic decomposition of sediment resulting in the evolution of methane and hydrogen sulphide gases, causing odour and corrosion problems.	Apply chlorine dioxide or sodium hypochlorite or other oxidising chemicals such as hydrogen peroxide at lift stations. Another method of odour control to consider is the administration of nitrate in the sewer to create anoxic conditions to prevent methanogenesis and sulphidogenesis, and possibly allow for autotrophic denitrifiers in the sewer biofilm to utilise sulphide as a substrate during autotrophic denitrification, thus oxidising it to sulphate or sulphur.
Increased detention time in pipes and pump stations (where present) cause septic conditions in the conveyed sewage. Septic sewage stimulates the growth of *Thiotrix* sp. and is often the cause of bulking sludge in BNR processes. Bulking sludge has poor settling properties and, if not controlled effectively, will lead to the effluent quality deterioration.	Lower height of level switch to initiate pump station sump emptying at lower levels, to reduce detention time. Consider the installation of variable speed pumps to improve energy efficiency.
Blockages and damage to pumps in pump stations due to higher than normal solids and grit concentration.	If not present, pump stations could be modified to include grit traps, screens and grinders to reduce the impact of the solids on the existing pumps. Regular flushing of sumps and pumps may help to reduce blockages.
When water utilities are actively pursuing programmes of eliminating inflow and infiltration of non-sewage flows in order to extent the hydraulic capacity of the receiving plant, this will result in reduced flows even if water demand management is not implemented.	The same responses to reduced flow will apply when non-sewage water ingress is minimised. The impact will be greater in areas of aging infrastructure with loose connections and cracks in pipes, and in poorly maintained areas with a large number of open sewer manholes.

This may be due to a requirement to extend the existing plant lifespan, avoiding the need for extension by lowering the hydraulic load.	Sabotaging or vandalism of manholes and removing manhole covers should be discouraged by appropriate penalties of perpetrators, including scrap metal dealers that sells stolen items
Impact of high strength industrial effluent on pipelines due to reduced dilution effect: • Low pH effluent may result in rapid corrosion of pipelines leading to sewer collapse. • High concentrations of fat from food industries, particularly abattoirs and meat processing industries, can result in major blockages under low flow conditions. • High suspended solids and organic loading will contribute to settled solids in the pipelines under low flow conditions, exacerbating the development of septic conditions and formation of odours.	The municipality may need to implement stricter by-laws to reduce the impact of more concentrated industrial effluent on the conveyance system by lowering the allowable discharge concentrations. A consultation process with industries is necessary and this may delay impact mitigation.
Incidents of high storm water flow after long periods of low flow may cause flooding, especially where blockages are present, causing overflow of raw sewage from manholes presenting a health and environmental risk.	In the case of flooding events, collection of stormwater for non-potable uses can be encouraged to reduce runoff within home boundaries. Collection points could be underground reservoirs under car parks or suitably constructed sections of the landscape. To develop an enabling environment for storm water collection the water and sanitation departments have to collaborate with those sections dealing with the built environment and urban planning. Storm-water management practices should encourage the construction of drainage pathways to define storm-water conveyance systems which are separate from wastewater will ensure that wastewater services do not become more vulnerable as the climatic conditions change. Developers or community members with infrastructure that cause storm water to flow into the sewer should be penalized.

Table 2 Expected impacts and proposed adaptation strategies for low wastewater flows when planning new conveyance infrastructure

Impact	Response / Description
Sedimentation of solids due to reduced flow (flow reductions greater than 20% from normal dry weather flow are expected). Blockages as a result of sand, faecal solids and industrial fat deposition.	Hydrodynamic shear stress considerations should be incorporated in the design of sewer pipe slopes. An increase pipe steepness to maintain equivalent scouring velocity (Vs). For a 75% flow reduction, the slope of a given pipe must nearly double to maintain Vs. This practice would require deeper cuts to lay the pipe and increased capital costs. However, these costs may be more than offset if sedimentation and hydrogen sulphide generation are reduced. Minimum design critical shear stress of 0.15 to 0.2 kg/m^2 to prevent sedimentation and hydrogen sulphide problems for sewers with $n \leq 0.013$[1] For sewers with an $n \geq 0.015$ a minimum design critical shear stress of 0.2 kg/m^2 is recommended. (These conclusions were valid for pipe sizes up to 150 cm^2)
Blockages resulting from invasion of tree roots in search of water through cracked or damaged pipes.	Avoid new sewer lines on tree lined streets, near curb lines with trees. Avoid locating new pipes close to other pipes with history of root problems. Use seamless pipe where possible and avoid laying pipes close to the surface.
Anaerobic decomposition of sediment resulting in the evolution of methane and hydrogen sulphide gases causing odour and corrosion problems	Minimum design sheer stresses apply as above for prevention of sedimentation. In addition, the design flow depth should not exceed two-thirds of the sewer diameter.
Increased detention time in pipes and pump stations (where present), causing septic conditions in the conveyed sewage	Provision of the smallest diameter pipe that will accommodate the design flow. Installation of variable speed pumps to maximise energy efficiency.
Blockages and damage to pumps in pump stations due to higher than normal solids and grit concentration.	Pump stations should be designed to include grit traps, screens and grinders to mimimise blockages and potential damage to the pumps. The location of any silt trap should allow easy access for a dump truck or trailer to be brought into close proximity to the trap for ease of cleaning. Preferably locate the silt trap some distance away from the residential areas for odour control.
Infiltration through cracks and loose joints and stormwater ingress through open manholes	If conveyance systems are designed for reduced flows, provision must be made to prevent non-sewage water ingress.
Impact of high strength industrial effluent on pipelines due to reduced dilution effect, such as corrosion.	Where long term demand management measures are planned municipalities should start the required consultative process with industries to notify of the intention to

	reduce the allowable discharge concentration of pollutants as dictated by the by-laws. This will often require substantial investment by industries which may be economically prohibitive.
Improved storm water management	<u>Integration of stormwater in water and wastewater service plans</u> The units which are responsible for storm water, potable water, and wastewater have to have a point of integrated planning. This way the potential of stormwater as a benefit is enhanced while the negative impacts are eradicated. Municipalities have to eliminate the tendency to separate these service units to avoid the continued limitation in services provision which come with this approach. <u>Legislature and by-laws to encourage industrial establishments to make use of storm water</u> Many manufacturing industries can afford to use and reuse storm water for their processes. By including this in legislature, storm water collection and use by industries can be encouraged and even enforced.

[1] Mannings roughness coefficient

[2] Yao (1976)

4 Adaptive interventions in response to reduced wastewater at wastewater treatment plants

While water-savings or restriction programs are expected to result in some reduction in wastewater flows, they are not expected to reduce the mass of pollutants discharged to the sewer. A distinction must be made between the effects of water saving on existing facilities and on those yet to be designed and built. In the former instance, a wastewater facility would have been designed to treat a certain waste flow and pollutant load. The design flow and pollutant load would have been determined based on population projections and historic records of per capita waste generation rates and wastewater strength. The effect of a water conservation program initiated sometime during the life of the plant will be to reduce expected flows while still retaining the expected pollutant load. Waste water strength obviously will increase. In the case of new facilities, the existence of or intention for a water conservation program should be considered in the design process.

The volume of wastewater entering a treatment plant varies depending on the hour of the day, day of the week, and month of the year. In addition, flow tends to increase annually as more homes and businesses are connected to the sewer system. Thus, in most cases, a municipal treatment plant must be designed to accommodate a fairly wide range of flows. It is conventional engineering practice to design a plant to treat the average daily dry weather flow during at least the last year of the design period. The design is then checked to make sure that the process units will continue to function reasonably well during extreme high and low flows.

If the same peak and minimum flow factors apply it is apparent that even if a savings program is implemented the flows will remain within the flow envelope within which the plant will perform adequately. Thus, from the point of view of hydraulics of an existing plant, the flow variations resulting from water savings may be much smaller than those that result from normal diurnal changes in use of the sewer system and consequently no adverse impact on performance might be expected. In fact, again from the point of view of hydraulics, the reduction in flow could extend the life of the plant. Clearly, however, organic loading as well as hydraulic loading must be considered in an analysis of the effects of water savings on treatment plant design.

It should be noted that the effects of lower flows and resultant higher concentrations of pollutants would likely affect each plant differently, in some cases beneficially, in others insignificantly or negatively. The type and capacity of individual unit processes would be the major determining factor. Plants that rely heavily on trickling filters are expected to be more affected by higher concentrations of pollutants than activated sludge systems, especially in winter when efficiencies normally decrease due to slower biological reaction rates at lower temperatures. Plants which incorporate activated sludge systems may in fact realise positive benefits due to increased retention times in process tanks and increased solids removal in the clarifiers.

Existing treatment facilities originally designed for non-water conserving communities may be found to have ample or sufficient hydraulic capacity, but may need additional biological and biosolids treatment and disposal capacities as water conservation efforts and practices are put in place and flows gradually decrease to the plant. Conversely, when planning future infrastructure for water conserving communities, smaller collection systems and flow based wastewater treatment processes may be considered, but the biological and biosolids treatment and disposal systems for water conserving communities will continue to be similar in size and capacity to systems required for non-water conserving communities.

By-laws and regulations take legislation into practical measures in order to ensure accountability. Legislation is enforceable and legally binding, and is often promulgated by parliament with the guidance of national institutions. This creates a necessity for local government institutions to create by-laws that are in line with promulgated legislature. In communities where water stresses and financial issues are prominent, the development of appropriate by-laws in line with adaptation plans can improve the state of water services, prevent water wastage, and in the process, protect water resources. Appropriate regulations could have a positive impact on the behaviours of community members, water boards, municipal ratings, and water service providers (Dube et al., 2016). When dealing with the impact of lower wastewater flows, municipalities may consider stricter by-laws to be enforced on industrial effluent dischargers, to reduce the load of organic material, solids, fats and potentially toxic contaminants that may further impact the conveyance infrastructure and WWTW.

Error! Reference source not found. presents the expected impacts of reduced flow on existing WWTW and proposed adaptive interventions that should be considered, assuming that the flow reduction is sufficient to cause a reduced average dry weather flow below that typical of diurnal flow variations. These include issues caused by both reduced hydraulic loading and increased organic loading.

Table 4 presents planning and design guidelines for municipalities considering the implementation of a demand management strategy, or in high risk areas for lower future rainfall. The introduction of operational flexibility is key, and designers are encouraged to consider multiple units and the use of recirculation pumping capabilities to maintain constant influent flow and wastewater strength during low flow periods.

Table 3 Expected impacts and proposed practical adaptation interventions for low wastewater flows on wastewater treatment plant unit processes

Unit Process	Impact	Intervention
Emergency bypass or storage dams	Incidences of occasional high flows during longer periods of low flow conditions due to storm water entering the conveyance system.	Provision should be made for adequate emergency storage facilities at the WWTW to prevent impact to downstream unit processes. Direct bypass of high flows to the discharge should be avoided to prevent pollution of the environment.
Head of works		
Mechanical aerated degritter	Excess organic material may settle with the grit when flow reductions exceed 20%, resulting in odour and disposal issues, as well as potentially disrupting downstream nutrient removal through the reduced availability of organic material. Excess organic material and increased detention time may result in odours due to production of hydrogen sulphide. This may also emanate directly from the sewer pipeline. Lower than normal daily quantity of grit can be expected due to increased sedimentation in conveyance pipelines.	Head of works are designed to accommodate a very wide range of flows, from minimum daily to peak wet weather, and as such, with the occasional exception of velocity controlled grit chambers, reductions of flows to existing head of works should normally be readily accommodated and in most cases could result in an additional increment of available capacity. Pre-chlorination may be necessary to decrease odours, either with installed pre-chlorination equipment or a portable device or manually. Other commercially available odour control chemicals may also be dosed. Covers on any inlet structures should be left open to prevent build-up of odorous and toxic gases. Where excess organic material settles, it may be necessary to rinse the grit before disposal to return the organic solids to the process.
	Incidences of higher than normal flow during a significant rainfall event due to ingress introduces slugs of grit from the conveyance pipelines to the degritter	Grit slugs in excess of the degritter capacity will need to be removed manually.
Velocity controlled channel degritter (using proportioned weirs, Parshall flumes, or other fixed control sections to maintain a nearly constant velocity as liquid flow and depth of liquid in the chamber varies)	Velocity-controlled grit chambers are very sensitive to wastewater flow. If, because of conservation, minimum design flow falls below the proportioning range of these grit chambers, excess organic deposition will occur.	Where excess organic material settles, it may be necessary to rinse the grit before disposal to return the organic solids to the process. Pre-chlorination may be necessary to decrease odours, either with installed pre-chlorination equipment or a portable device or manually.

		Grit slugs in excess of the degritter capacity will need to be removed manually. If possible one or more of the channels should be permanently closed off to increase the velocity through the remaining channels.
Primary settling tanks	Large grit load after first heavy rain following drought conditions may carry through the degritters and enter the primary sedimentation tanks, clogging sludge draw off lines and PST mechanisms Reduced flow will increase the residence time of that basin, increasing the risk of settled solids becoming septic and producing gas causing them to float to the top. Anaerobic wastewater with a high concentration of organic matter provides an excellent environment for the growth of a filamentous bacteria such as *Sphaerotilus natans*. If these bacteria establish in the tank they may fail to settle out and cause problems with primary settling, and will be transferred to downstream processes and may be responsible for blockages on trickling filters. Floating sludge due to nitrification in anaerobic pipelines. The readily biodegradable organic substrate required for biological nutrient removal and enhanced phosphorus removal is also consumed under septic conditions, which may result in poor nutrient removal. Odour problems related to septic conditions.	The clarifier may need to be dewatered and the silt pressure-hosed off to remove settled grit when blockages occur. Both grit blockages and septic sludge conditions can be countered by maintaining a high solids-removal rate which can be accomplished with existing equipment. Treated effluent can be recirculated back to the head of the plant to decrease the hydraulic detention time and dilute the incoming wastewater. It may be necessary to add a coagulating agent such as alum to improve the settling characteristics of the solids in the wastewater if settling is poor due to nitrification or bulking due to filamentous bacteria. Chlorine and hydrogen peroxide can be applied directly to the primary clarifier to improve odour problems. Commercial odour control chemicals are also available for this purpose. If plant flexibility allows one or more PST can be taken out of service to reduce detention time in remaining tanks. The pumping routine can be altered so that sludge withdrawal pumps come on more frequently during the night.
Activated sludge	An increased sludge age and MLSS (mixed liquor suspended solids) concentration is required to improve efficiency at higher organic loading rates. Reduced hydraulic load may increase the risk of knock out of activated sludge systems by toxic industrial effluent that previously may have been adequately diluted.	Return sludge recycle rate should be increased. If the plant is operating at maximum recycle capacity then additional recycle capacity may need to be installed. If the flow is greatly reduced one or more basins could be taken out of service if plant flexibility allows for this. Higher concentrations of industrial effluent may necessitate stricter by-laws to reduce impact on the biological systems.

		Industries will assist service provision if they have established wastewater purification plants at their premises.
Biofilters (trickling filters)	Carry over of filamentous bacteria from the PST to the primary trickling filter, clogging up the filter and causing ponding. Ponding can also be caused by the growth of sulphur bacteria in the filter. Blockages in filter arms will lead to poor distribution of effluent onto the filter. Ponding and blockages will lead to short circuiting of effluent and poor treatment efficiency. Odour problems due to long retention times and blockages.	Periodic ploughing of surface media may help to prevent ponding. A filter arm flush should be performed if a blockage is detected, and flushed debris should be removed from surface of filter for disposal with screenings. If necessary blocked orifices should be manually cleaned. Filters can be flushed by “walking” the filter arms, manually controlling the filter arm rotational speed. Increasing the recycle rate to the biofilters may improve performance and reduce odour. If possible one or more filters could be taken out of service to improve the performance of the remaining filters. Chlorine addition and recirculation of treated effluent may reduce the odour problem, but will also disturb the natural populations in the filter and may upset the process for several months.
Secondary clarifiers (activated sludge) or humus tanks (biofilters)	Poor settling due to increased solids loading. Rising sludge due to denitrification of biofilter effluent in humus tanks Bulking in secondary clarifiers due to excessive filamentous bacterial growth in the aeration basins	A flocculent such as alum can be added to the line from the trickling filter or activated sludge reactor to the final clarifier to act as a coagulating agent to improve settling. Increasing sludge draw off to reduce detention time and prevent denitrification in humus tanks. Surface sludge should be washed down daily. Bulking sludge can be improved by reducing the sludge age (mean cell residence time) in the aeration basins of the activated sludge process, as well as recycle of water from clarifier to head of works if plant flexibility allows.
Chemical dosing	The addition of ferric chloride for phosphate removal depends primarily on wastewater pH and phosphate concentration. Theoretically, an increased ferric chloride dosage would be needed for phosphorus removal under conditions of reduced flow and increased loading.	Practically, because of inherent variability in wastewater characteristics, chemical dosing is conservatively overdesigned and should not be adjusted significantly for reduced flow. Stoichiometric equations cannot accurately predict appropriate chemical dosages because of numerous competing reactions. Bench-scale testing of chemicals

		under reduced flow conditions should be undertaken to verify the predicted effect of reduced flows on phosphorus removal, and dosages increased if necessary.
Disinfection	When wastewater flows are reduced through conservation by up to 20% and the effluent quality has not deteriorated, improved bacterial kill can be expected at a certain chlorine concentration. This is because contact time would increase proportionately. If there has been a deterioration in final effluent quality, particularly with respect to organic material and ammonia, the chlorine demand will increase.	Equivalent destruction of bacteria could in theory be accomplished in an existing facility by reducing the chlorine dosage when final effluent quality remains unchanged. It should be noted that the reduction in specific chlorine dosage generally may not be linearly proportional to the increase in contact time because chlorination of wastewaters produces chloramines, which are less effective in disinfection than hypochlorous acid or hypochlorite ion. Changing specific chlorine dosage would change the proportion of chlorine species in the water. Where final effluent quality has deteriorated there may be a need to increase the chlorine dosage. This should be monitored in terms of the residual free chlorine concentration and microbiological final effluent quality.
Sludge handling	There may be an increase in primary sludge production resulting from reduced hydraulic flows through the PSTs. This increase is highly dependent on the nature of the specific wastewater and the design of the clarifier, but should not be very large. The necessity for increased BOD_5 removal can be used to estimate an increase in waste activated sludge; total waste sludge production would likely increase about 1.5% by weight for a 20% reduction in flow.	Facilities needed to handle sludge including pumps, digesters, chemical conditioners, vacuum filters, centrifuges, incinerators, filter presses, thickening tanks, drying beds, and landfill capacity should not be affected significantly as a result of water conservation programmes.
Waste stabilisation lagoon systems	When algal ponds receive a high organic load but a low hydraulic load, dispersion of the organic material in the initial stages of the pond systems may be poor. This results in the release of ammonia-nitrogen and hydrogen sulphide at high concentrations that may become toxic to the growth of algae. As a result of the toxicity, large areas of the ponds may therefore not be utilized effectively and the capacity of the systems will be reduced.	The reduction in effective capacity due to toxicity may necessitate the addition of more ponds in series. Because relative evaporation and percolation losses are likely to be higher at the lower-flow, longer retention-time conditions, it is possible that no increase in lagoon volume may be necessary and even an increase in capacity may result. This will need to be evaluated on a per-system basis, depending on the quality of the final effluent and impact of increased organic loading.

Final effluent quality	Depending on the ability of the plant and operators to make provision for the reduced flows, the final effluent may either improve in quality, deteriorate or stay the same. It is likely that, particularly in plants relying on biofilters, the ammonia and nitrate concentrations may be raised in the final effluent. In extreme cases concentrations of organic material (COD), phosphates and microbiological contamination may also be unacceptably high. This will impact on the quality of the receiving water body, affecting efforts to improve instream water quality standards or meet objectives to protect freshwater ecosystems.	All effort should be made by the WWTW to adapt to lower flow conditions. Where non-compliant effluent is unavoidable, stricter discharge standards may need to be imposed on other WWTW and users discharging in to the same water body that may have more adaptive flexibility. Municipalities should engage with DWS as soon as compliance is compromised. Online monitoring of control parameters throughout the plant, such as the DO concentration in the activated sludge reactor, will allow for immediate response to out-of-spec readings. Senior process controllers should receive SMS notifications to enable rapid response.

Table 4 Expected impacts and proposed practical adaptation technologies and strategies for designing new wastewater facilities under conditions of long term flow reduction

Unit Process	Impact / Description	Design Guideline
Emergency bypass or storage dams	Incidences of occasional high flows due to storm water entering the conveyance system.	Provision should be made to construct adequate emergency storage facilities at the WWTW to prevent impact to downstream unit processes and direct bypass of high flows to the discharge should be avoided to prevent pollution of the environment. Mixers should be installed into storage dams to prevent septic conditions as far as possible, and allowance should be made to slowly blend the stormwater into the incoming effluent stream for treatment. In the long term, stormwater management strategies should be a priority to prevent mixing of wastewater and stormwater.
Head of works		
Mechanical aerated degritter	Excess organic material may settle with the grit when reductions exceed 20%, resulting in odour and disposal issues, as well as potentially disrupting downstream nutrient removal through reduced availability of organic material. Incidences of higher than normal flow introduce slugs of grit from the conveyance pipelines to the degritter.	The design of new headworks could include size reductions with some cost savings; however, capacity must always be provided for the peak wet-weather flows. It may be desirable to increase the design peak capacity of grit removal facilities for plants whose sewer systems are subject to sedimentation and inflow/infiltration because heavy rains flush accumulated sediments from the sewer system.
Velocity controlled channel degritter	Velocity-controlled grit chambers are very sensitive to wastewater flow. If, because of conservation, minimum design flow falls below the proportioning range of these grit chambers, excess organic deposition will occur. With the occasional exception of velocity controlled grit chambers, reductions of flows to existing head of works should be readily accommodated and in all cases could result in an additional increment of available capacity	Flexibility should be introduced into the design to allow for some channels to be closed off to maintain velocity in the remaining channels

Primary sedimentation	Large grit load after first heavy rain may carry through the degritters and enter the primary sedimentation tanks, clogging sludge draw off lines and clarifier mechanisms Reduced flow will increase the residence time of that basin, increasing the risk of settled solids becoming septic and producing gas causing them to float to the top. The readily biodegradable organic substrate required for biological nutrient removal and enhanced phosphorus removal is also consumed under septic conditions, which may result in poor nutrient removal.	Typical hydraulic loading for primary clarifiers would range from 32.6 to 48.9 m^3/m^2.d for maximum 24 hour flows to 81.5 to 122.2 m^3/m^2.d for peak flows. Reduction of flow to existing sedimentation basins can be readily accommodated and would be less than the typical design range. A reduction in wastewater flow of up to 20% would provide enhanced solids removal, the extent of which would depend on the nature of the wastewater. New sedimentation facilities could be designed to be smaller, particularly in those cases where peak wet weather flows are handled by standby facilities or attenuated in equalization basins. Provision can be made for a return pipeline to recirculate treated final effluent to before the primary clarifiers to reduce the retention time and dilute the incoming effluent. Flexibility could be introduced into the design to allow one or more PST to be bypassed, reducing detention time in remaining tanks. Flexibility to alter the pumping routine by increasing sludge withdrawal when necessary, perhaps diurnally.
Activated sludge	An increased sludge age and MLSS (mixed liquor suspended solids) concentration is required to improve efficiency at higher organic loading rates.	Allow for the installation additional recycle capacity in terms of both pump and pipe capacity to make provision for increased return sludge flows. Allow for numerous treatment units rather than one to allow for the flexibility to bypass one of the units during periods of low flow.
Biofilters	Long detention times, poor flow distribution, blockages and odours	The design should allow for recycle of biofilter effluent to improve performance. Flexibility to allow a biofilter to be taken out of service to improve performance of remaining biofilters.
Secondary clarifiers (activated sludge) or humus tanks (biofilters)	Poor settling due to increased solids loading. Rising sludge due to denitrification of biofilter effluent in humus tanks.	Make provision for the dosing of a flocculent such as alum to the line from the trickling filter or activated sludge reactor to the final clarifier to act as a coagulating agent to improve settling.

	Bulking in secondary clarifiers due to excessive filamentous bacterial growth in the aeration basins.	Introduce flexibility to alter the pumping routine by increasing sludge withdrawal when necessary to reduce detention time and prevent denitrification in humus tanks. Allow for recycle water from clarifier back to head of works to assist in preventing the formation of bulking sludge.
Chemical dosing	Theoretically, an increased ferric chloride dosage would be needed for phosphorus removal under conditions of reduced flow and increased loading.	Practically, because of inherent variability in wastewater characteristics, chemical dosing is usually conservatively overdesigned and should not be adjusted significantly for reduced flow. Provision should be made for variable speed dosing pumps and additional chemical storage if higher dosing is required, as determined by bench-scale testing of chemicals under reduced flow conditions.
Disinfection	Improved bacterial kill can be expected at a certain chlorine concentration at lower flows due to an increase in contact time, provided the effluent quality has not deteriorated.	Equivalent destruction of bacteria could in theory be accomplished in an existing facility by reducing the chlorine dosage. In new facilities the chlorine contact tank could be designed smaller to save on capital expenditure, particularly if other provisions have been made to ensure plant performance under ow flow conditions to safeguard the final effluent quality.
Sludge handling	The increase in primary sludge production is highly dependent on the nature of the specific wastewater and the design of the clarifier, but should not be very large. The necessity for increased BOD_5 removal may necessitate an increase in waste activated sludge; total waste sludge production would likely increase about 1.5% by weight.	Facilities needed to handle sludge including pumps, digesters, chemical conditioners, vacuum filters, centrifuges, incinerators, filter presses, thickening tanks, drying beds, and landfill capacity should not be affected significantly as a result of water conservation programmes.
Waste stabilisation lagoon systems	When algal ponds receive a high organic load but a low hydraulic load, dispersion of the organic material in the initial stages of the pond systems is poor. This results in the release of ammonia-nitrogen and hydrogen sulphide at high concentrations that may become toxic to the growth of algae. As a result of the toxicity, large areas of the ponds are therefore not utilized effectively and the capacity of the systems are reduced.	The reduction in effective capacity due to toxicity may necessitate the addition of more ponds in series. Designers should provide for additional anaerobic pond capacity. Relative evaporation and percolation losses are likely to be higher at the lower-flow, longer retention-time conditions, so it is possible that no increase in lagoon volume may be necessary and even an increase in capacity may result. This will need to be evaluated on a per-system basis,

		depending on the quality of the final effluent and impact of increased organic loading.
Final effluent quality	Depending on the ability of the plant and operators to make provision for the reduced flows, the final effluent may either improve in quality, deteriorate or stay the same. Non-compliant effluent will impact on the quality of the receiving water body, affecting efforts to improve instream water quality standards or meet objectives to protect freshwater ecosystems.	All effort should be made to design the WWTW to be flexible and adapt to lower flow conditions. Municipalities should consult with DWS to determine the most suitable manner to mitigate impact to the water quality in the catchment, which may require the enforcement of more stringent discharge limits.

5 Effects on water re-use programmes

Water re-use is likely to become more prevalent in many municipalities going forward, with some already having implemented this, or at feasibility stage. For example, the City of Cape Town and the town of Beaufort West have already implemented water re-use programmes, with Beaufort West having implemented direct potable re-use, and the City of Cape Town using wastewater effluent for irrigation and industrial process water. The Ekurhuleni Metropolitan Municipality in Gauteng has conducted a feasibility study for wastewater re-use for future implementation.

Wastewater reclamation plants may require predetermined effluent quality, and drought conditions impacting on the final effluent compliance may impact the performance of any reclamation plants, and may also affect the design for planned plants. A major issue for water authorities contemplating recycling wastewater is that, as water becomes scarcer, programmes are developed to increase the efficiency of water use and there is an increase in the price of water to consumers. Both serve to lower the amount of wastewater available for recycle, which would be exacerbated by drought conditions. This may mean that municipalities might be unable to supply their re-use customers with the volume of reclaimed water they are obligated to contractually. Depending on the relative costs of internal water recycling compared with freshwater supply and discharge costs, it may be economically viable for private firms and industries to invest in water recycling and thereby further reduce outflows of wastewater. Investments in internal wastewater recycling by industries may reduce their freshwater intakes by up to 95% (Luckmann et al., 2016). This in turn will result in further reduced revenue to the authorities.

The increased salt concentration as a result of flow reduction on wastewater reuse for crop and landscape irrigation and industrial uses is not expected to have a noticeable impact on nett benefits (gross benefits less costs) of water conservation. Thus, water conservation should not be counterproductive to wastewater re-use. However, adequate information should be obtained for specific constituents affecting proposed wastewater re-use projects, particularly when intended for irrigation. The data should include, as a minimum, analyses of total dissolved solids (TDS), hardness and boron concentrations as well as the sodium absorption ratio.

6 Environmental and health implications

Lower minimum flows in rivers due to drought conditions imply less volume for dilution and, hence, higher concentrations downstream of point discharges such as wastewater treatment works (WTWW). This could affect efforts to improve water quality standards or meet quality objectives to restore and protect freshwater ecosystems. As treated wastewater becomes a larger fraction of surface water flow, an increase on the concentrations of selected wastewater contaminants, including conductivity, nitrate, and pharmaceuticals and endocrine disrupting compounds (EDCs) is likely in the rivers receiving WWTW discharge. This may ultimately place more pressure on WWTW to comply with even more stringent discharge standards (Whitehead et al. 2009), and may result in stricter by-laws being imposed on local industries. While occasional algal blooms in summer are a natural feature of the river ecology, the frequency and intensity of these may increase. When an algal bloom occurs, there are large diurnal variations in dissolved oxygen and, on poor-quality rivers, low oxygen levels can be exacerbated by pollution events during summer low-flow conditions.

In many of the rural areas, and in particular during severe drought, communities are dependent on natural streams to wash themselves as well their clothes and eating utensils. When the discharge from wastewater treatment plants is the only water available in the region, the risk of infections and spread of diseases may be unacceptably high.

An important consideration is that a drought is often terminated by heavy rainfall. The initial run-off from contaminated areas may be highly polluted. The risk of transmittance of diseases and pollution of water courses are therefore initially very high after the end of a drought.

It is important that municipalities enter consultative processes with industries as soon as low flow conditions are experienced in order to warn them of potential adjustments to the local by-laws and tariffs. Local communities, particularly those dependant on the rivers for personal hygiene and washing purposes, should be educated on the risks of higher pollutant loads.

7 Financial implications

Energy and chemicals are the primary operations and maintenance (O&M) cost items affected by wastewater flow reductions.

The major change in energy use for wastewater collection systems is mainly due to decreased operating time by lift station pumps. At the WWTW, there may be a decrease in energy use due to less pumping requirements for the reduced hydraulic load. There is not expected to be a reduction in the aeration requirements due to the organic load being the same. In some cases the requirement for aeration may in fact increase due to the lower hydraulic load.

The overall chemical use can increase or decrease depending on the operational practice during the flow reduction period. The amount of chlorine used for disinfection is expected to decrease, provided there is no deterioration in the final effluent quality, whereas chlorine dosing to control odour and growth of filamentous bacteria may increase. Dosing of chemicals for improved settling such as polymers, lime, alum or ferric hydroxide are likely to increase.

The capital cost of a new facility designed to treat wastewater for a 10-year period, assuming implementation of a water savings program, would be less than for a similar facility designed assuming no water saving. The process units that could be down-sized represent about 40% of the total cost of an activated sludge facility. These treatment plant process units are those based on hydraulic loading and include head of works, primary and secondary clarifiers, effluent chlorination facilities and effluent outfall. Some reduction in aeration tank sizing may be possible, due to the requirement to reduce the mean cell residence time to prevent excessive growth of filamentous bacteria. If the changes in flow and wastewater composition can be anticipated and incorporated into the design and operating plans, water conservation can lead to significant reduction in a facility's costs as well as reductions in the pollution load on the receiving waters, thereby providing environmental benefits at essentially no cost to the community. It should be noted, however, that these cost savings could be accrued only when infiltration and inflow are small. If wet weather flows far exceed dry-weather flows, the need to provide hydraulic capacity for these large flows will eliminate the opportunity for cost savings.

8 References

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