WATER RESEARCH COMMISSION RESEARCH REPORT TT800-19

APPENDIX 1

SITE RESEARCH REPORT

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CHAPTER 1: ‘Z’ Wastewater Treatment Plant

The ‘Z’ WWTP is located in Pretoria North. It lies north of Roodeplaat Dam (refer to Figure 1). The plant treats primarily domestic wastewater and some industrial wastewater. The works are owned and operated by the City of Tshwane Metropolitan Municipality (CoT).

In phase 1 of construction the plant (Module 1) was designed to treat 30 Mℓ/day using two biological nutrient removal (BNR) reactors, its’ start-up was made in June 1990. Due to the lower than initially expected raw sewage concentrations, the current maximum capacity of Module 1 is up to 45 Mℓ/day. In phase 2, an additional 40 Mℓ/day module (Module 2) was started-up in June 2014, to increase the overall capacity of the works to 85 Mℓ/day.

Phase 3 of construction was planned and designed, but the implementation is currently on-hold. This phase will implement a tertiary level of treatment with additional final settling tanks, chemical precipitation of phosphorous with metal salts and filtration.

Figure 1: Aerial view of ‘Z’ WWTP (Google Earth, 2016)

1.1 Process description

A description of the works is indicated below as per information collected from the Golder Associates Report (2007) and from the mechanical operation and maintenance manual available on site. The general process flow diagram of the treatment works is provided in Figure 2:

- **Inlet works** consists of:
  - Three mechanical front raked coarse screens (8 mm) and one manual screen on standby for the overflow.
  - Five vortex degritters.
  - Splitter box to divide the flow per two modules.

- Fine rotary drum screens (3 mm) upstream of the PSTs (one screen for Module 1 and two (duty/standby) for Module 2).

- **Module 1** consists of:
  - Four PSTs (22 m diameter).
  - Primary sludge is not wasted in the PSTs, rather these units are operated as fermenters. The PSTs are on a 4-day retention cycle, where one of the 4 PSTs pumps the fermented sludge to the balancing tank. There is an option to pump the sludge directly to the biological reactors, digesters or fermenters.
  - Balancing tank (5 000 m^3).
  - Two biological reactors including nitrogen and phosphorus removal (19 575 m^3 each) including 18 compartments divided in 5 anaerobic, 5 anoxic and 8 aerobic zones. Nitrates are recycled with 6 duty a-recycled pumps. Reactors are aerated with fine bubble diffusion and there are 3 duty/1 standby blowers with VSD per reactor.
  - Four final settling tanks (FSTs) (32 m diameter) with two separated units per reactor.
  - Two rapid sand filters with continuous backwash. Each sand filter unit has 114 cells and is 166 m^2.

- **Module 2** consists of:
  - Three PSTs (25 m diameter).
  - PS is wasted in the northern most unit to the PS fermenters/thickeners.
  - The other two units are on a 4-day retention cycle, with one of the 2 PSTs pumps the fermented sludge to the balancing tank.
  - Balancing tank (12 000 m^3).
  - Two biological reactors including N and P removal (19 575 m^3 each) including 18 compartments divided in 5 anaerobic, 5 anoxic and 8 aerobic zones. Nitrates are recycled with 6 duty a-recycled pumps. Reactors are aerated with fine bubble diffusion and there are 3 duty/1 standby blowers with VSD per reactor.
  - Four FSTs (35 m diameter) with two separated units per reactor.

- **Disinfection** consists of:
  - The tertiary effluent and biological effluent from Modules 1 and 2 respectively feed into two chlorine contact tanks.
  - Treated effluent is stored in a maturation dam which has an overflow into the Roodeplaat Dam. If the effluent quality is substandard, there is a possibility to bypass the treated effluent and discharge it directly into the Roodeplaat Dam.

- **Sludge handling and disposal** consists of:
  - PS from one of the 3 PSTs in Module 2 is pumped to fermenters. The PS is then pumped to the ADs.
  - Biological sludge is pumped from the biological reactors to the dissolved air floatation (DAF) tanks in addition to Module 1's sand filter backwash.
  - Thickened biological sludge is pumped to the ADs.
  - Primary and biological sludge are digested in two mesophilic anaerobic digesters including mixing and heating (6 000 m^3 each).

  - Digested sludge is stored and mixed in a day tank and is subsequently dewatered in 7 belt presses, however, currently only 4 belt presses are operational.

- **Return liquors treatment** consists of:

  - Dewatering return liquors are taken to two precipitation tanks where a lime slurry is dosed to increase the pH and precipitate orthophosphate. The same precipitation tanks were designed to strip ammonia, but the aeration system was not installed.
  - The precipitate is settled out via two sedimentation/thickening tanks (10 m diameter each).
  - The thickened sludge is transported to the day tank and the treated return liquors are pumped to the beginning of Module 2 PSTs.

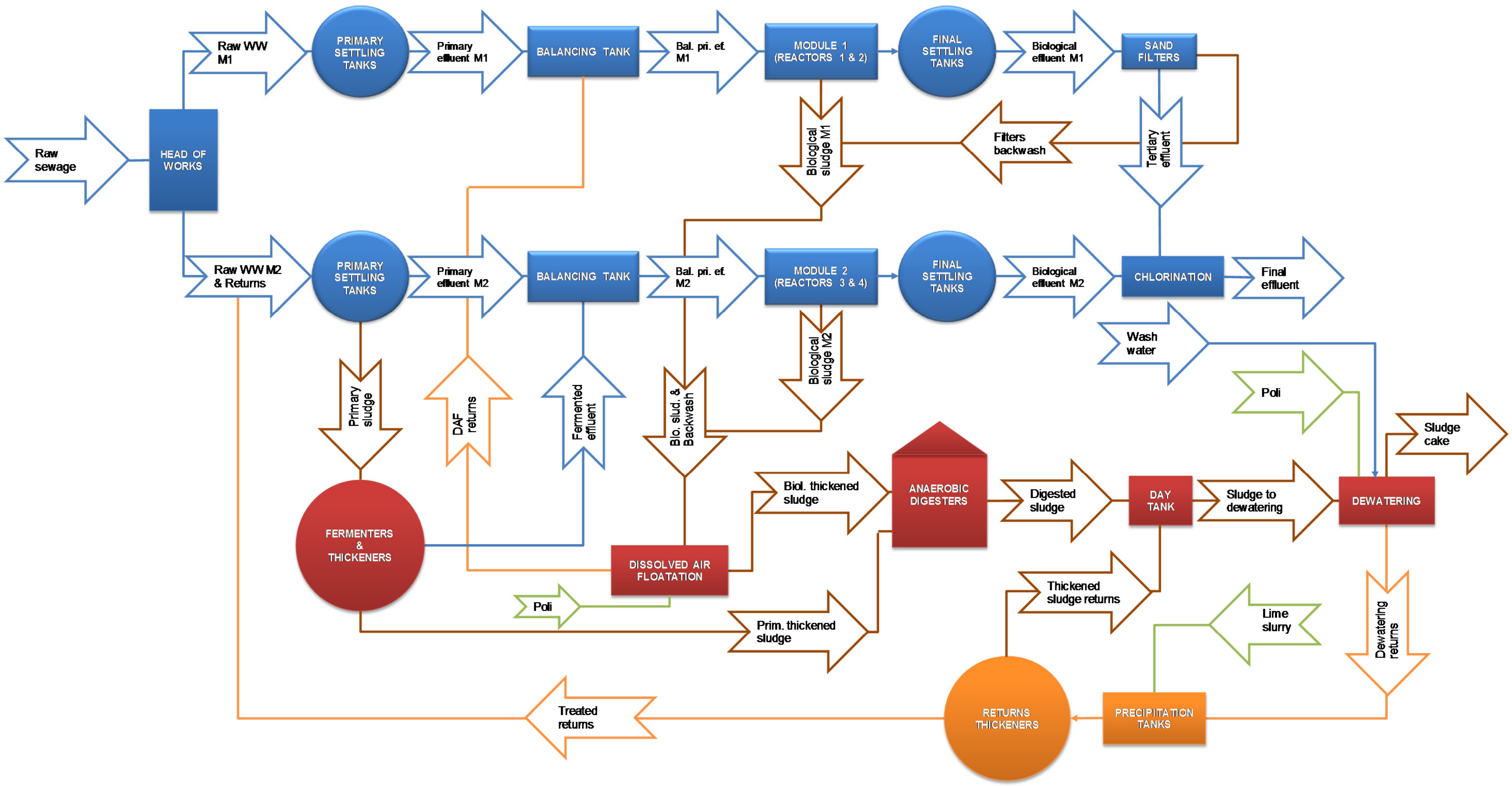

Figure 2: General process flow diagram of 'Z' WWTP

1.2 Design capacity

The total design capacity of the plant is indicated in Table 1. It is noted that the original designs of the two modules did not consider the additional load and flows from the sludge return liquors.

Table 1: Design flows and loads at 'Z' WWTP

Parameters	Module 1	Module 2	Total
Flow (Mℓ/d)	45	40	85
COD (kg/d)	22 500	20 000	42 500
TKN (kg/d)	2 100	1 867	3 967
TP (kg/d)	390	347	737

1.3 Effluent standard requirements

The latest water use license for 'Z' WWTP was granted to CoT in 2011 by the Department of Water Affairs. The water use license number is 27/2/2/A223/101/8. The final treated effluent requirements currently stipulated in the water use licence are as per Table 2.

Table 2: Effluent requirements for 'Z' WWTW

Parameter	Effluent standards	Method of compliance
COD (mg/ℓ)	50.0	90% compliance
TSS (mg/ℓ)	10.0	
NH_4 (mg N/ℓ)	1.0	
$NO_3 + NO_2$ (mg N/ℓ)	6.0	
PO_4 (mg P/ℓ)	0.1	

1.4 Technical performance

'Z' WWTP appears to be a well operated and maintained facility. The plant has a reasonable level of automation, including SCADA system. The operation team on site consists of only 4 process controllers divided by 3 shifts per day and a plant manager. Financial constraints have been affecting the appointment of additional process controllers as well as delaying the construction of phase 3.

On 20 September 2016, a site audit was held, and the following items were referred as the main points for beneficiation from the technical point of view:

- Waste activated sludge pumps were out of service. This was an isolated occurrence and currently already resolved.
- The new fermenters/thickeners for primary sludge are not helping to improve the quantity of volatile fatty acids that would allow a more efficient biological phosphorous removal. Per the experience of the operations team on site the biological phosphorous removal is optimised when using the PSTs as fermenters. Thus, the new fermenters/thickeners are no longer in operation.
- The anaerobic digesters are still not properly heated due to:
    - boilers and heating equipment were not operational, and the licensing process was to be finalised.
    - biogas storage in the double membrane gasholders is still not occurring since the gasholders were not installed yet.

- 3 out of 7 belt presses require to be serviced by the contractor (belt presses are still under the liability period).

- Critical struvite formation was constantly blocking the return liquors pumps and pipelines. As per the information from site, the struvite is only formed after the return liquors are precipitated with hydrated lime. To minimize the struvite formation, the operation team has been flushing the return liquors with final effluent daily.

1.5 Process performance

1.5.1 Influent characteristics

As indicated in the Figure 3 during the operational window selected (January 2015 to June 2016) 'Z' WWTP treated on average a total of 59 Mℓ/d (69% of the design capacity). The split between the two modules was on average 40% to Module 1 and 60% to Module 2, once during most of this period only one BNR reactor was operational in Module 1.

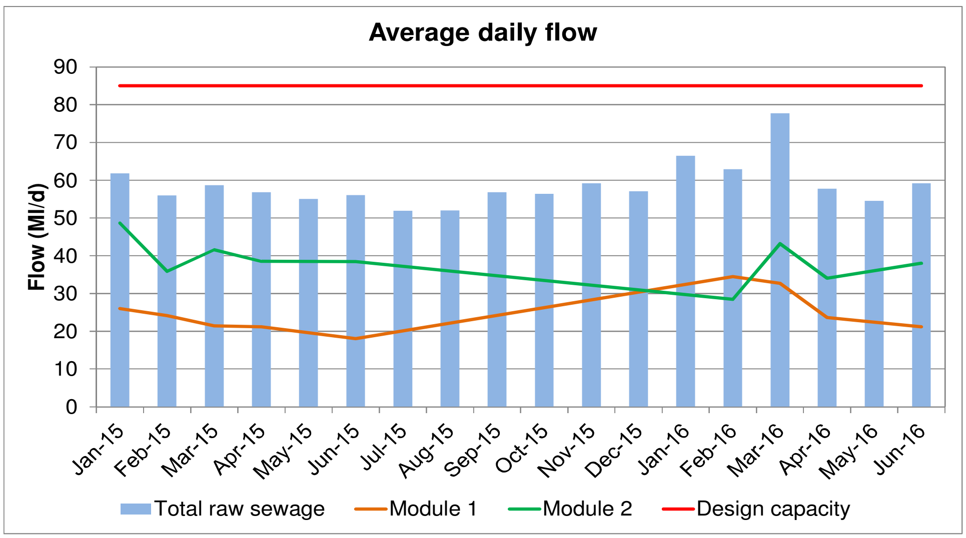

Figure 3: Average daily flow at 'Z' WWTP

The average influent concentrations and loads are indicated in Table 3 as well as the historical averages in Figure 4 and Figure 5. In general, the raw sewage shows a higher dilution rate than expected at the design stage. Currently the plant is treating 41% of the COD design load, 48% of the TKN design load and 30% of the TP design load.

Table 3: Average raw sewage concentrations and loads at 'Z' WWTP

Parameter	Average concentration (January 2015 to May 2016)		Average load (January 2015 to May 2016)	
COD	295	mg/ℓ	17 303	kg/d
TSS	136	mg/ℓ	7 971	kg/d
TKN	32	mg/ℓ	1 885	kg/d
NH_4	24	mgN/ℓ	1 435	kg/d
$NO_3 + NO_2$	0.07	mgN/ℓ	4.0	kg/d
PO_4	1.7	mgP/ℓ	101	kg/d
TP	3.7	mg/ℓ	217	kg/d

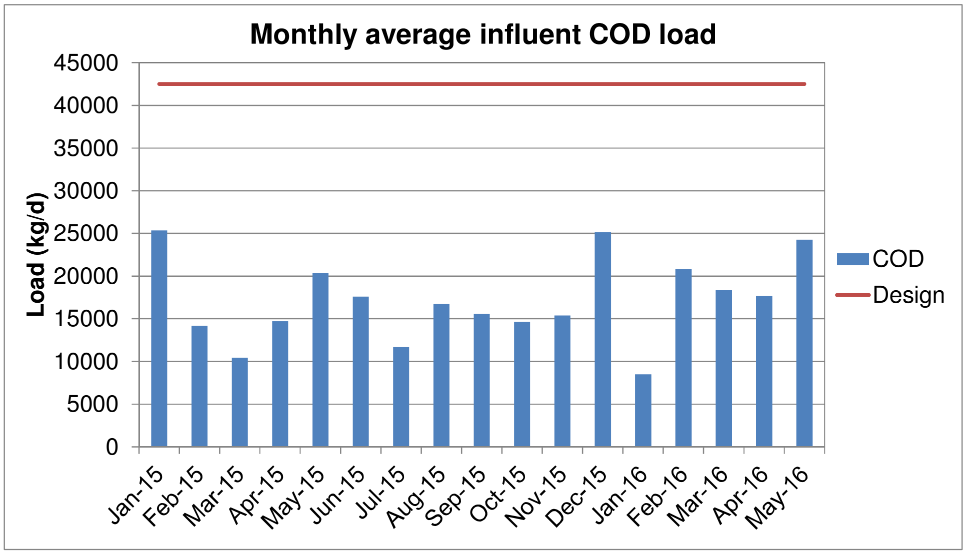

Figure 4: Average COD load at 'Z' WWTP

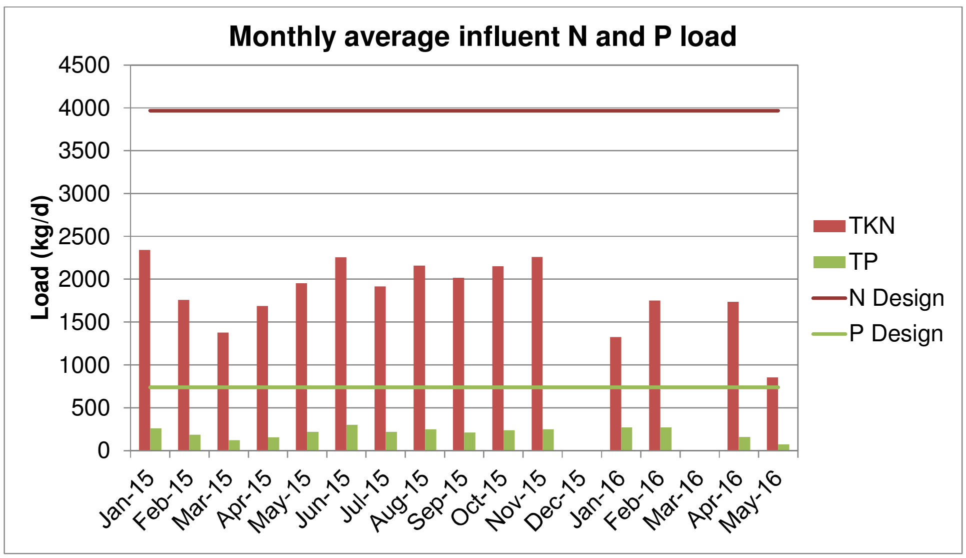

Figure 5: Average TKN and TP loads at 'Z' WWTP

1.5.2 Effluent quality

Considering the very stringent effluent standard requirements (Table 4) applicable at 'Z' WWTP, the plant shows an excellent performance regarding COD and TSS removal with 100% compliance in the research period (Table 4). However, with respect to nitrate plus nitrite and orthophosphate, the plant performance requires optimization as the average compliance rates were only 18% and 29% respectively (Table 4). Despite these non-compliances, the plant has a remarkably low average orthophosphate effluent quality (0.2 mgP/ℓ) considering only biological *P* removal is in place. The historical monthly average concentrations in the final effluent from January 2015 to May 2016 is in Figure 6 and Figure 7.

Table 4: Average final effluent quality and plant compliance at 'Z' WWTP

Parameter	Effluent quality standards	Average concentration (January 2015 to May 2016)	Average compliance (January 2015 to May 2016)
COD	50	30 mg/ℓ	100%
TSS	10	4.6 mg/ℓ	100%
NH_4	1.0	0.4 mgN/ℓ	88%
$NO_3 + NO_2$	6.0	7.6 mgN/ℓ	18%
PO_4	0.1	0.2 mgP/ℓ	29%

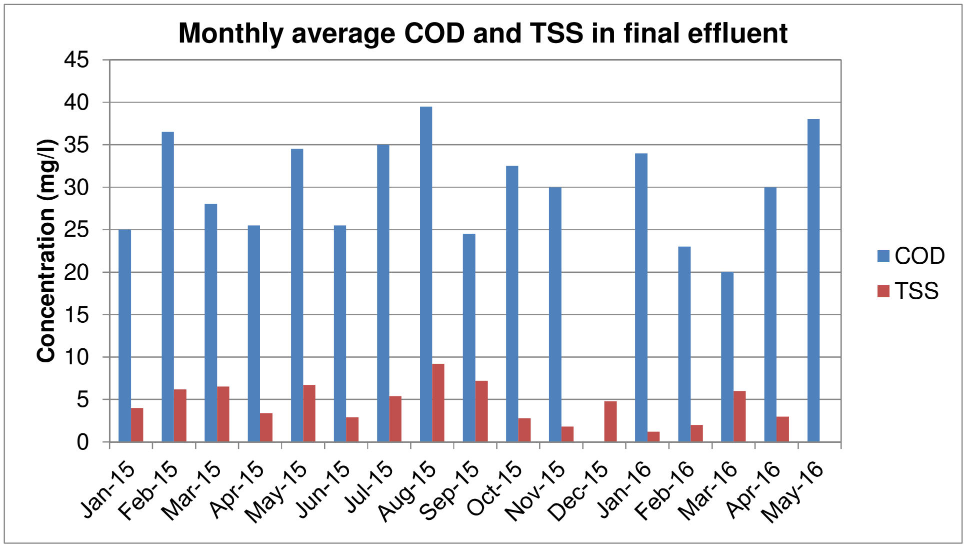

Figure 6: Monthly average COD and TSS in the final effluent at 'Z' WWTP

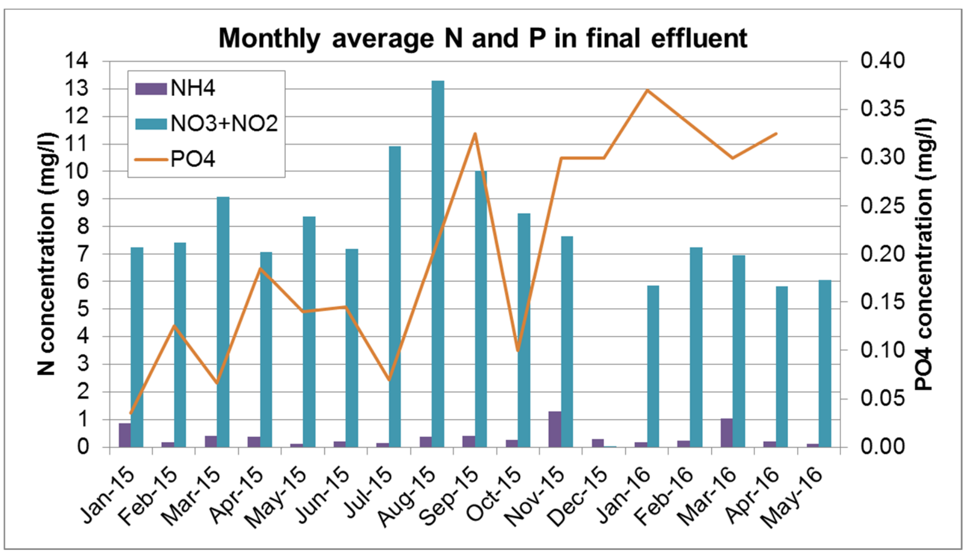

Figure 7: Monthly average ammonia, nitrate+nitrite and orthophosphate in the final effluent at 'Z' WWTP

1.5.3 Sludge treatment

1.5.3.1 Sludge characteristics

At 'Z' WWTP, PS is only extracted from one of three PSTs at Module 2. The remaining 6 PSTs (four on Module 1 and two on Module 2) are operated as fermenters to increase the hydrolysis processes and augment the quantity of VFAs which facilitates a more efficient biological P removal. Therefore, the biological system is essentially operated based on an extended aeration configuration. Consequently, the plant tends to have; a higher energy consumption, additional secondary sludge production, lower stabilisation of the secondary sludge and a lower biological capacity compared to the original design.

Table 5 indicates the characteristics of the PS and WAS prior floatation and AD. As the plant's analytical programme does not monitor the PS nor WAS (before floatation), the indicated values are only an estimate.

Table 5: Characteristics of the primary and biological sludge at 'Z' WWTP

Parameter	Primary sludge (from PST)	Biological sludge (*)	
		Before floatation	After floatation
Flow (m³/d)	100	2 800	250
Dry solids (%)	1.2	0.33	3.5
Sludge mass (kg/d)	1 166	9 211	8 750

(*) Including the sludge in the backwash water from the rapid sand filters.

1.5.3.2 Sludge floatation

The floatation or thickening process is only applied to sludge wasted from the biological reactors and the backwash water from the rapid sand filters. The thickening occurs in 4 DAF units. Historical performance of the biological thickened sludge is presented in Figure 8. The dry solids content of the biological thickened sludge is between 3.0% and 4.5% (w/v), however, per the experience of the plant operational team it is extremely difficult to pump concentrations above 3.5%. Therefore, few of the analytical values may be over measured. The organic fraction is about 75%. The average operational solid load is about 3.7 kg/m².h, below the design sludge load (4.0 kg/m².h).

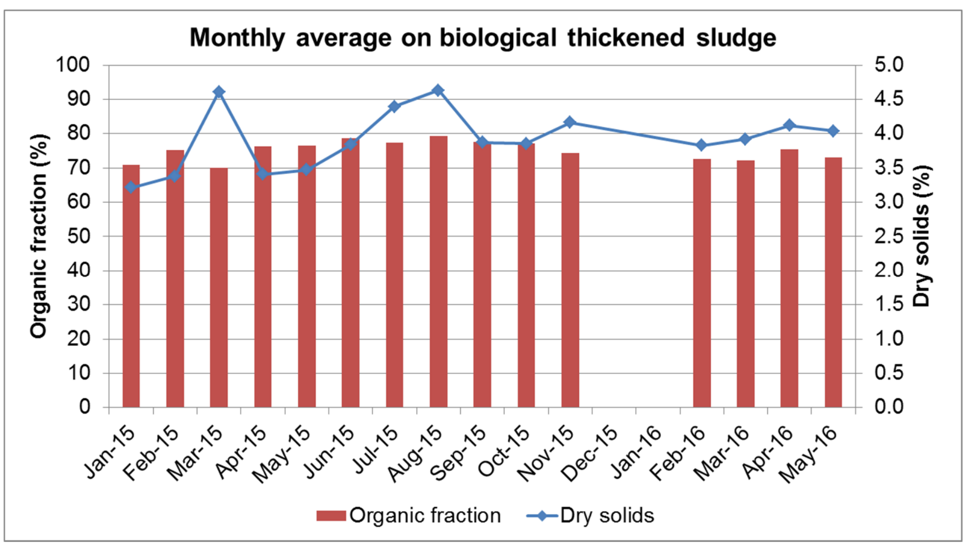

Figure 8: Monthly average organic fraction and dry solids content in the biological thickened sludge at 'Z' WWTP

1.5.3.3 Anaerobic sludge digestion

Primary and biological sludge are digested under mesophilic conditions in two ADs, pumped mixed and heated. The ADs have been in operation since January 2016, however several issues occurred during the commissioning of the gasholders and boilers, as well as with the licensing of the last units. These hurdles have been creating critical challenges to the heating system, thus the digesters are being operated with temperatures below the optimal temperature: 33ºC to 37ºC. The max temperature reached in the digesters was approximately 30ºC and only during a few weeks. Since the start-up, the digesters have been running at ambient temperature (15ºC to 30ºC) at most times. At this range of temperatures, the anaerobic stabilization of the sludge is slower and less efficient when compared with stable heated anaerobic digesters.

From February 2016 to May 2016, the dry solids content in the digested sludge was stable and approximately 2.5% (w/v) and the organic fraction was on average 68% (Figure 9). The average retention time in the anaerobic digesters was approximately 40 days. Typically for digesters in mesophilic conditions (35ºC), the minimum recommended retention time is 20 days. If the AD occurs at ambient temperatures around 20ºC, it is recommended that there is at least 60 days of retention time for reasonably mixed digesters. In fact, the destruction of VSS in the ADs was on average 32%, which appears reasonable considering that 90% of the sludge has a biological origin. In theory, the destruction rate could be slightly higher, varying from 34% to 37%, if the digestion temperature was about 35ºC.

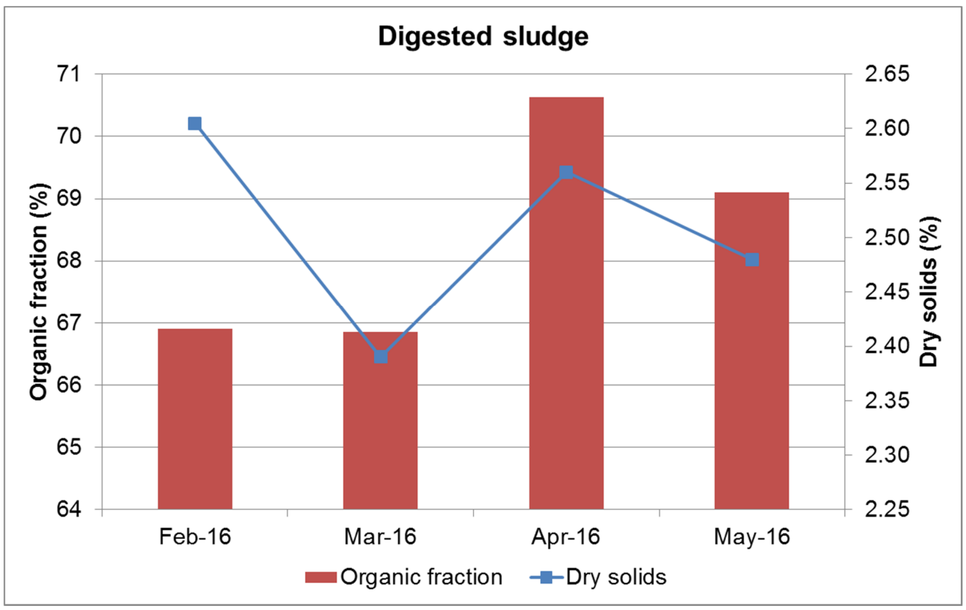

Figure 9: Monthly average organic fraction and dry solids content in the digested sludge at 'Z' WWTP

1.5.3.4 Sludge dewatering

During the monitoring period (February to May 2016), only 4 out of 7 belt presses were in operation. Typically, the belt presses have been running 8 hours per day and 7 days per week.

Per the few analytical results available, the average dry solids content in the sludge cake was approximately 13% (Figure 10) which is slightly lower than the typical range coming out of belt presses (15% to 18%). The dewatering facility has only been in operation since January 2016, therefore, further optimisations may be required to improve the dryness of the sludge cake.

On average these 4 belt presses have been running within the solids and hydraulic design loads capacities, i.e. approximately 240 kgDS/h/belt press (design capacity is 714 kgDS/h/belt press) and approximately 9 m³/h/belt press (design capacity is 35 m³/h/belt press).

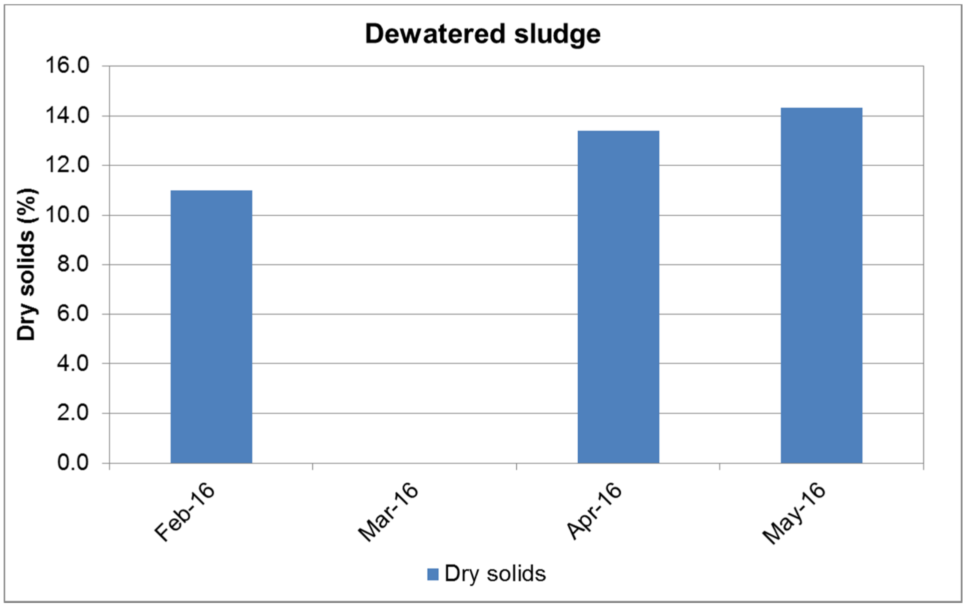

Figure 10: Monthly average dry solids content in the dewatered sludge at 'Z' WWTP

1.5.4 Treatment of dewatering sludge return liquors

The filtrate from the belt presses is routed to two precipitation channels where hydrated lime, in a slurry form, is dosed to promote the reduction of phosphate (through precipitation). Ammonia stripping is not possible as the reaction tank doesn't have an aeration system.

The recorded monthly average orthophosphate and ammonia concentrations in the dewatering return liquors from February to September 2016, are indicated in Figure 11. The average concentrations were approximately 323 mg NH_4-N/ℓ and 269 mg PO_4^--P/ℓ. The ratio of ammonia to orthophosphate in the return liquors appears unbalanced with very high orthophosphate concentrations compared to ammonia. It can be partly explained by the significant bio-P activity (high P content sludge), but the prepared mass balance shows a different ratio then observed and there is no clear reason to justify it. The ammonia concentration in the dewatering return flows is much lower than the ammonia concentration in the digested sludge. As there are no active processes for the removal of ammonia in the sludge return liquors line the most likely reason would be dilution. However, the dilution caused by the wash water pump is not sufficient to justify the difference. Further investigations would be required to identify this observation.

After precipitation, the treated dewatering returns showed concentrations about 215 mg NH_4 N/ℓ and 190 mg PO_4^-P/ℓ. The average removal efficiency of ammonia and orthophosphate has been poor and only about 28% and 32% respectively (Figure 12). Moreover, it appears that most of the reduction in orthophosphate and ammonia concentrations is due to dilution from the lime slurry dosed in the reaction tank.

From January to September 2016, the lime dosage was about 30 kg $Ca(OH)_2$/h on average, corresponding to 0.6 g $Ca(OH)_2/\ell$. The design dosing rate was 70 kg $Ca(OH)_2$/h, corresponding to approximately 0.3 g $Ca(OH)_2/\ell$. Although there are pH meters installed in the precipitation tanks, the sensors are out of service and therefore there is no indication if the optimum pH (± 9.5) has been achieved. Considering the low P removal efficiency, the lime dosage appears to be insufficient.

The lime dosing is causing a critical struvite formation which has been constantly blocking the return liquors pumps and pipelines. Struvite formation has not been detected in any processes upstream of the precipitation tanks.

Generally, the low efficiency of the current treatment facility for sludge return liquors indicates that the existing solution requires further optimisation and/or replacement.

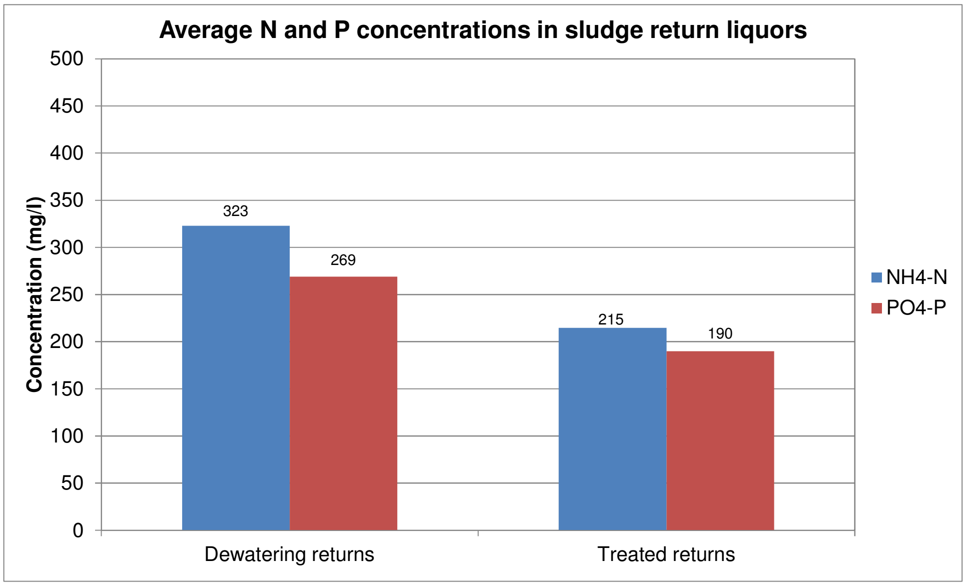

Figure 11: Average ammonia and orthophosphate concentrations in the sludge return liquors at 'Z' WWTP

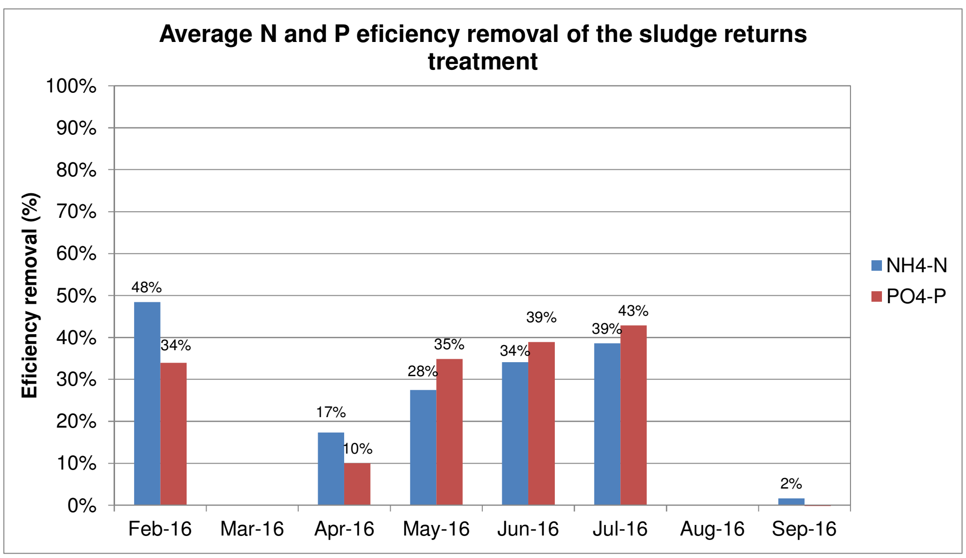

Figure 12: Average ammonia and orthophosphate efficiency removal in the SRL treatment facility at 'Z' WWTP

1.6 Impact of the sludge return liquors

1.6.1 Plant mass balance

A complete mass balance of the 'Z' WWTP was prepared to understand and evaluate the magnitude of the impacts of the sludge dewatering return liquors on the main treatment process addressed in the following sections. The result of the plant mass balance elaborated with the average data available from January 2015 to September 2016 is provided in Table 6. Once the analytical data available did not cover all streams and parameters, the following assumptions were required to complete the mass balance:

- Efficiency of COD removal in PSTs = 30%
- Efficiency of TSS removal in PSTs = 70%
- Efficiency of TKN removal in PSTs = 9%
- Efficiency of TP removal in PSTs = 11%
- COD in biological sludge: COD/MLVSS = 1.4
- Organic fraction in primary sludge = 80%
- TP removed with the biological sludge: TP/MLSS = 3%
- TKN removed with the biological sludge: TKN/MLSS = 8%
- Waste activated sludge = 5 100 mg/ℓ
- Efficiency of solids capture in belt press = 99%
- Wash water flow to clean the dewatering equipment = 0.18 Mℓ/d
- Water for lime slurry make-up = 0.075 Mℓ/d
- Back wash water for rapid sand filters = 1.0 Mℓ/d

To confirm the assumptions above and improve the accuracy of the mass balance it would be recommended to double-check the following parameters with an analytical programme during at least 3 days:

- Primary sludge:
  - COD, TSS, TKN and TP.
- Fermenters effluent:
  - pH, COD, TSS, TKN and TP.
- DAF units:
  - TSS in, TSS returned and DS sludge.
- Digested sludge:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.
- Dewatering returns:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.
- Sludge cake (dewatered sludge):
  - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.
- Outlet of reaction tank:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.
- Thickened sludge from return clarifiers/thickeners:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.
- Return liquors after treatment:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.

The following flows should be also confirmed:

- Primary sludge to digestion.
- Biological thickened sludge to digestion.
- Daily wash water to the dewatering facility.
- Water for lime slurry make-up.
- Dilution water added to the sludge return liquors sump.
- Return sludge liquors recycled to Module 2.

Table 6: Results of the mass balance at 'Z' WWTP

Water streams	Raw sewage	Raw WW M1	Raw WW M2	Raw WW M2 & Returns	Balanced primary effluent M1	Balanced primary effluent M2	Biological effluent M1	Biological effluent M2	Tertiary effluent M1	Final effluent
Flow (Ml/d)	58.7	23.6	35.4	36.0	26.2	35.9	24.8	34.5	24.8	59.0
COD (kg/d)	17303	6960	10440	11220	7430	10098	736	1050	715	1764
TKN (kg/d)	1885	758	1138	1262	804	1225	19.6	23.8	15.7	39
NH4 (kg/d)	1435	577	866	988	586	954	7.9	9.4	6.5	16
NO3+NO2 (kg/d)	4.0	1.6	2.4	2.4	1.6	2.4	199	268	166	434
TP (kg/d)	217	87	131	240	103	232	7.0	14	11	25
PO4 (kg/d)	101	40	61	169	41	163	2.0	7.8	6.6	14
TSS (kg/d)	7971	3206	4809	4839	3667	3673	146	180	115	295
COD (mg/l)	295	295	295	312	284	281	30	30	29	30
TKN (mgN/l)	32	32	32	35	31	34	0.8	0.7	0.6	0.7
NH4 (mgN/l)	24	24	24	27	22	27	0.3	0.3	0.3	0.3
NO3+NO2 (mgN/l)	0.1	0.1	0.1	0.1	0.1	0.1	8.0	7.8	6.7	7.3
TP (mgP/l)	3.7	3.7	3.7	6.7	3.9	6.4	0.3	0.4	0.4	0.4
PO4 (mgP/l)	1.7	1.7	1.7	4.7	1.6	4.5	0.1	0.2	0.3	0.2
TSS (mg/l)	136	136	136	135	140	102	5.9	5.2	4.6	5.0

Sludge streams	Primary sludge	Filters backwash	Biological sludge & backwash	Primary thickened sludge	Biological thickened sludge	Digested sludge	Thickened sludge returns	Sludge to dewatering	Sludge cake
Flow (Ml/d)	0.10	1.00	2.80	0.05	0.25	0.30	0.002	0.30	0.06
COD (kg/d)	1122	31	9686	1107	9216	7170	43	7213	7103
TKN (kg/d)	38	3.9	734	36	734	771	18	788	646
NH4 (kg/d)	34	1.5	1	33	0.9	199	14	214	77
NO3+NO2 (kg/d)	0.0	33	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TP (kg/d)	8.8	1.0	302	8.5	286	295	7	302	185
PO4 (kg/d)	6.2	0.3	0	6.0	0	265	5	271	157
TSS (kg/d)	1166	31	9211	1160	8750	7491	45	7536	7461
COD (mg/l)	11543	31	3459	22774	36863	24014	22658	24005	122887
TKN (mgN/l)	390	3.9	262	744	2937	2580	9298	2623	11170
NH4 (mgN/l)	351	1.5	0	674	3.4	668	7394	711	1332
NO3+NO2 (mgN/l)	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TP (mgP/l)	91	1.0	108	175	1145	987	3594	1004	3205
PO4 (mgP/l)	64	0.3	0	123	0	888	2766	900	2714
TSS (mg/l)	12000	31	3289	23865	35000	25088	23800	25079	129083

Sludge return liquors streams	Fermented effluent	DAF returns	Dewatering returns	Treated returns
Flow (Ml/d)	0.05	2.55	0.42	0.57
COD (kg/d)	15	471	823	780
TKN (kg/d)	1.7	45.6	143	125
NH4 (kg/d)	1.3	8.8	137	122
NO3+NO2 (kg/d)	0.0	0.0	0.0	0.0
TP (kg/d)	0.3	16	116	110
PO4 (kg/d)	0.2	0.4	114	108
TSS (kg/d)	7	461	75	30
COD (mg/l)	312	185	1948	1367
TKN (mgN/l)	35	17.9	337	219
NH4 (mgN/l)	27	3.4	323	215
NO3+NO2 (mgN/l)	0.1	0.0	0.0	0.0
TP (mgP/l)	6.7	6	275	192
PO4 (mgP/l)	4.7	0.2	269	190
TSS (mg/l)	135	181	178	53

1.6.2 Influent characteristics

The dewatering sludge return liquors, after chemical treatment, are combined with the raw sewage and both feed Module 2 at downstream of the inlet works. Since the anaerobic digesters have been in operation (from January 2016) and as indicated in Table 7 the current influent load of Module 2 increased due to the recirculation of the sludge return liquors. For example, the TKN load increased by approximately 11% and the PO_4^-P load increased by approximately 179% (Table 7). The phosphorous load returned from the sludge liquors appears to be extremely high and outside of the typical range for sludge liquors (5% to 30%) and therefore it should be further investigated.

None of the two modules were designed considering the additional loads returned from the sludge liquors. However, the plant is currently under loaded compared to the design capacity, it should be noted that the denitrification capacity is not sufficient to comply with the nitrate effluent quality required. In the future, should the plant reach its design capacity, the operation of Module 2 may be even more impacted.

Table 7: Impact of dewatering return liquors in the influent characteristics at 'Z' WWTP

Parameter	Raw sewage to the plant	Sludge returns	Module 2 raw ww (incl. returns)	Impact on Module 2 raw ww	Impact on total plant raw ww	Typical impact on raw ww (*)
Flow (Mℓ/d)	58.7	0.57	36.0	1.6%	1.0%	0.5% – 1.0%
COD (kg/d)	17 303	780	11 220	7.5%	4.5%	5% – 10%
TKN (kg/d)	1 885	125	1 262	11%	6.6%	9% – 13%
NH_4 (kg/d)	1 435	122	988	14%	8.5%	9% – 13%
TP (kgP/d)	217	110	240	84%	50%	5% - 30%
$PO_4^{-}P$ (kg/d)	101	108	169	179%	108%	5% - 30%
TSS (kg/d)	7 971	30	4 839	0.6%	0.4%	2% - 5%

(*) Based on Royal HaskoningDHV process design tool and excluding any dedicated treatment to the sludge return liquors

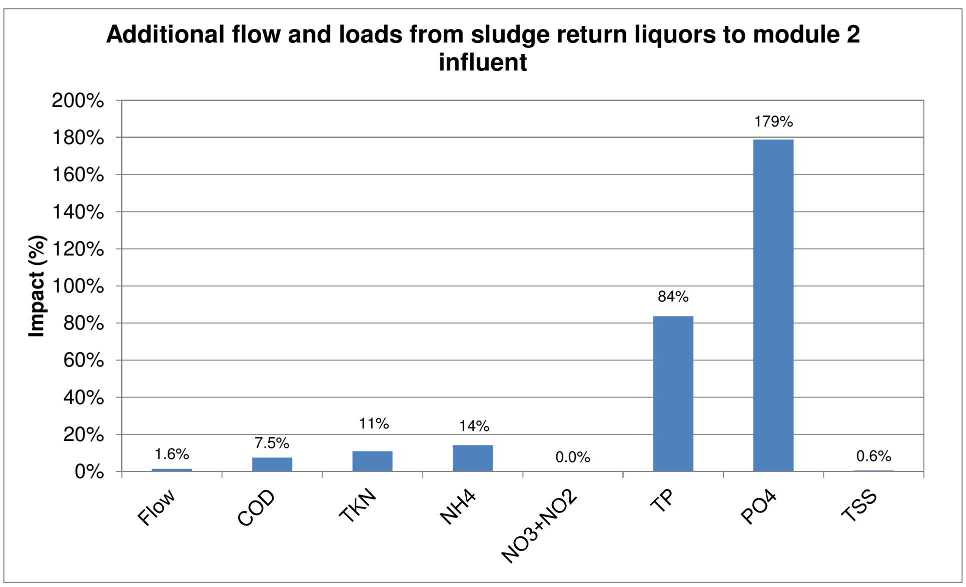

Figure 13: Additional flow and loads entering Module 2 from the SRLs treatment facility at 'Z' WWTP

Comparing the influent ratios from Module 1 (without return liquors) with a typical South African sewage (Table 8), generally the raw sewage at Plant 'Z' is slightly unbalanced, especially in terms of P characteristics (lower than usual). With respect to Module 2 (including return liquors), there is an unfavourable low COD/ PO_4 ratio for biological P removal, which has a significant influence from the return liquors with very high orthophosphate concentrations.

Table 8: Influent ratios with and without return liquors at 'Z' WWTP

Ratios	Module 1 influent (without return liquors)	Module 2 influent (with return liquors)	Typical values in South African ww (*)
COD / TSS	2.2	2.3	2.0
COD / TKN	9.2	8.9	8.2
COD / NH_4	12	11	14
COD / TP	80	47	54
COD / PO_4	172	66	117

(*) WRC Report TT389/09, Process Design Manual for Small Wastewater Treatment Works

1.6.3 Biological effluent quality

The average effluent quality of Modules 1 and 2 (biological effluent) is presented in Table 9. On average, both modules cannot meet the nitrate+nitrite effluent standard requirement and Module 2 cannot meet the orthophosphate standard requirement. It is important to note that the effluent quality requirements regarding orthophosphate is very stringent and it is a challenge to comply with this effluent requirement based only in biological phosphorous removal.

Nevertheless, assessing Figure 14 and Figure 15 from January 2015 to May 2016, it is noted that Module 1 kept a fairly stable orthophosphate effluent quality during the monitoring period, while in Module 2 the orthophosphate effluent quality appears to be in deterioration (since August 2015) and has been constantly high from January 2016 onwards. Especially from January 2016, this deterioration appears to coincide with the commissioning and start-up of the anaerobic digestion process and the recycling of the sludge liquors back to the beginning of Module 2.

Module 2 has been also responsible for 60% of the treatment of the incoming flow to the plant and it may also be a factor to add when considering possible reasons for the orthophosphate non-compliance. Considering that the orthophosphate concentrations were always very low (< 1.0 mgP/ℓ), it is difficult to judge if the recycling of the sludge liquors is the only factor affecting phosphorous compliance.

Table 9: Average effluent quality of the biological effluent from Modules 1 and 2 at 'Z' WWTP

Parameters	Module 1 (biological effluent)	Module 2 (biological effluent)
COD (mg/ℓ)	30	30
NH_4 (mg N/ℓ)	0.3	0.3
$NO_3 + NO_2$ (mg N/ℓ)	8.0	7.8
PO_4 (mg P/ℓ)	0.1	0.2
TSS (mg/ℓ)	5.9	5.2

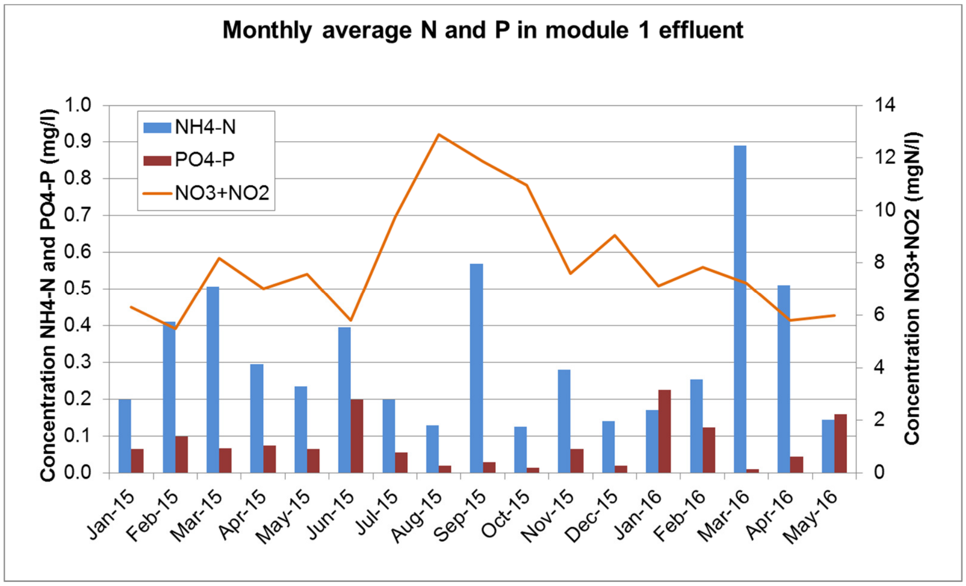

Figure 14: Monthly AV ammonia, nitrate+nitrite and orthophosphate effluent quality at 'Z' WWTP from Module 1

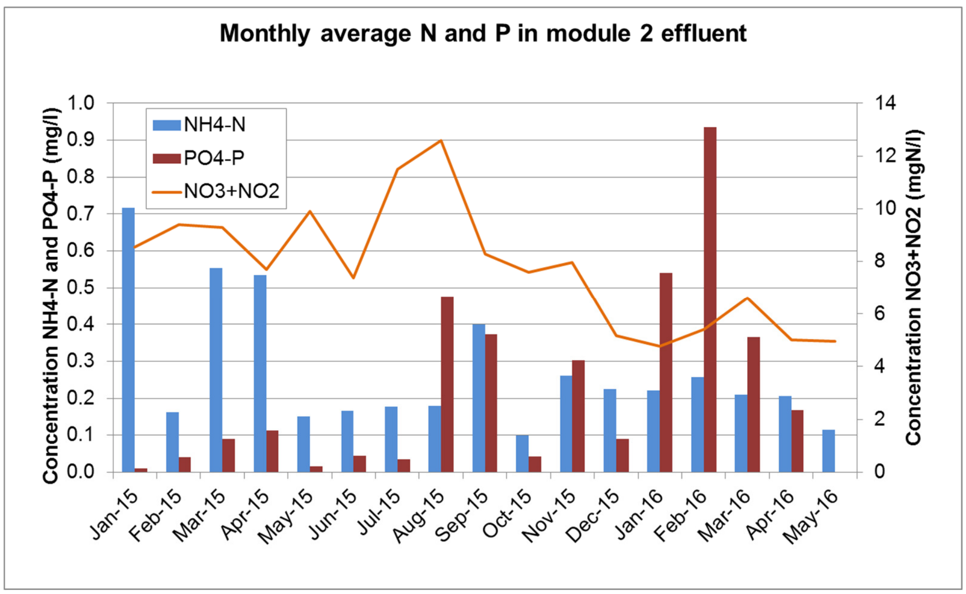

Figure 15: Monthly AV ammonia, nitrate+nitrite and orthophosphate effluent quality at 'Z' WWTP in Module 2

1.6.4 Aeration demand

At 'Z' WWTP the 4 BNR reactors are aerated through a fine bubble aeration system including disc diffusers and 3 duty/1 standby blowers per reactor. The oxygen supply to each reactor is controlled by a semi-automatic cascade method where the ammonia effluent concentration will define the best dissolved oxygen set points in the 4 oxygen sensors in different compartments.

The plant does not have individual energy meters in the aeration system, thus, historical consumption data is not available. However, from 9 to 10 February 2015 the operator measured the power per reactor in Module 2 (Figure 16). Sludge digestion and sludge return liquors were not available on site at the time and the impact of the sludge liquors was not included. Per these results, the average specific energy consumption in Module 2, without the contribution of the sludge return liquors and to keep an average O_2 setpoint of 1.9 mg O_2/ℓ, were 0.14 kW/m³ and 0.61 kW/kgCOD.

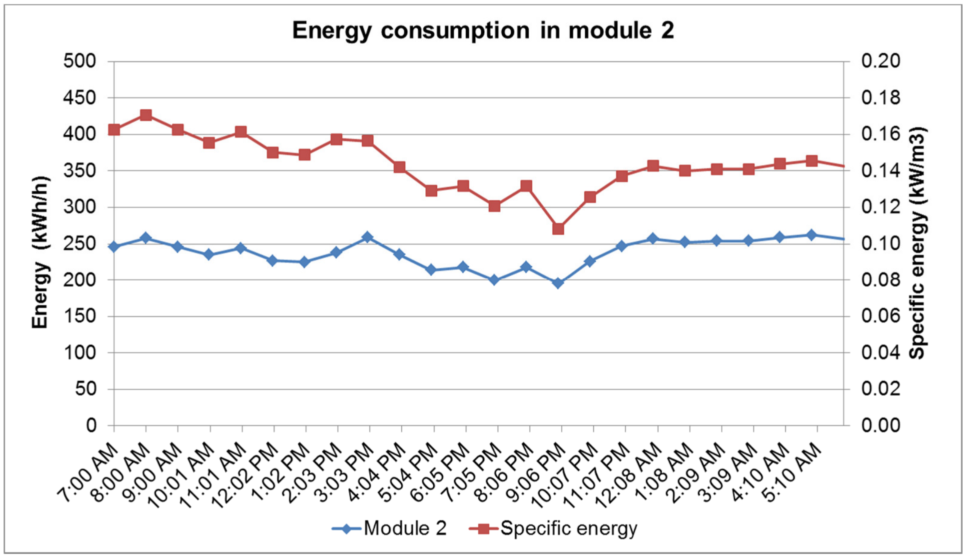

Figure 16: Aeration energy consumption in Module 2 at 'Z' WWTW without contribution of sludge return liquors

Since the additional ammonia load returned from the dewatering sludge liquors to the beginning of Module 2 is approximately 12% and the COD load has increased in 7.5% it is expected that the aeration requirements to improve the carbon removal and the nitrification capacity have increased from 7% to 10%.

1.6.5 Biological treatment capacity

Module 2 is currently treating 50% of the design COD load, 60% of the TKN design load and 62% of the TP design load. The specific biological sludge production is calculated in 0.56 kg MLSS/kgCOD removed and appears to be higher than usual for an extended aeration. On average, the sludge retention time have been around 36 days.

The additional loads from the sludge return liquors are still not over riding the capacity of Module 2, however, currently the biological treatment is not able to meet the nitrate standard. Therefore, the denitrification conditions (a-recycle capacity and anoxic volume) need to be assessed.

It should be noted that should the plant design capacity be reached in future, Module 2 may not be able to accommodate extra load from the return liquors since the plant was not designed to treat that e load.

1.7 Conclusions and recommendations

The site research conducted at 'Z' WWTP indicates the following conclusions regarding the impact of the sludge return liquors in the plant performance:

1. The return liquors are only recycled to Module 2 and therefore the influent ammonia and orthophosphate loads in this module have increased in 11% for TKN and 84% for TP. The phosphorous load appears to be extremely high and should be further investigated. Nevertheless, to minimize the impact of the sludge return liquors it should be considered an equal split between the two modules available.

2. Module 2 effluent quality is not complying with the nitrate+nitrite and orthophosphate quality standards. It is noted a deterioration in the Module 2 biological effluent quality since January 2016 and especially in the orthophosphate parameter. The overall plant performance regarding N and P compliance has been also negatively impacted since January 2016. This deterioration

appears to be coincident with the start-up of the ADs and the recycling of the sludge liquors to Module 2.

3. The efficiency of the sludge liquors treatment facility appears to be negligible and mostly influenced by a water dilution from the lime slurry and eventually others not quantified. The lime dosing is causing critical problems with struvite formation in the return flow pumps and pipelines, thus requires optimisation and/or replacement.

In addition, the following generic conclusions and recommendations should be noted:

4. The plant is generally well operated and shows a good level of maintenance.

5. The current hydraulic demand in the plant is 69% of the design capacity. The influent flow is split: 40% of the flow goes to Module 1 and 60% to Module 2.

6. The plant is currently under loaded compared to its design capacity. As an example, the current COD load is only 41%, TKN load is 48% and TP load is 30% compared to the design capacity.

7. It must be noted, that although the plant is under loaded, based on its original design, the effluent quality does not comply with the effluent requirements for N and P. Particularly for N, it implies that the plant cannot handle more N since the denitrification capacity is not sufficient or is not optimised. It is recommended to evaluate the denitrification process including the a-recycle capacity, the simultaneous denitrification rate and the readily biodegradable COD fraction available. Regarding the orthophosphate removal, it is important to bear in mind that currently this plant has a very stringent standard requirement (< 0.1 mg P/ℓ). Although only biological P removal is in place the plant has been able to meet on average a remarkable low orthophosphate concentration, i.e. 0.2 mgP/ℓ. Considering the stringent effluent requirements, a chemical precipitation step with metal salts to complement the biological P removal should be considered.

8. The AD process has been running since January 2016 and it is still not optimised. The digesters have been operated at ambient temperatures (20ºC to 25ºC). It is a matter of urgency to bring the boilers and gasholders into operation to increase the process temperature to at least 35ºC to improve the digestion stability and increase the volatile solids destruction. Please note that an optimised sludge digestion process will increase the N and P concentration in the sludge return liquors.

9. The dryness of the dewatered sludge could also be optimised since only 13% DS (w/v) has been reached. An optimisation of the polymer dosage and type shall be considered.

CHAPTER 2: 'W' Wastewater Treatment Plant

The 'W' WWTP is located in Klip River in Southern Johannesburg (refer to Figure 17). It lies north of Meyerton. The works is owned and operated by East Rand Water Care Association (ERWAT).

'W' WWTP has a total capacity of 170 Mℓ/d. Module 1 was commissioned in 1979 and has a capacity of 40 Mℓ/d. Modules 2 and 3 were commissioned in 1989 and 1993 respectively, each having a capacity of 40 Mℓ/d. The fourth module was completed in 2008 and its capacity is 50 Mℓ/d.

The plant currently treats influent from the Germiston and Alberton areas. The treated effluent is discharged into the Klip River.

Figure 17: Aerial view of 'W' WWTP (Google Earth, 2016)

2.1 Process Description

A description of the 'W' WWTP is indicated below as per information found in the operation and maintenance manuals for Modules 1, 2-3 and Module 4 (Mott MacDonald, 2016, Bradford, Conning and Partners, 1994 and Sintec, 2008 respectively). The general process flow diagram of the works in indicated in Figure 18.

- The **inlet works** consist of two parallel head of works which split flow between Modules 1-3 and Module 4:
  - Each module consists of:
    - Three screening chambers[1] which each have,
    - A stone trap and trash rack,
    - A fine screen.
  - Three vortex degritters,

[1] *The head of works for Module 4 has three screening chambers but currently only two of the three have screens*

- At each inlet, there is an overflow weir upstream of the screens which directs excessive inflow to a 19 000 m³ emergency dam.

- **Module 1** consists of:
  - Two PSTs:
    - The tanks are 25 m in diameter,
    - The total usable volume of each tank is 3 252 m³.
  - Two primary BNR reactors and two secondary BNR reactors:
    - Primary reactors have a total volume of 2 690 m³,
    - Secondary reactors have a total volume of 3 250 m³,
    - Primary reactors have 8 surface aerators and secondary reactors have 5 surface aerators.
  - FSTs:
    - Four primary clarifiers upstream of the secondary BNR reactors,
    - Four secondary clarifiers downstream of the secondary BNR reactors,
    - All clarifiers have a 30 m diameter,
    - The total usable volume of each tank is 1 767 m³.

- **Modules 2-3** consist of the following:
  - One balancing tank per module (7 350 m³ each),
  - Two 25 m diameter PSTs per module,
  - Primary sludge screening:
    - Module 2:
      - Single mechanical screen with one manually raked screen on standby.

- **Module 3** consists of:
  - Two identical mechanical fine screens which can each work on a standby or duty basis,
  - Two BNR reactors (one per module with 15 898 m³),
  - Each reactor has 3 aerated zones which have fine bubble diffused air aeration systems,
  - Air provided by five centrifugal blowers (4 duty, 1 standby),
  - Four 25 m diameter clarifiers.

- **Module 4** consists of:
  - Two adjacent balancing tanks (5 250 m³ each),
  - Two 34 m diameter PSTs,
  - A BNR reactor (21 688 m³),
  - Aerated zones equipped with fourteen surface aerators,
  - Four 34 m diameter clarifiers.

- **Disinfection** consists of the following:
  - Two identical 2 000 m³ chlorine contact tanks serve Modules 1-3 and 4 respectively,
  - Treated effluent is stored in maturation ponds, which discharge into the Klip River.

- **Sludge handling and disposal** consists of the following:
  - Primary sludge from the PSTs is pumped to anaerobic digesters,

- Biological sludge is pumped to five 10 m diameter DAF units with 424 m^3 each (1 unit per module except Module 4 which includes two units),
- Thickened biological sludge is pumped to anaerobic digesters,
- Primary sludge and biological thickened sludge are anaerobically digested in sixteen units:
  - Module 1: four digesters (not heated or mixed),
  - Module 2-3: six digesters (heated and biogas mixed),
  - Module 4: four digesters (heated and pump mixed),
- Sludge dewatering:
  - 60% of digested sludge is diverted to drying paddies,
  - 40% of digested sludge is mechanically dewatered in four belt presses:
    - Presses operate for 12 hrs per day, 7 days a week.

- **Sludge return liquors**:
  - Sludge return liquors from the DAF units of Modules 1-3 are recycled to the beginning of the biological reactors,
  - Sludge return liquors from the DAF units of Module 4 are recycled to upstream of the balancing tank,
  - Sludge dewatering returns (filtrate) and wash water (from belt press cleaning) split equally between Modules 1-3 and 4 and are recycled to downstream of the inlet works of the respective modules.

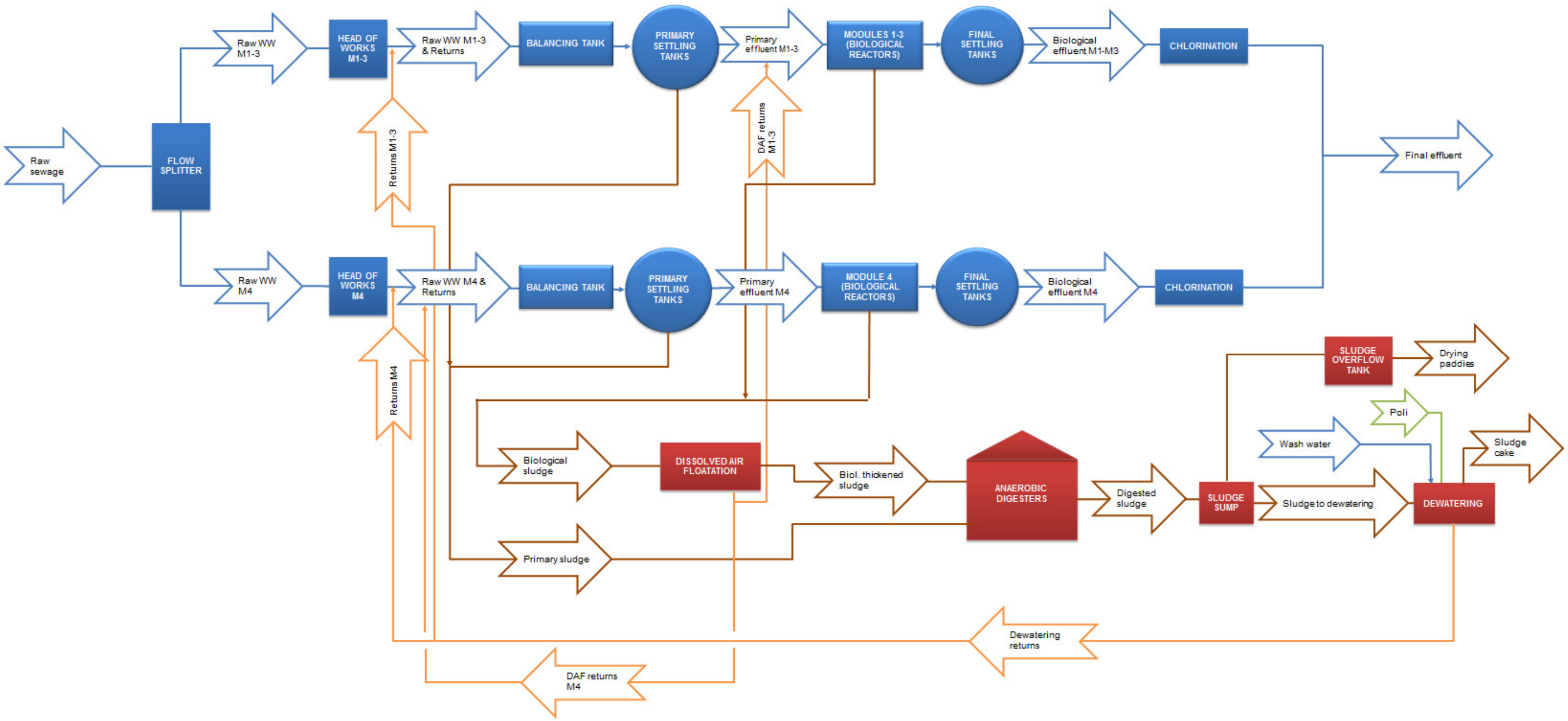

Figure 18: General Process Flow Diagram for 'W' WWTP

2.2 Design Capacity

The total capacity of the plant is indicated in Table 10.

Table 10: Design flows and loads at 'W' WWTP

Parameters	Module 1	Module 2-3	Module 4	Total
Flow (Mℓ/d)	40	80	50	170
COD (kg/d)	44 000	88 000	55 000	187 000
TSS (kg/d)	22 000	44 000	27 500	93 500
TKN (kg/d)	2 400	4 800	3 000	10 200
Ammonia (kg/d)	1 120	2 240	1 400	4 760
Total P (kg/d)	480	960	600	2 040
Ortho P (kg/d)	280	560	350	1 190

2.3 Effluent Standard Requirements

'W' WWTP current water use license number is 08/C22C/FG/646. The stipulated final effluent requirements are indicated in Table 11.

Table 11: Effluent requirements for 'W' WWTP

Parameter	Final Effluent Requirements
COD	70 mg/ℓ
TSS	20 mg/ℓ
Nitrate+Nitrite	9 mg/ℓ
Ammonia	4 mg/ℓ
Ortho P	0.7 mg/ℓ
E-Coli	500 CFU/100 mℓ

2.4 Technical Performance

'W' WWTP is a Class A plant. There are three shifts per day. Each shift is manned by one process controller (Class 4) and three assistant operators. There is one plant manager and a regional manager (Class 5). There is also a 24-hour standby plant manager for the plant.

The operating staff of 'W' WWTP highlighted the following issues at the plant:

- The DAF for Module 1 is old, has a poor efficiency and breaks down regularly. There are plans to replace/refurbish this unit.
- The pressurisation equipment used for the DAF units in Modules 1 & 3 regularly fails and requires replacement.
- Four surface aerators in Module 1 and three surface aerators in Module 4 are out of service for more than a year.
- The blowers for Modules 2-3 fail regularly.
- The primary sludge transfer pumps regularly undergo mechanical failure which, if not rectified quickly, can cause the overflow of solids in the PST's.
- The disinfectant used for Modules 1-3 causes regular blockages. The dosing pump for these modules also fails regularly. In Module 4 there is regular failure of the motive water pump.

2.5 Process performance

2.5.1 Influent Characteristics

As indicated in Figure 19, during the operational window selected (September 2015 to August 2016), 'W' WWTP treated on average a total of 252 Mℓ/d (148% of the design capacity). This indicates that the plant is currently operating above its design capacity. The split between Modules 1-3 and Module 4 is on average 78% and 22% respectively.

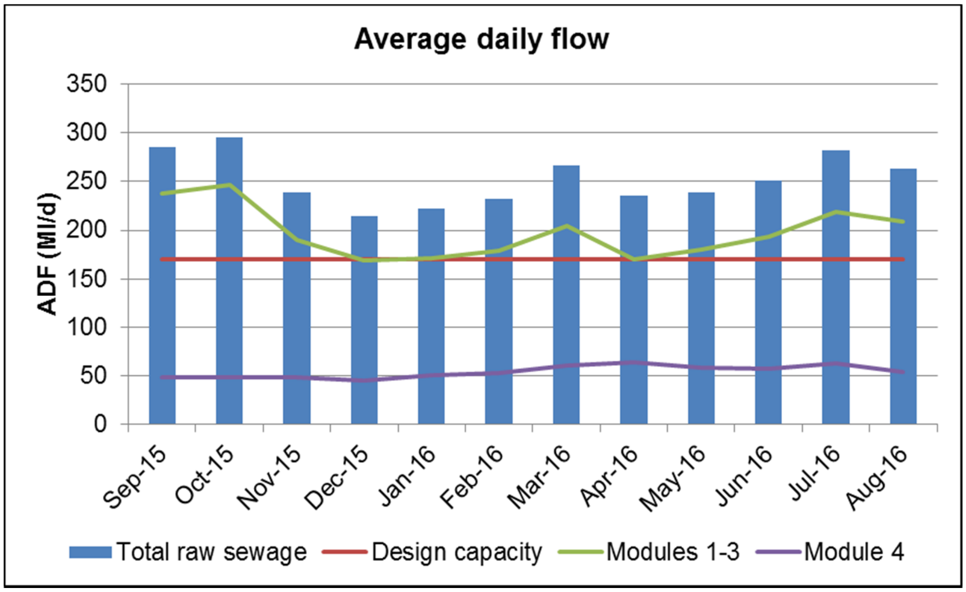

Figure 19: Average daily flow at 'W' WWTP

The average influent concentrations and loads are indicated in Table 12 as well as the historical averages in Figure 20 and Figure 21. Currently, the plant is treating 99% of the COD design load, 120% of the TKN design load and 75% of the TP design load.

Table 12: Average raw sewage concentrations at 'W' WWTP

Parameter	Average Concentration (September 2015 to August 2016)		Average Load (September 2015 to August 2016)	
COD	729	mg/ℓ	185 560	kg/d
TSS	195	mg/ℓ	49 265	kg/d
TKN	49	mg N/ℓ	12 285	kg/d
NH_4	24	mg N/ℓ	6 006	kg/d
PO_4	2.9	mg P/ℓ	733	kg/d
TP	6.1	mg P/ℓ	1 547	kg/d

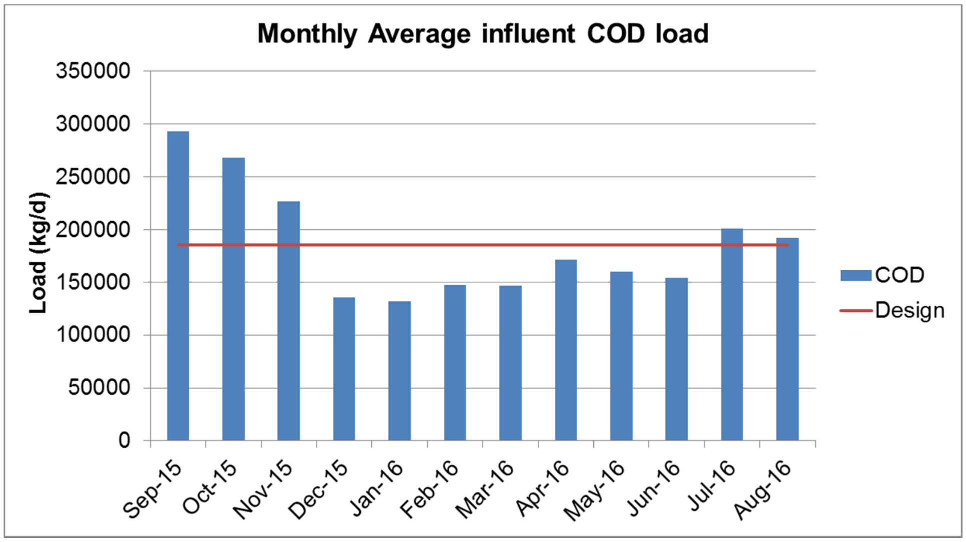

Figure 20: Average COD load at 'W' WWTP

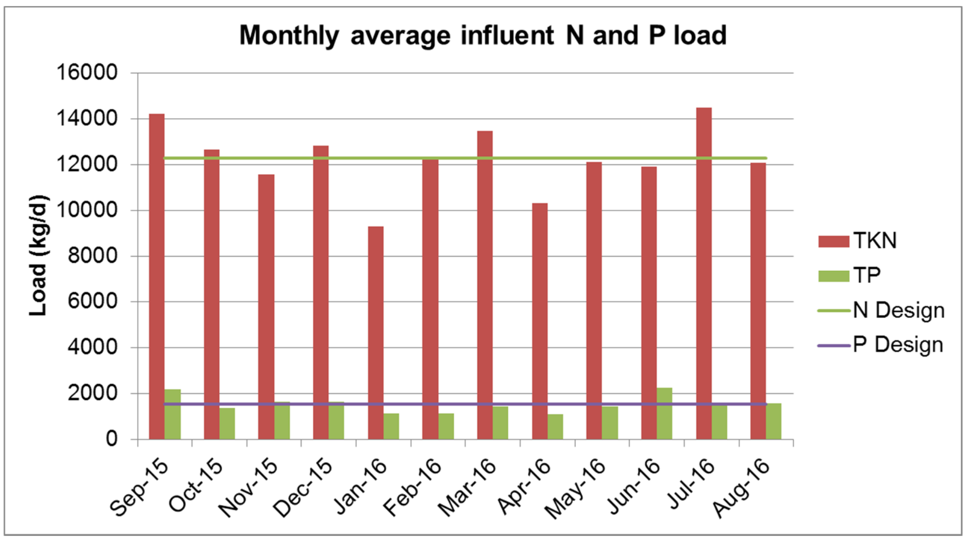

Figure 21: Average TKN and TP load at 'W' WWTP

2.5.2 Effluent Quality

This plant displays good performance, Table 13 indicates the average quality of treated effluent. For all parameters, compliance is 100% and above. This is surprising given that the plant, on average, treats influent flows that are higher than its capacity. The historical monthly average concentrations in the final effluent from September 2015 to August 2016 are indicated in Figure 22 and Figure 23.

Table 13: Average final effluent quality and plant compliance at 'W' WWTP

Parameter	Final Effluent Requirements	Average Concentration (September 2015 to August 2016)	Average compliance (September 2015 to August 2016)
COD	70 mg/ℓ	32 mg/ℓ	100%
TSS	20 mg/ℓ	11 mg/ℓ	100%
Nitrate+Nitrite	9 mg/ℓ	4.4 mg/ℓ	100%
Ammonia	4 mg/ℓ	0.9 mg/ℓ	100%
Ortho P	0.7 mg/ℓ	0.2 mg/ℓ	100%

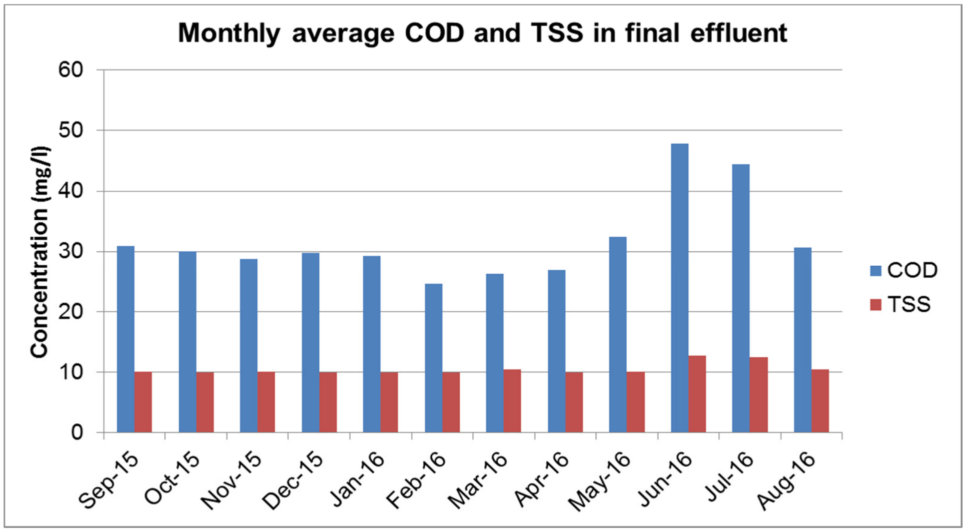

Figure 22: Monthly average COD and TSS in the final effluent at 'W' WWTP

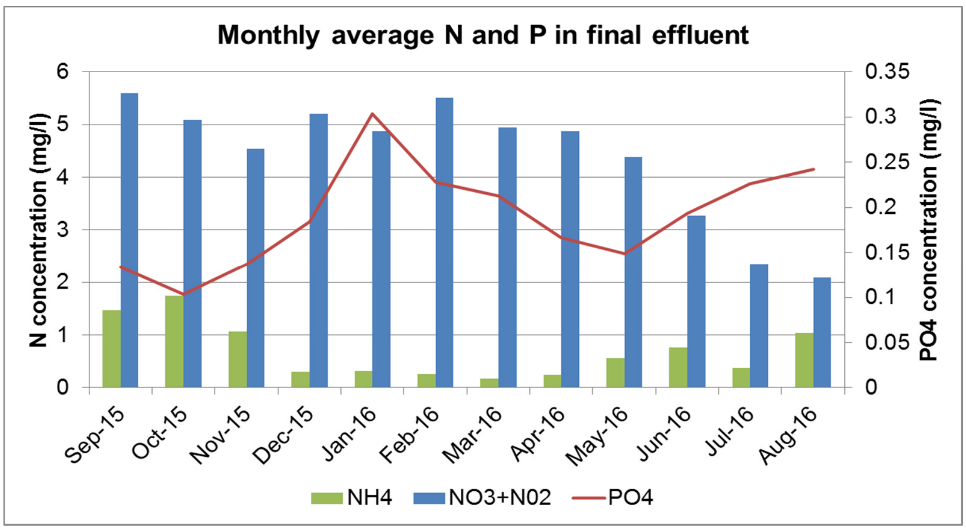

Figure 23: Monthly average ammonia, nitrate+nitrite and orthophosphate in the final effluent at 'W' WWTP

2.5.3 Sludge Treatment

2.5.3.1 Sludge Characteristics

At 'W' WWTP, PS is removed from all the settling tanks in all four modules and is sent to the ADs. The biological sludge is mostly wasted from the aeration tanks (except for Module 1, wasted from the RAS line), thickened in DAF units and finally sent to the ADs. Table 14 indicates the characteristics of the PS and WAS prior floatation and AD.

Table 14: Characteristics of the primary and biological sludge at 'W' WWTP

Parameter	Primary sludge (from PST)	Biological sludge (from BNR)	
		Before floatation	After floatation
Flow (m^3/d)	844	5 150	413
Dry solids (%)	4.55	0.55 (*)	5.12
Sludge mass (kg/d)	38 380	28 323	21 126

(*) Average value considered for all four modules.

2.5.3.2 *Sludge floatation*

The thickening of sludge at 'W' WWTP occurs in five DAF tanks (one per module except Module 4 which has two units). The historical dry solids and organic fraction of the biological thickened sludge is presented in Figure 24. The average dry solids content of the biological thickened sludge is 5.1%. The average organic fraction is 73.9%. The solids capture in Modules 1-3 DAF units is poor and approximately 70%. Module 4 indicates higher solids capture, around 90%. The overall average solids capture of the units is approximately 75% which is significantly lower than the expected 90 to 95%.

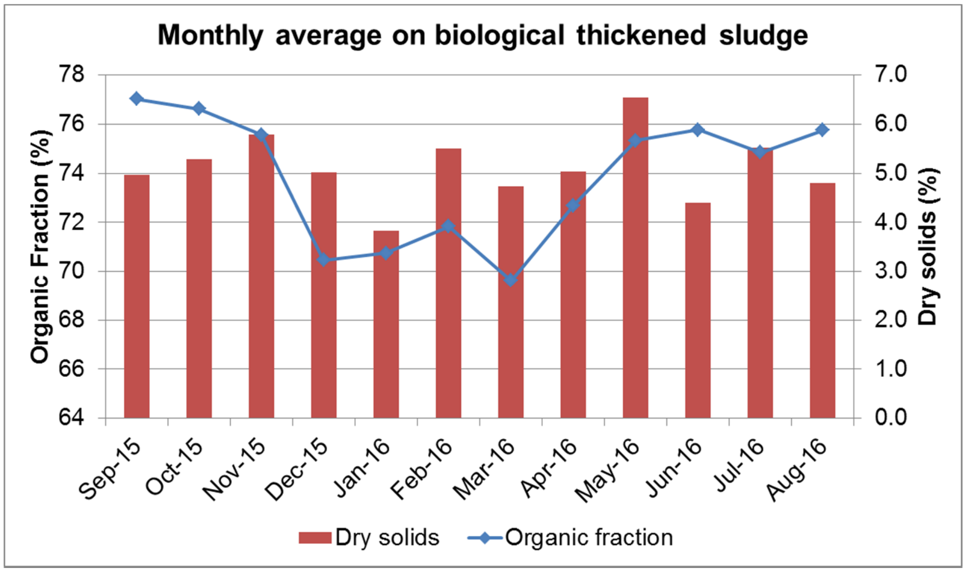

Figure 24: Monthly average organic fractions and dry solids content in the biological thickened sludge at 'W' WWTP

2.5.3.3 *Anaerobic sludge digestion*

Primary and biological sludge at 'W' WWTP are digested in 14 ADs. Table 15 indicates the digester arrangement at the works.

Table 15: Digester arrangement at 'W' WWTP

Module No.	Number of digesters	Digester conditions
1	4	Sludge not heated or mixed, high retention time
2-3	6	Sludge heated and mixed (using biogas)
4	4	Sludge heated and mixed (using pumps)

From September 2015 to August 2016, the average dry solids content was 3.3% and the organic fraction was 60.1% in the digested sludge (Figure 25).

The calculated HRT for the ADs is on average 102 days for Module 1 (cold digesters) and 31 days for Modules 2-4 (heated digesters). These times indicate proper retention capacity for cold digestion (usually 60 to 90 days) and for heated digestion at 35-37ºC (usually 15-20 days). The organic fraction of non-digested sludge is 71%. Per the long average retention time in the digesters, a higher destruction of VSS, about 60%, is expected. However, on average the calculated destruction of VSS is only 41%.

The operations staff at 'W' WWTP indicated that the average temperature in the heated digesters during winter is 29-32°C. On colder days, the minimum temperature drops to 25°C. These values are below the expected temperatures (35-37°C). During summer, the average temperature in the heated digesters is about

37°C. At the time of compilation of this document, the digesters for Module 1 were in the process of being refurbished with heating and pump mixing equipment.

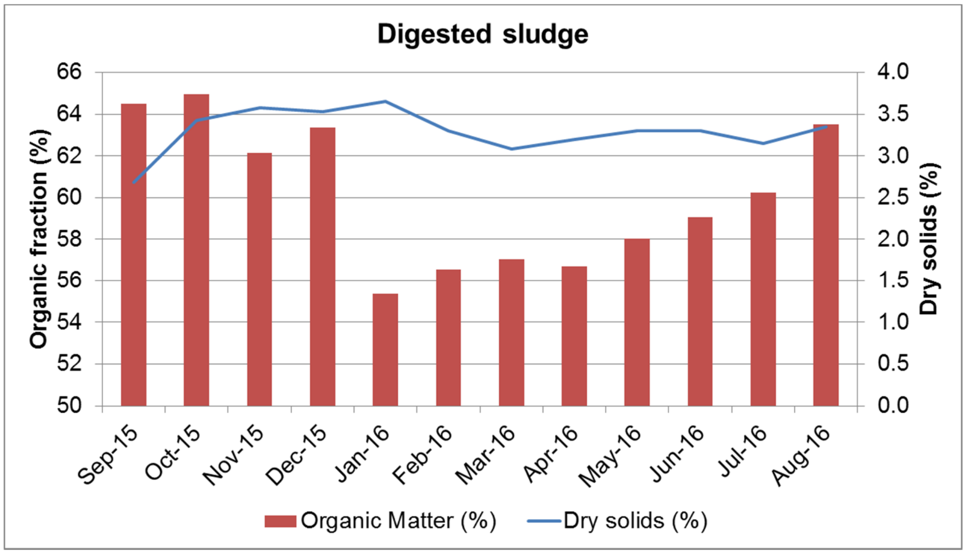

Figure 25: Monthly average organic matter and dry solids in the digested sludge at 'W' WWTP

2.5.3.4 Sludge dewatering

The digested sludge stream splits: 60% of the digested sludge is sent to drying paddies and 40% of the digested sludge goes to belt presses. There is a total of 4 belt presses at 'W' WWTP which operates 7 days a week for 12 hours. The drying paddies, on average, handle 28.7 tonnes/d of digested sludge and the belt presses, 18 tonnes/d of dewatered sludge.

The average dry solids content of the belt press sludge cake is 19%, which is slightly above the typical range coming out of belt presses (15-18%). Figure 26 indicates the dry solids content of the dewatered sludge in the belt presses between September 2015 and August 2016.

The calculated average solids capture in the mechanical dewatering is roughly 90% which is slightly lower than the optimal efficiency of 95%.

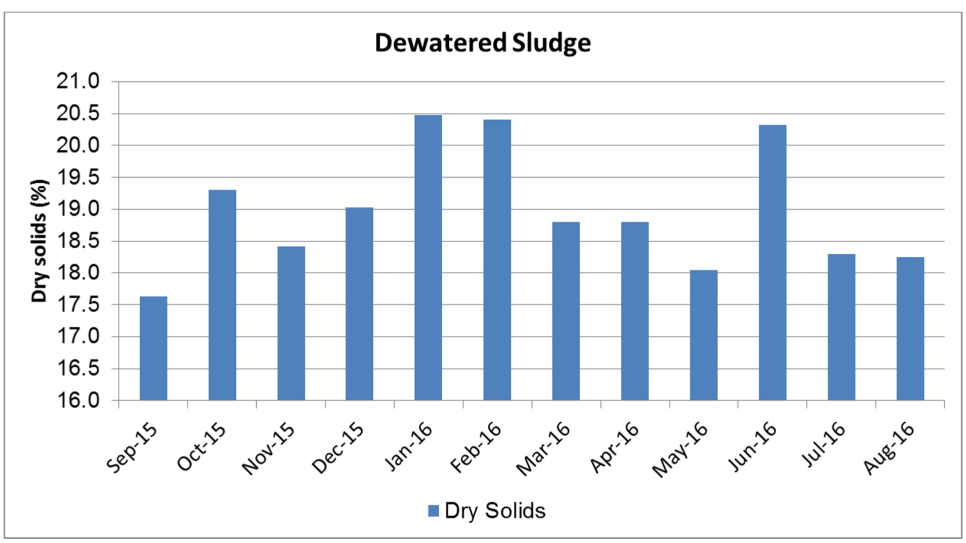

Figure 26: Average dry solids in the dewatered sludge at 'W' WWTP

2.5.3.5 Quality of dewatering sludge and wash water return liquors

There are two return liquor streams from the dewatering facility at 'W' WWTP, namely, sludge dewatering liquors (filtrate) and wash water liquors (from belt press washing). These streams combine and are split equally between Modules 1-3 and Module 4. At the plant, return liquors are not treated. Figure 27 indicates the average ammonia and orthophosphate concentrations in the combined return liquors.

The average ammonia and orthophosphate concentrations during the monitoring period (September 2015 to August 2016) were 431 mg N/ℓ and 52 mg P/ℓ respectively. The average TSS and COD concentrations during this period were 1 897mg/ℓ and 2 350mg/ℓ respectively.

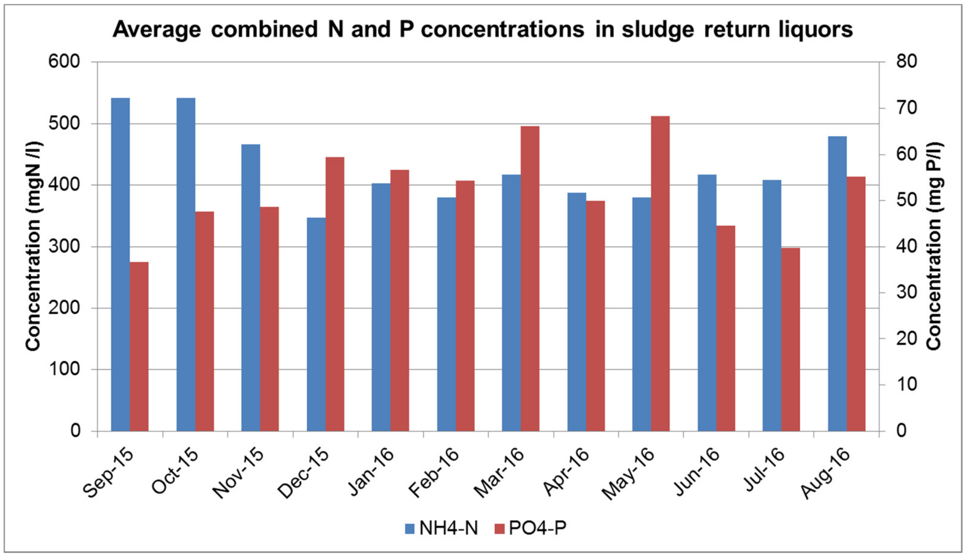

Figure 27: Average combined ammonia and orthophosphate concentrations in the SRLs at 'W' WWTP

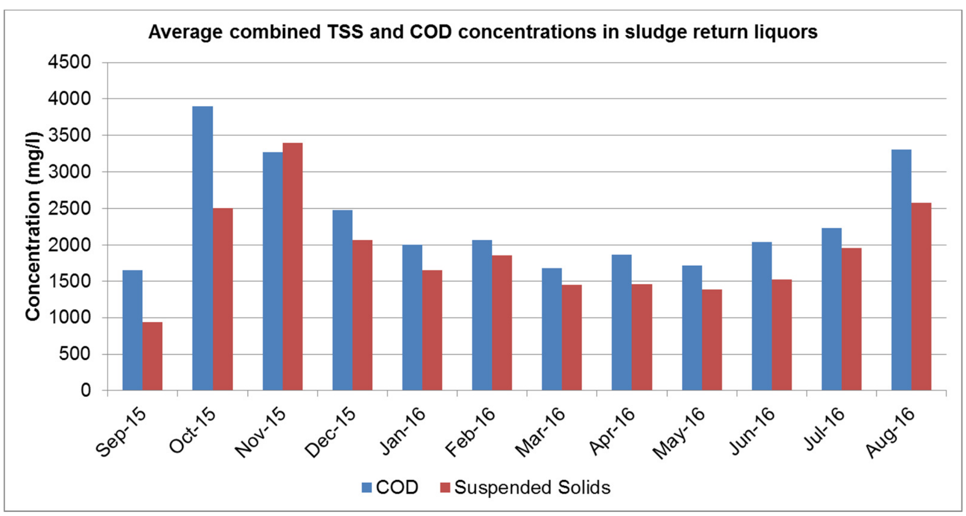

Figure 28: Average combined TSS and COD concentrations in the SRLs at 'W' WWTP

2.6 Impact of the sludge return liquors

2.6.1 Plant mass balance

A complete mass balance of the 'W' WWTP was prepared to understand and evaluate the magnitude of the impacts of the sludge dewatering return liquors on the main treatment process. The results, elaborated with the average data available from September 2015 to August 2016, is provided in Table 16. The analytical data available did not cover all streams and parameters, the following assumptions were required to complete the mass balance:

- COD in biological sludge: COD/MLVSS = 1.4
- Average WAS = 5 500 mg/ℓ
- Sludge to dewatering = 40%
- Sludge to paddies = 60%
- duty spent washwater pumps × 17 m³/h, 12 h/d
- Return liquors to Modules 1-3 = 50%
- Return liquors to Module 4 = 50%

To confirm the assumptions above and improve the accuracy of the mass balance it would be recommended to double-check the following parameters with an analytical programme during at least 3 days applicable to each module:

- Primary sludge:
  - COD, TSS, TKN and TP.
- DAF units:
  - TSS in and TSS returned.
- Digested sludge:
  - COD, TKN, NH_4^-N, TP and PO_4^-P.
- Dewatering returns:
  - TKN, NH_4^-N and TP.
- Sludge cake (dewatered sludge):
  - COD, TKN, NH_4^-N, TP and PO_4^-P.

The following flows should be also confirmed:

- Biological sludge to DAF units.
- Biological thickened sludge to digestion.
- Daily wash water to the dewatering facility.
- Return sludge liquors recycled to Modules 1-3 and Module 4.

Table 16: Results of the mass balance at 'W' WWTP

Water streams	Raw sewage	Raw WW M1-3	Raw WW M4	Raw WW M1-3 & Returns	Raw WW M4 & Returns	Primary effluent M1-3	Primary effluent M4	Biological effluent M1-3	Biological effluent M4	Final effluent
Flow (Ml/d)	252	198	55	198	56	201	56	197	55	252
COD (kg/d)	185560	144737	40823	145956	42621	122922	34025	6036	1445	7480
TKN (kg/d)	12285	9582	2703	9869	3030	9197	2695	613	134	747
NH4 (kg/d)	6006	4685	1321	4909	1546	4920	1546	265	27	292
NO3+NO2 (kg/d)	0	0	0	0	5.1	16	5	827	269	1096
TP (kg/d)	1547	1206	340	1256	413	1427	377	226	59	285
PO4 (kg/d)	733	571	161	599	189	607	189	53	7.1	59.9
TSS (kg/d)	49265	38427	10838	39331	12302	16592	3858	2093	548	2641
COD (mg/l)	736	733	748	737	759	611	608	31	26	30
TKN (mgN/l)	49	49	50	50	54	46	48	3.1	2.4	3.0
NH4 (mgN/l)	24	24	24	25	28	24	28	1.3	0.5	1.2
NO3+NO2 (mgN/l)	0	0	0	0	0.1	0	0.1	4.2	4.9	4.4
TP (mgP/l)	6.1	6.1	6.2	6.3	7.4	7.1	6.7	1.1	1.1	1.1
PO4 (mgP/l)	2.9	2.9	3.0	3.0	3.4	3.0	3.4	0.3	0.1	0.2
TSS (mg/l)	195	195	199	199	219	82	69	11	10	10

Sludge streams	Primary sludge	Biological sludge	Biological thickened sludge	Digested sludge	Sludge to dewatering	Sludge to paddies	Sludge cake
Flow (Ml/d)	0.844	5.150	0.413	1.26	0.50	0.75	0.08
COD (kg/d)	39073	29287	21844	34797	13919	20878	12542
TKN (kg/d)	1523	1983	1480	3003	1201	1802	628
NH4 (kg/d)	0	13	1.1	1118	447	671	0
NO3+NO2 (kg/d)	0	0	0	0	0	0	0
TP (kg/d)	160	1520	846	1006	712	294	613
PO4 (kg/d)	0	10	0.8	136	54	81	0
TSS (kg/d)	38380	28323	21126	41085	16434	24651	14626
COD (mg/l)	46312	5687	52938	27697	27697	27697	162605
TKN (mgN/l)	1806	385	3586	2390	2390	2390	8136
NH4 (mgN/l)	0	2.6	2.6	890	890	890	0
NO3+NO2 (mgN/l)	0	0	0	0	0	0	0
TP (mgP/l)	190	295	2050	801	1416	390	7951
PO4 (mgP/l)	0.0	1.9	1.9	108	108	108	0
TSS (mg/l)	45491	5500	51196	32702	32702	32702	189627

Sludge return liquors streams	DAF returns M1-3	DAF returns M4	Dewatering returns	Returns to M1-3	Returns to M4
Flow (Ml/d)	3.69	1.04	1.04	0.52	0.52
COD (kg/d)	7443	579	2438	1219	1219
TKN (kg/d)	516	40	574	287	287
NH4 (kg/d)	12	1.3	447	224	224
NO3+NO2 (kg/d)	16	5.1	0	0	0
TP (kg/d)	296	23	98	49	49
PO4 (kg/d)	8.5	0.8	54	27	27
TSS (kg/d)	7198	560	1808	904	904
COD (mg/l)	2014	555	2350	2350	2350
TKN (mgN/l)	140	39	553	553	553
NH4 (mgN/l)	3.2	1.2	431	431	431
NO3+NO2 (mgN/l)	4.2	4.9	0	0	0
TP (mgP/l)	80	22	95	95	95
PO4 (mgP/l)	2.3	0.8	52	52	52
TSS (mg/l)	1948	537	1897	1743	1743

2.6.2 Influent characteristics

The sludge return liquors include dewatering sludge liquors and DAFs supernatant. For Modules 1-3 dewatering sludge liquors are combined with the raw wastewater, while the DAFs supernatant is only discharged downstream of the primary treatment. For Module 4 all sludge liquors (DAF supernatant and dewatering liquors) are combined with the raw wastewater prior primary settling. DAF returns from each module are recycled to each respective module. Dewatering returns are split equally between Modules 1-3 and Module 4.

Table 17 indicates that the impact of dewatering sludge return liquors on raw wastewater from Modules 1-3 falls below typical range for most parameters. For Module 4, the effect of the return liquors is higher and is above the typical range for most parameters. The impact for Module 4 is more substantial because it treats a disproportionate amount of the return liquors compared to the treatment capacity of the module.

Figure 29 and Figure 30 indicate the impact of the dewatering return liquors for all relevant parameters.

Table 17: Impact of dewatering return liquors in the influent characteristics at 'W' WWTP

Parameters	**Modules 1-3**		**Impact on Modules 1-3**	**Module 4**		**Impact on Module 4**	**Impact on total raw WW**	**Typical impact on Raw WW (*)**
	Raw WW	Raw ww & Dewatering returns		Raw WW	Raw ww & Sludge returns			
Flow (Mℓ/d)	197.6	198.1	0.3%	54.6	55.1	1.0%	0.4%	0.5% – 1.0%
COD (kg/d)	144 737	145 956	0.8%	40 823	42 042	3.0%	1.3%	5% – 10%
TKN (kg/d)	9582	9 869	3.0%	2 703	2 990	10.6%	4.7%	9% – 13%
NH_4 (kg N/d)	4685	4 909	4.8%	1 321	1 545	16.9%	7.4%	9% – 13%
TP (kg/d)	1206	0	4.1%	340	0	14.5%	6.4%	5% – 30%
PO_4 (kg P/d)	571	1 256	4.7%	161	389	16.8%	7.4%	5% – 30%
TSS (kg/d)	38427	599	2.4%	10 838	188	8.3%	3.7%	2% – 5%

(*) Based on Royal HaskoningDHV process design tool and excluding any dedicated treatment to the sludge return liquor

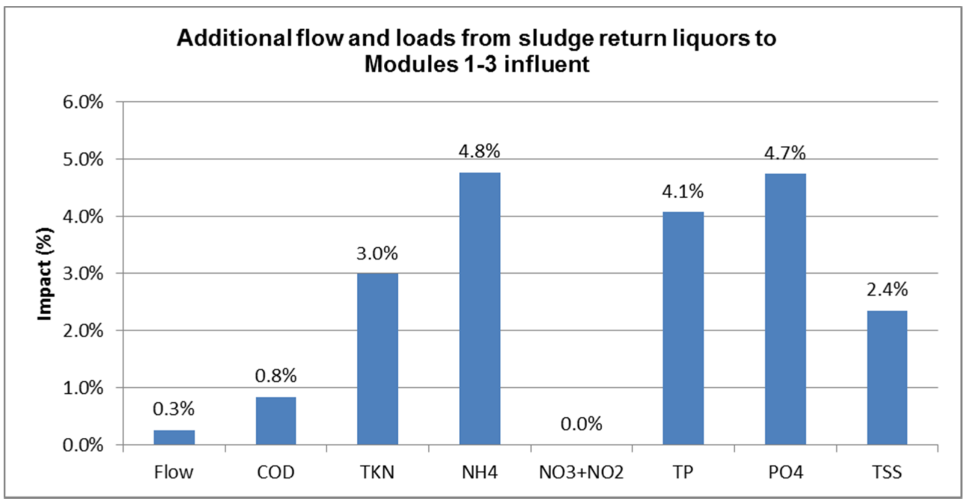

Figure 29: Additional flow and loads entering Module 1-3 from the sludge return liquors treatment at 'W' WWTP

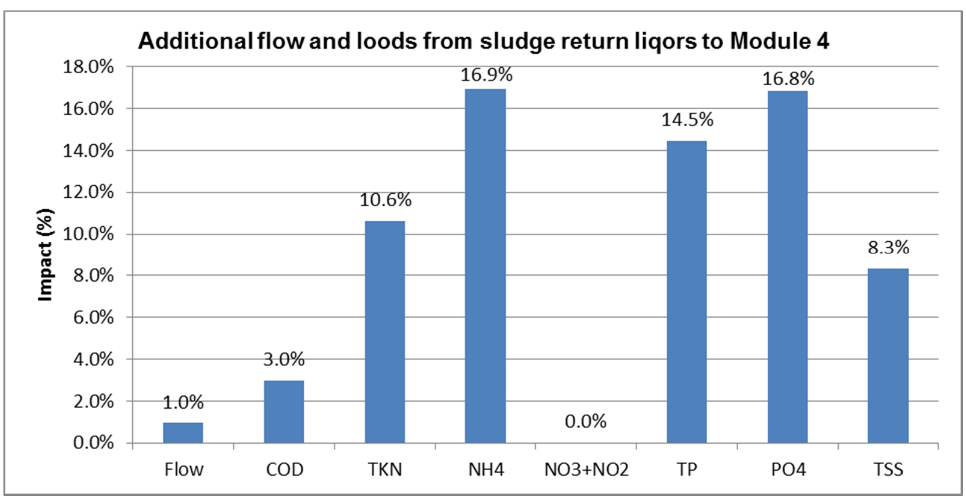

Figure 30: Additional flow and loads entering Module 4 from the dewatering sludge return liquors at 'W' WWTP

Currently, 40% of the digested sludge is dewatered using belt presses, with the other 60% being dried on drying beds/paddies. If in future all the digested sludge was dewatered using belt presses and the return liquors were split evenly between Modules 1-3 and Module 4, there would be a slight additional impact on the influent load on Modules 1-3 and a more significant impact in Module 4. In this scenario, Module 4 would see an increment of load due to the dewatering return liquors in of 27% for NH_4^-N, 23% for TP, 27% for PO_4^-P and 13% for TSS.

Comparing the influent ratios for Modules 1-3 and Module 4 (including dewatering returns) with a typical South African sewage (Table 18), it is noted that all ratios lie above the typical ranges. The reason behind that is the unusual low influent solids and nutrients (N and P) concentrations compared to the influent COD concentration. In practice, this does not have an impact in the plant's performance.

Table 18: Influent ratios with and without return liquors at 'W' WWTP

Ratios	Modules 1-3	Module 4	Typical SA Raw WW*
	Raw WW & Returns	Raw WW & Returns	
COD/TSS	3.6	3.6	2.0
COD/TKN	15	14	8.2
COD/ NH_4	30	27	14
COD/TP	116	108	54
COD/ PO_4	244	223	117

(*) WRC Report TT389/09, Process Design Manual for Small Wastewater Treatment Works

2.6.3 Biological effluent quality

The average effluent quality of Modules 1-3 and Module 4 (biological effluent) is presented in Table 19. On average, all parameters in the biological effluent meet the effluent standard requirements.

Assessing Figure 31 from September 2015 to August 2016, it is noted that Modules 1-3 have a lower ammonia concentration between December 2015 and April 2016. This could be due to the higher summer temperatures helping facilitate nitrification. This also accounts for why there is a higher nitrate and nitrite concentration during this period resulting from higher nitrification capacity with more NO_x production. Apparently, the denitrification capacity does not exactly follow the improved nitrification capacity in summer period. For Module 4 Figure 32 indicates that ammonia concentrations are stable through the year seasons and lie below 1.0 mg N/ ℓ (with an exception in Jun 2016).

Table 19: Average effluent quality of the biological effluent at 'W' WWTP

Parameters	Modules 1-3 (biological effluent)	Module 4 (biological effluent)
COD (mg/ℓ)	31	26
NH_4 (mg N/ℓ)	1.3	0.5
$NO_3 + NO_2$ (mg N/ℓ)	4.2	4.9
PO_4 (mg P/ℓ)	0.3	0.1
TSS (mg/ℓ)	11	10

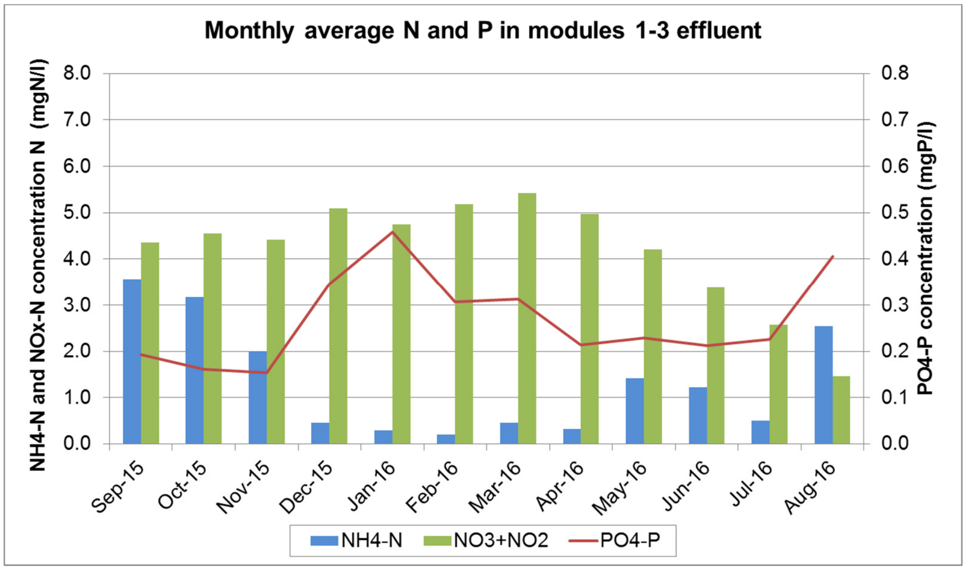

Figure 31: Monthly AV ammonia, nitrate+nitrite and orthophosphate effluent quality from Modules 1-3 at 'W' WWTP

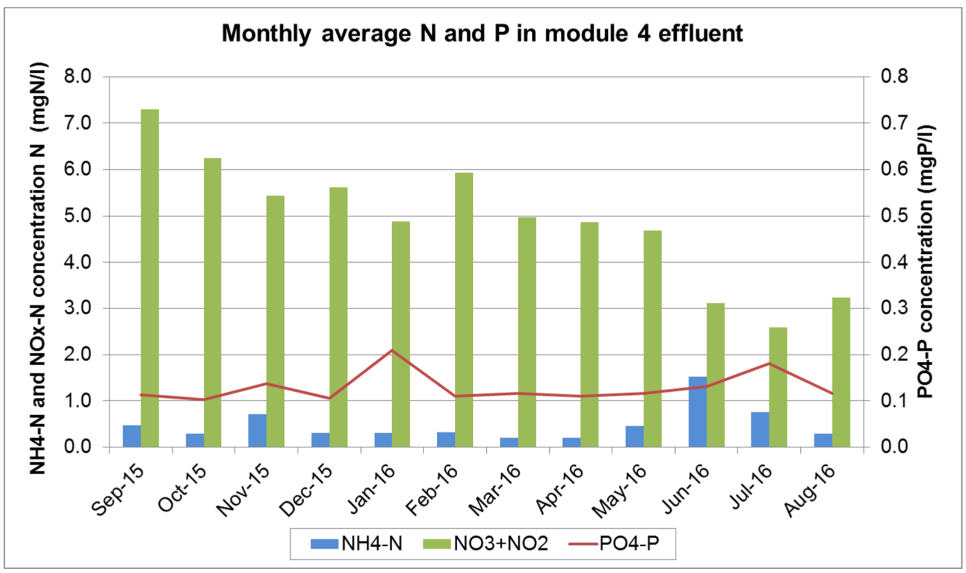

Figure 32: Monthly AV ammonia, nitrate+nitrite and orthophosphate effluent quality from Module 4 at 'W' WWTP

2.6.4 Aeration demand

At Waterval, the four modules include surface aerators and fine bubble diffusers with blowers. The aeration equipment installed is as following:

- Module 1:
  - 16 × 37 kW stage 1 surface aerators running 24 hours/day.
  - 10 × 37 kW 2 stage surface aerators running 24 hours/day.
  - Currently, four stage 1 surface aerators are out of service.
- Modules 2-3:

- 5 × fixed speed 375 kW centrifugal blowers (4 duty, 1 standby) provide air for fine bubble aeration system. Duty blowers run 24 hours/day.

- Module 4:
  - × 75 kW surface aerators running 24 hours/day.
  - 10 × 55 kW surface aerators running 24 hours/day.
  - Currently, three surface aerators are out of service.

The plant does not have individual energy meters in the aeration system and therefore historical consumption records are not available. However, for the current operating conditions, i.e. only 40% of the digested sludge is dewatered and respective sludge liquors returned to treatment, it is estimated that about 72 000 kW/d are spent in aeration in the biological reactors (55 500 kW/d in Modules 1-3 and 16 500 kW/d in Module 4).

If in future 100% of the digested sludge is dewatered, the flow and load of the sludge liquors will increase, and it is expected that the total aeration consumption also increases in at least 5% (as per current split 3% in Modules 1-3 and 10% in Module 4).

If side stream treatment for the current returns is considered, it should be possible to decrease the total aeration capacity in the biological treatment by 8% and if in the future 100% of the sludge is dewatered, the reduction in the aeration demand should be at least 12%.

2.6.5 Biological treatment capacity

The current inflow to all modules is above the plant design flow. Modules 1-3 are treating 165% and Module 4 receiving 112% of their design flows. For Modules 1-3 COD, TKN and ammonia loads are greater than the design loads. For Module 4 only TKN and ammonia loads are slightly greater than the design loads (refer to Table 20).

For the current high flow/load treated in Modules 1-3, it is surprising that its effluent requirements are still mostly compliant as referred in section 2.6.3. This may be justified by a reasonable sludge retention time in Modules 1-3, approximately 9 days, when the minimum SRT to nitrify at 14ºC is only 6 days. Module 4 shows a much higher SRT (19 days on average) and since it is much less overloaded, its performance is always excellent and not affected by variation of process temperature.

Table 20: Current biological treatment capacity at Waterval WWTW

Parameters	Modules 1-3			Module 4		
	Design	Actual		Design	Actual	
Flow (Mℓ/d)	120	198	165%	50	56	112%
COD (kg/d)	132 000	145 956	111%	55 000	42 621	77%
TSS (kg/d)	66 000	39 331	60%	27 500	12 302	45%
TKN (kg/d)	7 200	9 869	137%	3 000	3 030	101%
NH_4^-N (kg/d)	3 360	4 909	146%	1 400	1 546	110%
TP (kg/d)	1 440	1 256	87%	600	413	69%
PO_4^-P (kg/d)	840	599	71%	350	189	54%

2.7 Conclusions and recommendations

The site research conducted at 'W' WWTP indicates the following conclusions regarding the impact of the sludge return liquors in the plant:

1. The dewatering return liquors, rich in ammonia and ortho-phosphate, are recycled to the beginning of the treatment process, before primary treatment, and the flow is split: 50% to Modules 1-3 and 50% to Module 4. Considering that Module 4 corresponds to only 35% of the total biological capacity available, the current split of the returns is not proportional and therefore increases the impact of the return liquors on this module, i.e. an additional 17% of ammonia and ortho-phosphate to be treated as well as additional 8% in TSS. At the moment, this is not critical and not affecting the effluent quality of Module 4. In comparison, Modules 1-3, with 65% of the biological capacity available, shows an almost negligible impact in the increase of the inflow and influent load. Despite the current minimal impact on these modules, it would be recommended to make a proportional split of the dewatering returns per the capacity of the modules.

2. Currently only 40% of the digested sludge is mechanically dewatered and only the corresponding fraction of dewatering return liquors is recycled to the beginning of the treatment works. If, in the near future, 100% of the digested sludge is dewatered, an additional 60% of the dewatering returns will be added to the current influent. In that case the impact on Module 4 will be even higher (estimated in 27% increase on NH_4^-N and PO_4^-P each).

3. The DAF returns are also a point of concern and especially on Module 1 due to the age of the installation and continuous breakdowns in equipment. In general, the high TSS concentration returned from the DAF's supernatant indicates a non-optimal efficiency of the floatation units. Therefore, the hydraulic and solids loads should be properly checked as well as the pressurization systems.

4. Although Plant 'W' is overloaded the plant's performance is still compliant with the current standard effluent requirements. However, it should be noted that the plant has a relatively lenient requirement for ammonia and if more stringent effluent limits are applied (for example ammonia < 1 mgN/ℓ), Modules 1-3 would not be able to continuously comply (refer mainly to the winter season).

In addition, the following generic conclusions and recommendations shall be noted:

5. The plant is generally well operated and shows a good level of maintenance.

6. The current hydraulic demand in the plant is 150% of the total design capacity. Modules 1-3 have a current capacity of 165% of the design flow and Module 4 has 112% of its design flow. Also, the ammonia load coming in to Modules 1-3 is already at 146% of the design load. ERWAT is already planning the extension of the plant. This will be extremely helpful to alleviate the extra flow currently reaching Modules 1-3.

7. The anaerobic digestion process has been running smoothly and no critical issues were encountered. The long sludge retention time in the digesters (> 100 days in the cold digesters and > 30 days in heated digesters) is allowing 40% of VSS destruction. A slightly higher VSS destruction rate, close to 50-60%, was expected. It is recommended to double check the digestion temperature in the heated digesters and mixing conditions as well.

CHAPTER 3: 'K' Wastewater Treatment Plant

The 'K' WWTWP is located in the KwaZulu-Natal Phoenix industrial/residential area and is owned and operated by eThekwini Municipality. The plant treats mainly domestic sewage from these two areas, and only 10 to 15% of the influent is from industries. The 'K' WWTP has a treatment capacity of 80 Mℓ/d; consisting of a 15 Mℓ/d trickling filter module and a 65 Mℓ/d activated sludge module. The current ADWF is about 57 Mℓ/d. An overview of the 'K' WWTP site is presented in Figure 33.

The plant's key unit operations consist of primary sedimentation, trickling filters, AS treatment and AD. The biological effluent is clarified in secondary clarifiers and humus tanks and then discharged into the environment after chlorination. The WAS from the aerobic process is thickened and dewatered using mechanical presses. A portion of the PS (30%) is dewatered and incinerated in a fluidised bed reactor (FBR).

Figure 33: Aerial view of 'K' WWTP (Google Earth)

3.1 Process description

A description of the works is indicated below as per information retrieved from the plant's as-built drawings. The general process flow diagram of the treatment works is provided in Figure 34.

- **Inlet works** consists of:
  - Two mechanical stone traps,
  - Three mechanical inlet screens (new works),
  - Two aerated degritters.

- **Wastewater treatment** consists of:
  - 15 Mℓ trickling filter module:
    - Six PSTs
    - trickling filters
    - humus tanks
  - 65 Mℓ fully aerobic activated sludge module,
  - An aerobic process consisting of 16 aerators arranged in 4 lanes with 4 aerators per lane,
  - Eight SSTs.

- **Disinfection** consists of:
  - Final effluent from the SSTs is discharged into two maturation ponds which overflow via a third maturation pond into the uMhlangane River.

- **Sludge handling and disposal** consists of:
  - A portion of the PS (30%) is dewatered and incinerated in a fluidised bed reactor (FBR). The remaining primary sludge from the two PSTs is thickened and anaerobically digested. The FBR unit, however, is currently not in operation due to a planned upgrade to maximise its operations. This has been the situation for over 2 years. Thus, all the PS now undergoes thickening and is pumped to the anaerobic digesters,
  - WAS is pumped from the SSTs to the DAF unit while return activated sludge (RAS) is recycled to the AS system,
  - Thickened primary sludge is digested in four mesophilic anaerobic digesters including mixing and heating (2 000 m^3 each).
  - Digested sludge undergoes further digestion in two secondary digesters (2 310 m^3 each)
  - Digested sludge is stored in a digested sludge sump which subsequently feeds the dewatering plant. The digested sludge is fed to mechanical screw (Huber) presses via four sludge-feed lines.
  - Biological thickened sludge from the DAF unit is pumped to a secondary sludge feed sump from where it is fed to the dewatering plant and thereafter incinerated or beneficially applied to agricultural land.

- **Return liquors treatment** consists of:
  - All sludge return liquors from gravity thickeners, DAF, secondary digester and mechanical dewatering are returned upstream of the PSTs included in the AS module.

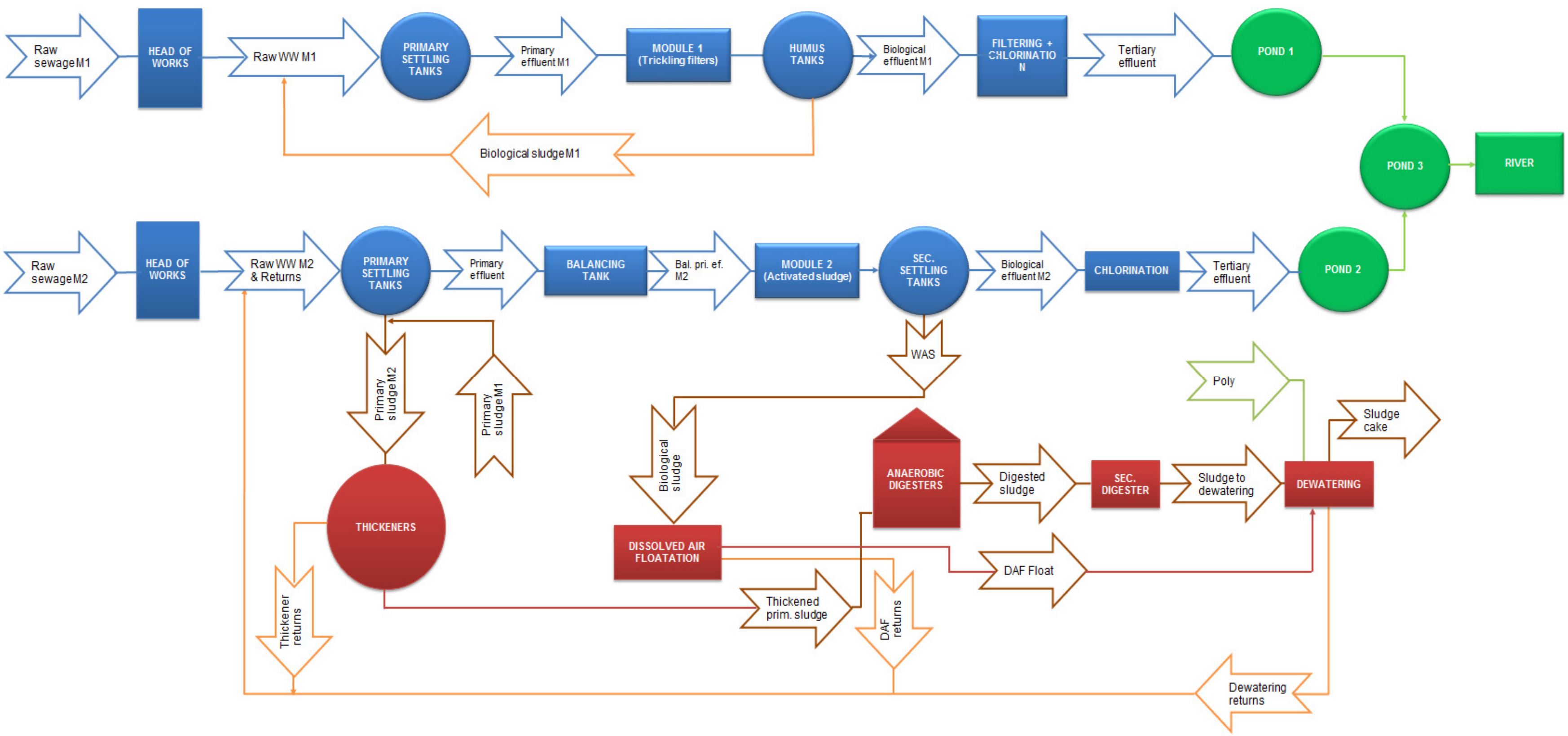

Figure 34: 'K' WWTP block diagram

3.2 Design capacity

The total design capacity of the plant is indicated in Table 21.

Table 21: Design flows and loads at 'K' WWTP

Parameters	Old works	New works	Total
Flow (Mℓ/d)	15	65	80
COD (kg/d)	12 000	50 000	62 000
TKN (kg/d)	520	3 600	4 120
TP (kg/d)	90	765	855

3.3 Effluent standard requirements

Currently, the 'K' WWTP does not have water use licence in place; implying that there are no existing wastewater limit values that specifically governs the discharge of effluent generated at the works. An application has been made in this respect. Table 22 presents general wastewater limit values applicable to discharge of wastewater into a water resource as gazetted in the Revision of General Authorisations in terms of Section 39 of the National Water Act, 1998 (Act No. 36 of 1998) – Gazette No. 36820 (6 September 2013). Considering the non-existence of a water use licence, it is assumed that the general standards will be applicable to the works.

Table 22: General requirements for effluent discharge applicable to 'K' WWTP

Parameter	Effluent standards	Method of compliance
COD (mg/ℓ)	75	90% compliance
TSS (mg/ℓ)	25	
NH_4 (mg N/ℓ)	6	
$NO_3 + NO_2$ (mg N/ℓ)	15	
PO_4 (mg P/ℓ)	10	

3.4 Technical performance

The Royal HaskoningDHV team conducted a site visit to the works on 28 November 2016. The 'K' WWTP appears to be a well operated and maintained facility with reasonable level of automation and optimization measures including SCADA system, VSDs and DO sensors.

However, the old works has been offline for about six months due to a fault to the inlet screens at the old works. The screens are currently being replaced by mechanical raked screens removed from the new works as a result of an upgrade. Consequently, all wastewater is currently being treated at the new works.

3.5 Process performance

3.5.1 Influent characteristics

Figure 35, the average daily flow of wastewater treated at 'K' WWTP between January 2014 and June 2016 is presented. On average, a total of 60 Mℓ/d of wastewater was treated at the works; implying 75% of the plant's design capacity. The new works treats approximately 90% of the flows (54 Mℓ/d) while the old works treats the remaining 10% (6 Mℓ/d); representing 83% and 40% of the design capacity of the new and old works respectively.

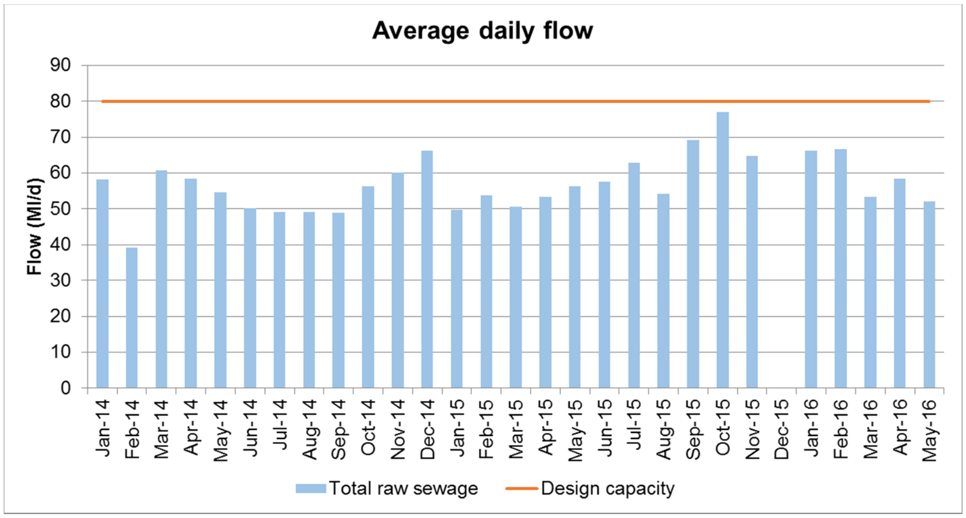

Figure 35: Average daily flow at 'K' WWTP

The average influent concentrations and loads are indicated in Table 23 and historical averages in Figure 36 and Figure 37. In general, the raw sewage shows a high loading rate but remains within the plant's design specification. Currently the plant is treating 67% of the COD design load, 72% of the TKN design load and 62% of the TP design load.

Table 23: Average raw sewage concentrations and loads at 'K' WWTP

Parameter	Average concentration (January 2014 to June 2016)		Average load (January 2014 to June 2016)	
COD	727.3	mg/ℓ	41 456	kg/d
TSS	612.8	mg/ℓ	34 930	kg/d
TKN	52.3	mg/ℓ	2 983	kg/d
NH_4	21.7	mgN/ℓ	1 234	kg/d
PO_4	3.2	mgP/ℓ	182	kg/d
TP	9.3	mg/ℓ	532	kg/d

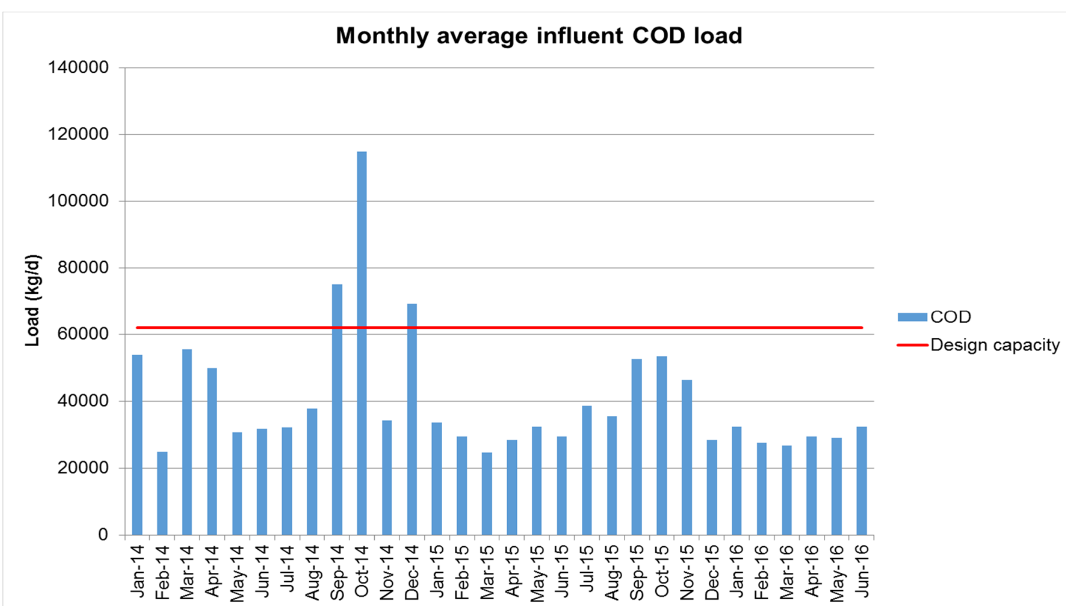

Figure 36: Average COD load at 'K' WWTP

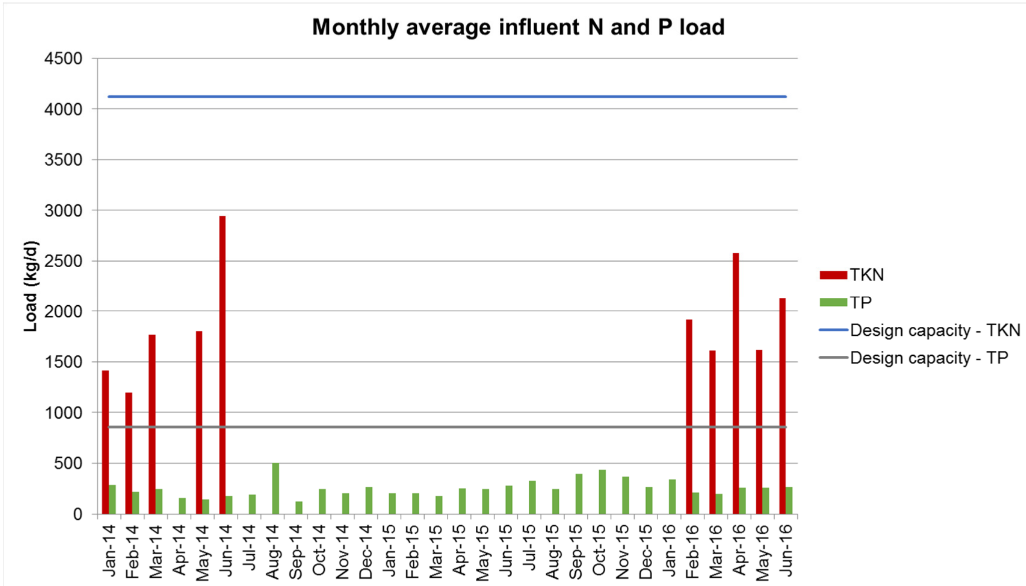

Figure 37: Average TKN and TP loads at 'K' WWTP

*Missing values were observed in TKN data between July 2014 and January 2016

3.5.2 Effluent quality

Benchmarking the final effluent discharged at 'K' WWTP (Table 24) against the effluent general wastewater discharge limits (refer to Section 3.3), excellent phosphorous removal is achieved at the plant as 100% compliance was observed during the period under review. However, the average concentrations of COD, TSS and NH_4 were beyond allowable limits in many instances or samples; representing 89%, 90% and 69% compliance respectively. Institution of process optimization measures is advised to ensure full compliance with specified limits.

Table 24: Average final effluent quality and plant compliance at 'K' WWTP

Parameter	Effluent standards	Average concentration (January 2015 to June 2016)	Average compliance (January 2015 to June 2016)
COD	75	48,4 mg/ℓ	89%
TSS	25	12,1 mg/ℓ	90%
NH_4	6	5,1 mgN/ℓ	69%
$NO_3 + NO_2$	15	3,8 mgN/ℓ	100%
PO_4	10	2,4 mgP/ℓ	100%

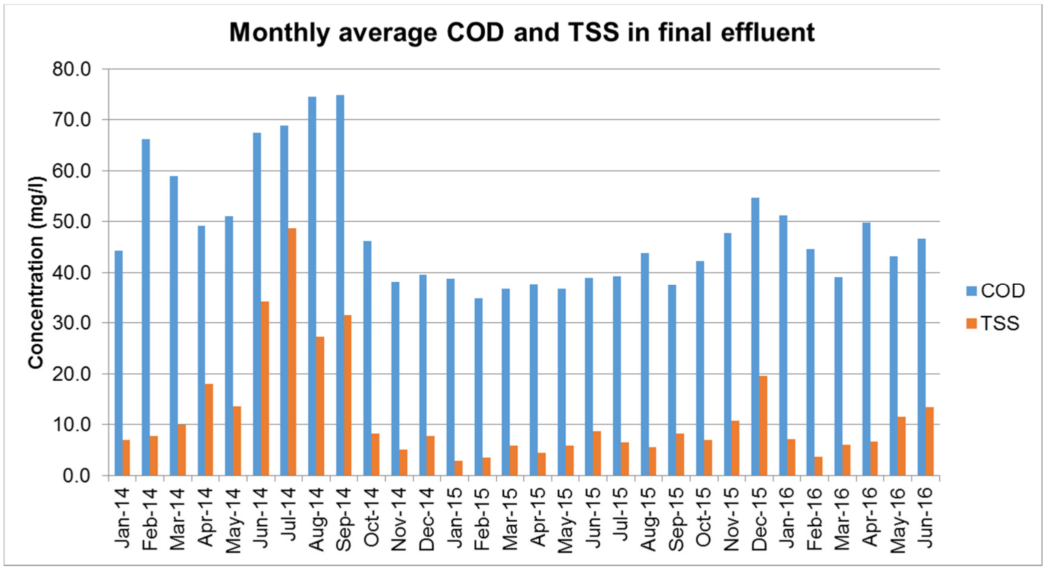

Figure 38: Monthly average COD and TSS in the final effluent at 'K' WWTP

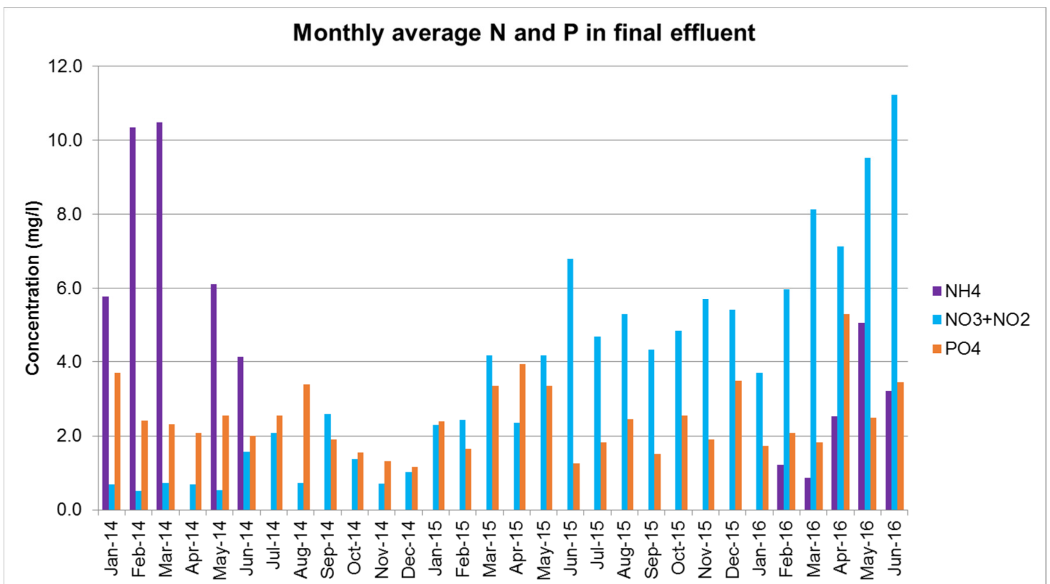

Figure 39: Monthly average ammonia, nitrate+nitrite and orthophosphate in the final effluent at 'K' WWTP

3.5.3 Sludge treatment

3.5.3.1 Sludge characteristics

At 'K' WWTP, PS from the PSTs at the old and new works is extracted and sent to two thickeners. Sludge from the humus tank is recycled to the incoming flow into the PSTs at the old works. Sludge production at the humus tanks is approximately 300 m³/day at 1-2% dry solids. Biological sludge is wasted from the SSTs and fed into the DAF unit. The design capacity of the plant with regards to sludge handling and treatment is 125 ton sludge per day; comprising approximately 65-ton digested sludge per day at 25% total solids and 60 ton WAS per day at 22% TS.

Table 25 indicates the characteristics of the PS prior and after thickening and WAS before and after floatation.

Table 25: Characteristics of primary and biological sludge at the new and old plants in 'K' WWTP

Parameter	Primary sludge		Biological sludge	
	Before thickening	After thickening	Before floatation	After floatation
Flow (m³/d)	1 300	650	665	186
Dry solids (%)	1.8	3.2	1.2	4.1
Sludge mass (kg/d)	22 967	20 670	8 279	7 626

3.5.3.2 Sludge thickening

Primary and biological sludge from the old works is combined with PS from the new works and all together are gravity thickened to 3.2% DS. The thickeners show a reasonable solids capture at 90%.

The historical performance of primary and biological thickened sludge is presented in Figure 40. The average dry solids content of the primary and biological thickened sludge is approximately 3.2% and 4.1 % (w/v) respectively, and it is aligned with the plant's design values. The organic fraction of the sludge is about 62% and 66% respectively. Also, the DAF units indicate a solids capture around 92%.

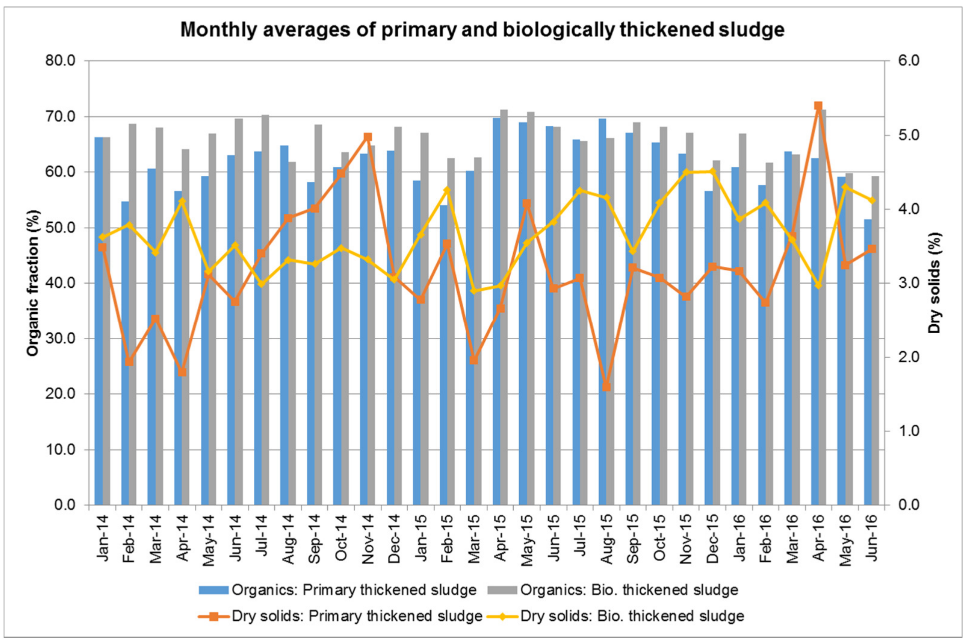

Figure 40: Monthly averages of organic fraction and DS content in the PS and WAS thickened sludge at 'K' WWTP

3.5.3.3 Anaerobic sludge digestion

PS is anaerobically digested in 4 digesters. The digesters were operated at between 30-35°C using heat produced from about 40% of biogas. The remaining biogas, comprising of approximately 65% methane and 35% CO_2 is flared to atmosphere. At this range of temperatures, the anaerobic stabilization of the sludge is considered efficient due to stability in the heating process of the ADs. Further stabilization of the sludge is achieved in two secondary digesters; allowing for the supernatant liquor separation and decantation.

The DS content of sludge digested during the period January 2014 to June 2016 ranged between 1.2% and 4.3%; averaging 2.7% (w/v), and the organic fraction was on average 60% (Figure 41). The average retention time in the ADs was approximately 15 days, which is just within the range (i.e. 15-20 days recommended retention time) for digesters operated under mesophilic conditions (35ºC). The destruction of VSS in the digesters is calculated to be 23%. This is less than the typical range (50% to 460%) of VSS destruction in PS anaerobically digested. It is recommended to thoroughly check the temperature as well as mixing conditions in the ADs.

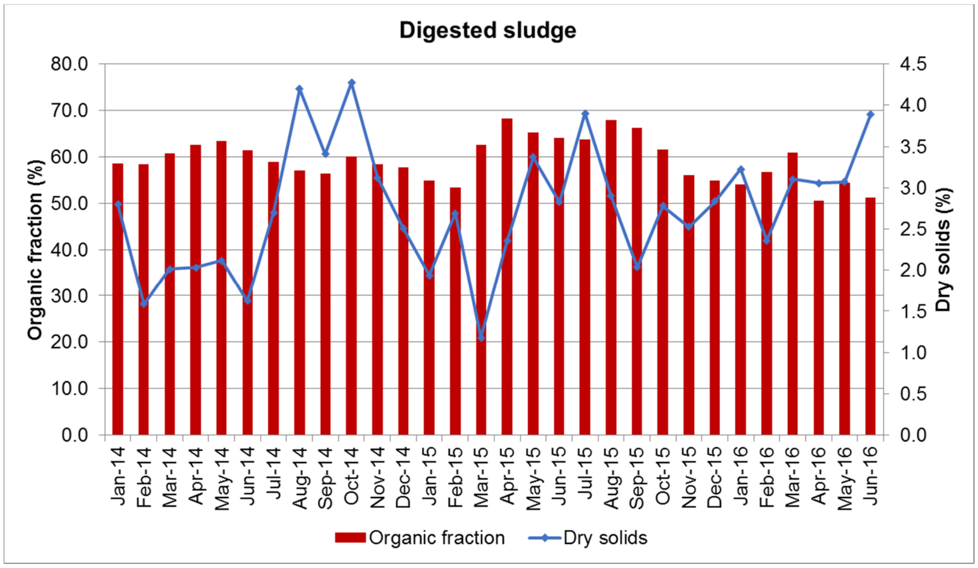

Figure 41: Monthly average organic fraction and dry solids content in the digested sludge at 'K' WWTW

3.5.3.4 Sludge dewatering

The combination of primary digested sludge and biological thickened sludge are mechanical dewatered using a centrifuge system; comprising 8 Huber units. Upon analysis of data received, the average DS content in the sludge cake was approximately 24% (Figure 42), which is within the typical operating range of mechanical screw presses (20-30%).

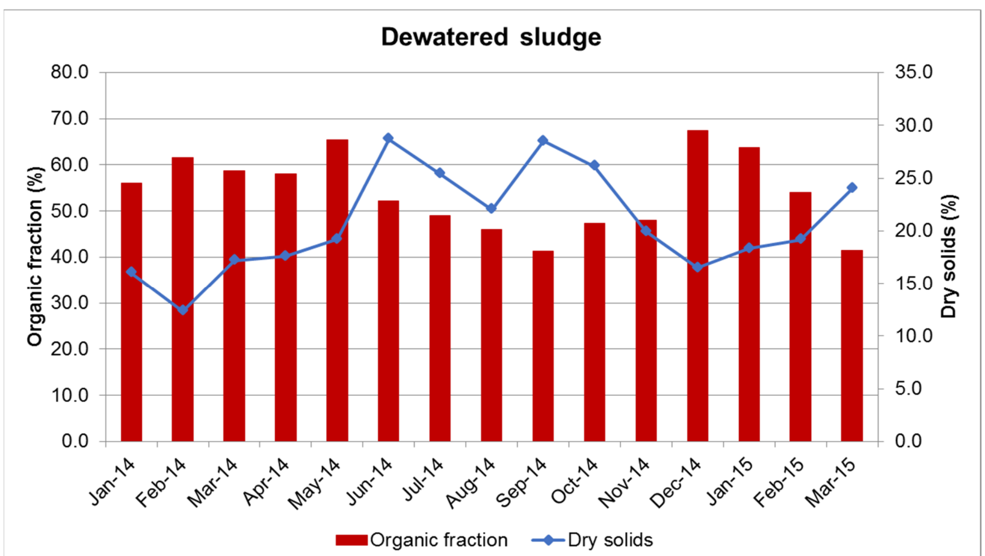

Figure 42: Monthly average organic fraction and dry solids content in the dewatered sludge at 'K' WWTP

3.5.4 Treatment of sludge return liquors

Per information received from process engineers at the works, no treatment is given to the sludge return liquors at the plant.

The recorded monthly average orthophosphate and ammonia concentrations in the return liquors from January 2014 to June 2016 are indicated in Figure 43. The average concentrations were approximately 18 mg NH_4 N/ℓ and 5 mg PO_4^-P /ℓ which appear to be very low and another indication that the anaerobic digestion process is not optimised.

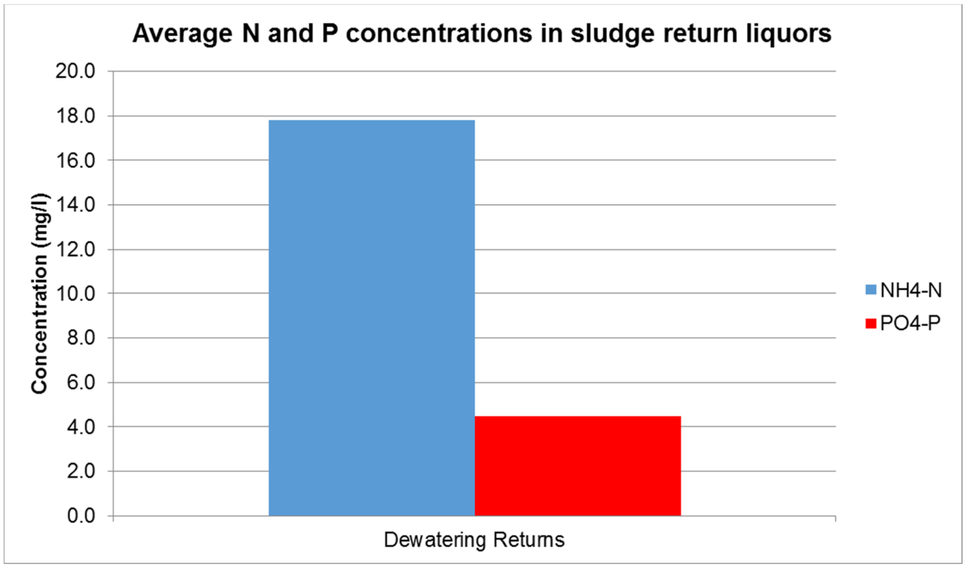

Figure 43: Average ammonia and orthophosphate concentrations in the sludge return liquors at 'K' WWTP

3.6 Impact of sludge returns liquors

3.6.1 Plant mass balance

A complete mass balance of the 'K' WWTP was prepared to understand and evaluate the magnitude of the impacts of the sludge dewatering return liquors on the main treatment process addressed in the following sections. The result of the plant mass balance, elaborated with the average data available from January 2014 to June 2016, is provided in Table 26. Once the analytical data available did not cover all streams and parameters, the following assumptions were required to complete the mass balance:

- COD in biological sludge: COD/MLVSS = 1.4
- TKN/SS ratio = 7%
- TP/SS ratio = 5%
- Washwater to dewatering plant = 20% of feed

To confirm the assumptions above and improve the accuracy of the mass balance it would be recommended to double-check the following parameters with an analytical programme during at least 3 days:

- Primary sludge (old and new):
  - COD, TSS, TKN and TP.
- Biological sludge:
  - COD, TSS, NH_4^-N, TKN, PO_4^-P and TP.
- Primary thickened sludge:
  - TSS in, TSS returned and DS sludge.
- DAF units:

- TSS in, TSS returned and DS sludge.

- Digested sludge:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.

- Thickeners returns:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.

- DAF returns:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.

- Digester returns:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.

- Dewatering returns:
  - COD, TKN, NH_4^-N, TP, PO_4^-P and TSS.

- Sludge cake (dewatered sludge):
  - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.

The following flows should be also confirmed:

- Primary sludge to thickener, and to digestion.
- Biological thickened sludge
- Dewatered sludge.
- Return sludge liquors recycled to new works.
- Washwater to dewatering.

Table 26: Results of the mass balance at 'K' WWTP

Water streams	Raw WW - Old works	Raw WW - New works	Raw WW - New works & Returns	Balanced primary effluent - Old works	Balanced primary effluent - New works	Secondary effluent - Old works	Secondary effluent - New works	Final effluent
Flow (Ml/d)	6.0	54.0	56.0	6.0	55.0	5.7	54.3	60.0
COD (kg/d)	2010.0	41191.2	46765.7	1218.0	32950.4	988.2	1757.9	2905.7
TKN (kg/d)	153.0	2106.0	2454.7	133.2	2233.8	22.2	211.9	459.3
NH4 (kg/d)	102.0	1404.0	1439.6	88.8	1439.6	14.8	141.3	306.2
NO3+NO2 (kg/d)	0.0	0.0	3.0	0.0	3.0	7.8	239.1	228.1
TP (kg/d)	23.9	374.2	589.5	25.3	524.6	28.7	273.8	302.6
PO4 (kg/d)	11.4	178.2	187.1	12.0	187.1	13.7	130.4	144.1
TSS (kg/d)	1008.0	30515.4	36779.6	414.0	17676.9	208.1	869.4	726.4
COD (mg/l)	335.0	762.8	835.1	203.0	599.1	173.4	32.4	48.4
TKN (mgN/l)	25.5	39.0	43.8	22.2	40.6	3.9	3.9	7.7
NH4 (mgN/l)	17.0	26.0	25.7	14.8	26.2	2.6	2.6	5.1
NO3+NO2 (mgN/l)	0.0	0.0	0.1	0.0	0.1	1.4	4.4	3.8
TP (mgP/l)	4.0	6.9	10.5	4.2	9.5	5.0	5.0	5.0
PO4 (mgP/l)	1.9	3.3	3.3	2.0	3.4	2.4	2.4	2.4
TSS (mg/l)	168.0	565.1	656.8	69.0	321.4	36.5	16.0	12.1

Sludge streams	Primary sludge - Old works	Primary sludge - New works	Total primary sludge	Primary thickened sludge	Biological sludge - Old works	Biological sludge - New works to DAF	DAF sludge to dewatering	Digested sludge to dewatering	Total feed to dewatering	Sludge cake
Flow (Ml/d)	0.3	1.0	1.3	0.7	0.3	0.7	0.2	0.5	0.7	0.1
COD (kg/d)	1107.0	13815.3	14922.3	13430.0	315.0	8692.5	7062.8	12849.6	19912.4	17816.6
TKN (kg/d)	42.2	220.9	354.1	318.7	22.4	581.4	534.4	285.1	819.4	669.2
NH4 (kg/d)	14.6	0.0	14.6	14.6	1.4	1.9	0.5	0.0	0.5	0.0
NO3+NO2 (kg/d)	0.0	0.0	0.0	0.0	0.0	2.9	0.8	0.0	0.8	0.0
TP (kg/d)	14.3	64.8	79.1	71.2	15.6	415.5	381.7	63.9	445.6	338.3
PO4 (kg/d)	0.0	0.0	0.0	0.0	0.6	1.6	0.4	0.0	0.4	0.0
TSS (kg/d)	894.0	19102.7	22966.7	20670.0	300.0	8278.6	7626.0	15995.2	23621.2	21482.6
COD (mg/l)	3690.0	13815.3	11478.7	20661.6	1050.0	13071.5	37972.0	27281.6	30308.1	197961.9
TKN (mgN/l)	140.8	220.9	272.4	490.3	74.8	874.3	2872.9	605.2	1247.2	0.0
NH4 (mgN/l)	48.8	0.0	11.3	22.5	4.8	2.9	2.9	0.0	0.8	0.0
NO3+NO2 (mgN/l)	0.0	0.0	0.0	0.0	0.0	4.4	4.4	0.0	1.2	0.0
TP (mgP/l)	47.7	64.8	60.9	109.6	52.1	624.9	2052.4	135.6	678.3	0.0
PO4 (mgP/l)	0.0	0.0	0.0	0.0	2.1	2.4	2.4	0.0	0.7	0.0
TSS (mg/l)	2980.0	19102.7	17666.7	31800.0	1000.0	12449.0	41000.0	33960.1	35953.1	238695.7

Sludge return liquor streams	Thickener Supernatant	DAF returns	Secondary digester SNL	Dewatering returns	Total return liquor streams
Flow (Ml/d)	0.7	0.5	0.2	0.7	2.0
COD (kg/d)	1929.2	604.4	945.0	2095.8	5574.5
TKN (kg/d)	35.4	47.1	116.0	150.2	348.7
NH4 (kg/d)	0.0	1.4	33.6	0.5	35.6
NO3+NO2 (kg/d)	0.0	2.1	0.0	0.9	3.0
TP (kg/d)	7.9	33.8	66.2	107.4	215.2
PO4 (kg/d)	0.0	1.1	7.3	0.4	8.9
TSS (kg/d)	2296.7	652.6	1176.4	2138.6	6264.2
COD (mg/l)	2968.0	1261.8	27281.6	3029.4	2787.5
TKN (mgN/l)	54.5	98.3	605.2	217.2	174.4
NH4 (mgN/l)	0.0	2.9	0.0	0.8	17.8
NO3+NO2 (mgN/l)	0.0	4.4	0.0	1.2	1.5
TP (mgP/l)	12.2	70.5	135.6	155.2	107.6
PO4 (mgP/l)	0.0	2.4	0.0	0.6	4.5
TSS (mg/l)	3533.3	1362.4	33960.1	3091.2	3132.4

3.6.2 Influent characteristics

The sludge return liquors are combined with the incoming raw sewage at the new works. As a result of only PS being digested at the plant, the concentration of return liquors is normal; with no significant impacts on the influent load to the new works, except for TP which increased by 36.4% (Table 27). The increase in TP loads is relatively higher than that of other parameters, but the ortho-P load coming from the sludge returns is low. Therefore, most of the TP load is from solids.

Although the concentration of other parameters appears to be insignificant on the plant, it is important to note that, if the management of the works decides to digest all the sludge produced at the works (i.e. subject WAS to anaerobic digestion) in the near future, it is expected that the return liquor concentration will increase 10 folds. This will, in turn, impact of the carbon and nutrients concentration in the aeration basin, necessitating higher aeration capacity.

Table 27: Impact of dewatering return liquors in the influent characteristics at 'K' WWTP

Parameter	Raw sewage to the plant	Sludge returns	New works raw ww (incl. returns)	Impact on new works raw ww	Impact on total plant raw ww	Typical impact on raw ww (*)
Flow (Mℓ/d)	60	2	56	3.6%	3.3%	0.5% – 1,0%
COD (kg/d)	41 456	5 575	46 766	11.9%	13.4%	5% – 10%
TKN (kg/d)	2 983	349	2 455	14.2%	11.7%	9% – 13%
NH_4 (kg/d)	1 237	36	1 440	2.5%	2.9%	9% – 13%
TP (kgP/d)	532	215	590	36.4%	40.4%	5% – 30%
PO_4^-P (kg/d)	182	9	187	4.8%	4.9%	5% – 30%
TSS (kg/d)	34 930	6 264	36 780	17.0%	17.9%	2% – 5%

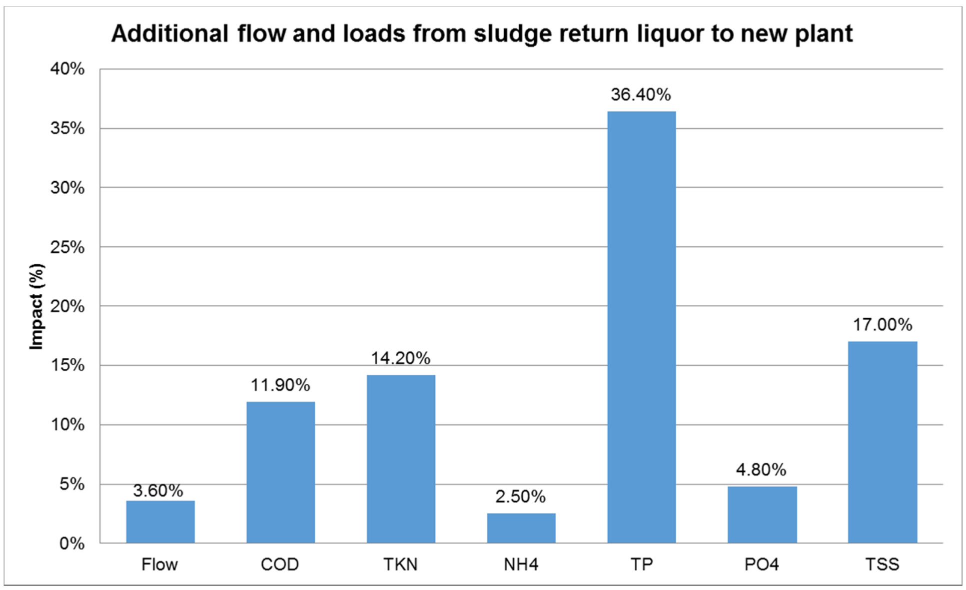

Figure 44: Additional flow and loads entering in Module 2 from the sludge return liquors treatment at 'K' WWTP

Comparing the influent ratios from the old works (without return liquors) with a typical South African sewage (Table 28), generally the raw sewage at 'K' WWTP is slightly unbalanced, especially in terms of P characteristics (lower than usual). With respect to the new works (including return liquors) it is noted that there is an unfavourable low COD/ PO_4 ratio for P biological removal, which has a significant influence from the return liquors with very high orthophosphate concentrations.

Table 28: Influent ratios with and without return liquors at 'K' WWTP

Ratios	Old works influent (without return liquors)	New works influent (with return liquors)	Typical values in South African ww
COD/TSS	2	1.3	2.0
COD/TKN	13.2	19.1	8.2
COD/ NH_4	19.7	32.5	14
COD/TP	84	79.3	54
COD/ PO_4	176.3	250	117

3.6.3 Biological effluent quality

The average biological effluent quality figures for the plant are presented in Table 29. As indicated, the plant can meet the effluent standard requirement for all the parameters. It is important to note that the general effluent quality requirements were used as benchmark in this case, as the plant, currently, does not have a water use licence. Application in this regard is however in progress, hence the assumption that the general limits apply.

Upon analysis of biological effluent data over the period January 2014 to June 2016, a gradual increase in average concentration of nitrate + nitrite in the biological effluent was observed at both old and new works (Figure 45). Orthophosphate levels were however not measured in the biological effluent at both works. In addition, only a few samplings were done/reported for ammonia.

Table 29: Average effluent quality of the biological effluent from old and new works at 'K' WWTP

Parameters	Old works biological effluent	New works biological effluent
COD (mg/ℓ)	57	64.1
NH_4 (mg N/ℓ)	4.8	2.9
$NO_3 + NO_2$ (mg N/ℓ)	2.5	4.4
PO_4 (mg P/ℓ)	2.1	2.4
TSS (mg/ℓ)	12	31.7

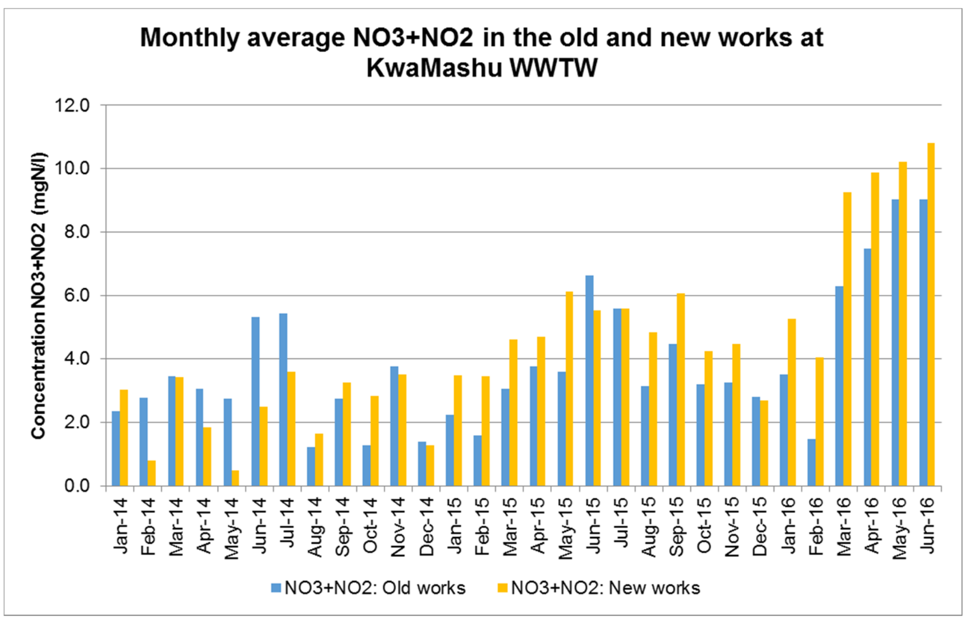

Figure 45: Monthly average nitrate + nitrite biological effluent quality at 'K' WWTP

3.6.4 Aeration demand

'K' WWTP currently has a conventional AS module arranged in 4 lanes. Each lane has 4 aerators installed on it; totalling 16 aerators. The power consumed per aerator is not measured at the plant and can therefore only be calculated. However, DO sensors and VSDs are installed to ensure adequate aeration and power optimization. Eight of the 16 aerators each have a motor size of 90 kW, while the motor size of each of the remaining eight is 45 kW. All aerators are run for 24 hours a day. Currently, the estimated energy requirements for aeration is about 19 000 kWh/d. If the current returns were treated the energy saving in aeration would be about 10%.

3.6.5 Biological treatment capacity

The new works currently treats 94% of the design COD load, 68% of the TKN design load and 77% of the TP design load. The specific biological sludge production is calculated in 0.28 kg MLSS/kgCOD removed and appears reasonable for a conventional AS system. On average the sludge retention time have been around 15 days.

The additional loads from the sludge return liquors are still within the capacity of the new works, however, optimization measures are necessary to avoid overshooting the plant's COD design capacity. It should be noted that if in the future WAS is digested, the new works may not be able to accommodate the extra load from the return liquors as additional aeration will be required.

3.7 Conclusions and recommendations

The site research conducted at 'K' WWTP indicates the following conclusions regarding the impact of the sludge return liquors on plant performance:

1. The new works receives 100% of the flow and loads from the sludge return liquors. With the sludge return liquors, the influent characteristics increased by 11.9% for COD, 14.2% for TKN, 36.4% for TP and 17% for TSS. The sludge return liquors at the plant appears to have little or minor impact on the plant as there is no significant increase in influent characteristics, especially on ammonia (2.5%) and orthophosphate (4.8%). The exception is in the case of TP which increased by 57.5%, showing an important TSS contribution (20.5%). Low ammonia and orthophosphate in the returns can be attributed to the non-digestion of WAS (only PS is digested) and the poor performance of the AD process.

2. Although the concentration of other parameters appears to be insignificant on the plant, it is important to note that, if WAS from the new plant is to be anaerobically digested in the future, the return liquor concentration is expected to increase significantly, thereby impacting on the concentration in the aeration basin; requiring higher aeration capacity.

3. The final effluent from the plant follows general discharge standards. However, at the old works, an increased TSS levels were observed in the effluent from the maturation pond. It suggests that the pond may require cleaning.

In addition, the following generic conclusions and recommendations shall be noted:

4. The plant is generally well operated and shows a good level of maintenance.

5. The plant is approaching its design capacity. Changes in the process configuration and increased loads due to return of sludge liquors may necessitate an upgrade of the plant soon.

6. For an AS plant that has not reached its design, an ammonia concentration of below 1 mg/ℓ is manageable. Considering the concentration from the AS plant is higher than 1 mg/ℓ, this indicates that there are challenges with the sludge retention time, aeration capacity or potentially toxicity.

7. High TSS coming from the return liquors indicates that the dewatering can be optimized. It is recommended to further investigate optimization. The high TSS in the return liquors lower the SRT in AS plant. The reduced SRT can impact the nitrification process.

8. The digester is performing poorly, with only 23% destruction of VSS while a performance of 40 till 60% can be expected.

CHAPTER 4: ‘P’ Wastewater Treatment Plant

The ‘P’ WWTP is situated approximately 1 km east of the MR102, Phoenix/Ottawa intersection and approximately 6.5 km from the Gateway Shopping Complex. The plant is owned and operated by the eThekwini Water and Sanitation Department and treats only domestic sewage. The plant, designed for a treatment capacity of 50 Mℓ/d, was constructed in 1987 with a design capacity of 12.5 Mℓ/d, and upgraded to 25 Mℓ/d in 1997. The existing works was designed based on a BNR AS principle, but now operates based on the AS principle with an installed capacity of 25 Mℓ/d. The current average flow into the plant is 24.5 Mℓ/d. With commissioning of an additional 25 Mℓ/d unit underway, the capacity of the works will increase to 50 Mℓ/d.

’P’ WWTPs key unit operations consist of a head of works, primary sedimentation, AS treatment, and anaerobic digestion systems. Currently the works has two PSTs, one activated sludge reactor and three clarifiers. A two-fold increase of these units is expected after the planned commissioning as the new module is a mirror image of the existing plant. Primary sludge is anaerobically digested in two anaerobic digesters, and digested sludge and biological sludge are dewatered before beneficially applied to land.

Figure 46: Aerial view of ‘P’ WWTP (Google Earth)

4.1 Process description

A description of the works is indicated below per information retrieved from the plant's as-built drawings and design manual of. The general process flow diagram of the treatment works is provided in Figure 47:

- Head of works consists of:
  - Two inlet channels,
  - One hand raked screen,
  - One mechanical screen fitted with screenings washer/compactor unit,
  - Two aerated grit removal chambers,
  - Two screw lift pumps for conveyance of raw sewage to the PSTs.

- Wastewater treatment consists of:
  - Four PSTs,
  - A 25 Mℓ conventional activated sludge process, with nutrient removal capacities,
  - Six SSTs.

- Disinfection consists of:
  - Final effluent from the SSTs is discharged into three maturation ponds which overflow into the river via the third maturation pond.

- Sludge handling and disposal consists of:
  - Primary sludge is anaerobically digested in two mesophilic digesters (2 600 m^3 each) including mixing and heating. Primary digested sludge is mechanically dewatered before beneficial application to agricultural land.
  - Three secondary digesters (510 m^3 each).
  - WAS is stored in a sludge sump from where it is pumped to a belt press for dewatering.
  - Primary digested sludge and biological sludge are fed to the dewatering plant consisting of a belt press via two sludge-feed lines.
  - Dewatered sludge is stored in silos before being applied to agricultural land.

- Return liquors treatment consists of:
  - Dewatering sludge return liquors are recycled upstream of the PSTs.

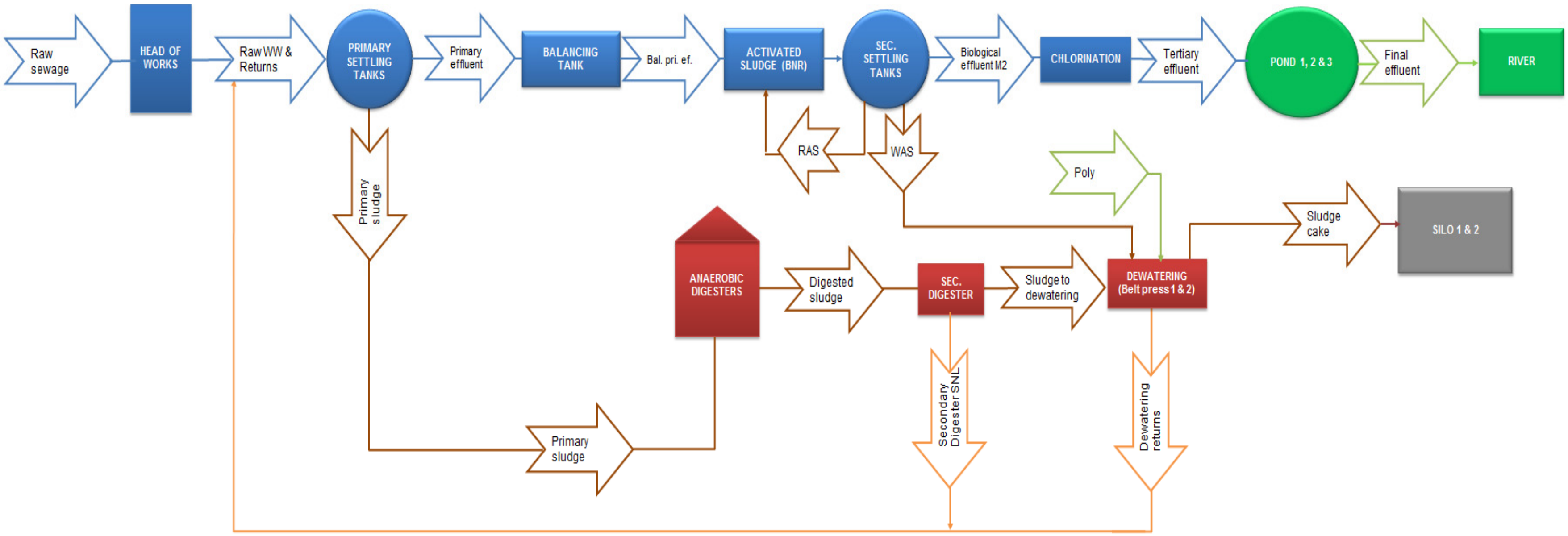

Figure 47: 'P' WWTP block diagram

4.2 Design capacity

The total design capacity of the plant is indicated in Table 30.

Table 30: Design flows and loads at 'P' WWTP

Parameters	Total
Flow (Mℓ/d)	25
COD (kg/d)	17 500
TKN (kg/d)	1 225
TP (kg/d)	675

4.3 Effluent standard requirements

Table 31 presents the standard effluent requirements applicable to the 'P' WWTP as obtained in the plant's water use licence (Licence No. 11/U20M/F/1177). It is important to note that an application for review of the limits is currently in progress; considering the ongoing upgrade to the works.

Table 31: Effluent discharge requirements applicable to 'P' WWTP

Parameter	Effluent standards	Method of compliance
COD (mg/ℓ)	75	
TSS (mg/ℓ)	25	
NH_4 (mg N/ℓ)	6	90% compliance
$NO_3 + NO_2$ (mg N/ℓ)	10	
PO_4 (mg P/ℓ)	10	

4.4 Technical performance

The Royal HaskoningDHV team conducted a site visit to the works on 28 November 2016. The 'P' WWTP appears to be a well operated and maintained facility. The operation team on site consists of 4 senior process controllers and 2 process controllers; operating 3 shifts per day and a plant manager.

However, the following observations were made regarding the technical performance of the plant. The dewatering plant comprising two belt presses were not in operation during the site visit. Hence secondary digested sludge as well as the WAS is recycled to the PSTs; resulting to high solids carry over in the PSTs. Per the plant superintendent, this has been the situation in the past two weeks. The construction of a new dewatering plant comprising two belt presses is on-going, and it is expected that sludge dewatering will be decommissioned upon start-up of the new belt presses. In addition, desludging of the PSTs is done manually. Automated desludging of the PSTs is recommended for investigation.

Sludge is currently stockpiled onsite as there is no contract in place for sludge disposal or off-take at the works. Generally, it is expected that the performance of the works will improve upon commissioning of the new works next year.

4.5 Process performance

4.5.1 Influent characteristics

In Figure 48, the average daily flow of wastewater treated at 'P' WWTP between January 2014 and September 2015 is presented. On average, a total of 24.5 Mℓ/d of wastewater was treated at the works; implying 98% of the plant's design capacity is reached, and therefore, the on-going upgrade is urgent.

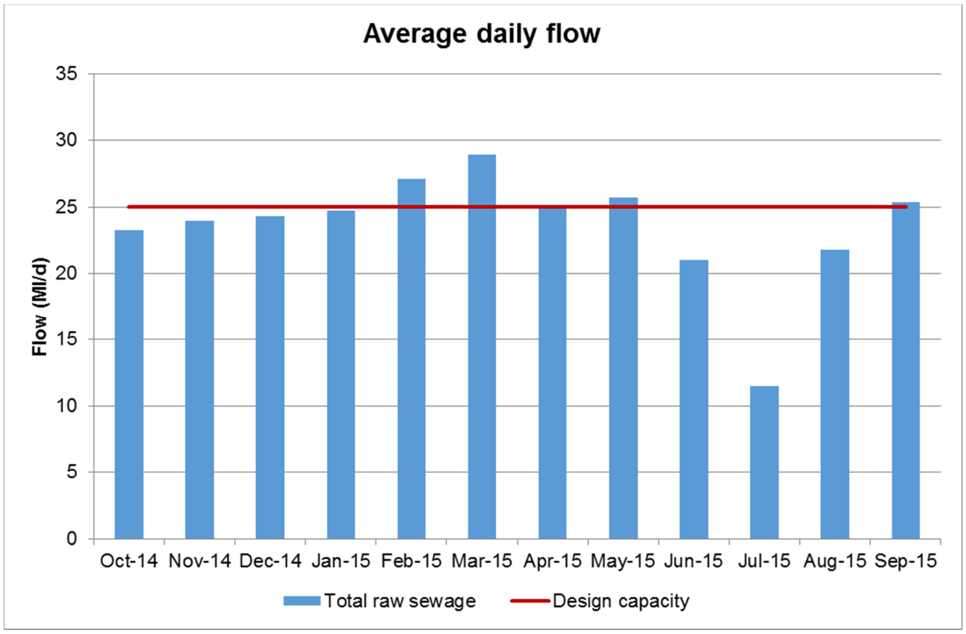

Figure 48: Average daily flow at 'P' WWTP

The average influent concentrations and loads are indicated in Table 32 as well as the historical averages in Figure 49 and Figure 50. In general, the raw sewage shows a high loading rate. Although the inflow to the plant and TP load are within the plant's design capacity (98% and 81% respectively), the COD and TKN influent characteristics (101% and 117% respectively), are slightly above the design load of the plant; implying that the plant is overloaded.

Table 32: Average raw sewage concentrations and loads at 'P' WWTP

Parameter	Average concentration (January 2014 to June 2016)		Average load (January 2014 to June 2016)	
COD	722	mg/ℓ	17 687	kg/d
TSS	373	mg/ℓ	9 141	kg/d
TKN	58.8	mg/ℓ	1 441	kg/d
NH_4	40.1	mgN/ℓ	982.5	kg/d
$NO_3 + NO_2$	18.7	mgN/ℓ	458.2	kg/d
PO_4	3.6	mgP/ℓ	88.2	kg/d
TP	22.2	mg/ℓ	545.2	kg/d

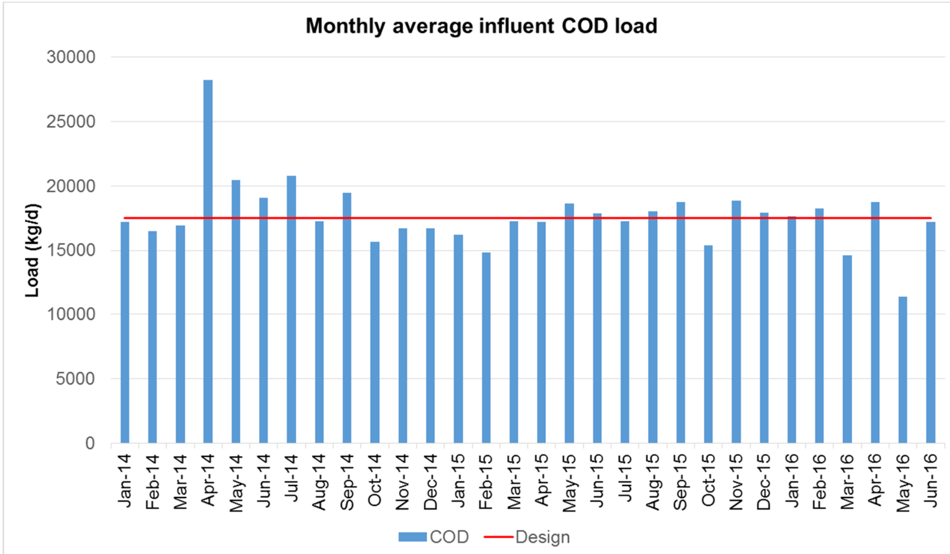

Figure 49: Average COD load at 'P' WWTP

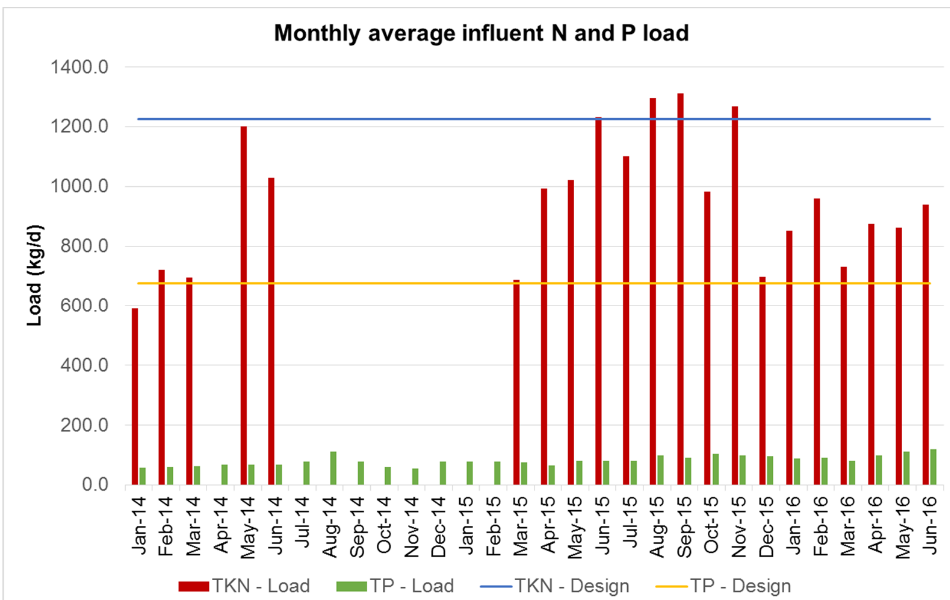

Figure 50: Average N and P loads at 'P' WWTP

*Missing values were observed in N data between July 2014 and February 2015

4.5.2 Effluent quality

In Table 33, performance of the works with respect to final effluent discharged is presented. Final effluent discharged at the works was benchmarked against the works' effluent discharge limits as specified in the plant water use licence. The results show significant compliance with the limits considering 88% and 95% compliance for COD and TSS respectively. Although, good P-removal is achieved at the plant (97% for ortho-P), poor ammonia removal (only 17% compliance) was noted during the period under review and constantly from August 2015 onwards.

Table 33: Average final effluent quality and plant compliance at 'P' WWTP

Parameter	Average concentration (January 2015 to June 2016)	Average compliance (January 2015 to June 2016)
COD	48.5 mg/ℓ	88%
TSS	9.8 mg/ℓ	95%
NH_4	17.7 mgN/ℓ	17%
$NO_3 + NO_2$	1.1 mgN/ℓ	100%
PO_4	3.5 mgP/ℓ	97%

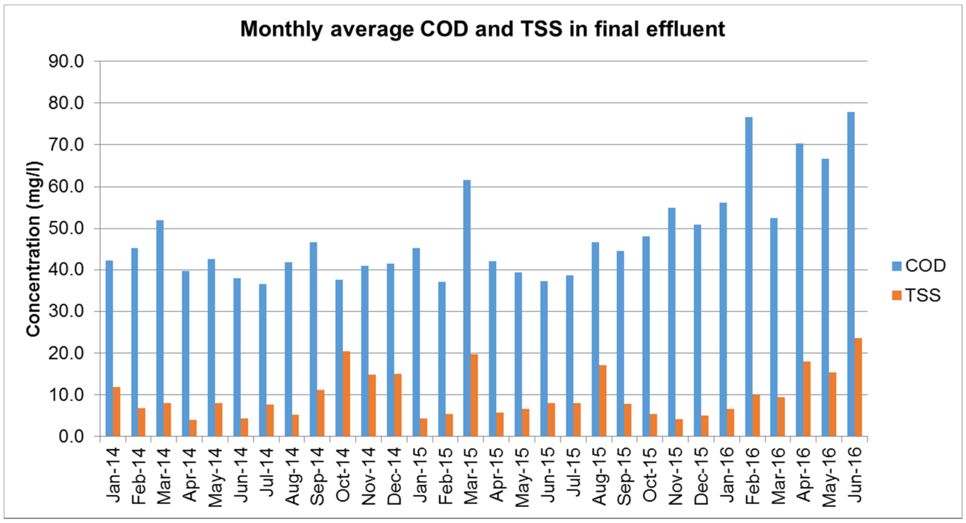

Figure 51: Monthly average COD and TSS in the final effluent at 'P' WWTP

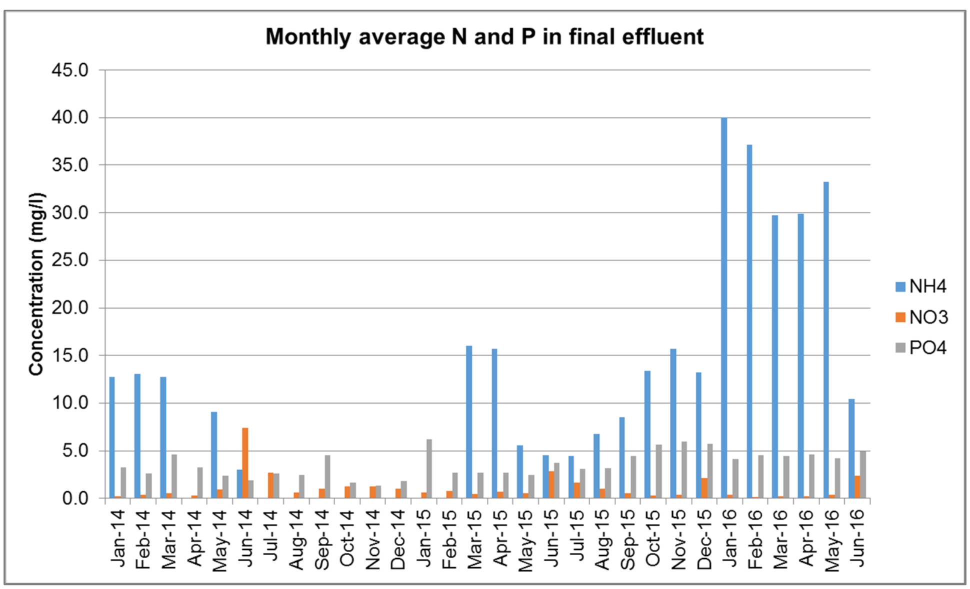

Figure 52: Monthly average ammonia, nitrate and orthophosphate in the final effluent at 'P' WWTP

4.5.3 Sludge treatment

4.5.3.1 Sludge characteristics

At 'P' WWTP, PS from the PSTs is sent directly to the ADs, as currently, there are no thickeners in operation. However, two new thickeners are to be commissioned in 2017 as part of the upgrade to the works. WAS is discharged from the SSTs and thereafter dewatered using a belt press.

Table 34 indicates the characteristics of the PS and WAS before and after dewatering.

Table 34: Characteristics of the primary and biological sludge at 'P' WWTP

Parameter	Primary sludge	Biological sludge
Flow (m^3/d)	185	147
Dry solids (%)	3.5	0.9
Sludge mass (kg/d)	5 732	1 377

4.5.3.2 Sludge thickening

No thickening is done to the PS at the works; however, two new 14 m diameter circular mechanically-scraped gravity sludge thickeners are currently being put in place as part of the upgrade to the works. Each thickener is designed to handle 200 m^3/day of sludge.

4.5.3.3 Anaerobic sludge digestion

At 'P' WWTP, only PS is anaerobically digested in 2 × 2 600m^3 heated and mixed (pumped mixing) digesters. The digesters are heated to mesophilic temperature (35°C) using about 40% of biogas. The primary digested sludge is allowed to stabilize in a secondary digester which comprises 3 cells. The dry solids content of primary sludge digested during the period January 2014 to June 2016 averaged 2% (w/v), and the organic fraction was on average 69%. The digesters are being operated under a temperature range of 30°C to 35°C which is within the optimal temperature range of 33°C to 37°C for mesophilic digesters, although further optimization of the process is advised. The average retention time in the ADs was approximately 36 days, which is higher than the minimum recommended retention time (20 days) for mesophilic digesters. The destruction of VSS in the ADs was on average 52% which is reasonable under mesophilic conditions, considering that only PS is digested.

Two new 18.3 m diameter primary digesters will be constructed as part of the on-going upgrade to the plant. The two new primary digesters are designed for thermophilic digestion with a retention period of 25 days but will however be operated under mesophilic conditions of 37°C.

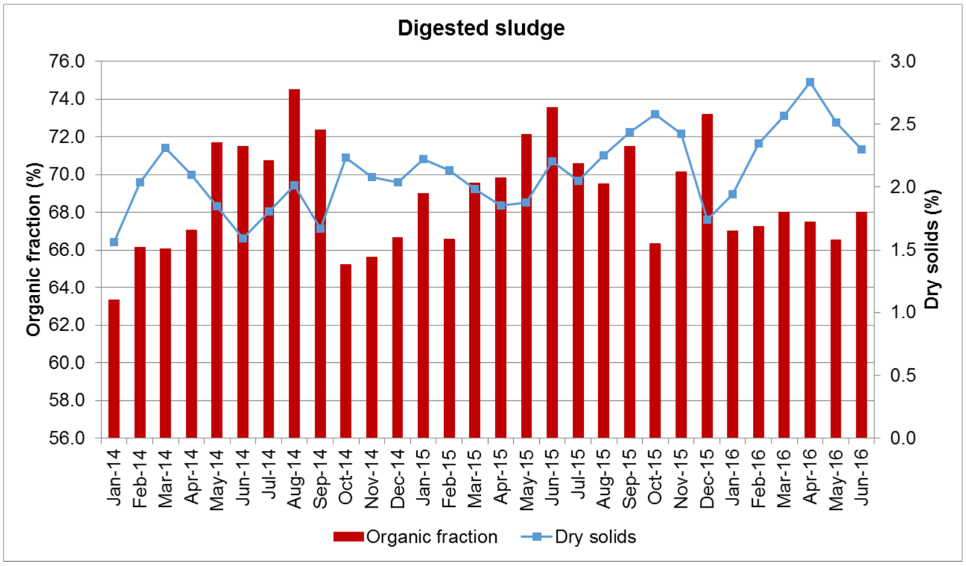

Figure 53: Monthly average organic fraction and dry solids content in digested sludge at 'P' WWTP

4.5.3.4 Sludge dewatering

Primary digested sludge and WAS are mechanically dewatered in two separate belt presses (belt press 1 and 2). The average DS content of sludge cake from the belt press (dewatered WAS) is 12.3%. Upon analysis of data made available, the average DS content in the sludge cake from the digested sludge is approximately 23%. The performance of the belt presses is satisfactory as their DS content are within the typical operating range of mechanical belt presses (10-15% for WAS and 20-30% for digested sludge). The historical performance of the dewatering plant is presented in Figure 54.

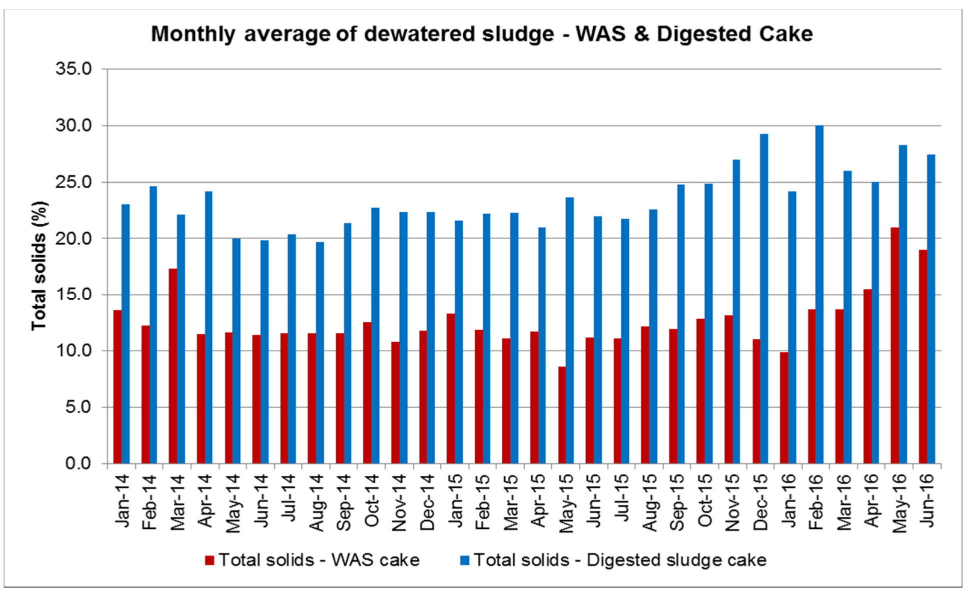

Figure 54: Monthly average of dry solids content in the dewatered sludge at 'P' WWTP

4.5.3.5 Treatment of sludge return liquors

Per information received from the process engineers, no treatment is given to the sludge return liquors at the plant. Analysis of the wastewater concentrations in the return liquors is presented in Figure 55. The average concentrations for ammonia and orthophosphate were approximately 111 mg/ℓ and 22.4 mg/ℓ respectively.

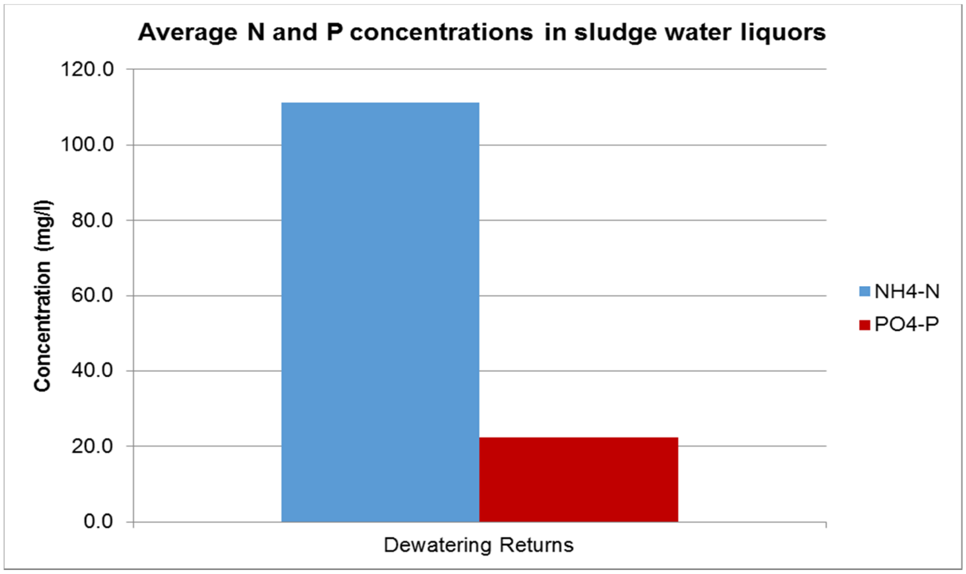

Figure 55: Ammonia and orthophosphate concentrations in the sludge return liquors at 'P' WWTP

4.6 Impact of sludge returns liquors

4.6.1 Plant mass balance

A complete mass balance of the 'P' WWTP was prepared to understand and evaluate the magnitude of the impacts of the sludge dewatering return liquors on the main treatment process addressed in the following sections. The result of the plant mass balance elaborated with the average data available from January 2014 to June 2016 is provided in Table 35. Once the analytical data available did not cover all streams and parameters, the following assumptions were required to complete the mass balance:

- Determination of TKN in primary influent = 150% of ammonia concentration
- COD in biological sludge: COD/MLVSS = 1.4
- TKN/MLSS = 7%
- TP/MLSS = 5%
- TP/ PO_4 ratio ~ 2.1
- VSS/TSS ratio = 75%

Table 35:Results of the mass balance at 'P' WWTP

Water streams	Raw WW	Raw WW & Returns	Primary effluent	Biological/Tertiary effluent	Final effluent
Flow (Ml/d)	24.5	24.8	24.6	24.4	24.4
COD (kg/d)	17687	18085	10816	1200	1186
TKN (kg/d)	1467	1591	1447	249	449
NH4 (kg/d)	978	1041	1041	188	433
NO3+NO2 (kg/d)	0	0	0	81	27
TP (kg/d)	184	244	217	70	98
PO4 (kg/d)	87	105	105	27	86
TSS (kg/d)	9141	10002	3447	865	240
COD (mg/l)	722	730.0	440	49.1	48.5
TKN (mgN/l)	60	64	58.9	10.2	18.4
NH4 (mgN/l)	40	42	42.4	7.7	17.7
NO3+NO2 (mgN/l)	0.0	0.0	0.0	3.3	1.1
TP (mgP/l)	7.5	9.8	8.8	2.9	4.0
PO4 (mgP/l)	3.6	4	4.3	1.1	3.5
TSS (mg/l)	373	404	140	35.4	9.8

Sludge streams	Primary sludge	Biological sludge to belt press	Primary Dig. sludge to belt press	Primary Dewatered Sludge	Biological Dewatered Sludge	Total Sludge Cake
Flow (Ml/d)	0.185	0.147	0.035	0.02	0.07	0.09
COD (kg/d)	7269	1446	864	5506	1273	6779
TKN (kg/d)	143	97.5	33.9	31.5	85.2	117
NH4 (kg/d)	0.0	1.1	0.0	0.0	0.3	0.3
NO3+NO2 (kg/d)	0.1	0.5	0.0	0.0	0.4	0.4
TP (kg/d)	26.8	147	10.2	8.3	138	147
PO4 (kg/d)	0.0	0.2	0.0	0.0	0.0	0.0
TSS (kg/d)	5693	1377	937	5244	1212	6456
COD (mg/l)	39293	18186	24676	239400	18186	72895
TKN (mgN/l)	774	1217	969	1370	1217	1255
NH4 (mgN/l)	0.0	4.5	0.0	0	4	3
NO3+NO2 (mgN/l)	0.4	6.1	0.0	0	6	4
TP (mgP/l)	145	1978	291	363	1978	1579
PO4 (mgP/l)	0.0	0.6	0.0	0	1	0
TSS (mg/l)	30773	17320	26773	228000	17320	69423

Sludge return liquor streams	Primary Sludge Returns (SNL)	Belt Press 1 Filtrate	Belt Press 2 Filtrate	Total return liquor streams
Flow (Ml/d)	0.15	0.019	0.11	0.27
COD (kg/d)	195	29.9	173	398
TKN (kg/d)	109	2.4	12.3	124
NH4 (kg/d)	62.4	0.4	0.8	63.7
NO3+NO2 (kg/d)	0.0	0.02	0.1	0.1
TP (kg/d)	50.1	1.8	8.4	60.3
PO4 (kg/d)	16.6	0.4	0.1	17.2
TSS (kg/d)	669	28.5	165	862
COD (mg/l)	1301	1574	1635	1448
TKN (mgN/l)	728	126	117	451
NH4 (mgN/l)	416	21.6	7.7	232
NO3+NO2 (mgN/l)	0.0	1.1	0.6	0.3
TP (mgP/l)	334	97.4	78.9	219
PO4 (mgP/l)	111	22.4	1.1	62.5
TSS (mg/l)	4457.6	1499	1557	3136

4.6.2 Influent characteristics

The dewatered sludge return liquors are combined with the incoming screened sewage and channelled into the PSTs. Table 36 presents analysis of sludge return liquors in relation to its impacts on influent characteristics. The NH_4^-N and PO_4^-P loads increased by approximately 6.5% and 20% respectively. The ammonia load is slightly below the typical range for sludge liquors. However, orthophosphate loads in the return liquors are high and well outside the typical range.

Table 36: Impact of dewatering return liquors in the influent characteristics at 'P' WWTP

Parameter	Raw sewage to the plant	Sludge returns	Raw ww (incl. returns)	Impact on total plant raw ww	Typical impact on raw ww (*)
Flow (Mℓ/d)	24.5	0.27	24.8	1.1%	0,5% – 1,0%
COD (kg/d)	17 687	398	18 085	2.3%	5% – 10%
TKN (kg/d)	1 467	124	1 591	8.5%	9% – 13%
NH_4 (kg/d)	978	64	1 041	6.5%	9% – 13%
TP (kg/d)	184	60	244	33%	5% - 30%
PO_4 (kg/d)	87	17	105	20%	5% - 30%
TSS (kg/d)	9 141	862	10 002	9.4%	2% - 5%

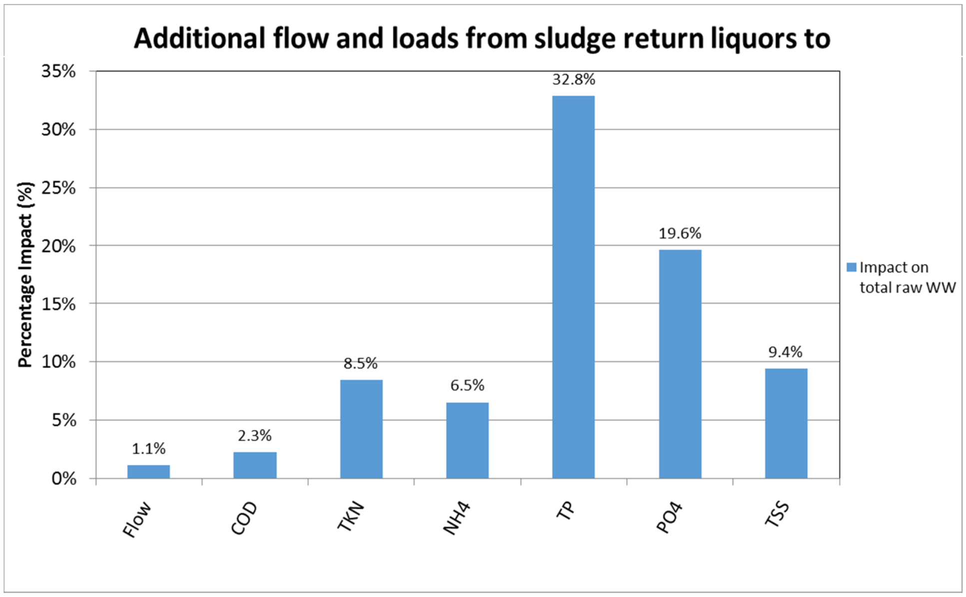

Figure 56: Additional flow and loads from sludge return liquors at 'P' WWTP

Comparative analysis between the influent ratios for the plant, (with and without return liquors), and typical South African sewage (Table 37), show minor variations for TSS; however significant imbalance is observed for COD: nutrients (N and P) ratios.

Table 37: Influent ratios with and without return liquors at 'P' WWTP

Ratios	Plant influent (without return liquors)	Plant influent (with return liquors)	Typical values in South African ww
COD/TSS	1.9	1.8	2.0
COD/TKN	12.1	11	8.2
COD/ NH_4	18	17	14
COD/TP	96	74	54
COD/ PO_4	202	173	117

4.6.3 Biological effluent quality

The average biological effluent quality figures for the plant are presented in Table 38. As indicated, the biological treatment meets the effluent standard requirement for all the parameters.

Table 38: Biological effluent at 'P' WWTP

Parameters	Biological effluent
COD (mg/ℓ)	49.1
NH_4 (mg N/ℓ)	7.7
$NO_3 + NO_2$ (mg N/ℓ)	3.3
PO_4 (mg P/ℓ)	1.1
TSS (mg/ ℓ)	35.4

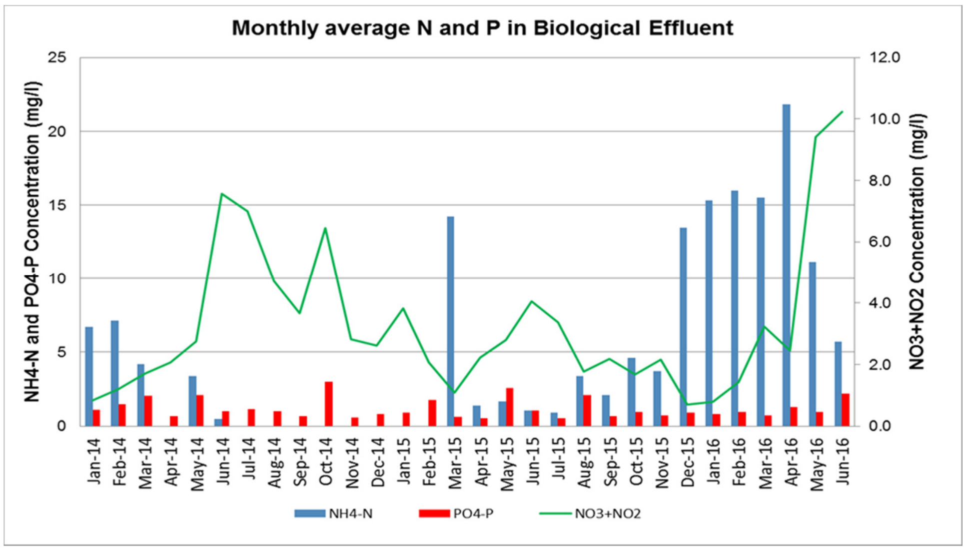

Figure 57: Monthly average ammonia, nitrate+nitrite and orthophosphate biological effluent quality at 'P' WWTP

4.6.4 Aeration demand

'P' WWTP currently has a conventional AS module arranged in two process trains. Each train has 4 aerators installed; totalling 8 aerators. However, aeration demand is not measured at the plant and can therefore only be calculated. There are no VSDs and no DO control sensors in the existing system; implying that no power optimization measure is in place at the moment. Design documents for the plant upgrade however indicate that VSDs and DO sensors will be included in the plant upgrade. Four of the 8 aerators each have a motor size of 75 kW, while the motor sizes of the remainder have a motor size of 50 kW. All aerators are run for 24 hours a day. Currently the aeration consumption is about 12 000 kWh/d. It is estimated that less than 10% of the aeration consumption is due to the current sludge liquors returns.

4.6.5 Biological treatment capacity

The plant has reached its design capacity for COD and TKN treatment. The loads are above 100% for both parameters with and without return liquors' flows (Table 39). This may justify higher level of ammonia in the final effluent (17.7 mg/ℓ) and consequent non-compliance with stipulated effluent requirements set at 6 mg/ℓ, hence the need for the on-going upgrade. Moreover, an application for review of the plant's Water Use Licence in terms of the discharge limits in relation to the proposed expansion of the works is in progress.

Table 39: Load comparison (actual vs. design) at 'P' WWTP

Parameters	Design	Without return liquors		With return liquors		Percentage change (%)
		Actual	Treatment capacity (%)	Actual	Treatment capacity (%)	
Flow (Mℓ/d)	25	24.5	98%	24.8	99%	1%
COD (kg/d)	17 500	17 687	101%	18 085	103%	2%
TKN (kg/d)	1 225	1 466	120%	1 590	130%	10%
TP (kg/d)	675	184	27%	243	36%	9%

4.7 Conclusions and recommendations

The site research conducted at 'P' WWTP indicates the following conclusions regarding the impact of the sludge return liquors in the plant performance:

1. Return liquors are recycled upstream of the PSTs as a combination of the belt press filtrate and secondary digester supernatant. The incoming ammonia and orthophosphate loads to the PSTs have an impact of 6.5% and 20% respectively in the influent loads.

2. Currently the plant is not compliant with the required effluent standard for ammonia. It is evident that that the plant is already overloaded in terms of COD and TKN even without the return of sludge liquors. The overloading of the plant is further aggravated upon recirculation of sludge return liquors to the PSTs.

In addition, the following generic conclusions and recommendations shall be noted:

3. The technical performance of the plant is generally good and shows a good level of maintenance.

4. The plant is presently undergoing an upgrade

5. The current hydraulic demand in the plant is 98% of the design capacity, when compared to its design capacity is 101% for COD, and 120% for TKN.

6. Final effluent quality is not complying with the ammonia discharge quality standards. The biological treatment may require optimisation to improve nitrification performance.

7. Although the plant is operating above its design capacity, improved process performance is expected upon completion and operation of the new section of the plant. Further optimization of the process is expected upon installation of VSDs and DO level sensors in the AS process. This may improve the plant's aeration demand and its electricity consumption.

CHAPTER 5: ‘C’ Wastewater Treatment Plant

The ‘C’ WWTP lies next to Muizenberg in the Southern Suburbs of Cape Town (refer to Figure 58). The plant primarily treats domestic wastewater and some industrial wastewater. The works are owned and operated by the City of Cape Town (CoCT).

The plant was initially designed to treat an ADWF of 150 Mℓ/d and consisted of six parallel modules, each of 25 Mℓ/d capacity. In 1999, an additional two 25 Mℓ/d modules were constructed. Currently, the plant has a total capacity of 200 Mℓ/d over eight parallel modules.

Figure 58: Aerial view of ‘C’ WWTP (Google Earth, 2016)

5.1 Process description

The treatment process used at the ‘C’ WWTP includes primary sedimentation followed by AS reactors. An extensive maturation pond system is the final treatment step. ‘C’ WWTP was designed for partial denitrification and biological P removal. Primary and biological thickened sludge are anaerobically digested followed by mechanical dewatering (out of operation). Currently, the digested sludge is dewatered in drying beds and the filtrate is sent to ponds.

A description of the unit processes and unit operations of the works is indicated below as per the plant operational manual and the general process flow diagram of the treatment works provided in Figure 59.

- **Inlet works** consists of:
  - Five mechanical coarse screens and one manual screen on standby,
  - Two degritting channels,
  - Splitter box.
- **Primary Treatment**:
  - Eight PSTs (23 m diameter).

- **Biological treatment**:
  - Eight conventional activated sludge reactors including anaerobic, anoxic and aerobic compartments (6 × 2 391 m^3 and 2 × 7 675 m^3). Air is provided by fine bubble diffusion aeration,
  - Twenty-two final clarifiers (18 × 26 m diameter and 4 × 31 m diameter).
- **Final Treatment**:
  - Maturation pond.
- **Sludge handling and disposal** consists of:
  - PS thickened in three gravity thickeners,
  - Biological sludge thickened in two DAF units,
  - Combined thickened sludge that is anaerobically digested under mesophilic conditions with the provision of heat and mixing (6 × 5 280 m^3),
  - Digested sludge is dewatered in drying beds.
- **Sludge return liquors**:
  - Return liquors from the gravity thickening and DAF process operations are blended and recycled to the beginning of the biological reactors,
  - The filtrate from the sludge drying beds is discharged into ponds and not it does not return to the treatment works.

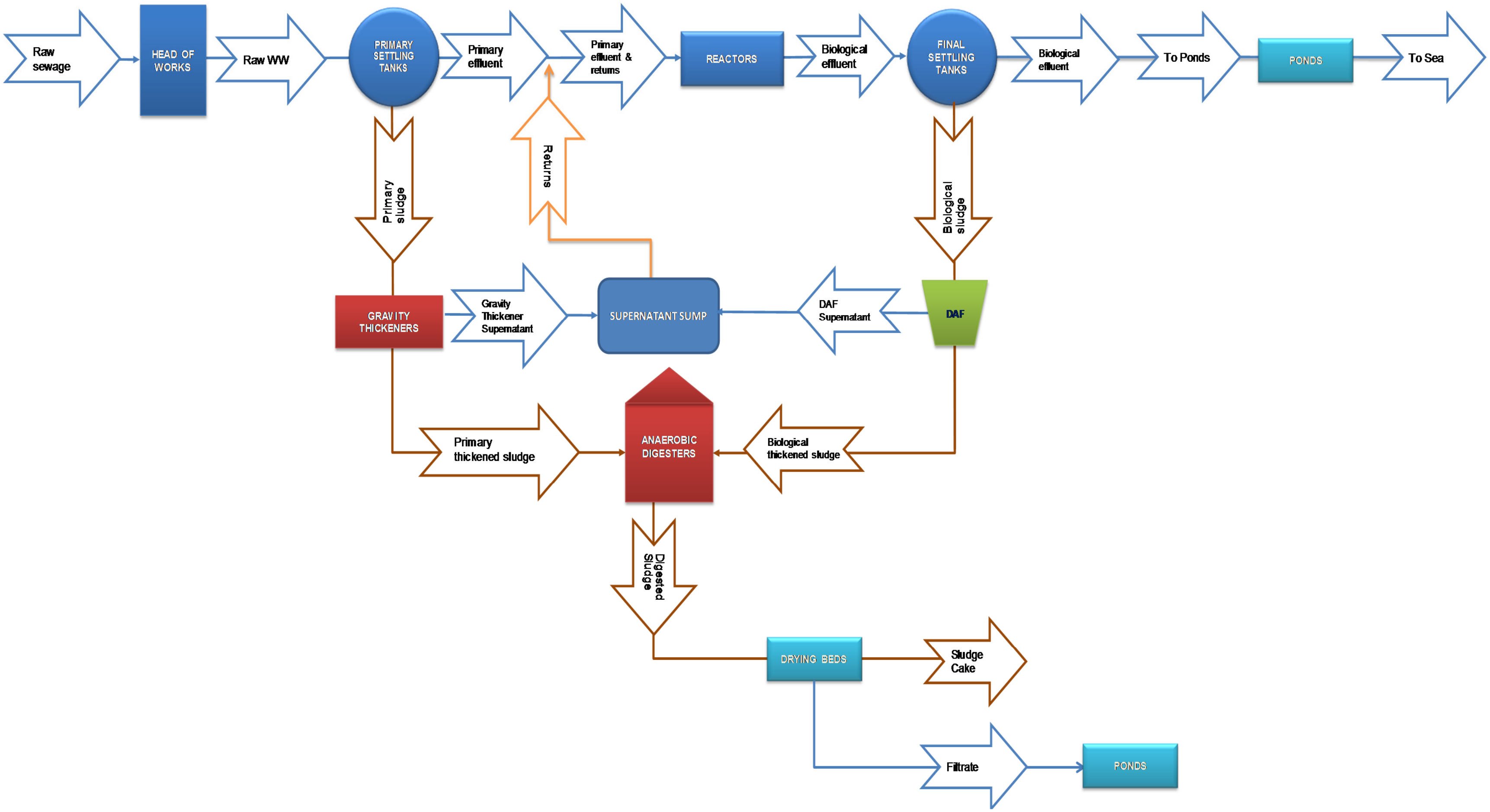

Figure 59: General process flow diagram of 'C' WWTP

5.2 Design capacity

The plant treatment capacity as per 'C' WWTP Process Controller Operational Handbook is shown below in Table 40.

Table 40: Design flows and loads at 'C' WWTP

Parameters	Each module	Total
Flow (Mℓ/d)	25	200
COD (kg/d)	15 000	120 000
TKN (kg/d)	1 465	11 720

5.3 Effluent standard requirements

The final treated effluent quality requirements currently stipulated in 'C' WWTP's water use licence are as per Table 41.

Table 41: Effluent standard requirements at 'C' WWTP

Parameter	Effluent standards	Method of compliance
COD (mg/ℓ)	75	90% compliance
TSS (mg/ℓ)	25	
NH_4 (mg N/ℓ)	10	
$NO_3 + NO_2$ (mg N/ℓ)	10	
PO_4 (mg P/ℓ)	1.0	

5.4 Technical performance

The technical performance of the 'C' WWTP appears to be fair with key unit operations not in use. The plant has a reasonable level of automation, including a SCADA system. The operation team on site consists of 4 process operators, 4 process controllers, 7 senior process controllers, 1 principal process controller, 1 assistant manager, 1 administration clerk and 1 plant manager. There is also additional grounds staff.

Three site audits where conducted on the 'C' WWTP with the last site audit carried out in October 2016. From the site visits the following items were noted as the main points for beneficiation from a technical point of view:

- The belt presses are currently not in use therefore, as per design the sludge is not dewatered and dried into pellets. Digested sludge is pumped to the drying beds instead.
- There is insufficient emergency sludge drying bed area, and insufficient dewatered sludge temporary stockpile area.
- There is a hydraulic restriction in few of the return sludge lines that limits the rate of sludge removal from secondary sedimentation leading to losses of sludge over the weirs at times that adversely affects effluent quality.
- There is an algae bloom in summer that adversely affects the final effluent quality with ammonia and phosphates increasing to 28 mg/ℓ and 6 mg/ℓ respectively in the ponds.

- Insufficient secondary sludge pre-thickening capacity; requires another DAF unit. PS thickening needs to be improved.

5.5 Process performance

5.5.1 Influent characteristics

As indicated in the Figure 60 during the operational window selected (September 2015 to August 2016), ‘C’ WWTP treated on average a total of 120 Mℓ/d (60% of the design capacity).

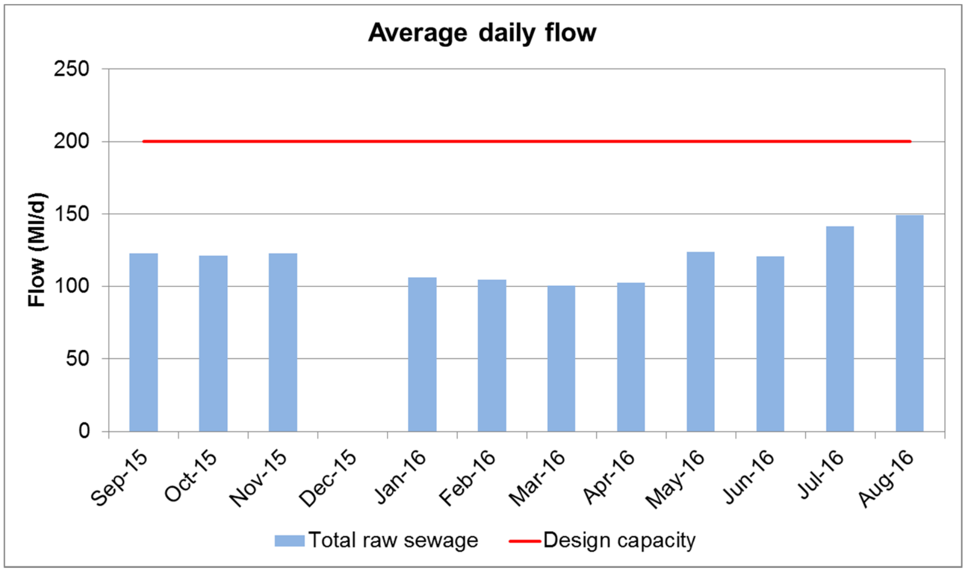

Figure 60: Average daily flow at ‘C’ WWTP

The average influent concentrations and loads are shown in Table 42. Currently, the plant is treating 94% of the COD design load and 83% of the TKN design load. The historical averages are illustrated below for the monthly average COD load and for the monthly average *N* and *P* influent load in Figure 61 and Figure 62 respectively.

Table 42: Average raw sewage concentrations and loads at ‘C’ WWTP

Parameter	Average concentration (September 2015 to August 2016)		Average load (September 2015 to August 2016)	
COD	940	mg/ℓ	112 603	kg/d
TSS	548	mg/ℓ	65 637	kg/d
TKN	81	mg/ℓ	9 719	kg/d
NH_4	43	mgN/ℓ	5 101	kg/d
PO_4	7	mgP/ℓ	890	kg/d
TP	14	mg/ℓ	1 637	kg/d

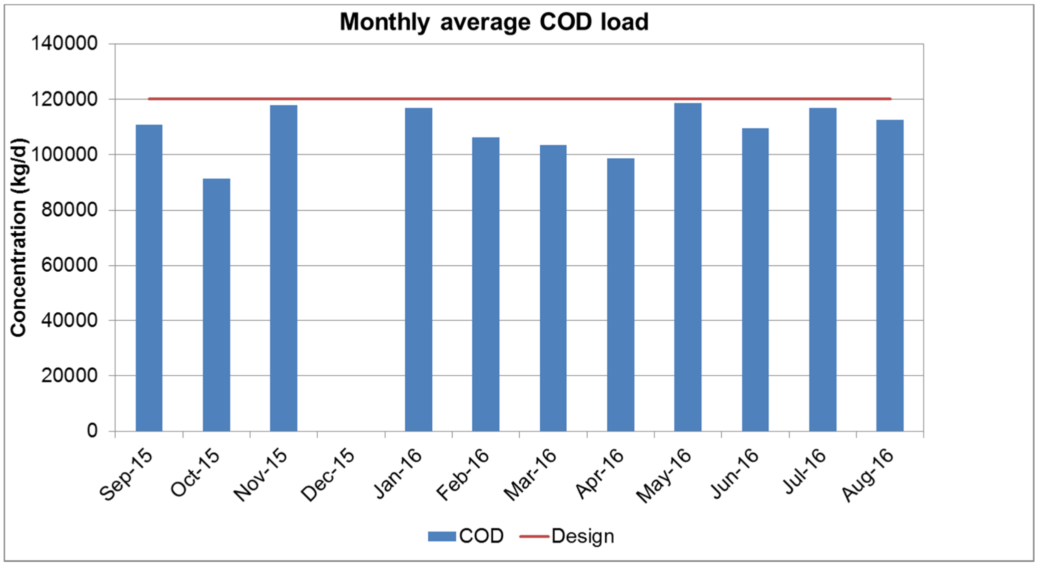

Figure 61: Average COD and TSS load at 'C' WWTP

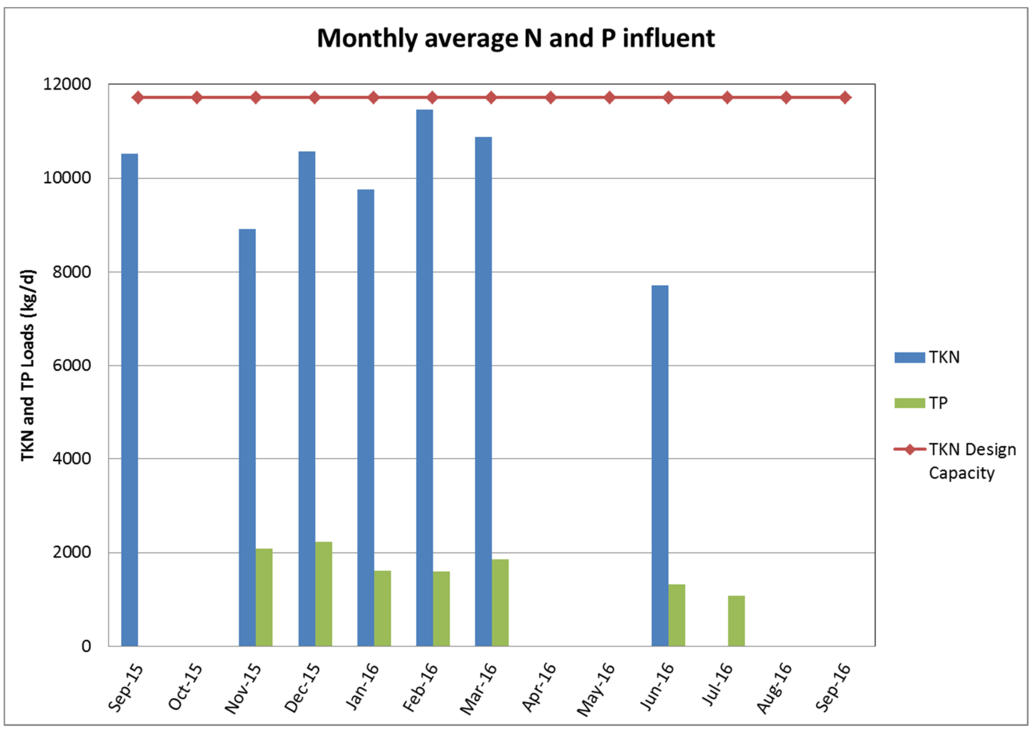

Figure 62: Average TKN and TP loads at 'C' WWTP

5.5.2 Effluent quality

As per the historical results from September 2015 to August 2016, the process performance of this plant is poor, with low compliance for most of the parameters. Table 43 indicates the average concentrations and compliance of the final effluent. The plant requires to be optimised for nutrient (N and P) and suspended solids removal. The historical monthly average concentrations in the final effluent from September 2015 to August 2016 are indicated in Figure 63 and Figure 64.

Table 43: Average final effluent quality and plant compliance at 'C' WWTP

Parameter	Effluent quality standards	Average concentration (September 2015 to August 2016)	Average compliance (September 2015 to August 2016)
COD	75 mg/ℓ	80 mg/ℓ	38%
TSS	25 mg/ℓ	26.5 mg/ℓ	62%
NH_4	10 mgN/ℓ	28 mgN/ℓ	0%
$NO_3 + NO_2$	10 mgN/ℓ	1 mgN/ℓ	100%
PO_4	1.0 mgP/ℓ	6 mgP/ℓ	0%

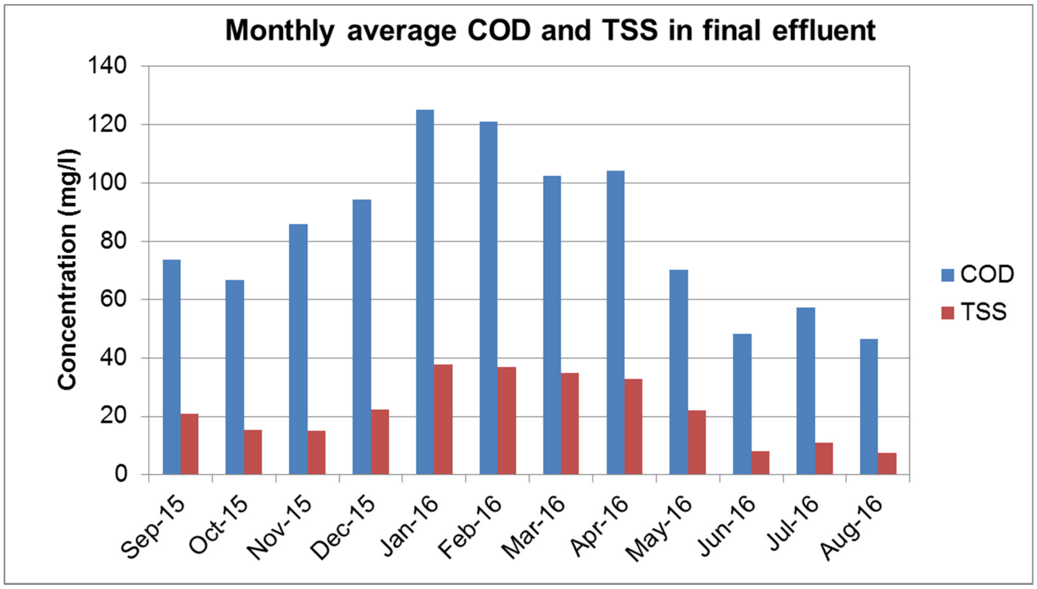

Figure 63: Monthly average COD and TSS in the final effluent at 'C' WWTP

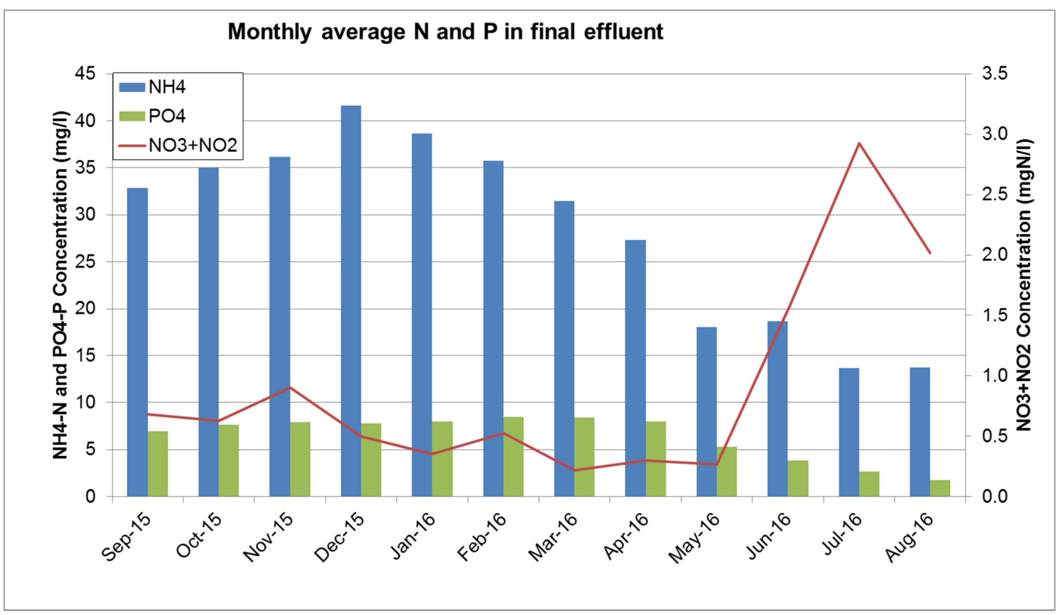

Figure 64: Monthly average ammonia, orthophosphate and nitrate+nitrite in the final effluent at 'C' WWTP

5.5.3 Sludge treatment

5.5.3.1 Sludge characteristics

At 'C' WWTP, PS is extracted from all eight PSTs. Table 44 indicates the characteristics of the PS and biological sludge prior to gravity thickening and DAF units, as well as prior to AD. The indicated values are derived from analytical results from the unit operations.

Table 44: Characteristics of the primary and biological sludge at 'C' WWTP

Parameter	Primary Sludge (from PST)		Biological sludge (from FST)	
	Before Thickening	After Gravity Thickening	Before floatation	After floatation
Flow (m^3/d)	2.77	0.76	1.30	0.35
Dry solids (%)	1.8	3.93	1.68	3.67
Sludge mass (kg/d)	45 946	29 859	15 731	15 155

5.5.3.2 Sludge thickening

There are two streams of sludge that undergo thickening. The sludge from the PSTs is pumped to gravity thickeners and sludge from the SSTs is sent to the DAF units. The average DS content of the gravity thickened sludge is 3.9%, while the average DS content of the biological thickened sludge is 3.7%. The organic fractions for the gravity thickened and biological thickened sludge are 83.2% and 82.6% respectively. The monthly averages for gravity thickened sludge and biological thickened sludge are illustrated in Figure 65 and Figure 66 respectively.

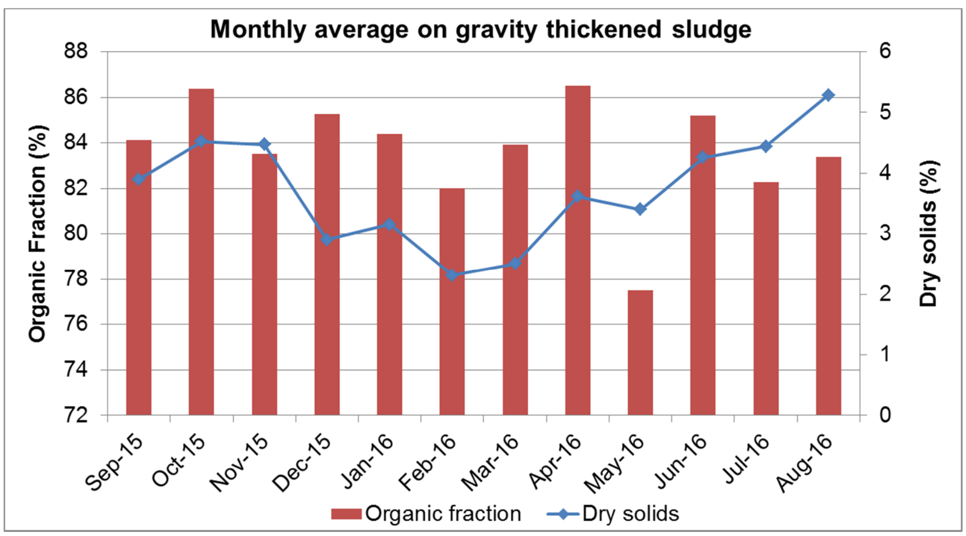

Figure 65: Monthly average organic fraction and dry solids content in the gravity thickened sludge at 'C' WWTP

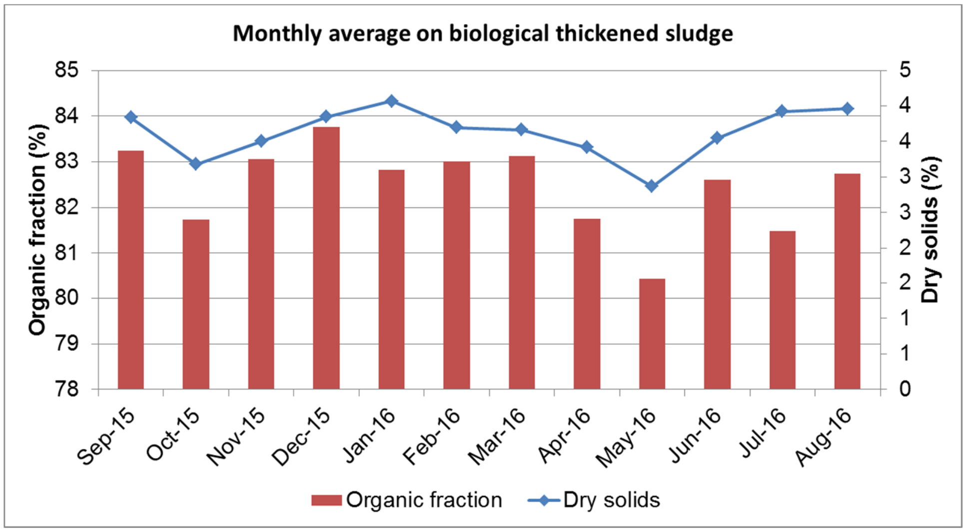

Figure 66: Monthly average organic fraction and dry solids content in the biological thickened sludge at 'C' WWTP

5.5.3.3 Anaerobic sludge digestion

Primary and biological sludge are digested under mesophilic conditions in three ADs that are pumped mixed and heated.

During the selected monitoring period (September 2015 to August 2016), the DS content in the digested sludge was, on average, 2.8% (w/v) and the organic fraction was, on average, 79.6% and the trend is illustrated in Figure 67. The average retention time in the ADs was approximately 14 days. Typically for digesters in mesophilic conditions (35ºC), the minimum recommended retention time is 18- 20 days. The Plant 'C' ADs are operated between 37-38ºC and indicate 64% VSS destruction. Considering the relatively high VSS destruction, it appears that 14 days is a reasonable retention time for these digesters at these temperatures and including mixing.

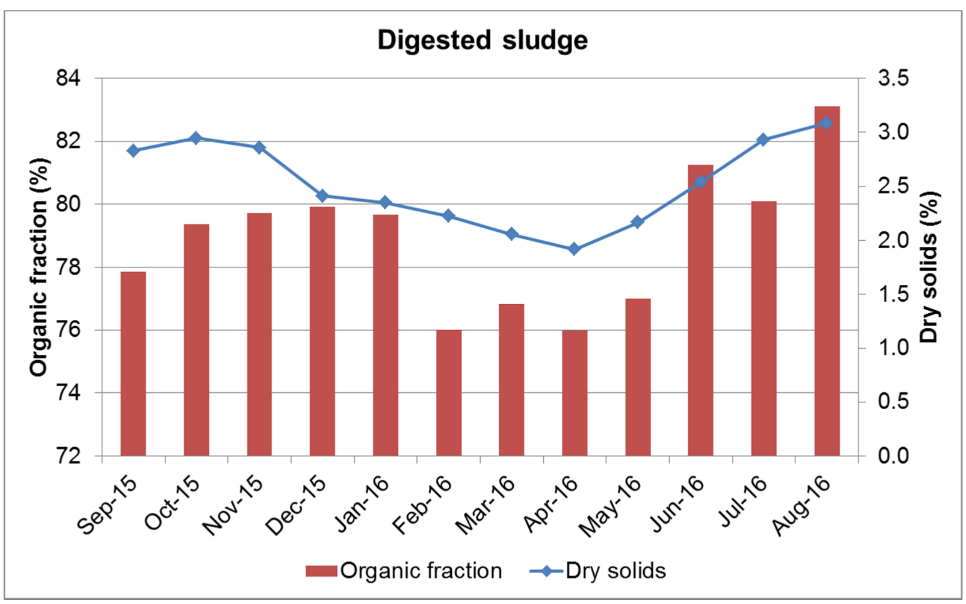

Figure 67: Monthly average organic fraction and dry solids content in the digested sludge a 'C' WWTP

5.5.3.4 *Sludge dewatering*

'C' WWTP has belt presses which are not currently in use. Sludge drying beds are used for the dewatering of sludge at the works. There is no analytical data available regarding the dryness of the sludge cake.

5.5.3.5 *Treatment of sludge return liquors*

Currently, there is no treatment of the sludge return liquors at 'C' WWTP. The supernatant from the gravity thickeners and DAF units is returned to the biological reactors and the analytical results indicate relatively high TSS concentrations (> 4 000 mg/ℓ). The filtrate from the drying beds gravitates to ponds. There is no analytical data available regarding the quality of the filtrate.

5.6 Impact of the sludge return liquors

5.6.1 Plant mass balance

A complete mass balance of the 'C' WWTW was prepared to understand and evaluate the magnitude of the impacts of the return liquors on the main treatment process. The results of the plant mass balance, elaborated with the average data available from September 2015 to August 2016, are provided in Table 45. Once the analytical data available did not cover all streams and parameters, the following assumptions were required to complete the mass balance:

- Efficiency of COD removal in PSTs = 53%
- Efficiency of TSS removal in PSTs = 70%
- Efficiency of TKN removal in PSTs = 11%
- Efficiency of NH_4 removal in PSTs = 0%
- Efficiency of TP removal in PSTs = 9%
- Efficiency of ortho-phosphate removal in PSTs = 0%
- COD in biological sludge: COD/MLVSS = 1.4
- Organic fraction in primary sludge = 83%
- TP removed with the biological sludge: TP/MLSS = 4%
- TKN removed with the biological sludge: TKN/MLSS = 7%
- Dryness of the sludge cake = 35%

To confirm the assumptions above and improve the accuracy of the mass balance, it would be recommended to double-check the following parameters with an analytical programme for at least a 3-day period:

- Primary sludge:
    - COD, TSS, TKN and TP.

- Gravity thickeners:
    - TSS in, TSS returned and DS sludge.

- DAF units:
    - TSS in, TSS returned and DS sludge.

- Digested sludge:
    - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.

- Sludge cake:
    - DS sludge

- Filtrate from the Drying beds:
    - COD, TKN, NH_4^-N, TP, PO_4^-P and DS.

The following flows/volumes should be also confirmed:

- Supernatant from gravity thickeners
- Supernatant from DAF units
- Filtrate from the drying beds
- Sludge cake
- Biological thickened sludge to digestion

Table 45: Results of the mass balance at 'C' WWTP

Water streams	Raw sewage	Primary effluent	Primary effluent & Returns	Biological Effluent	Final Effluent
Flow (Ml/d)	120	117	120	119	119
COD (kg/d)	112603	52923	74484	10297	9487
TKN (kg/d)	9719	8650	9066	2561	3438
NH4 (kg/d)	5101	5101	5123	2342	3265
NO3+NO2 (kg/d)	0	0	0	173	113
TP (kg/d)	1637	1489	1564	453	832
PO4 (kg/d)	890	890	892	297	709
TSS (kg/d)	65637	19691	36354	3118	2461
COD (mg/l)	940.2	452	444	87	80
TKN (mgN/l)	81.2	74	54	22	29
NH4 (mgN/l)	42.6	44	40	20	28
NO3+NO2 (mgN/l)	0.0	0	0	1.5	1.0
TP (mgP/l)	13.7	13	9	3.8	7.0
PO4 (mgP/l)	7.4	8	7	2.5	6.0
TSS (mg/l)	548.0	168	164	26	21

Sludge streams	Primary sludge	Biological sludge	Primary thickened sludge	Biological thickened sludge (DAF)	Digested sludge	Sludge Cake
Flow (Ml/d)	2.8	1.5	0.8	0.4	1.17	0.09
COD (kg/d)	59679	18187	38785	17522	37181	29418
TKN (kg/d)	1069	1131	695	1089	1784	809
NH4 (kg/d)	0	30	0	8.1	824	82
NO3+NO2 (kg/d)	0	0	0	0	0	0
TP (kg/d)	147	633	96	610	706	245
PO4 (kg/d)	0	3.8	0	1.0	467	140
TSS (kg/d)	45946	15731	29859	15155	33354	30019
COD (mg/l)	21555	12125	51032	42484	31713	343000
TKN (mgN/l)	386	754	914	2641	1522	9430
NH4 (mgN/l)	0	20	0	20	703	961
NO3+NO2 (mgN/l)	0	0	0	0	0	0
TP (mgP/l)	53	422	126	1479	602	2855
PO4 (mgP/l)	0	2.5	0	2.5	399	1635
TSS (mg/l)	16595	10487	39289	36745	28449	350000

Sludge return liquors streams	Gravity Thickener Returns	DAF returns	Supernatant from thickeners & DAF	Dewatering filtrate
Flow (Ml/d)	2.01	1.09	3.10	1.09
COD (kg/d)	20895	666	21561	7763
TKN (kg/d)	374	41	416	975
NH4 (kg/d)	0	21	21	742
NO3+NO2 (kg/d)	0	0.0	0	0
TP (kg/d)	52	23.2	75	461
PO4 (kg/d)	0	2.7	3	327
TSS (kg/d)	16087	576	16662	3335
COD (mg/l)	10402	612	6963	7144
TKN (mgN/l)	186	38	134	898
NH4 (mgN/l)	0	20	7	683
NO3+NO2 (mgN/l)	0	0	0	0
TP (mgP/l)	26	21	24	424
PO4 (mgP/l)	0	2.5	1	301
TSS (mg/l)	8009	529	5381	3069

5.6.2 Influent characteristics

The supernatant return liquors from the gravity thickener and DAF operation units are combined with the PST effluent, i.e. downstream of the PSTs. Return liquors are redistributed to all the bioreactors.

A desktop investigation was carried out to determine the impact of return liquors to the bioreactor if filtrate from the dewatering is returned to the bioreactor inflow. Since return liquors are introduced downstream to the PSTs, the analysis was carried out on primary effluent. Table 46 gives a summary of the calculations of the impacts of return liquors on the biological reactors

Table 46: Impact of return liquors and dewatering return liquors on influent characteristics at 'C' WWTP

Parameters	Primary Effluent	Return Liquors (Thickeners and DAF)	Primary Effluent and Return Liquors	Primary Effluent, Return Liquors and Filtrate	Impact without filtrate (current)	Potential impact with filtrate	Typical impact on raw ww (*)
Flow (Mℓ/d)	117	3.10	120	121	2.6%	3.6%	0.5% – 1.0%
COD (kg/d)	52 923	21 561	74 484	82 247	40.7%	55.4%	5% – 10%
TKN kg/d)	8 650	416	9 066	10 041	4.8%	16.1%	9% – 13%
NH_4 (kg/d)	5 101	21	5 123	5 864	0.4%	15.0%	9% – 13%
TP (kg/d)	1 489	75	1 564	1 564	5.0%	36%	5% – 30%
PO_4 (kg/d)	890	3	892	1 353	0.3%	52.1%	5% – 30%
TSS (kg/d)	19 691	16 662	36 354	36 681	84.6%	101%	2% – 5%

(*) Based on Royal HaskoningDHV process design tool and excluding any dedicated treatment to the sludge return liquors

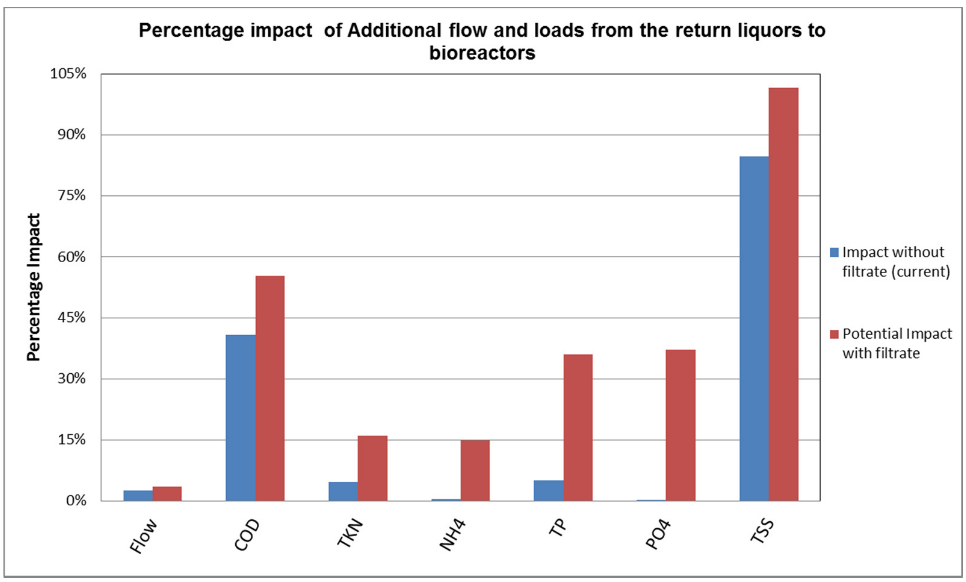

Figure 68: Additional flow and loads entering the bioreactors from the sludge return liquors and filtrate treatment at 'C' WWTP

Comparing the influent ratios for the Plant 'C' bioreactors with a typical South African sewage (Table 47), generally the primary effluent (settled wastewater) at Cape Flats is slightly unbalanced with the ratio of COD to nutrients.

Table 47: Influent ratios with and without return liquors at 'C' WWTP

Ratios	Primary Effluent	Primary Effluent & Return Liquors (Thickener & DAF)	Primary Effluent, Return Liquors and Filtrate (Future)	Typical SA Raw WW
COD/TSS	2.7	2.0	2.3	2.0
COD/TKN	6.1	8.2	7.2	8.2
COD/ NH_4	10	14.5	12.3	14
COD/TP	36	48	38	54
COD/ PO_4	59	83	64	117

(*) WRC Report TT389/09, Process Design Manual for Small Wastewater Treatment Works

5.6.3 *Biological effluent quality*

The average quality of biological effluent is presented in Table 48. On average, the biological treatment cannot meet the required standards for COD, ammonia, phosphate and TSS. Since most of the parameters are outside of the effluent requirements it is recommended to check the nitrification capacity, aeration capacity and anaerobic, anoxic and aerobic volumes required for the current and future influent loads.

Table 48: Average quality of the biological effluent at 'C' WWTP

Parameters	Biological Effluent
COD (mg/ℓ)	87
NH_4 (mgN/ℓ)	19.8
$NO_3 + NO_2$ (mgN/ℓ)	1.5
PO_4 (mgP/ℓ)	2.5
TSS (mg/ℓ)	26.3

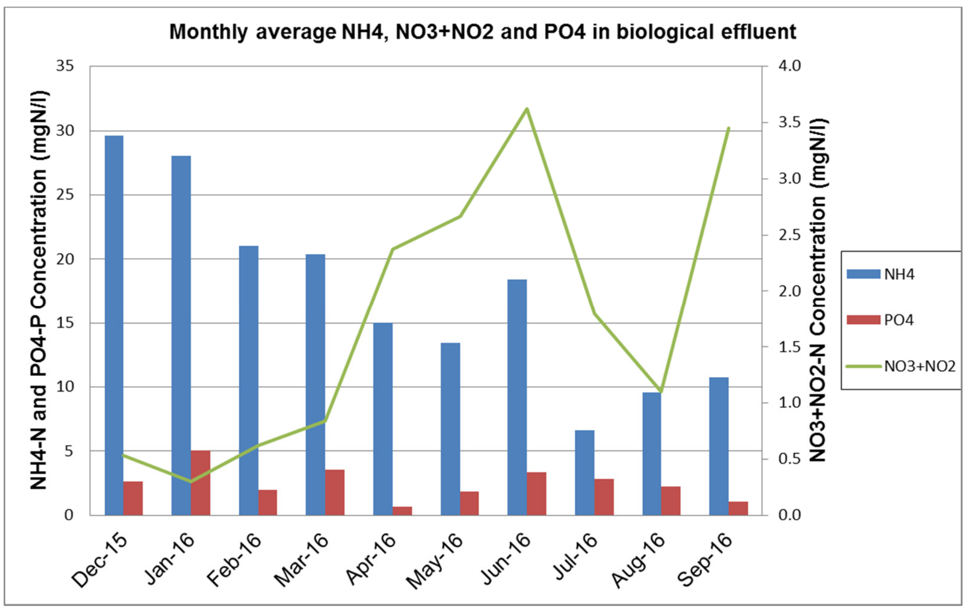

Figure 69: Monthly average ammonia, nitrate+nitrite and orthophosphate biological effluent quality at 'C' WWTP

5.6.4 *Aeration demand*

Information regarding the existing aeration capacity on site is not available. The 8 AS reactors are aerated with fine bubble diffusion. Theoretically, the current aeration energy consumption is roughly 63 400 kWh/d. If in future, the filtrate from the dewatering would be returned upstream of the biological reactors, the energy consumption should increase by ± 15%.

5.6.5 *Biological treatment capacity*

The bioreactors are currently treating 62% of the design COD load, 77% of the TKN design load. The specific biological sludge production is calculated in 0.25 kg MLSS/kgCOD removed. On average the sludge retention time have been around 9 days.

The current additional loads of ammonia and orthophosphate from the return liquors (supernatant from gravity thickeners and DAF units) are negligible such that they do not impact in the treatment capacity of the bioreactors. However, there is a significant increase in the COD and MLSS with respective increases of 40% and 84%. Naturally, the impact of the nutrient loads will be much higher if, in the future, the dewatering returns are recycled to the biological reactors.

5.7 Conclusions and recommendations

The site research conducted at ‘C’ WWTP indicates the following conclusions regarding the impact of the sludge return liquors in the plant performance:

1. Only the return liquors from the gravity thickeners and DAF units are recycled to all bioreactors, the incoming ammonia and orthophosphate loads to the bioreactors are marginal, with negligible impact on the bioreactors. The impact was determined to be 0.4% and 0.3% for ammonia and ortho-phosphate respectively.

2. If filtrate from the dewatering (drying beds or mechanical dewatering) is included in the return flows, then the impact was determined to be 15% and 52% for ammonia and ortho-phosphate respectively. These are significant impacts on the bioreactor’s performance, especially as the biological treatment is continuously showing a poor performance. Considering this eventual future scenario, the aeration consumption would raise in ± 15% compared with the current situation.

In addition, the following generic conclusions and recommendations should be noted:

3. The technical performance of the plant is satisfactory and shows a need for maintenance and repairs of some unit operations. A tender for the refurbishment of the dewatering operations unit has been put out in the year 2017.

4. The current hydraulic demand in the plant is 60% of the design capacity. The current loading for the plant compared to its design capacity is 94% for COD, and 83% for TKN. However, considering the plant is non-compliant with the effluent requirements it can be concluded that the plant is operating over its actual capacity.

5. Biological and final effluent quality is not complying with the COD, TSS, ammonia and orthophosphate discharge quality standards. The biological treatment requires optimisation to improve its performance. A more detailed process audit should be carried out.

CHAPTER 6: 'D' Wastewater Treatment Plant

The 'D' WWTP is located within the metropolis of Port Elizabeth. It is in the flood plain of the Swartkops river (refer to Figure 70). The plant treats primarily domestic wastewater with some industrial wastewater. The plant is owned and operated by the Nelson Mandela Bay Municipality (NMBM).

Phase 1 of the plant (Unit 1), built in 1977, is a Huisman Orbal Aeration System, designed to treat 1.86 Mℓ/day. Capacity was increased with the addition of a 2.75 Mℓ/day BNR (Ames Costa, Unit 2) reactor in 1977, built to comply with general standards. Considering future growth, the addition of Unit 3, a 4.25 Mℓ/day 3-stage Phoredox reactor was built in 2009. However, the raw sewage flows have been much lower than initially expected, resulting in only the latest BNR reactor being operated.

WAS was pumped to Kuduskloof landfill site until 2009, this was due to the upgrade in 2009 that included a new chlorine contact tank, chemical dosing for the effluent from the oxidation ditch and refurbishment of the sludge lagoon. A further phase envisioned is the onsite dewatering of the WAS from the sludge lagoon as an alternative method of sludge disposal.

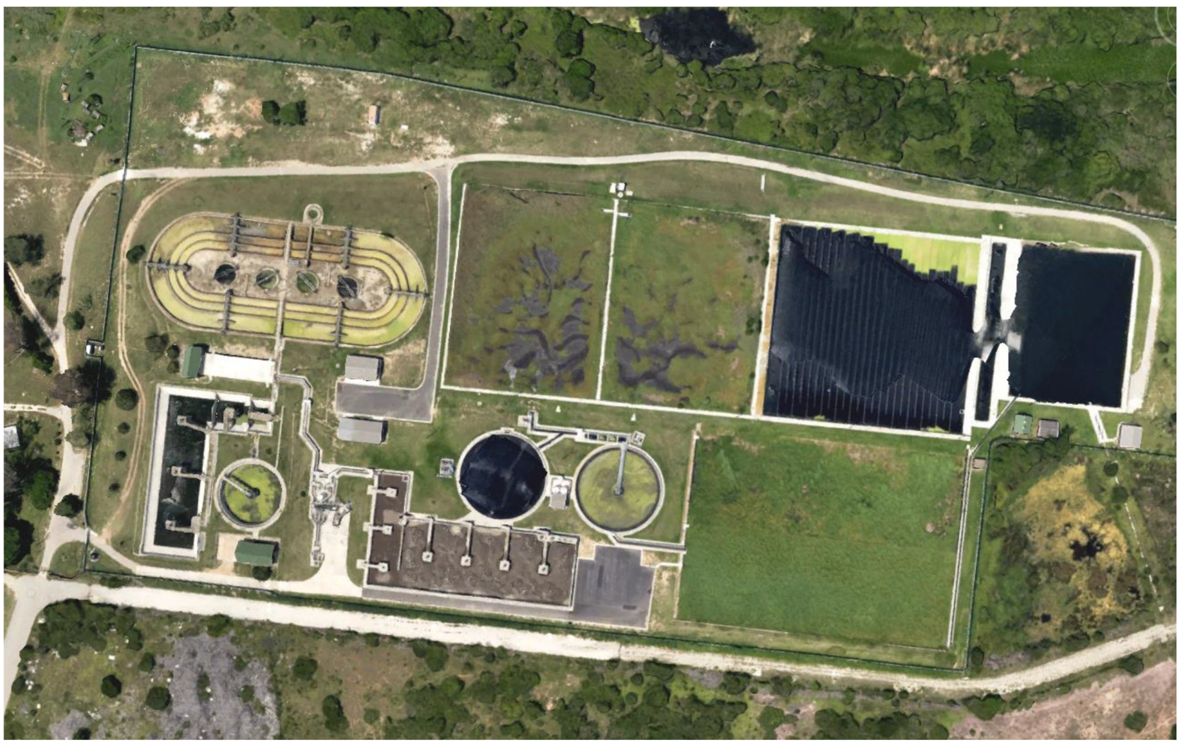

Figure 70: Aerial view of 'D' WWTP (Google Earth, 2016)

6.1 Process description

A description of the plant is below, based on site visits and drawings obtained from Hatch Goba. As mentioned, due to low flow (~4 Mℓ/day), only Unit 3 is in operation. Thus, Units 1 and 2 will be discussed briefly and without results. The general process flow diagram of the treatment works is provided in Figure 71:

- Sewage is pumped to the plant; this causes the flow to be controlled using a controlled flood peak. On days of power failure, the plant receives no flow.

- **Inlet works** consists of:
    - Two mechanical front raked coarse screens (8 mm) and a bypass channel for peak wet weather overflow,
    - Two vortex degritters,
    - Flow split with flumes between the units.
- **Unit 1** is a Huisman Orbal System, an oxidation ditch type reactor, with horizontal disc aerators, with four 7.1 m diameter Dortmund cone clarifiers are in the centre.
- **Unit 2** is an Ames Crosta system with one 23 m diameter clarifier.
- **Unit 3** is a BNR plant designed as a 3-stage Phoredox system, for N removal, but built with the option of changing to either a UCT or Johannesburg system, should P removal be required. According to process controller records, this system is operated at a sludge age of about 30 days. This 3-Stage Phoredox reactor has a volume of 5 400 m^3 with anaerobic, anoxic and aerobic mass fractions of 7.2%, 14.3% and 78.5% respectively. The system has 3 mixers (anaerobic and anoxic zones) and 4 surface aerators with VSDs controlled by influent flow and immersion depth.
- **Chemical dosing** consists of:
    - Ferric dosing with a 29 m diameter phosphate settling tank (not in operation).
- **Disinfection** consists of:
    - A chlorine dosing station, shallow mixing channel and chlorine contact tank before entry into the maturation ponds,
    - Maturation is either a pond, or a reed-bed (which had been de-weeded and moved at the time of the site visit, thus currently out-of-use).
- **Sludge handling and disposal** consists of:
    - Two sludge lagoons (each 61.75 m × 62.1 m × approximately 1.4 m deep), with a multi-level withdrawal of supernatant,
    - No sludge had been removed from the lagoons since pumping to the landfill stopped in 2009. The lagoons overflowed in July 2016. The sludge lagoons require emptying, a contract is currently being arranged by the metro to empty the lagoons and dry the sludge.
- **Return liquors treatment** consists of:
    - Supernatant of the sludge lagoon, which is returned to Unit 3 at the start of the aeration section.

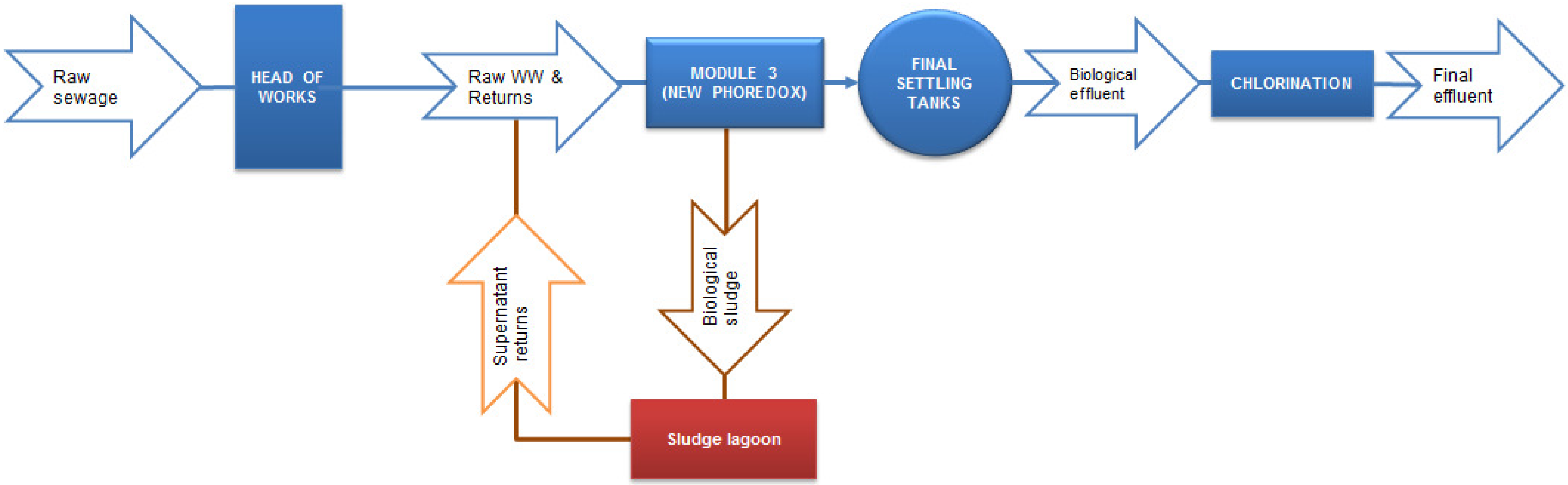

Figure 71: General process flow diagram of 'D' WWTP

6.2 Design capacity

The total design capacity of the plant is indicated in Table 49. It is noted that the original designs of Units 1 and 2 probably did not consider the additional load and flows from the sludge return liquors. The design characteristics of Units 1 and 2 are not available.

Table 49: Design flows and loads at 'D' WWTP

Parameters	Unit 1	Unit 2	Unit 3	Total
Flow (Mℓ/d)	1.86	2.75	4.25	8.86
COD (kg/d)	837	1 238	1 913	3 988
TKN (kg/d)	93	137	212	442
TP (kg/d)	30	44	68	142

6.3 Effluent standard requirements

The latest water use license for 'D' WWTP was granted to NMBM in 2011 by the Department of Water Affairs. The final treated effluent quality requirements currently stipulated in the water use licence are as per Table 50. These requirements are more lenient than general standards for ammonia, but more stringent for COD, TSS and phosphate.

Table 50: Effluent standard requirements at 'D' WWTP

Parameter	Effluent standards	Method of compliance
COD (mg/ℓ)	65	
TSS (mg/ℓ)	18	
NH_4 (mg N/ℓ)	8	90% compliance
$NO_3 + NO_2$ (mg N/ℓ)	15	
PO_4 (mg P/ℓ)	1.0	

6.4 Technical performance

'D' WWTP appears to be a well operated and maintained facility. Current items down for maintenance, at the time of site visit, include the recycle pump for the ferric dosing and the supernatant pump at the sludge lagoons. The plant has a reasonable level of automation, including SCADA system. The operation team on site consists of 6 process controllers divided by 3 shifts per day and a plant manager and a plant super intendant.

6.5 Process performance

6.5.1 Influent characteristics

As indicated in Figure 72 below, during the operational window selected (September 2015 to August 2016) 'D' WWTP treated on average a total of 4 Mℓ/d (45% of the design capacity). Units 1 and 2 are currently not operational and are therefore not studied in this report.

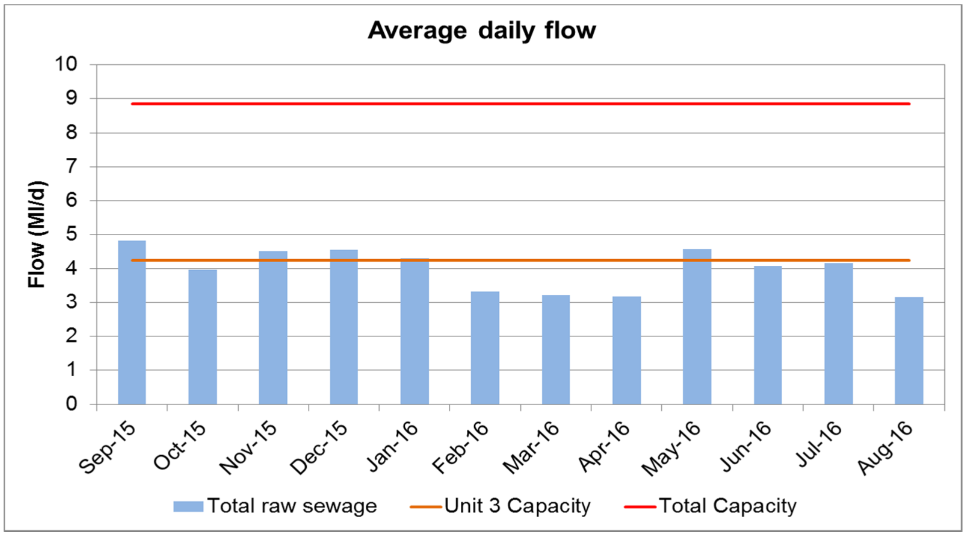

Figure 72: Average daily flow at 'D' WWTP

The average influent concentrations and loads are indicated in Table 51, with historical data for COD in Figure 73 and NH_4^-N and PO_4^-N in Figure 74. The design was made for primarily domestic sewage of 450 mg/ℓ and, per the year's results studied, this is accurate. However, TP is lower than predicted. To calculate the design load capacity of the whole plant, Unit 3's design info was used for the other two Units, with their respective design flows.

Table 51: Average raw sewage concentrations and loads at 'D' WWTP

Parameter	Average concentration (September 2015 to August 2016)		Average load (September 2015 to August 2016)	
COD	468	mg/ℓ	1 882	kg/d
TSS	234	mg/ℓ	942	kg/d
TKN	56	mg/ℓ	225	kg/d
NH_4	42	mgN/ℓ	168	kg/d
PO_4	4.2	mgP/ℓ	17	kg/d
TP	6.5	mg/ℓ	20	kg/d

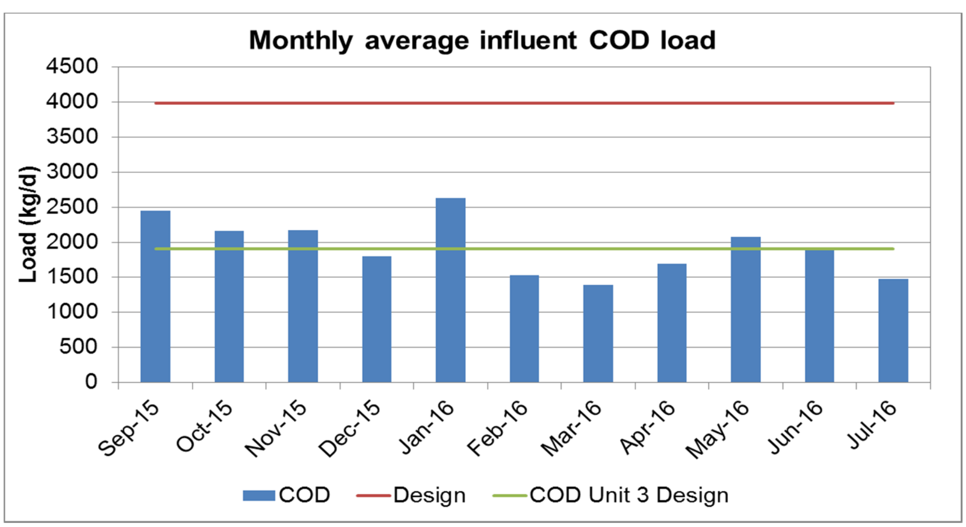

Figure 73: Average COD concentrations in the influent at 'D' WWTP

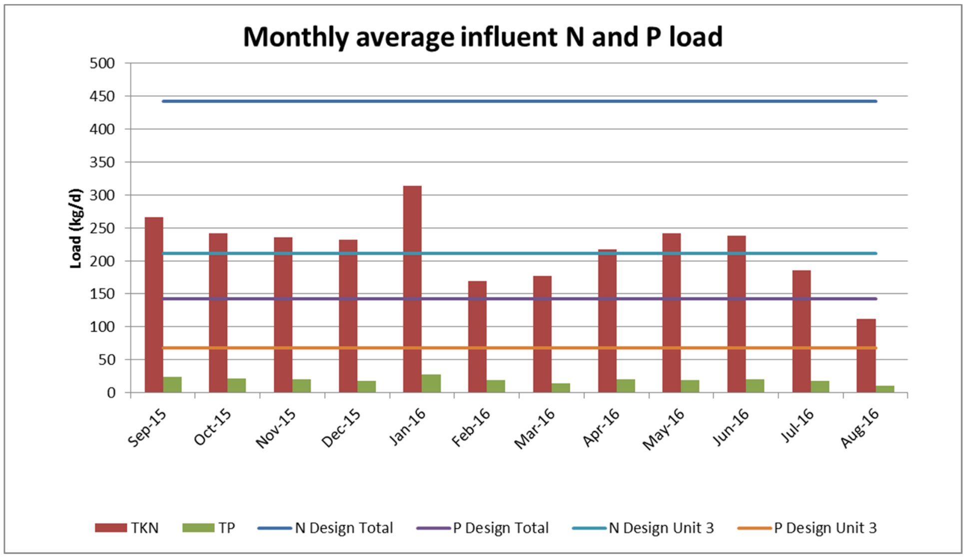

Figure 74: Average TKN and TP concentrations in the influent at 'D' WWTP (calculated proportionately as per assumptions given in mass balance section 6.6.1)

6.5.2 Effluent quality

With the re-application for licence in 2011, the effluent requirements on Plant 'D' were less stringent (Table 52). Average final effluent quality is shown in Table 52 with historical graphs in Figure 75 and Figure 76 below. Unit 3 has generally complied; the only parameter which fails is phosphate. From the results below, unit 3 has generally complied; the only characteristic which fails is phosphate. From the results below, the unit removed COD and TSS well. Ammonia at 5.0 mg/ℓ is higher than the Unit 3 design of 0.5 mg/ℓ, but it does not exceed the effluent quality limits required by the Water Use Licence.

Table 52: Average final effluent quality and plant compliance at 'D' WWTP

Parameter	Effluent standards	Average concentration (August 2015 to July 2016)	Average compliance (August 2015 to July 2016)
COD	65	49 mg/ℓ	100%
TSS	18	13 mg/ℓ	100%
NH_4	8.0	5.0 mgN/ℓ	100%
$NO_3 + NO_2$	15	3.3 mgN/ℓ	100%
PO_4	1.0	3.4 mgP/ℓ	10%

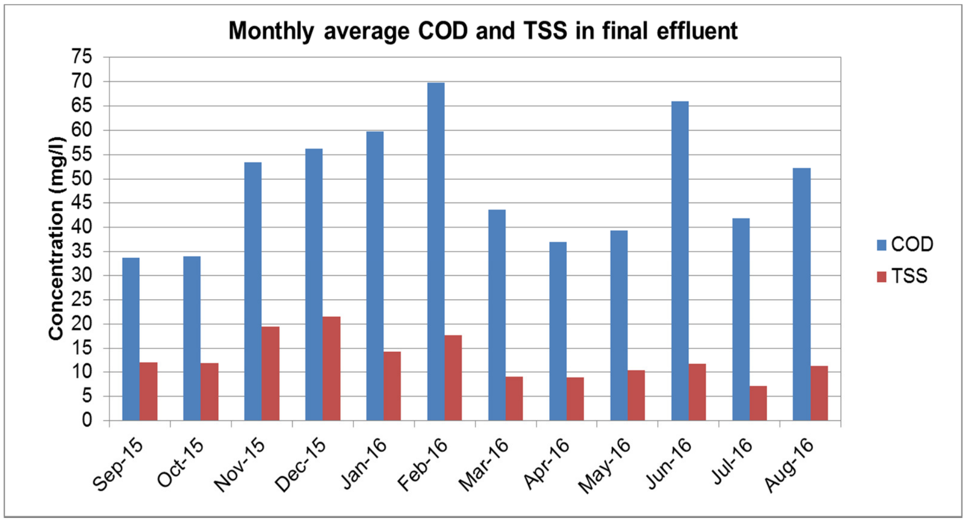

Figure 75: Monthly average COD and TSS in the final effluent at 'D' WWTP

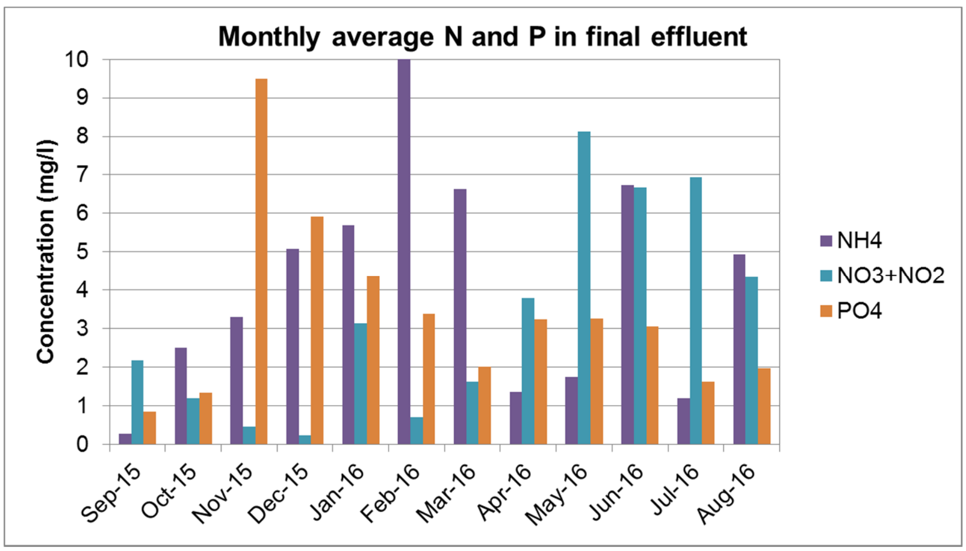

Figure 76: Monthly average ammonia, nitrate+nitrite and orthophosphate in the final effluent at 'D' WWTP[2]

6.5.3 Sludge treatment

6.5.3.1 Sludge characteristics

At 'D' WWTP, WAS is removed from Unit 3 via the clarifier under flow (RAS line). Table 53 indicates the characteristics of the WAS withdrawn from Unit 3 via the underflow.

Table 53: Characteristics of the biological sludge at 'D' WWTP

Parameter	Biological Sludge
Flow (m³/d)	130
Dry solids (%)	0.72
Sludge mass (kg/d)	941

[2] *Final effluent concentration for NH_4 February 2016 is 20.3 mg/ℓ. Suppressed to enhance visualisation.*

6.5.3.2 Sludge thickening

Wasted sludge is thicker than the sludge in the reactor, as it comes from the RAS line. Further thickening occurs in the sludge lagoons. However, no results are available for the sludge lagoon as no sludge samples are taken and sludge is not withdrawn from the lagoon allowing no steady state digester" concentration. The lagoon can therefore be thought of as permanent storage with the occasional measured addition of fresh wasted activated sludge.

6.5.4 Sludge return liquors

Unit 3, a Phoredox layout reactor, is operated for N and P removal, and therefore the supernatant from the sludge lagoon is high in P as well as N. This is seen in the average monthly concentrations in Figure 77 below.

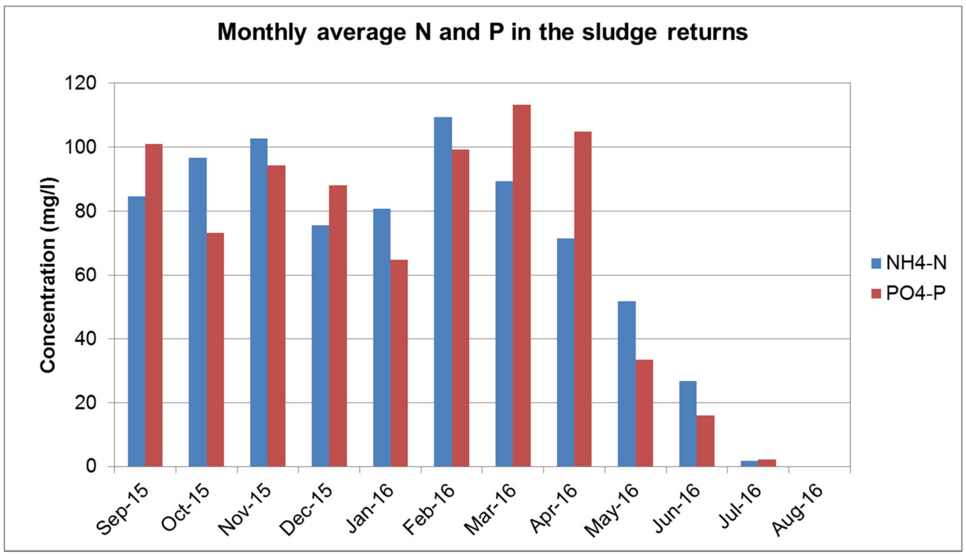

Figure 77: Average ammonia and orthophosphate concentrations in the sludge return liquors at 'D' WWTP

6.6 Impact of the sludge return liquors

6.6.1 Plant mass balance

A complete mass balance of the 'D' WWTP was prepared to understand and evaluate the magnitude of the impacts of the sludge return liquors on the main treatment process addressed in the following sections. The result of the plant mass balance elaborated with the average data available from September 2015 to August 2016 is provided in Table 54. When the analytical data available did not cover all streams and parameters, the following assumptions were required to complete the mass balance:

- COD in biological sludge: COD/MLVSS = 1.481
- TP removed with the biological sludge: TP/MLSS = 3%
- PO_4/TP in influent = 0.65
- NH_4/TKN ratio in influent = 0.75
- NH_4/TKN ratio in solution = 0.85
- f_n (TKN:VSS ratio of activated sludge) = 0.08

Flow measurement on the effluent is consistently lower than that on the influent. This is due to the use of reclaimed effluent on site, for grit washing, irrigation etc.

Table 54: Results of the mass balance at 'D' WWTP

Water streams	Raw sewage	Raw WW U3 & Returns	Biological effluent U3	Final effluent	Biological sludge	Supernatant returns
Flow (Ml/d)	4.02	4.09	3.97	3.03	0.13	0.08
COD (kg/d)	1882	1987	159	148	1046	105
TKN (kg/d)	225	235	28	18	56	11
NH4 (kg/d)	168	174	16	15	1	5
NO3+NO2 (kg/d)	0.0	0.0	13.6	9.9	0.6	0.0
TP (kg/d)	26	34.1	7.8	15.7	21.2	8.1
PO4 (kg/d)	17	22.4	5.1	10.2	0.2	5.5
TSS (kg/d)	942	1028	58	39	706	86
COD (mg/l)	468	485	53	49	8056	1380
TKN (mgN/l)	56	57	7	6	435	140
NH4 (mgN/l)	42	42	5	5	5	72
NO3+NO2 (mgN/l)	0.0	0.0	4.5	3.3	4.5	0.0
TP (mgP/l)	6.5	8.3	2.6	5.2	163.2	106
PO4 (mgP/l)	4.2	5.5	1.7	3.4	1.7	72
TSS (mg/l)	234	251	19	13	5439	1136

6.6.2 Influent characteristics

The supernatant from the sludge lagoon is returned to Unit 3 at the start of the aerated zone. This supernatant contributes to the load on the reactor, particularly in terms of nitrogen, phosphate and suspended solids. For simplicity, it will be added to the raw sewage load on the reactor. The impact of the supernatant load on Unit 3 is shown in Table 55 and Figure 78 below. The current return liquors have a low impact in the influent flow, as well as in COD and nitrogen loads. However, the influent phosphate load is significantly impacted through the additional load recycled from the supernatant of the lagoon (additional 32% orthophosphate). As per Table 54 above, Unit 3 is not complying with the phosphate standard effluent requirement. This can be easily explained as there is currently no removal mechanism of phosphate from the WWTW. The phosphate removed from the waterline is transformed into in particulate phosphate in the form of sludge. The sludge will accumulate in the lagoon. As the lagoon is acting as an anaerobic tank, phosphate shall be released in the lagoon and then returned to the biological treatment. If no outlet in the form of an external sludge discharge is facilitated the influent concentration will become eventually the effluent concentration.

Table 55: Impact of dewatering return liquors in the influent characteristics at 'D' WWTP

Parameter	Raw sewage to the plant	Supernatant returns	Unit 3 raw ww (incl. returns)	Impact on Unit 3 raw ww	Typical impact on raw ww (*)
Flow (kℓ/d)	3 991.6	76.11	4 067.7	1.9%	0.5% – 1.,0%
COD (kg/d)	1 869	105	1 974	5.6%	5% – 10%
TKN (kg/d)	223	13	236	5.9%	9% – 13%
NH_4 (kg/d)	167	5	173	3.2%	9% – 13%
TP (kgP/d)	26	8.1	34.1	31%	5 – 30%
PO_4^-P (kg/d)	16.8	5.5	22.3	32.3%	5 – 30%
TSS (kg/d)	936	86	1 022	9.2%	2% - 5%

(*) Excluding any dedicated treatment to the sludge return liquors

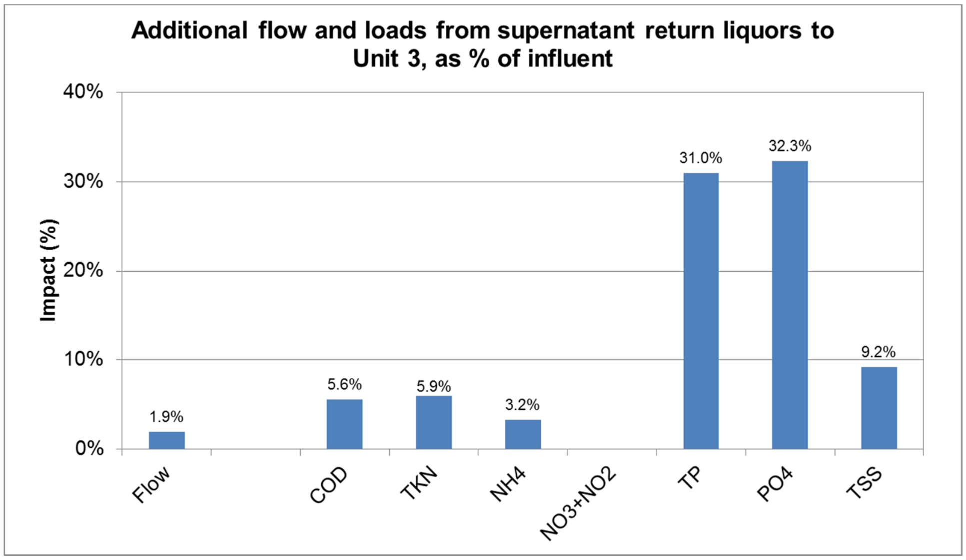

Figure 78: Additional flow and loads entering Unit 3 from the sludge return liquors treatment facility at 'D' WWTP

Comparing the influent ratios from Unit 3 (without return liquors) with a typical South African sewage (Table 56), generally the raw sewage at Plant 'D' is balanced, but a bit low in P. When the return liquors are included, the P increases, but the TP:COD ratio remains lower than average, continuing to be favourable for removal.

Table 56: Influent ratios with and without return liquors at 'D' WWTP

Ratios	Unit 3 influent (without return liquors)	Unit 3 influent (with return liquors)	Typical values in South African ww
COD/TSS	0.501	0.518	0.5
TKN/COD	0.119	0.120	0.122
TKN/COD	0.090	0.088	0.07 – 0.09
TP/COD	0.014	0.017	0.019
PO_4/COD	0.009	0.011	0.009

6.6.3 Biological effluent quality

The quality of the biological effluent leaving Unit 3 (before the non-operational ferric dosing and before chlorination and maturation), is as follows:

Table 57: Average biological effluent quality and final effluent at 'D' WWTP

Parameter	Average biological effluent	Average final effluent
COD	53 mg/ℓ	49 mg/ℓ
TSS	13.0 mg/ℓ	13 mg/ℓ
NH_4	5.3 mgN/ℓ	5.0 mgN/ℓ
$NO_3 + NO_2$	4.5 mgN/ℓ	3.3 mgN/ℓ
PO_4	1.7 mgP/ℓ	3.4 mgP/ℓ

From the above table, it can be seen that, after having passed through the maturation ponds, the nitrate concentration has dropped, and the phosphate has increased. This can be partly attributed to sludge spills from the lagoon into the maturation pond, when the lagoon became full in the first half of 2016.

6.6.4 *Aeration demand*

At 'D' WWTP, Unit 3 has four surface aerators with 37 kW each running 24 hours per day. Energy is not measured and can therefore only be estimated. The current energy consumption with aeration is about 3 552 kWh/d. In the current process treatment, the additional loads of ammonia and COD from the supernatant returns are low and not having a critical impact in the aeration energy consumption (lower than 5%).

6.6.5 *Biological treatment capacity*

Unit 3 is currently treating about 100% of its design load, see Table 58 below. Actually, 98% of COD and 106% of TKN loads are currently treated on site. These loads refer to the raw wastewater (excluding returns). This might explain the higher effluent ammonia (5 mg/ℓ) compared to the design figure (0.5 mg/ℓ). Considering the biological reactor and aeration capacity are fully optimised, it appears that Unit 3 in Plant 'D' is operating at its max capacity. Any future increase in load (even coming from the internal sludge return liquors) will require either one of the old reactors to be brought back into operation, or a new replacement to be built and operated.

The sludge retention time aimed by the process controllers is 30 days, higher than the design of 20 days. However, a brief calculation based on influent characteristics and reactor MLSS give the sludge age at 18 days. This difference can be due to inconsistent wasting of sludge, or that sludge is wasted from the underflow and not directly from the reactor, making concentration less consistent and therefore sludge age less easily defined.

Table 58: Unit 3 load comparison (actual vs design) at 'D' WWTP

Parameters	**Unit 3**		
	Design	Actual	
Flow (Mℓ/d)	4.25	4.02	95%
COD (kg/d)	1913	1882	98%
TKN (kg/d)	212	225	106%
TP (kg/d)	68	19.9	29%

6.7 Conclusions and recommendations

From the site research conducted at 'D' WWTP, the following conclusions and recommendations are applicable:

1. The plant is currently under loaded since the measured raw sewage flow is about half the design capacity. Concentration is within design range.

2. Unit 3, being the only unit currently in operation, is running at full capacity about COD and *N* loads.

3. Unit 3 receives 100% of the flow and loads from the sludge lagoon supernatant, with a contribution of 34% TP. This return flow consumes 5% of the aeration capacity of Unit 3.

4. The *P* is not removed from the system, as sludge is not removed from the plant, and no treatment of dewatering liquor is provided. Therefore, the effluent *P* is high.

5. The effluent ammonia, at 5 mg/ℓ is higher than the design of 0.5 mg/ℓ, but within effluent quality limits. Incomplete nitrification at an AS plant point in general to challenges in aeration or low

SRT. Incomplete nitrification can make an WWTP unstable therefor it is recommended to start a second module.

In addition, the following generic conclusions and recommendations shall be noted:

6. The plant is generally well operated and shows a good level of maintenance.

7. The sludge lagoons should be emptied at 5-year intervals as per design. It must be noted that this mitigating action will likely not be sufficient to ensure compliance on orthophosphate.

8. It is should be checked if there are further optimisations to be applicable in Unit 3 and if required bring other unit into operation to further improve the plant performance.