AN INDEPENDENT INVESTIGATION AND ADVISORY ON THE ROLE OF WATER, SANITATION AND HYGIENE IN THE 2023 CHOLERA OUTBREAK IN HAMMANSKRAAL, SOUTH AFRICA

WORK PACKAGE 4: WATER AND SANITATION SAFETY ASSESSMENT AND ENVIRONMENTAL MONITORING

Part 1: Assessment of the Functionality and Compliance Status of Two Wastewater Treatment Works (Rooiwal and Temba) in the Outbreak Area

Final Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

Following the outbreak of Cholera disease in the Hammanskraal area, the Water Research Commission appointed Virtual Consulting Engineers for Work Package 4: Water and Sanitation Safety Assessment and Environmental Monitoring. Among others the scope of work included assessing the functionality and compliance status of the water and wastewater treatment facilities within the designated outbreak areas.

AIMS

The aim of this projects was to assess the functionality and compliance status of the wastewater treatment systems in the designated outbreak area, which included Rooiwal and Temba Wastewater Treatment Works.

METHODOLOGY

Physical site inspections were conducted at the Rooiwal and Temba Wastewater Treatment Works to assess the operational status of the treatment infrastructure and verify process control practices. Effluent quality data from the City of Tshwane laboratory were evaluated to assess the performance of the works. Site information, old contract documentation and raw wastewater data were used to calculate the process capacity using IWA's activated sludge model.

RESULTS AND DISCUSSION

Based on the assessment of the two-wastewater treatment works was found:

1. Both wastewater treatment works are dysfunctional due to lack of infrastructure maintenance and poor housekeeping / site keeping. The condition of the equipment at Rooiwal WWTW suggests decades of neglect and poor decision making. Temba WWTW is in a better condition than Rooiwal, but the activated sludge plant is only partially constructed.
2. Only around one third of the process unit and mechanical equipment is in operation.
3. Flow meters on site are not calibrated.
4. The flow meter readings are entered incorrectly and inflows versus outflows are not balanced.
5. Wastewater sample analyses are not structured in a database, rendering this work fruitless.
6. Small design flaws are evident throughout the works, and from different eras over the plant's life. The inlet works is inadequate for a treatment plant of this capacity, especially in comparison to similarly sized treatment works. The bio-reactor volume is too small, while by contrast, the aeration capacity is too large.
7. Biofilter technology is old and the Rooiwal Eastern works were constructed before nutrient removal became important, and this module will not be capable of producing compliant effluent from the 55 Ml/d it receives.
8. Process control is lacking, and no organogram of the staff could be found.
9. Rooiwal WWTW is operating above its design capacity, while the operational capacity of Temba WWTW could not be verified due to unavailability of information.

RECOMMENDATIONS

1. The current administration and management of the Rooiwal and Temba Wastewater Treatment Works must account for their lack of performance in those areas where they have control, and where they continue to expend cost on salaries, but without any benefit to the works.
2. Collection of data and recordkeeping must add value and the City of Tshwane must start a campaign to calibrate equipment, verify and beneficiate raw data, to abstract useful information for planning purposes, so that eventual upgrades of the works can be based on sound evidence.
3. The obvious refurbishment works and salvaging of mechanical and electrical equipment must proceed forthwith, as an emergency project, and must include those items that will bring the works to life again.
4. The process units at Rooiwal WWTW are not well integrated with each other. To facilitate the eventual upgrade of the works, an expert wastewater engineer needs to be appointed to develop a plant-wide model, from the inlet works through to the sludge digestion and dewatering, and this model must be used to develop a masterplan for the works.
5. The works must be repaired, re-configured and re-invented as part of an upgrade project with the aim of direct effluent reclamation, meeting SANS 241 Drinking Water standards, which would be a proper incentive for effluent to comply.
6. The staff responsible for operations and maintenance at the Wastewater Treatment Works should either be upskilled and placed under the management of competent and capable professionals, or replaced by a commercial team if needs be, or alternatively, a combination of operational models needs to be found through which the current lack of performance can be turned around. This is an urgent intervention and needs to start forthwith to arrest bad practice prior to the commissioning of a refurbished works.
7. Different contracting models should already have been investigated, such as DPWI’s Repair and Maintenance Programme, with a sufficiently long period of performance (greater than the normal 36 months), or a Public-Private-Partnership, including goals set against the Green Drop System, etc. to run the works on the basis of professional process control, with performance-based remuneration.

ACKNOWLEDGEMENTS

The project team thanks the following people for their contributions to the project:

Name	Affiliation
Cholera Advisory Panel	Various Institutions
Dr Eunice Ubomba-Jaswa (Research Manager)	Water Research Commission
Community Members	Hammanskraal

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ACRONYMS, ABBREVIATIONS AND TERMINOLOGY

AS	Activated Sludge
BNRAS	Biological Nutrient Removal Activated Sludge
COD	Chemical Oxygen Demand
MLSS	Mixed Liquor Suspended Solids
PST	Primary Settling Tank
RAS	Return Activated Sludge (underflow from final clarifiers)
SVI	Sludge Volume Index (expressed as ml/g)
TKN	Total Kjeldahl Nitrogen
WAS	Waste Activated Sludge
WWTW	Wastewater Treatment Works
Backlog maintenance	the combination of repair, refurbishment work, which is overdue with normal day-to-day maintenance work
Maintenance	continuing repair and corrective work and alterations to existing infrastructure and facilities to keep all systems in good operational condition, to provide the services for which they were designed, when the users require such services, at the most economical cost
Project	a temporary endeavour undertaken to create a unique product or service
Refurbishment	the process of repairing, replacing components, servicing and cleaning equipment to ensure that the condition of existing infrastructure and facilities is like new
Repair	the act of restoring defective, faulty or worn components to a good working condition
Replacement	the installation of new materials, components equipment and/or unit processes, in the place of their old equivalents, as part of a refurbishment process
Upgrade	work to improve the functionality of existing installations to meet increased demands in terms of capacity and improved standards

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Following the outbreak of a Cholera disease in the Hammanskraal area in May 2023, the Water Research Commission appointed Virtual Consulting Engineers for work Package 4: Water and Sanitation Safety Assessment and Environmental Monitoring. Among other the scope of work included assessing the functionality and compliance status of the water and wastewater treatment facilities within the designated outbreak areas.

1.2 PROJECT AIMS

The project aims were to:

- Assess the functionality of waste management systems within the designated outbreak areas,
- Assess the functionality and compliance status of the water (drinking) and effluent (wastewater) treatment facilities within the designated outbreak areas,
- Based on the water uses within the designated outbreak areas, collect relevant samples from the designated outbreak areas and conduct laboratory tests to confirm the presence of Vibrio cholerae and other waterborne disease pathogens using both culture and molecular methods.

1. Enviro
2. Wastewater
3. Water
4. Solid waste

1.3 SCOPE AND LIMITATIONS

The scope for this report included assessing the two-wastewater treatment works with the potential to impact the outbreak area. The two wastewater treatment works assessed were Rooiwal and Temba wastewater works. The scope of work was limited to an assessment of the operational status of the works, condition assessment of assets and, to the extent possible within the limited time frame and with scant information, process and plant assessment to determine the capacity of the works.

CHAPTER 2: INSPECTION OF ROOIWAL WASTEWATER TREATMENT WORKS

2.1 INTRODUCTION

The Rooiwal Wastewater Treatment Works (WWTW) consists of three sections, i.e. the Rooiwal Northern Works, the Rooiwal Eastern Works and the Rooiwal Western Works. The Rooiwal Northern Wastewater Treatment Works was inspected on 13 and 14 June 2023, while the Rooiwal Eastern WWTW was inspected on the 19th of June 2023. These two modules are currently in operation, but the Rooiwal Western Works has been out of commission, for a considerable time.

2.2 ROOIWAL NORTHERN WWTW

The plant serves the northern part of the City of Tshwane including the Rosslyn industrial hub. The works has a design capacity of 120 Mℓ/d and the COD design concentration was indicated as approximately 700 mg/ℓ (no documentation provided for this). According to the plant manager the plant receives raw COD in excess of 1000 mgCOD/ℓ an aerial view of the WWTW is presented in Figure 1

Figure 1: Aerial view of Rooiwal Northern WWTW, with clockwise from top left, Module 1, Module 2 and Module 3

2.2.1 Operational capacity

Figure 2 below shows that the plant consistently operates above the design capacity with some months recording an average daily flow of more than twice the design capacity. The out of commission BNRAS section of Module 1 also means that the available capacity of the plant is further reduced, therefore the capacity exceedance impact is even greater.

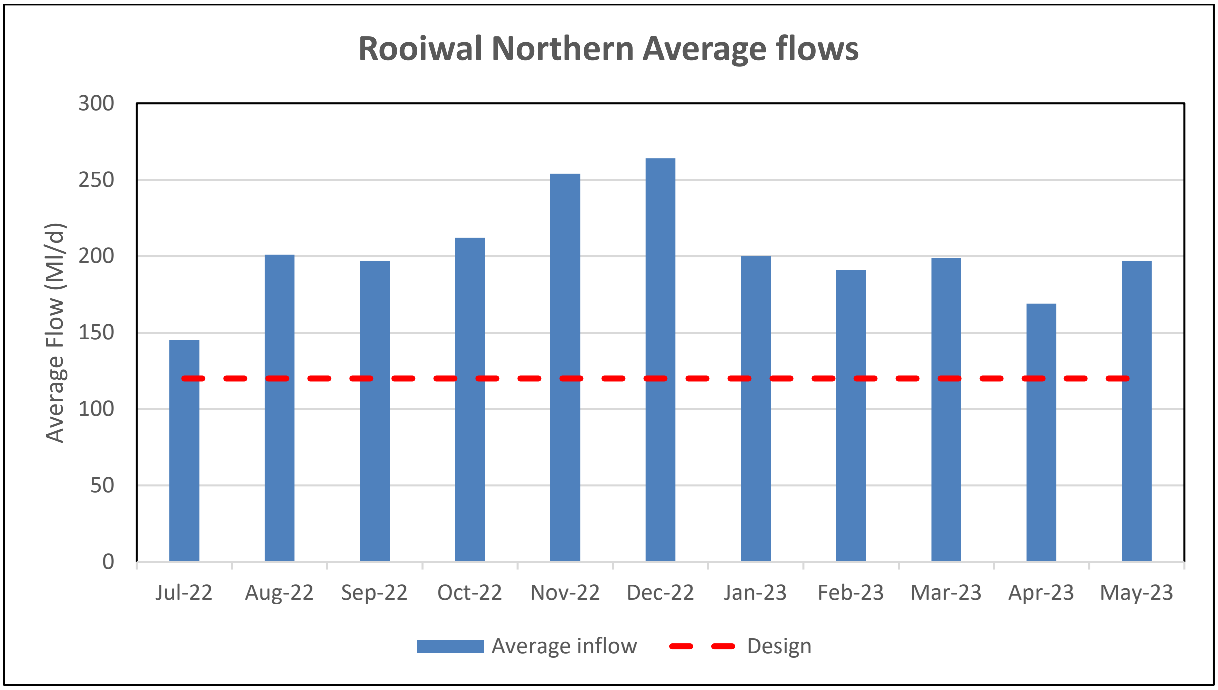


Figure 2: Average daily flows from July 2022 to May 2023

2.2.2 Flow splitting

The inflow to the works is currently split between Rooiwal Northern Works and the Eastern Works since the Western Works is out of commission. Flow splitting between the two sections takes place before the inlet works. There are three balancing dams, but these appear to have been in disuse for some time.

2.2.3 Inlet Works

Provision is made for installation of three mechanical fine screens. However, the three fine screens have been removed for long periods resulting in raw wastewater only passing through manual coarse screens. Cleaning frequency of the manual coarse screen is also inadequate. Unavailability of fine screens results in carrying-over of debris to downstream processes. The screen conveyor is available and working but evidently, it requires serious maintenance, also, poor screenings disposal practices were observed as screenings are left lying around the plant without indication of when they would be removed.

Figure 3: Manual screens currently in use

Figure 4: Poor condition of the conveyor belt

Figure 5: One of the mechanical screens left unattended

Figure 6: Screenings not safely stored

2.2.4 Grit removal

There are six vortex grit traps installed, two of which were not in operation as the submersible pumps were removed. The condition of the electrical and mechanical equipment also shows evidence of lack of maintenance. One of the three grit classifiers is no longer working and the pipes from the two chambers that fed it have been rerouted to another classifier. The removed grit is stored in skips before it is removed for disposal offsite. The grit removal area is dirty and unkept.

2.2.5 Primary settling

After the grit traps flow is split between the three modules, through three different channels. Each channel feeds to one of the three clarifiers installed. The flow distribution does not take place with positive overflow weirs, but occurs imperfectly on channel, floor level. This seems to be a design flaw, resulting from poor hydraulic profile. Furthermore, due to high inflows at the plant, it was observed that there is overflow in the channels and this results in raw sewerage being fed directly into the biological reactors. The PST bridge for one of the three PSTs is not working. Two of the three PSTs have excessive scum and fat layers. Excessive sludge bulking and rising were also evident. All PSTs equipment is in poor condition and requires urgent maintenance. Desludging equipment is working, and it was indicated that it discharges to the digesters once a day. However, the sludge conditions in the tanks still suggest inadequate desludging.

The fourth PST stands half-constructed. However, it is not at all clear how flow will be distributed proportionally to this PST, and furthermore, it appears to be constructed at a level lower than the old PSTs.

Figure 7: Sludge conditions in the PSTs

Figure 8: Debris carryover from PST

Figure 7 shows gas bubbles on the liquid surface. This is a tell-tale sign of anaerobic digestion due to infrequent sludge withdrawal.

2.2.6 Biological reactors

The inlet channel to the Activated Sludge Reactors splits the flow into a constant stream to the anaerobic zone, and a variable high flow via side stream overflow weir into the anoxic reactor. Ad-hoc masonry structural modifications have been made in the past to increase the side channel overflow weir level, but these structures are collapsing and overflowing. Based on the understanding of the UCT biological nutrient removal activated sludge (BNRAS) family of wastewater treatment process configurations, the introduction of raw wastewater directly into the anoxic zone is unconventional and needs to be investigated further with understanding of the raw wastewater characteristics.

The “bypass” shown in Figure 9, as well as the “re-aeration zone” (the final aerobic zone) possibly stems from a period before the COD mass balance approach to design introduced with IWA’s family of mathematical activated sludge models. “Re-aeration” normally refers to the 5-stage Bardenpho final zone downstream of a secondary anoxic zone, absent at Rooiwal.

All submersible mixers are out of commission. This results in sludge settling to the bottom of the reactor, where anaerobic digestion starts, producing fermentation products that inhibits the functioning of BRAS. Most likely, bacteria that are growing in the (limited) aerobic zone, return from clarifier underflow to meet its demise, trapped in the un-aerated zones. In such a system, nitrification has almost no prospect of success.

The aeration system is functioning very poorly. The three BNRAS systems are serviced by three sets of three 600kW turbo-blowers (i.e. nine aeration blowers on the plant). The configuration allows for two duties / one standby rotating blower per module. Currently, only one blower per module is in operation, and turned down to below 45% of its capacity of 22,000 (N)m^3/h. At the time of the inspection, machines were running between 7,000-8,000 (N)m^3/h. The process therefore receives less than 30% of the oxygen required.

The aeration pipework is not well designed, with reducers from 800 mmND to 400 mmND for no apparent reason. This results in air velocities of around 60 m/s, at design blower capacity. Good practice suggests normal maximum air velocities of 20 m/s, but never more than 25 m/s, under peak performance conditions. The pipework design is a contributing factor to the low blower utilization. In addition, the bubble diffusers and diffuser pipework leaks so much air that the fear exists that whole diffusers or sections of pipe may be dislodged. This is according to operators, the reason for running only one blower per module at turned down capacity.

Two A-recycle pumps are installed for each of the two reactors in each of the three modules. However, only Module 2's A-recycle pumps were working during the inspection. This is currently of no consequence, as the poor aeration and lack of mixing means that nitrification is not possible.

Figure 9: Typical conditions at the anaerobic zones

Figure 10: Foaming in the aeration basin

Figure 11: Leaking pipework in the diffusers

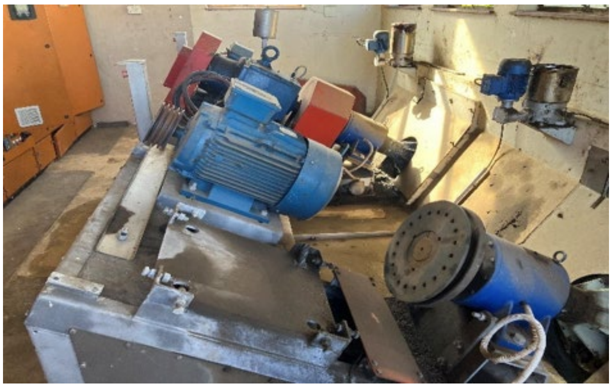


Figure 12: Typical condition of the RAS pumps, only one pump working

2.2.7 Secondary clarification

There are six clarifiers installed for each of the three modules. The condition of the clarifiers is generally poor, also exposing that maintenance is seriously lacking. It appears that scum removal equipment appears to have not been used in a long time, though it is working condition, indicating the lack of process controlling. The scum withdrawal pipes are overburdened with debris and plastic material which have been carried over due to inadequate screening at the inlet works.

Two RAS pumps are installed for each of the three modules. However, only one out of every two RAS pumps is working.

Only 6 of the 12 clarifiers bridges in Module 1 and 2 were rotating, while the others were not rotating. Only 3 of the 6 clarifiers in Module 3 were working. All clarifiers are characterized by excessive scum sludge buildup and bulking, the weirs launders and channels are not clean and characterized by slime, some evidence of algal growth and excessive accumulation of debris. Some of these are carried over into the final effluent contact tank and maturation ponds.

Figure 13: Typical condition of the clarifiers (module 2)

Figure 14: some clarifiers isolated for repairs (module 1)

Figure 15: Scum removal valves overburdened with debris

2.2.8 Disinfection.

Disinfection is normally achieved using chlorine gas. There are two dosing banks installed. Each bank feeds 925 kg chlorine cylinders. At the time of inspection disinfection was not taking place since there was no chlorine stock. Therefore, the operational status of the disinfection system could not be verified. However, it was observed that there is lack of safety signage and equipment around the dosing area. One of the two carriage water booster pumps was out of commission. After chlorine dosing, effluent flows into the disinfection contact tank. Sludge settling was still observed in this tank, indicating that the upstream process is ineffective. Debris and some floating materials were also observed in this, further also confirming the inadequate screening at the head of works. Based on the quality of the effluent, high chlorine demand is guaranteed and introduction of chlorine to effluent of such quality may result in formation of chloramines. Serious spillage was also observed around the disinfection and contact tank area.

Figure 16: Empty tanks connected and not dosing due to lack of stock

Figure 17: Conditions at the contact tank

2.2.9 Maturation ponds

The contact tank feeds several maturation ponds in series. The effluent in the maturation ponds still presented a smell like that of raw wastewater and excessive sludge settling was observed. The ponds were overgrown with vegetation at the time of inspection.

2.2.10 Operational monitoring

Not much operational monitoring is taking place at the plant, only MLSS is monitored every day, but there is indication that some days this is not done. It was also indicated that operators sample the reactor effluent every week and send the samples to Daspoort laboratory for analysis. The parameters monitored and the results of the analyses were not shared.

2.2.11 Effluent Quality

Daily samples are collected at the WWTW final effluent and sent to the city of Tshwane central laboratory located at the Daasport WWTW. The effluent quality results for the period April 2022 to May 2023 were received and compared to the General Authorization special limits to determine the effluent compliance. Given the importance of the Apies River as water resource to downstream users, this standard should be a reasonable expectation of final effluent quality. The average compliance results as presented in Table 1 below indicates the following:

- The effluent quality results confirm the process control and condition of equipment onsite, i.e. there is not much treatment taking place at the plant.

- High ammonia concentrations in the final effluent coupled with regularly undetected Nitrates/Nitrites also confirms the observation onsite, that conditions in the biological reactor would not allow for nitrification and denitrification processes to take place. Therefore, high ammonia content is carried over to the final effluent, which resembles in most cases the raw wastewater ammonium concentration. Over the past 12 months, the average effluent ammonium concentration has been around 34 mgN/l. Even if the data shows nitrate to comply with effluent standards, this is meaningless, because nitrate is not produced in the first place, and therefore its removal cannot be measured. Practically speaking, the plant removes no nitrogen.

- 0% microbiological compliance is also an indication that disinfection is ineffective, either due to lack of disinfectant stock and subsequent dosing as observed during inspection or due to high chlorine demand from poorly treated effluent

- 0% compliance for COD is also evidence of the poor conditions observed at the biological reactor and clarifiers. High effluent SS concentrations also confirm poor condition of the clarifiers.

- Poor phosphate compliance could be due to inadequate aeration resulting from breakdowns and poor design of diffusers which affects the growth of polyphosphate-accumulating microorganisms in the aeration basin. Poor clarifier conditions also contributes to the inadequate removal of phosphates.

Table 1: Summary of Rooiwal effluent quality compliance

Total Number of samples	No. of samples complying	No. of complying samples	% Compliance
COD	389	1	0%
EC	389	250	64%
NH_3-N	388	1	0%
NO_3^-/NO_2^--N	388	387	100%
SS	357	6	2%
o-PO_4^{3-}	387	87	22%
Faecal Coliforms	390	0	0%

If the effluent water quality were compared to the General Authorisation's general limit standards, which is a relaxed set of criteria, the situation would not look any better.

2.2.12 General Maintenance

The plant is in poor condition with most equipment not working or in poor working condition. This is a clear indication of lack of maintenance at this plant.

2.2.13 General Housekeeping and Site keeping

Housekeeping around the office area is fairly good, however, the plant area portrays a different picture. Overgrown vegetation is consistent throughout the plant, screenings are left lying around with no indication of whether collection will ever take place and spillages are left uncontained and unattended.

2.2.14 OHS

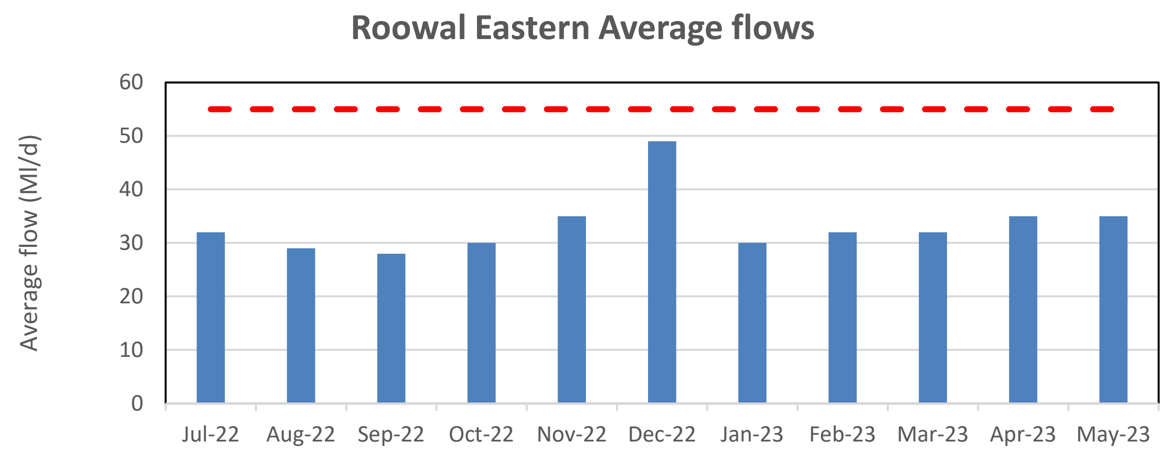
Safety signs and equipment are lacking throughout the plant. Overgrown vegetation also presents a serious safety risk.

2.3 ROOIWAL EASTERN WWTW INSPECTION

The Eastern WWTW receives raw sewage from the same line as the Rooiwal Northern WWTW. The plant has a design capacity of 55 Mℓ/d. This figure was indicated by the senior process controller confirmed by the value in the Green Drop report and DWS's Integrated Regulatory Information System (IRIS). No indication was made in terms of the design organic loading. The plant employs a biofiltration process and is divided into four identical modules. An aerial view of the Rooiwal Eastern WWTW is presented in the figure below.

Figure 18: Aerial view of Rooiwal Eastern WWTW

2.3.1 Operational capacity



	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23
Average inflow	32	29	28	30	35	49	30	32	32	35	35
Design	55	55	55	55	55	55	55	55	55	55	55

Figure 19: Average daily flows from July 2022 to May 2023

The average daily flow as presented in the figure above suggests that the plant operates below the design capacity. However, during inspection it was noted that most of the biofilters are out of commission and therefore available capacity is reduced. It is therefore highly likely that even at these flows, the plant was still hydraulically overloaded.

2.3.2 Inlet works

The inflow comes through a channel with a flume and a flow meter that is in working condition. Flow reading is recorded by the process controllers, but no evidence of recent calibration of the meter was available. There is provision for two mechanical fine screens, however both were not working during the inspection and only the manual screen was in use. The manual screen is too course and therefore achieves limited removal of debris. The screen conveyor is still in operation although maintenance is required. Screenings are stored in a skip bin before collection and disposal through burial off site.

Figure 20: Condition of inlet screens

Figure 21: Maintenance team onsite to fix the screen

2.3.3 Grit removal

There are two vortex grit traps, both of which have been out of operation for long periods of time. The inflow currently passes through one of the traps, where excessive grit accumulation was observed. Evidently, no more grit removal is taking place. The second grit trip is out of commission with plants growing inside.

Figure 22: One grit chamber out of commission for a long time

2.3.4 Primary settling

After the grit traps, wastewater flows into a flow division box which distributes flow to the primary settling tanks of the four identical modules. Each module consists of two primary settling tanks. All eight primary settling tanks' bridges were not working and the surface area was characterized by excessive scum buildup was observed on the surface area. Although it was indicated that desludging of the tanks is undertaken once a day, sludge floats were also observed in all the tanks indicating inadequate sludge removal. The desludging equipment for seven of the eight PSTs was working and only PST 3 sludge removal equipment was blocked. The effects of inadequate screening and grit removal were also observed in the tanks, as floating material and grit accumulation were evident.

Figure 23: Excessive scum and grit accumulation in the division box inlet chamber

Figure 24: Excessive scum layer observed in all PSTs and a broken-down scrapper arm

Figure 25: Broken scum baffle resulting in scum overflowing to the biofilters

Figure 26: Motor removed therefore scum scrapper not moving

2.3.5 Biofilters

The PSTs effluent flow into channels that feeds the filters, there is provision for flow monitoring for each filter's influent. However, most of these flow meters are no longer working. Each module has four interconnected filters. For Module 1, two filter arms were rotating. The third filter had little flow and the arm was not rotating due to blocked flow distribution holes. The fourth filter had no flow and had been out of operation for a long period.

Module 2 had three filters rotating but some flow distribution holes were evidently blocked, cleaning of these distribution holes is standard/basic operational maintenance. The fourth filter arm was not rotating and out of use for a long time. On the third module, only one filter was rotating while the other three arms were not working. On Module 4, three filter arms were rotating and one was not rotating. The reason for some of the filters not rotating is blocked inlet pipes and faulty center columns.

Algal growth and evidence of a thick sludge layer were observed on the surface of some filters and the filter underdrains are generally not clean, consisting of thick layers of slime, algal and vegetation growth in some instances.

Figure 27: Poor conditions at some of the filter underdrains

Figure 28: Filter out of commission for a long time due to faulty centre column

Figure 29: Evidence of algal growth observed in some of the filters

Figure 30: A layer of sludge observed in one of the filters out of commission

2.3.6 Humus tanks

Effluent from each set of filters flows into three humus tanks. The humus tanks are generally in poor condition: Plant and algal growth was observed on the surface of several humus tanks. Some scum withdrawal equipment has long been in disuse and the sections of the weirs are broken and launders show symptoms of not being cleaned in a long time. The scum and sludge withdrawal valves are left partially open therefore impacting on the treatment process.

Figure 31: Poor conditions apparent in most humus tanks

Figure 32: Broken scum baffle resulting in solids carryover

Figure 33: Scum and sludge removal valves always left partially open for no apparent reason

2.3.7 Disinfection

Effluent from all humus tanks combine into a final effluent sump with provision for disinfection, but the sump is covered with algae and duckweed. Disinfection is normally achieved through two chlorine gas dosing banks installed on a duty standby configuration. However, at the time of inspection there was no gas in the store. One empty tank was lying neglected in the field, the operational condition of the dosing equipment could not be verified since the chlorine room was locked. There was no safety equipment or signage around the chlorine room.

Figure 34: Empty chlorine gas cylinder left unattended in the sun

Figure 35: Dosing room with provision for two banks, only one cylinder connected but not dosing due to lack of stock

2.3.8 Final effluent

The final effluent from the sump is pumped to the power station and one farmer. The remainder of the effluent flows into a maturation pond before discharging into the Apies River. The maturation pond is characterized by excessive sludge buildup, indicating that the treatment process is ineffective.

Figure 36: Duckweed observed in the final water sump

Figure 37: Maturation Pond in poor condition and has excessive sludge accumulation

2.3.9 Operational monitoring

There is no operational monitoring taking place at the plant. Process controllers only record in and out flows once a day, and the readings are sent to the plant manager for filing.

2.3.10 Effluent quality

Weekly samples of the raw and final effluent are collected and sent to the City of Tshwane central laboratory located at the Daspoort WWTW. These results are then submitted to the Department of Water and Sanitation. From the observation made on site, effluent quality results are not used to improve operational processes.

2.3.11 Maintenance

There were no operation and maintenance manuals on site. There were no records of any preventative maintenance on site, and it was indicated that reactive maintenance is lacking due to inadequate budget allocations. Lack of infrastructure maintenance is evident throughout the plant.

2.3.12 Housekeeping

The plant is in a poor state with overgrown vegetation observed throughout the plant. The male showers are no longer working, and toilets are not in good shape. The area used as an office and lunch area by staff also requires maintenance and adequate furniture must be provided.

2.3.13 Occupational health and safety

There is a lack of safety signage and safety equipment throughout the plant.

2.4 SLUDGE HANDLING

The Waste Activated Sludge (WAS) and scum produced at the Rooiwal WWTW is treated at two sludge handling plants. One is located within the Rooiwal WWTW near the Northern Works and the other is outside the perimeter and north of the Rooiwal WWTW. The plants were inspected on 26 May 2023 for their condition, performance, and compliance.

The sludge handling plants consist, mainly, of belt presses, polymer dosing systems, compressors, wash water make-up, basins, mixers, and associated pumps and instruments that dewater the WAS and scum to produce dewatered sludge for composing purposes. It was observed that the two plants were underperforming or not capable of treating the Rooiwal WWTW sludge, as a collective. In fact, concrete slabs used to dry and process the dewatered sludge was found to be nearly empty, as shown on Figure , compared to the year 2015 when the sludge handling plants performed optimally, as indicated by the composting company Agrimat and seen on Figure 39.

Figure 38: Dewatered Sludge concrete slab c. 2023

Figure 39: Dewatered sludge concrete slab c. 2015

2.5 NORTHERN SLUDGE HANDLING PLANT

The sludge handling plant at the north of Rooiwal WWTW features a sump that receives sludge from the wastewater treatment plant. The inlet of the sump previously had mechanical screens, screw conveyors and skips that were used to further clean the incoming sludge. Currently, the sludge sump inlet works is not functioning as per the design, as shown on Figure 40. The dysfunction of the sump inlet screening equipment is evident at the composting plant where screenings and foreign objects are seen in compost, as shown on Figure 41.

Figure 40: Northern sludge handling plant inlet works screens taken out and screw conveyor dysfunctional

Figure 41: Screenings seen at the composting plant

An accumulation of scum was seen at the top of the sump causing partial anaerobic conditions, as shown on Figure 42. This is exacerbated by the fact that two floating surface aerators at the sludge handling sump are dysfunctional and have been taken out of the sump, as shown on Figure 43.

Figure 42: Accumulation of scum at the sludge handling sump

Figure 43: Floating surface aerators taken out

Since the sludge handling plant is not operated as it was designed, it was seen that the sludge overflows to the nearby fields, as shown on Figure 44. One of three pumps located near the sump is used to convey sludge to the main sludge handling building on manual mode, as shown on Figure 45. The other two pumps do not work and contribute to the overflowing of the pump.

Figure 44: Northern sludge handling plant inlet sump overflows to nearby fields

Figure 45: Sludge transfer pumps seen (One pump works whilst the other two are dysfunctional)

From the sludge handling sump, sludge is pumped into two storage tanks, as shown on Figure 46, which act as a buffer between the sump and belt presses for dewatering sludge. Both tanks are functional and in fair condition. Three pumps, shown on Figure 47, are installed to deliver sludge from the buffer storage tanks to the belt press. However, one of the three pumps is not working.

Figure 46: Buffer storage tanks before belt presses

Figure 47: Pump station for two out of four belt presses installed and correctly functioning

The sludge handling plant, in its previous functioning state, had four belt presses installed in parallel with two sludge pump stations of three pumps at each pump station. Each pump station was designed and equipped with two belt presses at a time. Only one of the pump stations works and the other three pumps of pump station number two have been removed.

At the time of the inspection only one Lektratek Water Technology, sludge dewatering belt press, shown on **Error! Reference source not found.**, worked and processed sludge at a rate of 2.44 ℓ/s. That is 30 percent of the design operating flow rate or capacity of the sludge dewatering belt press. At a two percent solid concentration, it means the sludge dewatering belt press was only producing around 175 kg/h of dry sludge versus 600 kg/h as per the original design.

Figure 48: Dewatering belt press No. 1 working, but one belt is severely torn

Figure 49: Dewatering belt press No. 4 out of commission and two other belt presses removed

Upon identifying the underperformance of the one belt press and querying the reason for operating at a lower capacity, it was the revealed that the screw conveyors transferring the dry sludge to an elevated hopper are not capable of handling the 600 kg/h of dry sludge. This is evident when looking at the screw conveyor that was overflowing shown on Figure 50.

Downstream of the sludge handling plant, it was seen that the elevated dry sludge hopper was at an extremely low level and the dry sludge inside the hopper appeared to be dry or sitting at the same level for weeks, as shown on Figure 51. This indicates that the sludge handling plant is barely operated. In fact, the composting plant operators confirmed that the sludge handling plant seldom delivers dry sludge to their facility. It was also pointed out that the sludge handling plant was only started upon the arrival of inspectors.

Figure 50: Dewatered sludge overflow at screw conveyor

Figure 51: Elevated dry sludge hopper at an extremely low level

The wash water system used as part of the sludge handling plant was located and deemed to be in correct working condition. The wash water pumps, and storage tanks were in a fair condition, as shown on Figure 52 and Figure 53.

Figure 52: Wash water pumps located and determined to be functioning and in a working condition

Figure 53: Wash water storage tanks seen to be functioning and in a fair condition

The MCC, shown on Figure 54, for the sludge handling plant is in a good condition and works. Outstanding equipment such as the second pump station and belt presses need to be installed and connected. The old MCC needs to be decommissioned if not working.

Figure 54: Sludge dewatering plant MCC and control panel in a working condition

Figure 55: Old MCC for sludge pumps, polymer station found not working

The polymer station, shown on Figure 56, is in a good working condition, however, housekeeping needs to be improved. The compressor, shown on Figure 57, was found to be in a good working condition.

Figure 56: Polymer dosing station and pumps are functioning and in a fair condition

Figure 57: Compressor for sludge dewatering belt press works and is in a fair condition

2.6 INTERNAL ROOIWAL WWTW SLUDGE HANDLING PLANT

The sludge handling plant within the Rooiwal WWTW receives sludge that is stored in what is supposed to be an aerobic sump. The sump's inlet screening equipment does not function and allows screenings to enter the sludge handling plant. The sump has mixers and surface aerators that do not work, as shown on Figure 58. Consequently, the top of layer of scum can be seen. The second sump, located between the inlet sump and belt presses, also has a thick layer of scum and floating surface aerators that do not function, as shown Figure 59.

Figure 58: Sludge handling sump one with mixers and aerators that do not work. A top layer of scum was seen

Figure 59: Floating surface aerators not working

The incoming sludge is pumped to six belt presses that function, as shown on Figure 60, except for one belt press which is used for spares to fix the five operational belt presses, as shown on Figure 61. The pumps used to deliver sludge to the belt presses are in a fair and working condition.

Figure 60: Sludge dewatering belt presses in a fair and working condition

Figure 61: Sludge dewatering belt press used for spares

At the time of the inspection, the sludge sent to the dewatering belt presses was 3 ℓ/s, seen on Figure 62, higher than the sludge handling plant located at the north of Rooiwal WWTW. Between the Northern sludge handling plant and that seen inside the Rooiwal WWTW, there is a total of 6 ℓ/s sludge processed. The dewatered sludge is conveyed to the Northern sludge handling plant, as shown on Figure 63. This operation is performed on a 24-hour basis.

Figure 62: Sludge Flow to Dewatering Presses

Figure 63: Dewatered sludge Conveyed to the Concrete Slap North of Rooiwal WWTW

2.7 PROCESS CAPACITY CALCULATION

2.7.1 Steady stage process design

The design capacity of the Rooiwal Wastewater Treatment works was analysed based on activated sludge steady state model, developed at University of Cape Town during the 1980s and more recently consolidated as a body of work on behalf of the International Water Association (IWA) by Henze et al (2009). Through the implementation of IWA's activated sludge model no 2 (ASM2) on spreadsheets, the steady state nature of biological nutrient removal activated sludge (BNRAS) wastewater treatment processes can be simulated accurately. The complete COD mass balance includes the oxygen consumed (Biochemical Oxygen Demand) as well as the COD equivalent of removed nitrate, which acts as terminal electron acceptor in the denitrification process. Effluent concentrations can be predicted reliably based on the kinetic model and mass balance. The model was further developed to include clarifier performance based on solids flux theory, with an assumption of sludge volume index, S-recycle rate as well as peak inflow rates, as formulated in Chapter 8 of the 1984 UCT/WRC design manual.

Aeration capacity is included in the spreadsheet, through a combination of empirical knowledge and first principle calculations. In the case of fine bubble diffused aeration, the standard oxygen transfer rate is a function of the manufacturer's certified test results, and assuming that most membrane diffusers are similar. In the case of the turbo-blowers, we calculate air flow requirements based on said oxygen transfer efficiency, as well as properties of compressed air, adjusted for (summer and winter) temperatures, relative humidities, and elevation above sea level (1,186.975 mamsl). This mathematical model of the treatment process can therefore be used to determine peak oxygen demands, as well as required clarifier sizes, based on typical diurnal flow and load variations.

2.7.2 Wastewater characterisation

Wastewater characteristics were for the purposes of this evaluation assumed as per Table 2. Importantly, the fractions add up to ensure that 100% of COD is defined. This fractionation is the basis for the activated sludge mass balance:

Table 2: Wastewater COD fractions

Fraction, particulate unbiodegradable, influent	fS'up	gCOD/gCOD	0.130
Fraction, soluble unbiodegradable, influent	fS'us	gCOD/gCOD	0.050
Fraction, particulate biodegradable, influent	fS'sp	gCOD/gCOD	0.250
Fraction, readily biodegradable, soluble, influent	fS'bs	gCOD/gCOD	0.205
Fraction, slowly biodegradable, soluble, influent	fS'ss	gCOD/gCOD	0.365
Total			1.000

The fractionation of nitrogen species adopts the following assumptions:

- All the Total Kjeldahl Nitrogen in the raw wastewater eventually undergoes enzymatic reaction and become available as free and saline ammonium.
- Nitrogen is removed (a.o.) through biomass, with a fraction of 0.075 gN/gTSS

For an average dry weather flow rate, loads can be determined based on flow weighted composite sample concencetrations. Raw data received from the City of Tshwane were in the form of laboratory certificates only, i.e. not organised in a structured database from where useful information could be abstracted. Furthermore, our own calculated averages (form City of Tshwane's lab certificates) for the key parameters differed from the values quoted by the plant manager on site. While it was said that COD concentrations exceed 1000 mg/l, with ammonium around 30 mg/l, our averages of raw data reveived is respectively 707 mg/l and 29 mg/l. COD concentrations in Canal West and Canal East had averages of 569 and 661 mg/l respectively, while the settled sewage average, from different sampling stations was 245 mg/l. Compared to the raw wastewater, this low COD is not realistic, as it represents 65% removal over primary settling tanks, where the upflow velocity is in excess of 4 m/h, and of which the intake structures is currently overflowing. Since the data on raw wastewater concentrations could not be verified, we worked with typical scenarios, as follows.

<u>High strength / concentrated wastewater</u>

- Chemical Oxygen Demand (COD_{raw} = 800 mg/l, $COD_{settled}$ = 640 mg/l)
- Total Kjeldahl Nitrogen (TKN = 65 mg/l)

<u>Low strength / diluted wastewater</u>

- Chemical Oxygen Demand (COD_{raw} = 500 mg/l, $COD_{settled}$ = 400 mg/l)
- Total Kjeldahl Nitrogen (TKN = 45 mg/l)

Flow meter readings at Rooiwal Northern works are recorded daily, but the usefulness of these data must be questioned, because:

(1) Flow meters are not calibrated (no calibration certificates could be shown)
(2) The meter readings for inflow and outflow per reactor could not be balanced.
(3) Readings which we assume must be in cubic meters per day are recorded in megaliteres per day, which is non-sensical.
(4) Flow meter readings which are stuck, are still entered, from which constant daily flows are calculated, which is clearly wrong.

Observations on site indicate that reactor 2.1, 2.2, 3.1 and 3.2 received near equal in flow rates, based on the equal water depths upstream of venturi flumes. These flow meters also give more or less the same reading per day, which makes it the most likely indication of flow. If these flow meters were indeed near accurate, the inflows per module (consisting of two reactors) for April 2023, ranged between 66-70 Ml/d. Preliminary process assessment indicates these high flow rate exceed the reactor and clarifier capacity by far, and we therefore worked with two flow scenarios, i.e. medium flow rate of 50 Ml/d per module, and low flow rate of 40 Ml/d per module.

2.7.3 Activated Sludge Process Configuration

At the Northern works, three almost identical modules are configured as variations on the theme of the well-known Three Stage Bardenpho process. This process is normally configured with

- an anaerobic zone, which received raw wastewater and Return Activated Sludge,
- followed by an anoxic zone, receiving anaerobic zone effluent with A-recycle for denitrification,
- followed by an aerobic zone, where nitrate rich A-recycle returns to anoxic.
- aerobic zone feeding clarifiers for sludge/liquid phase separation.

However, an unusual modification is found at Rooiwal, where a constant raw water stream flows into the anaerobic phase, but a long side channel weir separates higher flows to a lower channel that bypasses the anaerobic zone and feeds directly to the anoxic zone where the A-recycle enters. This process modification has been further modified by constructed brick walls to prevent overflow over the long side channel weir. In addition, drawings found show the final aeration zone as a “re-aeration chamber.” This term is normally reserved for the Five-stage Bardenpho process, in which a secondary anoxic zone follows the aerobic zone (to improve denitrification without A-recycle), which then requires intense re-aeration before feeding to clarifiers. In the absence of the secondary anoxic zone, the term re-aeration has no real meaning. Finally, the A-recycle pumps do not abstract sludge from the best position, but from the third of the four aerobic zones, before nitrification is complete.

For purposes of this evaluation, we simply considered the process as a three stage Bardenpho consideration, with the following reactor volumes:

- Anaerobic reactor volume 1,790 m^3
- Anoxic reactor volume 7,214 m^3
- Aerobic reactor volume 3,318 m^3

Each of the modules have two parallel reactor sets, which means these volumes are doubled in the modelling per module.

The challenging design aspect is often ensuring both nitrification and denitrification at 12°C. This is achieved by having: (a) a large enough aerobic zone and high enough aerobic sludge mass fraction to prevent excessive relative autotrophic decay and (b) a large enough anoxic zone to allow slow denitrification kinetics to complete denitrification. In the case of Rooiwal, with the reactor volumes and process configuration given, complete nitrification is achieved at sludge age of 30 days in winter.

2.7.4 Effluent quality expected with functional equipment

Calculations show that at winter temperatures (water @ 12°C) with a combined reactor size of 12,322 m^3, at 30-day sludge age the nitrification process is complete (ammonium = 1-2 mgN/l effluent) and denitrification is effective at the specified recycle rates, given the large anoxic zone (nitrate = 10 mgN/l effluent). Chemical oxygen demand is the sum of the defined soluble inert COD fraction and the TSS in the effluent, aimed at 15 mgTSS/l[1].

Phosphate removal has not been optimised in the three-stage Bardenpho process since the Return Activated Sludge always contain nitrate. This part of the process is not considered further, but there is an opportunity to re-look at the existing reactor to optimise the process configuration according to, for example, the *Johannesburg process configuration,* which can achieve:

- Better than 90% COD removal
- Better than 80% Nitrogen removal
- Better than 80% Phosphate removal

The purpose of the process evaluation is to establish the capacity of the works, as a function of the wastewater composition and flow rate, which would produce effluent of such quality.

2.7.5 Clarifier design and operation

Clarifier design and operating conditions is described by the flux theory of sludge. Central to the flux theory is the *diluted Sludge Volume Index*. We assume a DSVI of 140 ml/mg, which is not a good SVI, but reasonable, considering that:

(1) Plug flow properties in the reactor zone is not ideal to create the high food to biomass ratio required for low SVI sludges.
(2) Procedures for the removal of WAS is not clear from the surface of the aerobic reactor, thus preventing withdrawal of filamentous organisms with WAS removal.
(3) Satellite images dating back to 2004 show a constant presence of a scum layer on the clarifiers. Scum on the clarifier surface is strongly associated with bulking sludge.

For peak factors, we assume that in the high flow scenario (50 Ml/d) the balancing tanks which are currently not in operation, would be recommissioned and functioning, to reduce the peak hydraulic load factor to 1.50 in summer (wet weather peak) and 1.25 in winter (dry weather peak). In the low flow scenario (40 Ml/d) we consider the case where the balancing tank is still out of operation and assume hydraulic load factor to 2.50 in summer (wet weather peak) and 1.75 in winter (dry weather peak).

The flux theory of sludge accurately predicts that in cases where the Mixed Liquor Suspended Solids concentration increases to above 6,000 mgTSS/l, clarifiers will fail on sludge compression. Ideally, MLSS concentrations of less than 5,000 mgTSS/l should be achieved in the bioreactor, for the clarifiers to function

[1] The specified fraction of Fraction, soluble unbiodegradable, influent, fS'us = 0.05, for a raw wastewater [COD] = 1,000 mg/l, combined with the associated COD of the specified effluent solids concentration of 25 mgTSS/l, exceeds the specified maximum COD concentration of 75 mg/l

fully. An important function is to increase the sludge concentration (thickening) to separate the mixed liquor from the final effluent and return the sludge to the bioreactor. Where the feed sludge concentration from the reactor is too high, thickening cannot continue beyond the optimum concentration, and the system fails.

Of the sixteen scenarios considered, only four satisfy operation conditions, and these are:

(1) Summer temperature – low MLSS concentration / high flow – low peak factor / low strength / settled wastewater.

(2) Summer temperature – low MLSS concentration / low flow – high peak factor / low strength / settled wastewater.

(3) Winter temperature – medium MLSS concentration / high flow – low peak factor / low strength / settled wastewater.

(4) Winter temperature – medium MLSS concentration / low flow – high peak factor / low strength / settled wastewater.

The bottleneck in the system is caused by the high MLSS concentration. This cannot be improved by additional clarifiers (which is not practical on site), because it is primarily a function of the bio-reactor volume at given sludge age (minimum, required for nitrification) as well as the strength of the wastewater. The reactor volume is limiting. The calculations show that only with primary settling, even if imperfect, can the inert solids and organic load be decreased to allow an acceptable MLSS concentration in the reactor. The table with clarifier operating scenarios is included in Appendix A.

2.7.6 Aeration

A Fine Bubble Diffused Aeration system was installed at Rooiwal, consisting of three sets of three turbo blowers each, with stainless steel pipe manifold and porous membrane air diffusers submerged by 4.17 m of mixed liquor. New turbo blowers were manufactured by Siemens and installed in 2012 (model KA44SV-GL225, with 600kW MV electrical motors). Each blower has a maximum air flow discharge of 23,500 (N)m^3/h. Maximum turndown to 45% of maximum air flow is through diffuser control, which means power demand is not reliant on variable speed drives. The blowers are installed in three groups of three each, which means each module has a dedicated set of blowers, with 2 x duty, 1 x standby rotation.

With the current blower configuration, most machines are idle. Based on the wastewater flow and load scenarios, for the combined bioreactor/clarifier treatment capacity, a single blower can supply the aeration demand most of the time. Therefore, we considered a final scenario, which is a flow rate of 200 Ml/d in summer, of high strength raw (unsettled) wastewater. In this scenario, with combined reactor volume of 180,000 m^3 (sum of modules 1-3, plus a future module 4), we find the aeration demand on blowers are:

- six blowers delivering 19,980 (N)m^3/h each, at average load conditions.
- eight blowers delivering 23,474 (N)m^3/h each, at the peak organic load.

The scenario under which these demands need to be met by blowers is one of the worst cases, i.e. high strength wastewater, with no primary settling, and no flow balancing / homogenisation, which leads to a peak organic load / aeration peak factor of 1.5. Even in this scenario, the existing blowers can deliver enough air in a n+1 arrangement (duty, plus rotating standby).

2.7.7 Sludge dewatering

The mass balances for different scenarios for flow rate and strength of wastewater, predict Waste Activated Sludge removal of between 3 and 11 tonnes per day as dry solids. Equipment installed at the external sludge dewatering facility have a combined capacity of around 14 tonnes per day, assuming a 24 hours operation period.

2.7.8 Eastern Works Assessment

The Eastern Works biofilter capacity was calculated through methods set forth by the WRC[2]. This is a simplified model, based on organic loading (COD and TKN) and includes the volume of the biofilter reactor as well as the specific media specific surface area. Based on the hydraulic loading rates, corrected for temperature, an empirical approach is used to calculate removal efficiency. We found that although the said 55 Ml/d that the 16 biofilters were receiving, and the relatively low hydraulic loading rate of around 3.5 $m^3/m^2/d$, (range of typically 5-50 $m^3/m^2/d$), effluent quality would still not be good. We calculate that in the two scenarios of high strength wastewater, and low strength wastewater, the nitrification process doesn’t work at all, or works only to a limited extent, for summer or winter temperatures, with ammonium effluent concentrations of 31 mgN/l and 11 mgN/l respectively. This is because the COD loading is such that most of the aeration capacity is required to remove COD, which typically occurs before nitrification starts.

The COD loading on biofilters remains high, despite the presence of primary settling tanks. These tanks, however, with an average upflow velocity of 2.2 m/h is overloaded, and are expected to carry over solids to the biofilter. The PST removal of COD is therefore calculated to be less than ideal, with only around 30% removal as solids. The 12 humus tanks downstream of the biofilters also have a high average upflow velocity of 1.7 m/h, which is expected to carry over solids to the final effluent.

[2] Guidelines for the Application of Natural Stone Trickling Filters with Some Reference to Synthetic Meda, Water Research Commission publication TT178/02.

CHAPTER 3: INSPECTION OF TEMBA WASTEWATER TREATMENT WORKS

3.1 INTRODUCTION

Temba WWTW was inspected on the 26th of June 2023. The plant serves mainly Kanana, Temba and Kudube in the Hammanskraal area. The plant has a design capacity of 12.5 Mℓ/d and discharges into the Apies River. An aerial view of the works is presented in the figure below.

Figure 64: Aerial view of Temba WWTW (The Temba WWTW is around 25km downstream from the Rooiwal WWTW)

3.2 INLET WORKS

The inlet works of the Plant is located outside the premises of the main WWTW. At the time of inspection of the inlet works, there was no electricity onsite due to a cable fault at the plant and Eskom had been alerted of the power failure. There are two raw water balancing dams at the plant. The dams are characterized by algae and scum floats. The inlet works consists of one screen of which the operational condition could not be verified due to unavailability of electricity onsite.

One vortex grit chamber is installed but the grit removal pump has been taken out for inspection/repairs. Therefore, currently, there is no removal of grit from the chamber. From the grit chamber, the raw wastewater flows into a sump from which it is pumped into the main works located approximately 1 km from the inlet works. The operational status and condition of the pumps could not be assessed as the pump house was locked and there was no electricity on site. All flow was being channeled to the raw water balancing dams.

There are new inlet works consisting of two mechanical screens and two vortex grit traps, about 25km downstream for the main Temba WWTW, but this is not in use as there was never an official commissioning of the system.

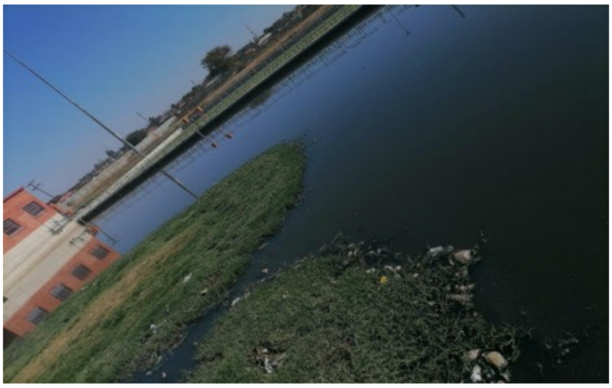


Figure 65: Condition at one of the raw water balancing dams

Figure 66: The only available grit pump removed for repairs

3.3 BIOFILTER MODULE

3.3.1 Primary settling tanks

The biofilter module inlet channel is fitted with a manual coarse and fine screen in series, after the screens a small grit TRAP is in place. The condition at this inlet works suggest that it is hardly visited as the screens are full of debris and the grit camber is full of grit. From this inlet works, raw wastewater flows into a division box which feeds three PSTs. The scum removal equipment in all three PST is not working but PCs remove the scum using skimmers. All desludging valves are working and desludging takes place twice a day, morning and evening. The sludge and scum are pumped into a sludge sump before being pumped into the Anaerobic Digesters. Only one sludge pump is installed, and the pump evidently requires maintenance. A standby pump should also be installed to allow for continuous operation should the duty pump fail.

Figure 67: Traces of duckweed indicating that there was a point where the PST was out for an extended period

Figure 68: Sludge and scum withdrawal equipment in working condition

3.3.2 Biofilters

The PSTs' effluent collects into a sump before it is pumped to the biofilters. There are three pumps installed to achieve pumping to the biofilters. However, only one pump is running, and the other two pumps are broken down. The sizes of the pumps could not be verified due to excessive water accumulation in the pump station. There are four biofilters, but only two are currently in operation. The plant supervisor indicated that this is because the third filter has excessive leaks and requires capital maintenance and was supposed to be part of the contract which installed the new BNRAS module, but this never happened.

Of the two filters currently in operation, both require unblocking of the distribution holes, one filter's center column is also leaking, and its media has a patch of grass growing on it. The distribution arms of the second filter in operation have loose end caps, resulting in overloading of the outer sections of the filter. No ponding was observed in any of the filters. The filter underdrains are well maintained with no signs of algal or vegetation growth.

Figure 69: No End-Caps on some filter arms

Figure 70: A patch of grass growing on the filter media

Figure 71: Problems on the centre column

Figure 72: Filter out of commission due to excessive leaks

3.3.3 Humus tanks

Three humus tanks are in place and in working condition. Traces of algal growth in the tanks may be an indication that the tanks have spent some time standing and not working. General maintenance is also required. The sludge withdrawal equipment is working, and tanks are desludged twice a day in the morning and afternoon. Overall, the humus tanks are in fair condition and produce a clear effluent. Humus tank effluent gravitates into a sump from which it further gravitates to the chlorine dosing point and into the contact channel.

Figure 73: Clear overflow from humus tanks, traces of algae also noted

3.4 PHASE 2 ACTIVATED SLUDGE MODULE

3.4.1 Biological Rectors

Phase two, which is the old, activated sludge module receives raw water directly from the inlet works, i.e. no primary settling in place. The AS module follows the Johannesburg process configuration and consists of two identical parallel reactors. For each reactor there are two 7.5 kW mixers and three 75 kW aerators. In the first reactor both mixers were not working but all three aerators were working, in the second reactor one mixer and one aerator were not working. Evidence of scum formation and sludge settling was observed around the mixers that are not working, which lead to dead zones. The A-recycle of the second reactor was also not working, decreasing denitrification efficiency. Overall, the reactor had an earthy smell and visually, the reactor effluent had good floc formation indicating that it is not in such bad condition.

Figure 74: Scum and sludge accumulating due to faulty mixers

Figure 75: Aerator not working

Figure 76: Good visuals of mixed liquor at the reactor effluent

3.4.2 Clarification

The effluent from each reactor basin flows into a clarifier. There was no overflow from either clarifier as the plant was not receiving flow due to the power outage at the inlet works. However, observations showed that one clarifier had minimal scum formation and the other one had significant floating scum. The reason for the excess scum in the first clarifier is the clarifiers bridge is not working. The weirs and channels were clean, and the desludging equipment was working. The operators only waste, as and when required based on the MLSS results, when MLSS exceeds 4000 mg/ℓ.

Figure 77: Excess scum formation due to faulty clarifier bridge motor

Figure 78: Leak at the sludge pump has created a serious spillage

3.5 PHASE 3 ACTIVATED SLUDGE MODULE

This module is also a BNRAS technology but was never officially commissioned, and it was indicated that the equipment was vandalized and some stolen before commission. Therefore, currently there is no flow to this module.

3.6 DISINFECTION AND CONTACT TANK

The chlorine dosing units are in a small shack next to the biofilter pumphouse. There is provision for four cylinders to be installed but there were only three cylinders connected and all dose at the same time. Therefore, no standby capacity is available which is concerning. The plant was not dosing due to no flow at the time of audit. However, the teams managed to test the equipment and it was working. Safety signage and equipment around the chlorine room is lacking. There are two carriage water booster pumps installed and both are in working condition.

At the time of inspection, the chlorine contact tank had been isolated for cleaning and the effluent was being channeled to the river without allowance for any contact time. This could lead to discharge of effluent containing high chlorine content to the river.

Figure 79: Contact tank isolated for cleaning

Figure 80: Dosing equipment without standby

3.7 SLUDGE HANDLING

Sludge from the PSTs is pumped to the four anaerobic digesters, however because the biofilter Module is receiving low flow, approximately 12.5 Mℓ/d as per supervisor's indication, there is not much sludge produced. Therefore, digestors are barely filled and the sludge is rarely removed from the digester. The problem with this is the potential blockage of the digesters. Sludge from the digester normally goes into sludge drying beds. Drying beds are in poor condition with rusted equipment and overgrown vegetation. The condition or even existence of sand in the drying beds could not be verified due to the overgrown vegetation.

The WAS from the clarifiers is pumped into a DAF unit located onsite. Visual inspection at the DAF unit suggested that the unit has been out of use for some time. Two pumps are used to recycle the underflow back to the settling tanks but only one pump was operational and the other one had been out for some time. The sludge is withdrawn into a sump before it is pumped to a sludge pond located at the inlet works. There was a leak on the running sludge pump, and this had created a serious spillage around the sludge pump area. The sludge pond at the inlet works is overgrown with reeds and vegetation, indicating lack of maintenance.

There is no operational monitoring equipment onsite, but it was indicated that samples are collected at the following points and sent to the Daspoort laboratory on a weekly basis:

- Raw
- After PSTs
- After biological reactor
- After clarifier
- After humus tanks
- Final

Figure 81: One of the DAF pumps not working

Figure 82: Poor condition of the drying beds

Figure 83: Excessive reeds and vegetation growth at the sludge ponds

Figure 84: Presence of duckweed in the DAF unit suggests long standing time

3.8 MAINTENANCE

Most of the equipment is in working condition. However, the long-standing time for the broken-down equipment suggests that maintenance is poor and if this continues there will be further breakdowns as the condition of most of the equipment is “fair” at best.

3.9 EFFLUENT QUALITY

Daily samples are collected at the Temba WWTW final effluent and sent to the city of Tshwane central laboratory located at the Daspoort WWTW. The effluent quality results for the period April 2022 to May 2023 were received and compared to the General Authorization special limits to determine the effluent compliance. The average compliance results as presented in Table 3 below indicates the following:

- The plant did not meet the minimum 95% compliance required for all the parameters listed in Table 3 below.
- Poor COD, NH_3/NH_4^+ and NO_3^-/NO_2^- compliance confirm the observations made during the site inspection where some aerators, mixers and A-recycle pumps were not working. Therefore, aeration, nitrification and denitrification processes could not be expected to function properly.

- Poor Fecal coliform compliance could be due to high chlorine demand arising from poor effluent quality or could be an indication of inadequate dosing rates or lack of dosing at time. Chlorine demand should be calculated and optimal dosing rates must be determined.

- Poor phosphate compliance could be due to inadequate aeration resulting from breakdowns aerators which affects the growth of polyphosphate-accumulating microorganisms in the aeration basin.

Table 3: Summary of effluent compliance for Temba WWTW

Total Number of samples	No. of samples complying	No. of complying samples	% Compliance
COD	397	147	37%
EC	417	298	71%
NH_3-N	426	123	29%
NO_3^-/NO_2^--N	426	32	8%
SS	372	212	57%
o-PO	426	330	77%
Faecal Coliforms	422	0	0%

By comparison to Rooiwal, even if the effluent compliance is far from compliant, there are some signs of life and this is correlated with the plant that seems to be in a somewhat better condition (still not good) than Rooiwal.

3.10 HOUSEKEEPING

There is evidence of some good housekeeping taking place at the main plant and the office area is clean, the surroundings are well kept, and grass is cut. Housekeeping was observed to be seriously lacking around the drying beds area. At the inlet works, housekeeping does not exist, overgrown vegetation and an unexplained spillage that is suspected to be water from the wetland was observed in the area. It is further suspected that the inlet works are located on a wetland.

3.11 OHS

There is a lack of safety signage and safety equipment throughout the plant and at the inlet works.

CHAPTER 4: CONCLUSIONS & RECOMMENDATIONS

4.1 FINDINGS AND CONCLUSIONS

Based on the findings from the site inspections conducted at the two wastewater treatment works, the following conclusions are made:

1) While the City of Tshwane's financial troubles are widely reported, much of the operation and maintenance required do not need additional funds, over and above those salaries paid to Operation and Maintenance staff. The salaries and wages paid seem fruitless if there's very little evidence of the added value,
2) Flow meter readings are collected from uncalibrated metres, entered against incorrect units and the inflows versus the outflows are not balanced,
3) Wastewater samples are collected and analysed, but laboratory data are saved as certificates only, and not captured in a structured database, and therefore do not contribute to useful information that should improve plant performance,
4) Unless the information gathered by the administration and management team is used to steer and improve the operation of the works, the collection of flow meter readings, and sampling and analysis of raw wastewater, process train steps and final effluent also remains a fruitless exercise. The unverified data in its current format is not useful for planning purposes,
5) The effluent is of such poor quality that it cannot be disinfected, which is the primary goal of any wastewater treatment works. Based on the final effluent quality data from the City of Tshwane, the plant fails to treat wastewater to any reasonable standard, and COD and ammonium largely resembles the raw wastewater concentrations. Whenever this is the case, then chemical disinfection is not practically possible.
6) The Rooiwal WWTW is in an extremely poor operational condition, and this is due to poor maintenance practices, and poor asset care, which in turn causes poor operational efficiencies along the treatment process train,
7) Apart from poor operations and maintenance, the housekeeping and site keeping at Rooiwal WWTW is extremely poor, and the site is unkempt and neglected, and raise concerns regarding operational Health and Safety, as well as plant security,
8) Rooiwal WWTW consist of an assembly of many old and heterogenous unique process units, some of which cannot be explained. Small design flaws are evident throughout the works, and from different eras over the plant's life. The inlet works is inadequate for a treatment plant of this capacity, especially in comparison to similarly sized treatment works,
9) Our process assessment show that the different unit processes of the three BNRAS modules are in disharmony with each other in terms of capacity. Different flow and load scenarios all point towards a bioreactor volume which is much too small, relative to other process units. The high MLSS concentration cause clarifiers to fail but increasing the number of clarifiers will not be productive under most scenarios, because the failure is due to exceeding of the maximum sludge thickening capability. In addition, the *Sludge Volume Index* is believed to be substandard, stemming from the process design, confirmed by observations of chronic scum formation on the clarifier surfaces, that date back to satellite images from 2004,
10) The Rooiwal Eastern Works reportedly receives 55 Ml/d, which is treated with biofilters. These process units date back to an age when nutrient removal was not important, and one cannot expect the biofilters to treat effluent to produce compliant effluent. Based on either low loading or high loading scenarios, the biofilters are not expected to nitrify well or at all, with calculated effluent concentrations of respectively 11 mgN/l and 32 mgN/l.
11) The three BNRAS modules have a maximum treatment capacity of around Mel/d each, based on the combined bioreactor and clarifier system, i.e. a total of only 120 Ml/d of nutrient removal capacity.
12) We believe that the turbo blowers have a combined aeration capacity equivalent of 200 Ml/d under the high strength wastewater scenario,

13) The Rooiwal Northern and Eastern works are operating far above capacity, even if the equipment were in operation, and the effects are worsened by the poor condition of mechanical / electrical equipment on the plant,
14) The Rooiwal Western works is completely out of commission, with trees growing from the trickling filters,
15) Rooiwal WWTW fails completely in its aim, which is to produce effluent of an acceptable quality,
16) The mechanical and electrical failures at Rooiwal WWTW, as well as process flaws, did not occur because of a series of recent breakdowns, but the condition of equipment, and the state of the works suggest the failures are caused by decades of neglect and poor decision making,
17) Temba WWTW is currently in a better condition than Rooiwal, but maintenance is also lacking, and that this plant will eventually fall into the same state of disrepair without an urgent turn-around strategy,
18) The Temba WWTW activated sludge plant is only partially constructed.

4.2 RECOMMENDATIONS

1) The current administration and management of the Rooiwal and Temba Wastewater Treatment Works must account for their lack of performance in those areas where they have control, and where they continue to expend cost on salaries, but without any benefit to the works,
2) Collection of data and recordkeeping must add value and the City of Tshwane must start a campaign to calibrate equipment, verify and beneficiate raw data, and to abstract useful information for planning purposes, so that eventual upgrades of the works can be based on sound evidence. Since the City of Tshwane neglects this duty, it is recommended they obtain the assistance of professional experts (scientists and engineers) for this campaign,
3) The obvious refurbishment works and salvaging of mechanical and electrical equipment must proceed forthwith, as an emergency project, and must include those items that will bring the works to life again, such as the following, in Phase 1:
   a. Inlet Works: screens, degritting equipment, sludge pumps at primary settling tanks, and balancing tanks,
   b. BNRAS reactors: submersible mixers in unaerated zones, A-recycle pumps,
   c. Clarifiers: clarifier bridges, RAS pumps, scum removal, structural repair to concrete surfaces,
4) While there is much attention for the eventual upgrade of the works, it is not at all obvious how this should be done, given our conclusion that the different process units are not well integrated, and given that the capacity of aerators is adequate to already treat 200 Ml/d. A business-as-usual approach to the appointment of engineers and contractors could easily perpetuate this mismatch. Our recommendation is therefore to appoint an expert wastewater engineer to develop a plant-wide model, from the inlet works through to the sludge digestion and dewatering. This model must then be used to develop a **masterplan** for the works. We recommend this masterplan should include ideas and suggestions, for consideration such as the following, in Phase 2:
   a. Inlet Works: plan for the replacement of the entire inlet works, with modern equipment and taking proper care of the unfavourable hydraulic profile, to remove debris and grit effectively, and split flow properly to different modules.
   b. Aeration: modify the three individual aeration pipe manifolds (one per module) to a common manifold, from which all modules, including a future module, will receive air, and modify the master control system to ensure process optimisation. At the same time, modify and replace sections of pipework on the existing reactors, where air pipe diameters are far too small. Plan a sequenced mid-life refurbishment programme of the 9 x existing 600kW blowers so their life expectancy can be extended to at least 2037 (i.e. 25 years since installation in 2012) and appoint a specialist contractor with a Service Level Agreement for the maintenance of these machines.
   c. BNRAS: reconfigure the existing three modules to work according to the modified UCT process, or the Johannesburg process configuration, by considering rotation of flow through mixer directions and recycle flows,

d. Total Reactor Volume: consider options to increase the reactor volume of module 4 (future) such that the whole of the works can have workable MLSS concentrations (i.e. maximum < 5,000 mgTSS/l), given the finding that the reactor volumes of Module 1-3 are too small for the current clarifier and aeration capacity, or consider an additional extremal volume for Module 1-3, e.g. upstream anaerobic zones, or downstream anoxic zones at the RAS pumps, and/or continually exchanging sludge between Modules in a grow/waste dynamic operation. These ideas require rigorous dynamic mathematical modelling.
e. New module: Plan a new module to receive a larger organic load, proportionally to the three existing modules, to lower the MLSS concentration in Modules 1-3 and still have the benefits of the large clarifier capacity to handle the hydraulic loads of peak flows. The Eastern Works is not optimised for nutrient removal and a new BNRAS Module should be designed to handle its flow as well.
f. Western Works: refurbish the old biofilters to treat all sludge reject water (filtrate and supernatant) that is normally high in ammonium, but a low flow, before returning to the environment, and rather than feeding this stream into the bioreactors. Introduce side stream process units for the precipitation of phosphate as struvite or similar beneficiated waste-based fertilizer.
g. Eastern Works: refurbish and repurpose the biofilters to polish final effluent to remove dissolved organic carbon to very low concentrations (in a lead/feast-lag/decay sequential process configuration) to reclaim effluent directly for drinking water.
h. New reclamation plant: design – as part of the upgrade project – a modern reclamation plant, downstream of suggested polishing steps, which will further treat through processes of rapid sand filtration, membrane technology and advanced oxidation, water to SANS 241 Drinking Water standard.

5) The staff responsible for operations and maintenance at the Wastewater Treatment Works should either be upskilled and placed under the management of competent and capable professionals, or replaced by a commercial team if needs be, or alternatively, a combination of operational models needs to be found through which the current lack of performance can be turned around. This is in an urgent intervention and needs to start forthwith to arrest bad practice prior to the commissioning of a refurbished works.
6) Different contracting models should already be investigated, such as DPWI's Repair and Maintenance Programme, with a sufficiently long period of performance (greater than the normal 36 months), or a Public Private Partnership, including goals set against the Green Drop System, etc. to run the works according to principles of professional process control, with performance-based remuneration.
7) A professional team, working against strict monitoring criteria, must be entrusted with reclamation of final effluent for drinking water, to build a more resilient water supply future, while at the same time reducing the environmental damage to the Apies River.
8) While the abstraction from the Leeukraal Dam for drinking water production is not referred to as drinking water reclamation from effluent, this practice should be made explicitly known as such, but with the proper administration, plant management and process control to follow best practice standards.

APPENDIX 1: BNRAS MODEL CALCULATION

ROOIWAL WASTEWATER TREATMENT WORKS - STEADY STATE DESIGN			RAW WASTEWATER TREATMENT IN BNRAS (N, de-N, P)																	
Wastewater temperature	T	°C	20	20	20	20	20	20	20	20	12	12	12	12	12	12	12	12		20
Sludge retention time / sludge age	R_s	d	18	18	18	18	18	18	18	18	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0		18
Yield of biomass on COD	Y_H	gCOD/gCOD	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67		0.67
Spec. rate of endogenous mass loss, 20	$b_{H, 20oC}$	1/d	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24		0.24
Spec. rate of endogenous mass loss, T	$b_{H, ToC}$	1/d	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19		0.24
Yield of autotrophs (AOB+NOB) on N	Y_A	gCOD/gN	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24		0.24
Autotrophs, max growth rate at Temp	μ_{AmT}	1/d	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14		0.35
Spec. rate of endogenous mass loss, 20	$b_{A, 20oC}$	1/d	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04		0.04
Spec. rate of endogenous mass loss, T	$b_{A, ToC}$	1/d	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03		0.04
Endogenous residue	f_H	-	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.20
Minimum sludge age required for nitrification	$R_{s, min}$	d	5.9	5.9	6.0	6.0	5.9	5.9	6.0	6.0	20.0	20.0	20.1	20.1	20.0	20.0	20.1	20.1		7.3
			raw	settled	raw	settled	raw	settled	raw	settled	raw	settled	raw	settled	raw	settled	raw	settled		raw
Flow rate, influent, average dry weather flow	Q_{IN}	ML/d	50.0	50.0	50.0	50.0	40.0	40.0	40.0	40.0	50.0	50.0	50.0	50.0	40.0	40.0	40.0	40.0		200
COD, unfiltered (total), influent conc.	Sti	kg/ML	500	400	800	640	500	400	800	640	500	400	800	640	500	400	800	640		800
Fraction, particulate unbiodegradable, influent	fS'up	gCOD/gCOD	0.130	0.080	0.130	0.080	0.130	0.080	0.130	0.080	0.130	0.080	0.130	0.080	0.130	0.080	0.130	0.080		0.130
Fraction, soluble unbiodegradable, influent	fS'us	gCOD/gCOD	0.055	0.075	0.055	0.075	0.055	0.075	0.055	0.075	0.055	0.075	0.055	0.075	0.055	0.075	0.055	0.075		0.055
COD, biodegradable, influent, conc.	Sbi	kg/ML	408	338	652	541	408	338	652	541	408	338	652	541	408	338	652	541		652
COD mass, biodegradable influent	Fsbi	kgCOD/d	20375	16900	32600	27040	16300	13520	26080	21632	20375	16900	32600	27040	16300	13520	26080	21632		130400
Mass of Autotrophic biomass		kgCOD	6801	7480	9560	10646	5441	5984	7648	8517	11370	12478	16125	17897	9096	9982	12900	14318		37970
Mass of Ord Heterotroph Orgs in bioreactor	MX,BH,COD	kgCOD	45913	38082	73460	60931	36730	30466	58768	48745	60506	50187	96810	80299	48405	40150	77448	64239		293841
Mass of Inert Part infl in bioreactor	MX, ICOD	kgCOD	58500	28800	93600	46080	46800	23040	74880	36864	97500	48000	156000	76800	78000	38400	124800	61440		374400
Mass of endogenous residue in bioreactor	MX,EHCOD	kgCOD	39669	32903	63470	52645	31735	26322	50776	42116	69317	57495	110908	91992	55454	45996	88726	73594		253879
Effluent total suspended soilds loss	15	kgTSS/ML, kgCOD	-14985	-16583	-14985	-16583	-11988	-13267	-11988	-13267	-24975	-27639	-24975	-27639	-19980	-22111	-19980	-22111		-59940
Total bioreactor sludge mass (excl Autotrophs)	15	kgCOD	129096	83202	215545	143073	103277	66561	172436	114458	202349	128043	338743	221452	161879	102434	270994	177162		862180
Total mass in bioreactor, excl TSS effluent			144081	99785	230530	159656	115265	79828	184424	127725	227324	155682	363718	249091	181859	124546	290974	199273		922120
Error Percentage			12%	20%	7%	12%	12%	20%	7%	12%	12%	22%	7%	12%	12%	22%	7%	12%		7%
Autotrophs as percentage of heterotrophs			13%	16%	12%	15%	13%	16%	12%	15%	16%	20%	14%	18%	16%	20%	14%	18%		11%
Anaerobic volume	V_anae	ML	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58		25.00
Anoxic volume	V_anx	ML	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64	6.64		65.00
Aerobic volume	V_aer	ML	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43	14.43		90.00
Total Reactor volume	V	ML	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64	24.64		180.00
Activated sludge [$COD_{reactor}$], excl Autotrophs.		kgCOD/ML	5238	3376	8746	5806	4191	2701	6997	4644	8211	5196	13745	8986	6569	4157	10996	7189		4790
COD to VSS ratio of the sludge	f_{cv}	gCOD/gVSS	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48		1.48
Ratio of VSS over TSS in the sludge	fi	gVSS/gTSS	0.75	0.83	0.75	0.83	0.75	0.83	0.75	0.83	0.75	0.83	0.75	0.83	0.75	0.83	0.75	0.83		0.75
MLSS concentration in reactor		kgTSS/ML	4719	2748	7880	4726	3775	2199	6304	3781	7397	4230	12383	7315	5918	3384	9907	5852		4315
--- including autotrophs		kgTSS/ML	4968	2996	8229	5078	3974	2396	6583	4062	7813	4642	12973	7906	6250	3713	10378	6325		4505
Waste activated sludge, mass flux from reactor		kgTSS/d	6802	4101	11266	6952	5441	3281	9013	5562	6418	3813	10657	6495	5134	3050	8525	5196		45053
Waste activated sludge, flow rate, from Reactor	Q_WAS_bio	m3/d	1441	1492	1430	1471	1441	1492	1430	1471	868	902	861	888	868	902	861	888		10440
Waste activated sludge, flow rate, from RAS	Q_WAS_ras	m3/d	618	640	613	630	618	640	613	630	372	386	369	381	372	386	369	381		4474
S-recycle flow rate	0.75	ML/d	37.50	37.50	37.50	37.50	30.00	30.00	30.00	30.00	37.50	37.50	37.50	37.50	30.00	30.00	30.00	30.00		150.00
MLSS concentration in S-recycle		kgTSS/ML	11012	6413	18386	11028	8809	5130	14709	8822	17260	9869	28894	17069	13808	7895	23115	13655		10069
COD in Effluent (Soluble and particulate)		kgCOD/d	2208	2421	3033	3321	1766	1937	2426	2657	2208	2421	3033	3321	1766	1937	2426	2657		12130
COD in WAS (particulate)		kgCOD/d	7172	4622	11975	7948	5738	3698	9580	6359	6745	4268	11291	7382	5396	3414	9033	5905		47899
COD oxydised with Nitrate		kgCOD/d	3703	4072	5205	5796	2962	3258	4164	4637	3683	4042	5223	5797	2946	3233	4178	4638		20672
Oxygen required for COD removal: excl DN		kgO2/d	15620	12956	24993	20730	12496	10365	19994	16584	16048	13311	25676	21297	12838	10648	20541	17038		99971
Oxygen required for COD removal: with DN		kgO2/d	11918	8884	19788	14934	9534	7107	15831	11947	12365	9269	20453	15500	9892	7415	16362	12400		79299
Oxygen required for Nitrification		kgO2/d	7494	8243	10534	11731	5996	6594	8427	9385	7454	8180	10571	11733	5963	6544	8457	9386		41841
			Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD	Balanced COD		Balanced COD
Biological Nitrogen Removal (nitrification & denitrification)																				
Influent nitrogen concentration	TKNin	kgN/ML	45.0	45	65.0	65	45.0	45	65.0	65	45.0	45	65.0	65	45.0	45	65.0	65		65.0
Influent mass of Total Kjeldahl Nitrogen	TKNin	kgN/d	2250	2250	3250	3250	1800	1800	2600	2600	2250	2250	3250	3250	1800	1800	2600	2600		13000
fraction of Nitrogen in biomass solids	i_N	gN/gTSS	0.075	0.083	0.075	0.083	0.075	0.083	0.075	0.083	0.075	0.083	0.075	0.083	0.075	0.083	0.075	0.083		0.075
Nitrogen lost with solids in effluent	$TKN_{EFF, TSS}$	kgN/d	56	62	56	62	45	50	45	50	56	62	56	62	45	50	45	50		225
Nitrogen removed with Waste Activated Sludge	N_{WAS}	kgN/d	510	340	845	577	408	272	676	462	481	316	799	539	385	253	639	431		3379
Circular reference bypass iterator >>>	*copy N_{was} as figures >>>*		*510*	*340*	*845*	*577*	*408*	*272*	*676*	*462*	*481*	*316*	*799*	*539*	*385*	*253*	*639*	*431*		*3379*
Nitrogen concentration in Waste Acti. Sludge	N_{was}	gN/m^3	826	532	1379	915	661	426	1103	732	1295	819	2167	1417	1036	655	1734	1133		755
Effluent ammonium load	$NH_4^+{}_{EFF}$	kgN/d	44	44	44	44	35	35	35	35	81	81	81	81	65	65	65	65		241
Effluent ammonium concentration	$NH_4^+{}_{EFF}$	kg/Ml	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6		1.2
		Eq 5.15	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	2	1.6	1.6	1.6	1.6	1.6	1.6	1.6		1.2
Total mass of ammonium oxidised	NH_4^+ nitrified	kgN/d	1640	1804	2305	2567	1312	1443	1844	2054	1631	1790	2313	2567	1305	1432	1851	2054		9156
Return Activated Sludge flow ratio	Q_RAS / Q_in		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75		0.75
A-recycle flow ratio	Q_A / Q_in		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0		3.0
Effluent nitrate load	$NO_3^-{}_{EFF}$	kgN/d	345	380	485	540	276	304	388	432	343	377	487	541	275	301	390	432		1927
Effluent nitrate concentration	$[NO_3^-{}_{EFF}]$	kg/ML	6.9	7.6	9.7	10.8	6.9	7.6	9.7	10.8	6.9	7.5	9.7	10.8	6.9	7.5	9.7	10.8		9.6
Nitrogen gas mass, removed to atmosphere	$N_{2\ OUT}$	kgN/d	1295	1424	1820	2027	1036	1139	1456	1621	1288	1413	1826	2027	1030	1131	1461	1622		7228
			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
			Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot	Balanced Ntot		Balanced Ntot
Oxygen demand / mechanical aeration						***Summer** air & water temperatures*								***Winter** air & water temperatures*						
Average daily biological oxygen demand		kgO2/d	19412	17127	30322	26665	15530	13701	24258	21332	19819	17449	31025	27233	15855	13959	24820	21786		121140
Organic load factor		---	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.5	1.5	1.5	1.5	1.50	1.50	1.50	1.50		1.50
Oxygen demand, at load factor		kgO_2/h	1213	1070	1895	1667	971	856	1516	1333	1239	1091	1939	1702	991	872	1551	1362		7571
Fine Bubble Diffused Aeration																				
Actual oxygen transfer efficiency @ water m	4.17	AOTE	8.8%	14.2%	13.6%	13.8%	14.3%	14.4%	13.9%	14.0%	17.5%	17.6%	17.2%	17.3%	17.3%	17.4%	16.9%	17.1%		13.6%
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Oxygen supply rate @ overall efficiency (%)		kgO_2/h	8432	7396	13546	11798	6642	5837	10573	9238	7067	6196	11255	9816	5713	5002	9152	7964		55606
Actual air requirement, based on peak load		$(A)m^3/s$	10.82	9.49	17.38	15.14	8.52	7.49	13.56	11.85	7.74	6.79	12.33	10.75	6.26	5.48	10.03	8.72		71.34
Number of reactors supplied per Module			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		8
Air flow rate, Rx **Zone 1**, per diffuser, for tota	3149	$(S)m^3/h$ /diffuser	17.32	1.83	3.35	2.92	1.64	1.44	2.62	2.29	1.49	1.31	2.38	2.07	1.21	1.06	1.93	1.68	*41%*	3.44
Air flow rate, Rx **Zone 2**, per diffuser, for tota	1756	$(S)m^3/h$ /diffuser	2.26	1.83	3.35	2.92	1.64	1.44	2.62	2.29	1.49	1.31	2.38	2.07	1.21	1.06	1.93	1.68	*23%*	2.83
Air flow rate, Rx **Zone 3**, per diffuser, for tota	1756	$(S)m^3/h$ /diffuser	2.26	1.83	3.35	2.92	1.64	1.44	2.62	2.29	1.49	1.31	2.38	2.07	1.21	1.06	1.93	1.68	*23%*	2.83
Air flow rate, Rx **Zone 4**, per diffuser, for tota	940	$(S)m^3/h$ /diffuser	3.37	1.83	3.35	2.92	1.64	1.44	2.62	2.29	1.49	1.31	2.38	2.07	1.21	1.06	1.93	1.68	*12%*	4.23
Number of blowers running			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		8
Actual air mass flow rate per blower, @ no		kg(A)air/s	5.30	4.65	8.52	7.42	4.18	3.67	6.65	5.81	4.30	3.77	6.84	5.97	3.47	3.04	5.56	4.84		8.75
Normal air requirement, per blower		$(N)m^3/s$	3.95	3.47	6.35	5.53	3.12	2.74	4.96	4.33	3.31	2.91	5.28	4.60	2.68	2.35	4.29	3.74		6.52
Blower percentage turndown (approximate position)			62%	55%	100%	87%	49%	43%	78%	68%	52%	46%	83%	72%	42%	37%	68%	59%		103%
Total differential pressure, at diffuser depth (n	4.17	kPa	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0		50.0
Thermodynamic air outlet temperature		K	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	310.8	310.8	310.8	310.8	310.8	310.8	310.8	310.8		350.0
Thermodynamic power demand (heat increase)		kW	224	196	360	313	176	155	281	245	163	143	260	227	132	116	211	184		369
Turbo blower/gearbox assembly efficiency, @ input shaft			80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%		80.0%
Power demand; turbo-compressor		kW	280	246	450	392	221	194	351	307	204	179	325	283	165	144	264	230		462
Power demand; motor absorbed current @ η	95.0%	kW	295	259	474	412	232	204	370	323	215	188	342	298	174	152	278	242		486
Calculated Aeration Efficiency (wire-to-water)		kgO2/kWh	2.1	2.1	2.0	2.0	2.1	2.1	2.1	2.1	2.9	2.9	2.8	2.9	2.9	2.9	2.8	2.8		1.9

			SUMMER								WINTER									
			High Flow				Low Flow				High Flow				Low Flow					
CLARIFIER DESIGN		**SYMBOL**	low/raw	low/settled	high/raw	high/settled	low/raw	low/settled	high/raw	high/settled	low/raw	low/settled	high/raw	high/settled	low/raw	low/settled	high/raw	high/settled	**UNITS**	***REF. WRC ('84)***
Sludge retention time		SRT	18	18	18	18	18	18	18	18	30	30	30	30	30	30	30	30	d	
Influent flowrate		Qi	50 000	50 000	50 000	50 000	40 000	40 000	40 000	40 000	50 000	50 000	50 000	50 000	40 000	40 000	40 000	40 000	m3/d	
MLSS concentration		Xt	4 968	2 996	8 229	5 078	3 974	2 396	6 583	4 062	7 813	4 642	12 973	7 906	6 250	3 713	10 378	6 325	mgTSS/l	
Underflow recycle ratio		s	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750		
Select diluted sludge volume index		DSVI	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	140.0	ml/mg	
Stirred specific volume index		SSVI	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	93.8	ml/mg	
Sludge settling characteristic constant		Vo/n	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1		
Sludge settling characteristic constant		n	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416		
Sludge settling characteristic constant		Vo	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30		
Sludge settling velocity (incorporating safety factor %)	80%	Vs	0.637	1.449	0.164	0.609	0.964	1.859	0.325	0.929	0.195	0.730	0.023	0.188	0.374	1.075	0.067	0.362	m/h	*Eq 8.14*
ADWF rate peak factor (without flow balancing)		PF	1.50	1.50	1.50	1.50	2.50	2.50	2.50	2.50	1.25	1.25	1.25	1.25	1.75	1.75	1.75	1.75		
Max inflow (peak wet weather flow)		PWWF	3 125	3 125	3 125	3 125	4 167	4 167	4 167	4 167	2 604	2 604	2 604	2 604	2 917	2 917	2 917	2 917	m3/h	
Settling tank area required (overflow rate < sludge settling vel		A	4 902	2 157	19 049	5 131	4 322	2 241	12 803	4 483	13 349	3 567	114 340	13 880	7 802	2 714	43 492	8 049	m2	*Eq 8.29*
Stilling well area at inner diameter		5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	m2	
Select number of tanks		n	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
Required tank diameter		D	32.3	21.5	63.6	33.1	30.4	21.9	52.2	30.9	53.3	27.6	155.8	54.3	40.7	24.1	96.1	41.4	m	*30.0*