WATER RESEARCH COMMISSION REPORT TT800-19

APPENDIX 2

RESULTS FROM MODELLING SIMULATION

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CHAPTER 1: 'W' WWTP

'W' WWTP has a total design capacity of 170 Mℓ/d; module 1 has a capacity of 40 Mℓ/d, modules 2 and 3 each having a capacity of 40 Mℓ/d and the fourth module has a capacity of 50 Mℓ/d. The results for the impact of SRL are presented in this section. The impact was determined on:

- Influent Characteristics
- Biological Treatment Capacity
- Biological Effluent Quality

1.1 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. Table 1 and Table 2 give a summary of the unit operations and process data. The general process flow diagram of the works is indicated in Figure 1 below. Flow is split between Modules 1-3 and Module 4.

Table 1: 'W' WWTP Unit Operations and Process

Key Unit Operations and Processes	Module 1	Module 2& 3	Module 4
Primary Settling Tanks	Yes	Yes	Yes
BNR System	Yes	Yes	Yes
Secondary Settling Tanks	Yes	Yes	Yes
Dissolved Air Flotation	Yes	Yes	Yes
Anaerobic Digesters	Yes	Yes	Yes
Dewatering	Yes	Yes	Yes

The pertinent data for the above unit operations and processes is summarised below in Table 2.

Table 2: 'W' WWTP Data

Key Unit Operations and Processes	Module 1	Module 2&3	Module 4
Primary Settling Tanks			
• Diameter (m)	25	25	34
BNR System			
• Volume (m³)	5 940	15 898 ea.	21 688
Secondary Settling Tanks			
• Diameter	30	25	34
Dissolved Air Flotation × 7			
• Diameter of ea. Unit (m)	10	10	10
• Volume of each unit (m³)	424	424	424
• Anaerobic Digesters	4	6	4
Dewatering Operates 12 h, 7 days per week			

- Thickened biological sludge is pumped to ADs.
- PS and biological thickened sludge are anaerobically digested in 16 units:
- SRL flows:
    - SRL from the DAF units of modules 1-3 are recycled to the beginning of the biological reactors.

- SRL from the DAF units of module 4 are recycled 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.
- 50% of the SRL flow is recycled to Modules 1-3 while the remaining 50% is recycled to Module 4.

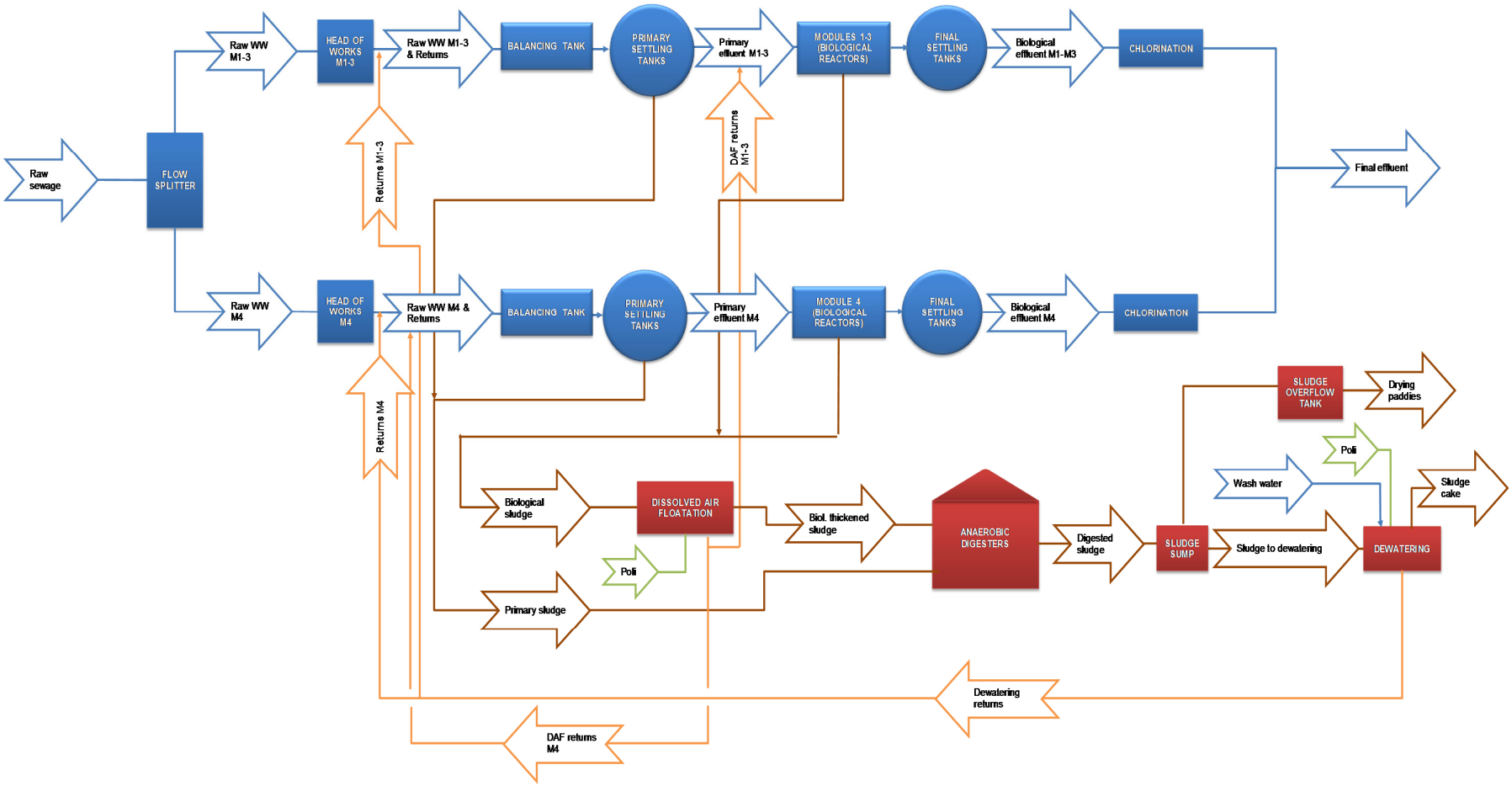

Figure 1: 'W' WWTP Process Flow Diagram

1.2 Impact of SRL on Influent Characteristics at 'W' WWTP

The influent characteristics impacted on by SRL flows are:

- Influent flow rate
- Influent COD Load
- Influent Ammonia Load
- Influent PO_4 Load

The impact of SRL on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of SRL for a given percentage side-stream treatment (0% side-stream treatment to 100% side-stream treatment and treated SRL stream is discharged with the final effluent) prior to return to the main water line.

1.2.1 Influent Flowrate

The impact of percentage side-stream treatment on the flow rate is illustrated below in Figure 2. Without side-stream treatment, 100% of SRL flow is returned to the activated sludge system. The flow to each module decreases along with side-stream treatment, and the treated SRL is discharged to the final effluent. The flow to Module 1 decreases from 40 Mℓ/d to 39 Mℓ/d. Flow to Modules 2 & 3 decrease from 83 to 79 Mℓ/d and the flow to Module 4 decreases from 52 Mℓ/d to 49 Mℓ/d.

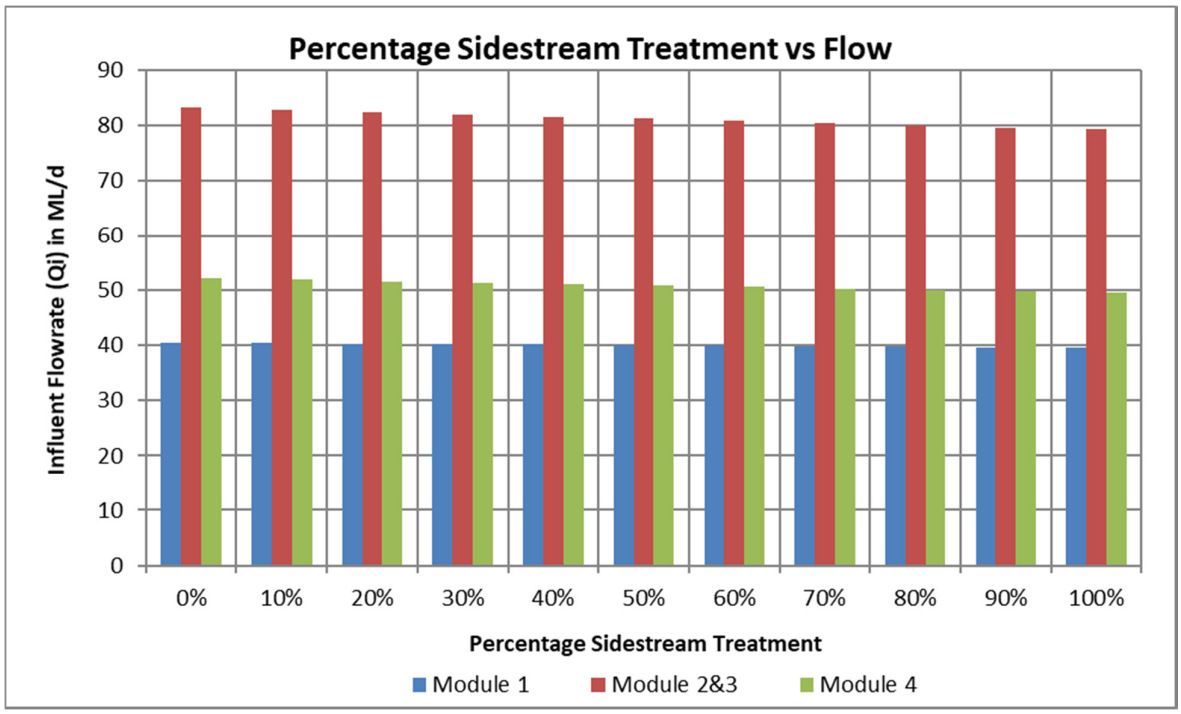

Figure 2: Impact of side-stream treatment on influent flow at 'W' WWTP

1.2.2 Influent COD Load

The impact of percentage side-stream treatment on the influent COD load to the AS system is illustrated below in Figure 3. Total COD load to Modules 1, 2&3 and 4 decreases respectively, from 17 386 kgCOD/d, 34 913 kgCOD/d and 21 834 kgCOD/d in relationship to the percentage side-stream treatment to 17 321 kgCOD/d, 34 642 kgCOD/d and 21 651 kgCOD/d.

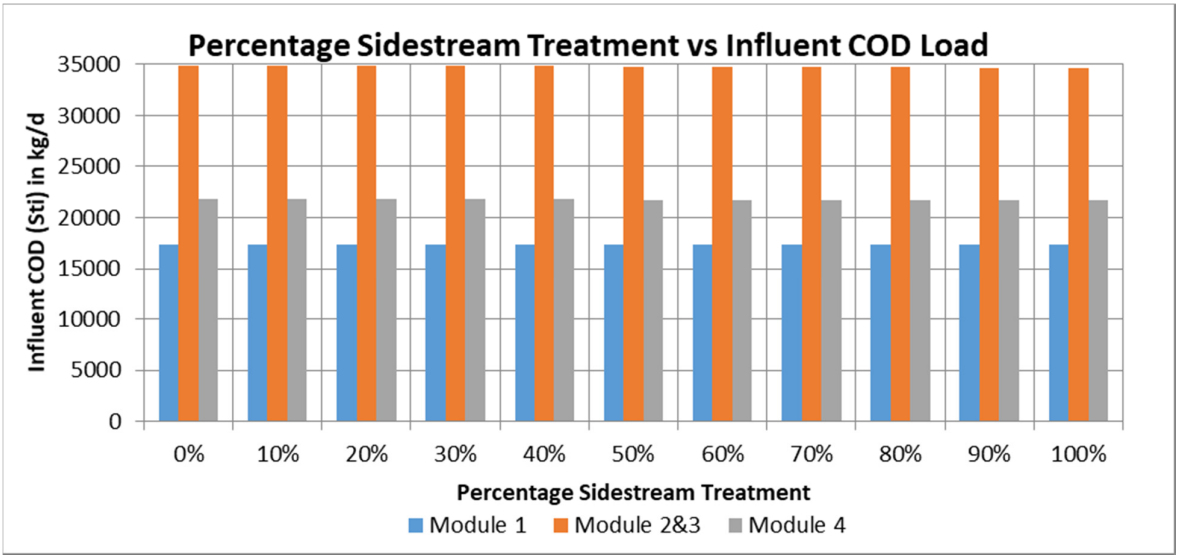

Figure 3: Impact of side-stream treatment on the influent COD at 'W' WWTP

1.2.3 Influent Ammonia Load

The impact of percentage side-stream treatment on the influent ammonia load to the AS system is illustrated below in Figure 4. Influent ammonia load to Modules 1, 2&3 and 4 decreases respectively from 1 890 kgN/d, 3 865 kgN/d and 2 420 kgN/d in relationship to the percentage side-stream treatment to 1 789 kgN/d, 3 579 kgN/d and 2 237 kgN/d.

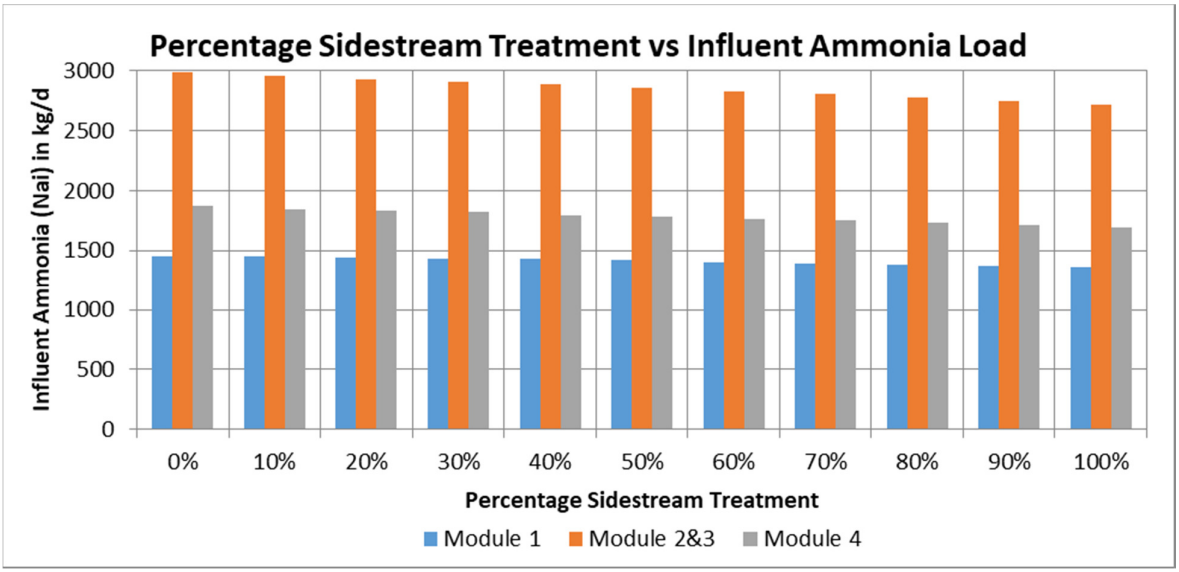

Figure 4: Impact of side-stream treatment on the influent ammonia at 'W' WWTP

1.2.4 Influent Phosphate Load

The impact of percentage side-stream treatment on the influent phosphate load to the AS system is illustrated below in Figure 5. Influent phosphate load to Modules 1, 2&3 and 4 decreases respectively from 478 kgP/d, 669 kgP/d and 427 kgP/d in relationship to the percentage side-stream treatment to 115 kgP/d, 230 kgP/d, 144 kgP/d.

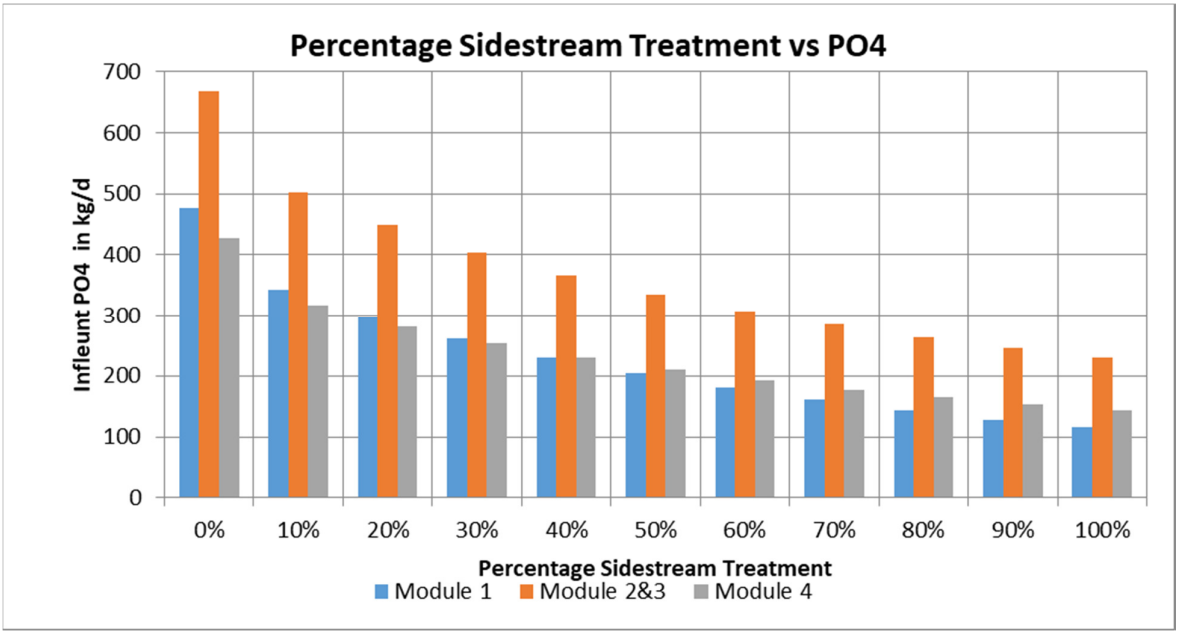

Figure 5: Impact of side-stream treatment on influent phosphate at 'W' WWTP

1.3 Impact of SRL on Biological Treatment Capacity at 'W' WWTP

The biological treatment capacity parameters impacted on by sludge return flows are:

- A-recycle
- Total oxygen demand
- Secondary sludge production

The impact of sludge return flows on each of the above influent characteristics is summarised in this section. Figure 6 to Figure 8 illustrate the impact of SRL for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

1.3.1 A-recycle

The impact of percentage side-stream treatment on the a-recycle ratio (nitrate aerobic to anoxic zone optimum flow rate/influent flow rate) of the AS system is illustrated below in Figure 6. The a-recycle flow ratio for each module increases along with side-stream treatment. The flow ratio for Module 1 increases from 3 to 4 while for Modules 2 & 3 and Module 4 the increase is from 3 to 4.

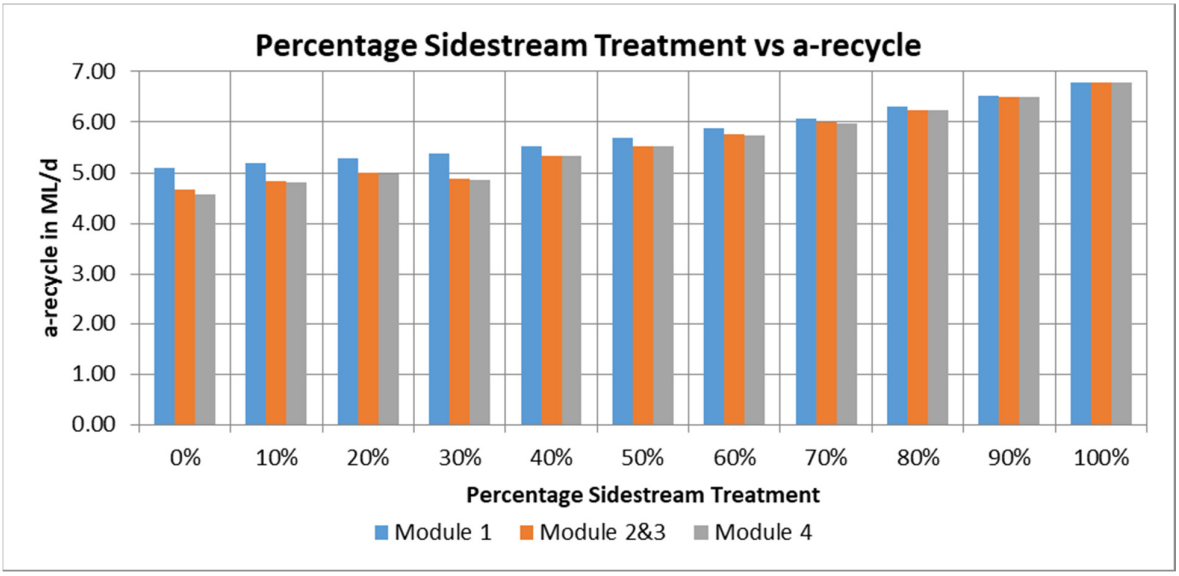

Figure 6: Impact of side-stream treatment on a-recycle at 'W' WWTP

1.3.2 Total Oxygen Demand

The impact of percentage side-stream treatment on the total oxygen demand (FOt) of the AS system is illustrated below in Figure 7. The FOt for each module decreases along with side-stream treatment capacity. The total oxygen demand for Module 1 decreases from 10 225 kgO/d to 10 117 kg/d. Total oxygen demand for Modules 2 & 3 decrease from 20 646 kgO/d to 20 234 kgO/d and the total oxygen demand for Module 4 decreases from 12 877 kgO/d to 12 646 kgO/d.

The aeration power requirement for each module decreases along with side-stream treatment. Aeration power requirement for Module 1 decreases from 511 kW to 505 kW, Modules 2 & 3 decrease from 1 032 kW to 1 012 kW and Module 4 decreases from 644 kW to 632 kW.

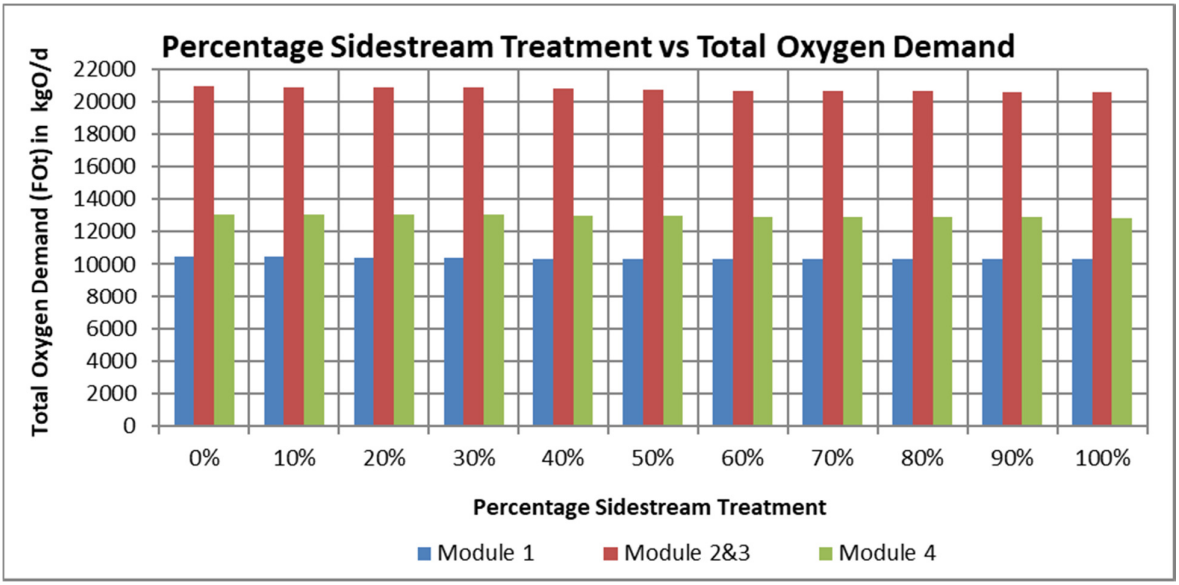

Figure 7: Impact of side-stream treatment on total oxygen demand at 'W' WWTP

1.3.3 Secondary Sludge Produced

The impact of percentage side-stream treatment on secondary sludge production from the AS system is illustrated below in Figure 8. The secondary sludge production for each module decreases along with side-stream treatment capacity. Secondary sludge production for Module 1 decreases from 7 109 kgTSS/d to 5 182 kgTSS/d, Modules 2 & 3 decreases from 13 267 kgTSS/d to 11 564 kg/d and for Module 4 decreases from 8 347 kgTSS/d to 7 228 kgTSS/d.

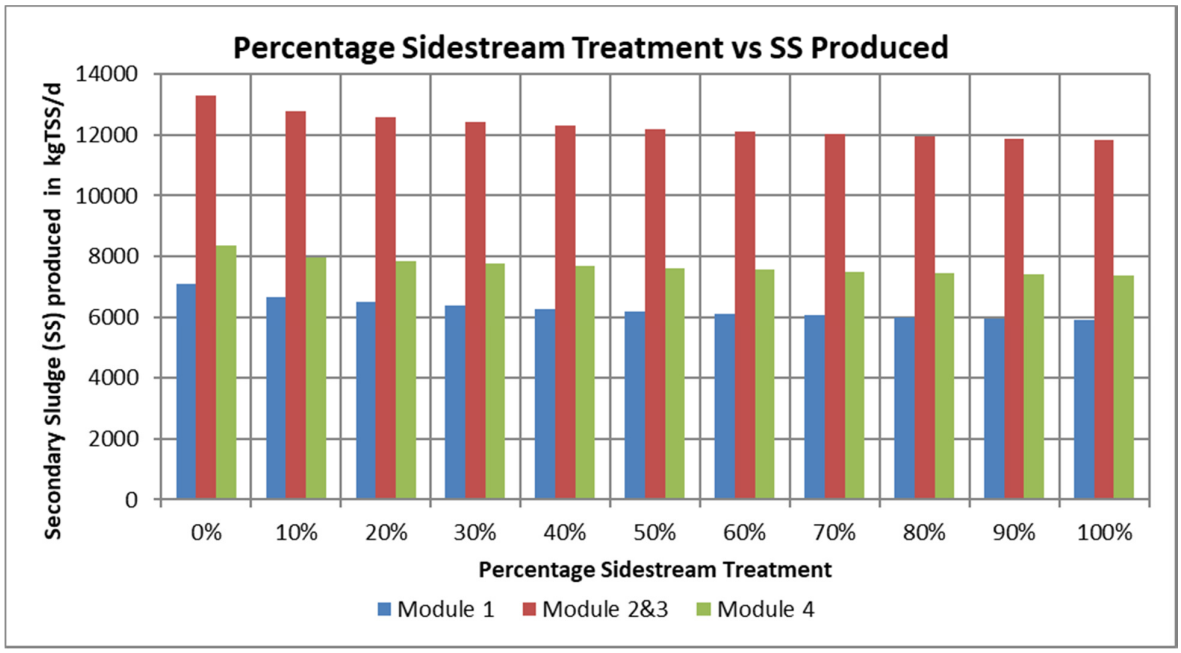

Figure 8: Impact of side-stream treatment on secondary sludge production at 'W' WWTP

1.4 Biological Effluent Quality

The biological effluent quality parameters impacted on be sludge return flows are:

- COD Concentration
- Ammonia Concentration
- Phosphates Concentration

1.4.1 Effluent COD Concentration

The impact of percentage side-stream treatment on the effluent COD from the AS system is illustrated below in Figure 9. The effluent COD concentration from Modules 1, 2 & 3 and 4 remains close to 70 mgCOD/ℓ with no variation. This predicted value is the COD concentration of the unbiodegradable organics from the influent, assuming that all influent biodegradable soluble organics have been utilised in the AS system.

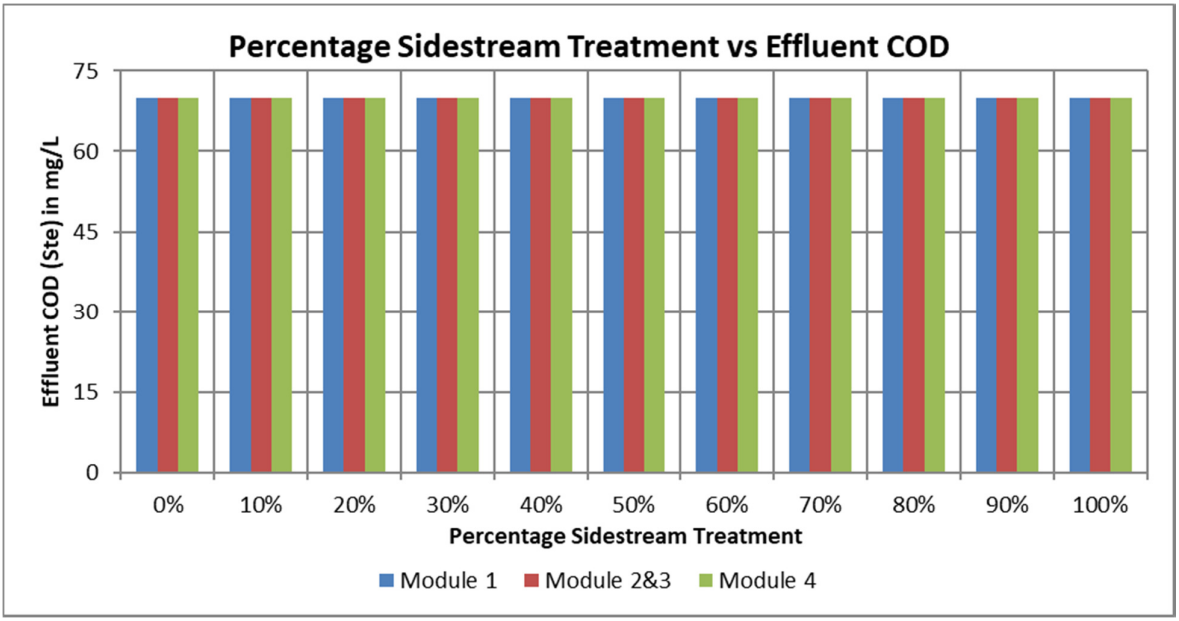

Figure 9: Impact of side-stream treatment on effluent COD at 'W' WWTP

1.4.2 Effluent Ammonia Concentration

The impact of percentage side-stream treatment on the effluent ammonia from the AS system is illustrated below in Figure 10. The effluent ammonia concentration from all modules remains constant at 2.20 mg/ℓ.

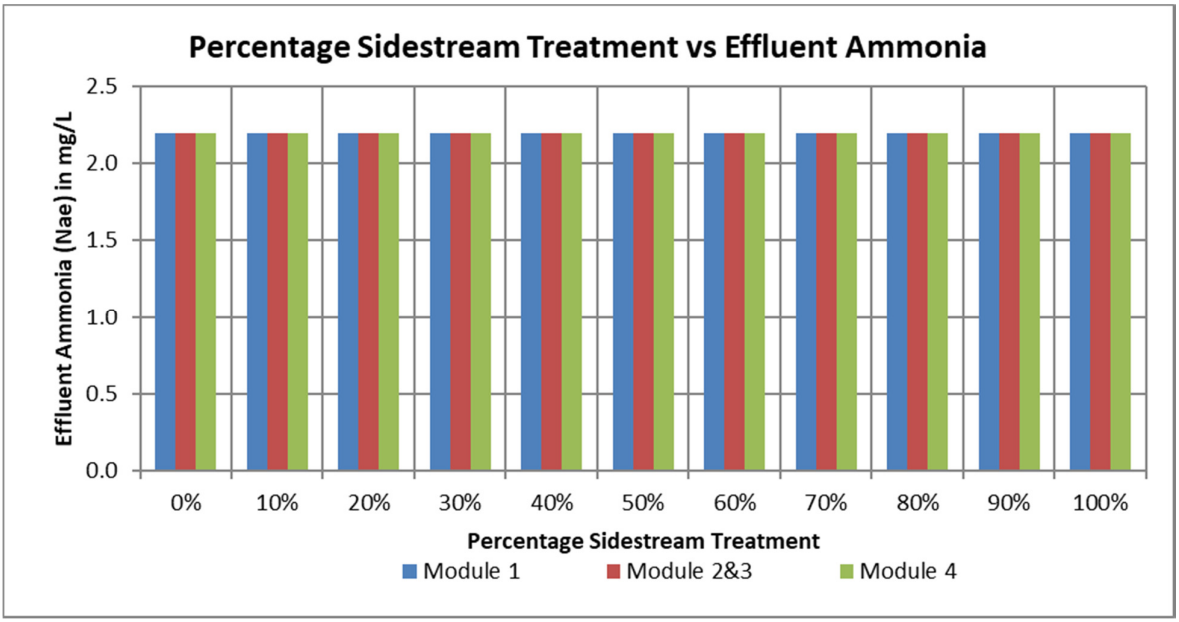

Figure 10: Impact of side-stream treatment on effluent ammonia at 'W' WWTP

1.4.3 Effluent Nitrate Concertation

The impact of percentage side-stream treatment on the effluent nitrate concentration from the AS system is illustrated below in Figure 11. The effluent nitrate concentration from Modules 1, 2 & 3 and 4 decrease respectively from 6.43 to 6.09 mg/ℓ; 6.47 to 6.09 mg/ℓ and 6.46 to 6.09 mg/ℓ.

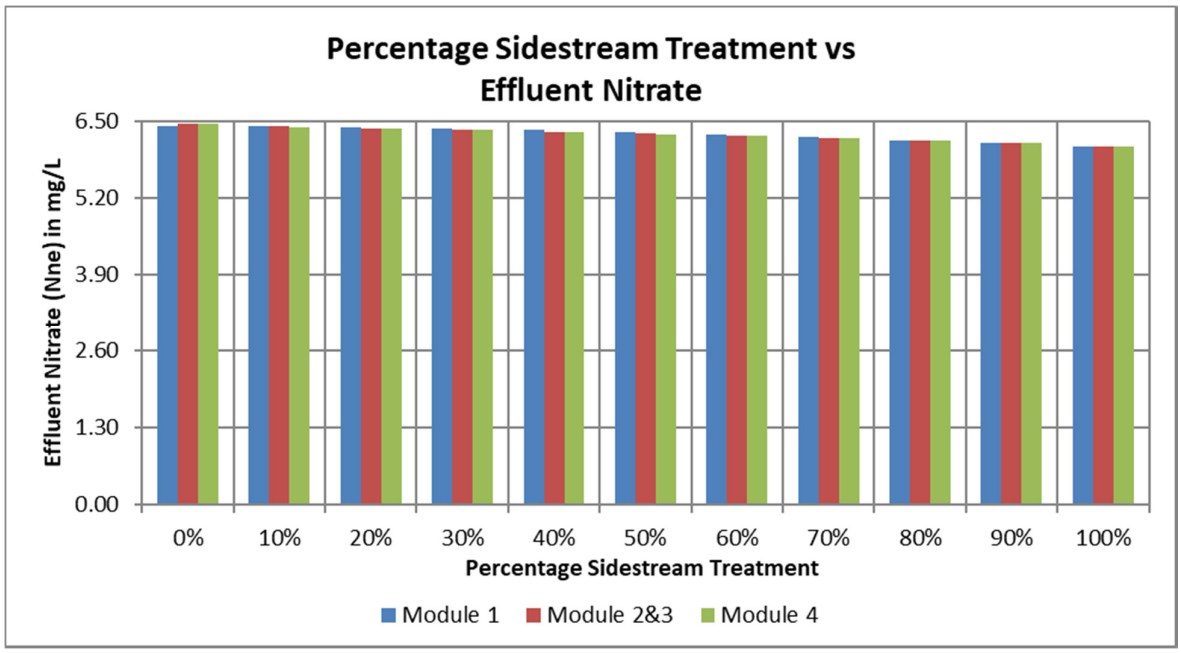

Figure 11: Impact of side-stream treatment on effluent nitrate at 'W' WWTP

1.4.4 Effluent Ortho-Phosphates Concentration

The side-stream treatment has no predicted impact on the effluent phosphates as the effluent OP remains constant at 0 mgP/ℓ.

1.5 Summary of Impacts of SLR on the 'W' WWTP AS System

Table 3 below summarises the percentage impact at a given percentage side-stream treatment starting from 0% to 100% side-stream treatment. The table shows both the average impact and the impact for each module at Plant 'W'.

Table 3: Percentage impact at given percentage side-stream treatment

Percentage Impact at given Percentage Side-stream Treatment at 'W' WWTP							
	Parameter	**0%**	**20%**	**40%**	**60%**	**80%**	**100%**
Influent	**Flow rate (Average)**	**4.2%**	**3.3%**	**2.5%**	**1.7%**	**0.8%**	**0.0%**
	Module 1	2.4%	1.9%	1.4%	0.9%	0.5%	0.0%
	Module 2&3	4.9%	3.9%	2.9%	2.0%	1.0%	0.0%
	Module 4	5.3%	4.2%	3.2%	2.1%	1.1%	0.0%
	COD (Average)	**0.67%**	**0.5%**	**0.4%**	**0.3%**	**0.1%**	**0.0%**
	Module 1	0.38%	0.30%	0.23%	0.15%	0.08%	0.00%
	Module 2&3	0.78%	0.63%	0.47%	0.31%	0.16%	0.00%
	Module 4	0.84%	0.67%	0.51%	0.34%	0.17%	0.00%
	Ammonia (Average)	**9.1%**	**7.5%**	**5.7%**	**3.8%**	**2.1%**	**0.0%**
	Module 1	7.1%	6.4%	5.1%	3.6%	1.9%	0.0%
	Module 2&3	9.9%	7.9%	6.2%	4.2%	2.1%	0.0%
	Module 4	10.1%	8.1%	5.7%	3.7%	2.2%	0.0%
	PO_4 (Average)	**234.7%**	**117.0%**	**73.3%**	**41.9%**	**18.4%**	**0.0%**
	Module 1	315.8%	159.5%	100.4%	57.6%	25.3%	0.0%
	Module 2&3	191.1%	95.2%	59.7%	34.1%	14.9%	0.0%
	Module 4	197.3%	96.4%	59.9%	34.1%	14.9%	0.0%
	a-recycle (Average)	**-29.5%**	**-25.1%**	**-20.3%**	**-14.5%**	**-7.7%**	**0.0%**
	Module 1	-24.7%	-22.1%	-18.3%	-13.2%	-7.0%	0.0%
	Module 2&3	-31.2%	-26.4%	-21.2%	-15.0%	-8.0%	0.0%
	Module 4	-32.5%	-26.7%	-21.5%	-15.3%	-8.1%	0.0%
Biological Reactor	**Total Oxygen Demand (Ave.)**	**2.2%**	**1.8%**	**1.4%**	**0.9%**	**0.5%**	**0.0%**
	Module 1	1.7%	1.5%	1.2%	0.8%	0.4%	0.0%
	Module 2&3	2.6%	1.9%	1.5%	1.0%	0.5%	0.0%
	Module 4	2.4%	1.9%	1.5%	1.0%	0.5%	0.0%
	Power Requirement (Ave.)	**2.2%**	**1.8%**	**1.4%**	**0.9%**	**0.5%**	**0.0%**
	Module 1	1.7%	1.5%	1.2%	0.8%	0.4%	0.0%
	Module 2&3	2.6%	1.9%	1.5%	1.0%	0.5%	0.0%
	Module 4	2.4%	1.9%	1.5%	1.0%	0.5%	0.0%
	SS Produced	**15.1%**	**7.6%**	**4.8%**	**2.7%**	**1.2%**	**0.0%**
	Module 1	20.2%	10.2%	6.4%	3.7%	1.6%	0.0%
	Module 2&3	12.1%	6.3%	4.0%	2.3%	1.0%	0.0%
	Module 4	12.9%	6.4%	4.0%	2.3%	1.0%	0.0%
Effluent	**COD Average**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Module 1	107.7%	107.4%	86.9%	61.2%	31.8%	0.0%
	Module 2&3	146.2%	131.0%	102.7%	70.9%	36.5%	0.0%
	Module 4	148.6%	133.0%	104.4%	72.2%	37.2%	0.0%
	NO_3	**6.1%**	**5.1%**	**4.1%**	**2.9%**	**1.5%**	**0.0%**
	Module 1	5.7%	5.3%	4.4%	3.2%	1.7%	0.0%
	Module 2&3	6.4%	5.0%	4.0%	2.8%	1.5%	0.0%
	Module 4	6.1%	4.9%	4.0%	2.8%	1.5%	0.0%
	PO_4 (Average)	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Figure 12 below shows the SRL impact on 'W' WWTP at 0% side-stream treatment. The highest impact was observed for influent phosphate load at 235% the effluent ammonia concentration.

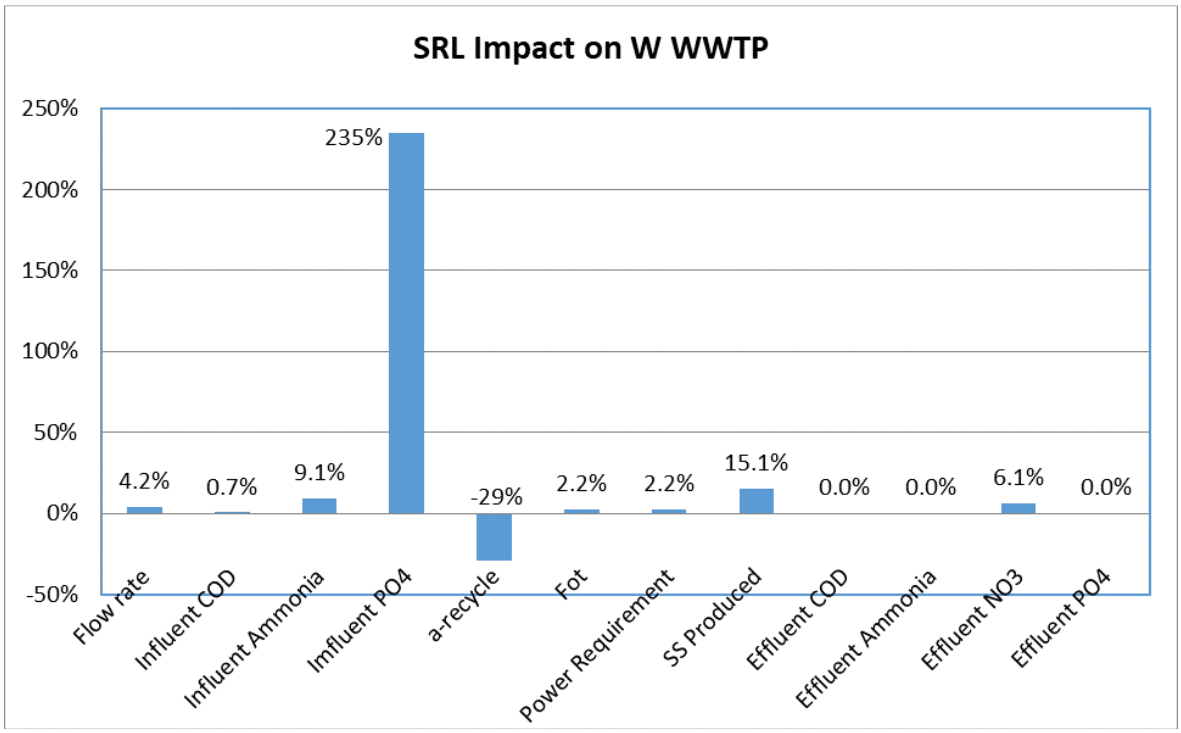

Figure 12: SRL Impact on 'W' WWTP at 0% side-stream treatment

CHAPTER 2: 'Z' WWTP

The results of the impact of return sludge liquors at 'Z' WWTP are presented in this section. The impact of the sludge return flows was determined on:

- Influent Characteristics
- Biological Treatment Capacity
- Biological Effluent Quality

2.1 Process Description

A description of the 'Z' WWTP is indicated below as per information found in the operation and maintenance manuals for Modules 1 and Module 2. Table 4 and Table 5 give a summary of the unit operations and process data. A general process flow diagram of the works in indicated below in Figure 13. SRL is returned to Module 2. At the current flow, Modules 1 & 2 have design capacity of 45 Mℓ/d and 40 Mℓ/d respectively.

Table 4: 'Z' WWTP Unit Operations and Processes

Key Unit Operations and Processes	Module 1	Module 2
Primary Settling Tanks	Yes	Yes
BNR System	Yes	Yes
Secondary Settling Tanks	Yes	Yes
Fermenters	Yes	Yes
Dissolved Air Flotation	Yes	Yes
Anaerobic Digesters	Yes	Yes
Dewatering	Yes	Yes

The pertinent data for the above unit operations and processes is summarised in Table 5.

Table 5: 'Z' WWTP Data Summary

Key Unit Operations and Processes	Module 1	Module 2
Primary Settling Tanks diameter	4 × 22 m	3 × 25 m
Balancing Tank Volume (m³)	5 000	12 000
BNR System Volume (m³)	2 × 19 575	2 × 19 575
Secondary Settling Tank Diameter	4 × 32 m	4 × 35 m
DAF Units	1 Unit	
Anaerobic Digesters	2 × 6 000 + 2 × 5 380 m³	

SLR treatment consists of:

- Dewatering return liquors conveyed to two precipitation tanks where lime slurry is dosed to increase the pH and precipitate orthophosphate. The same precipitation tanks were designed to strip ammonia.
- 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.

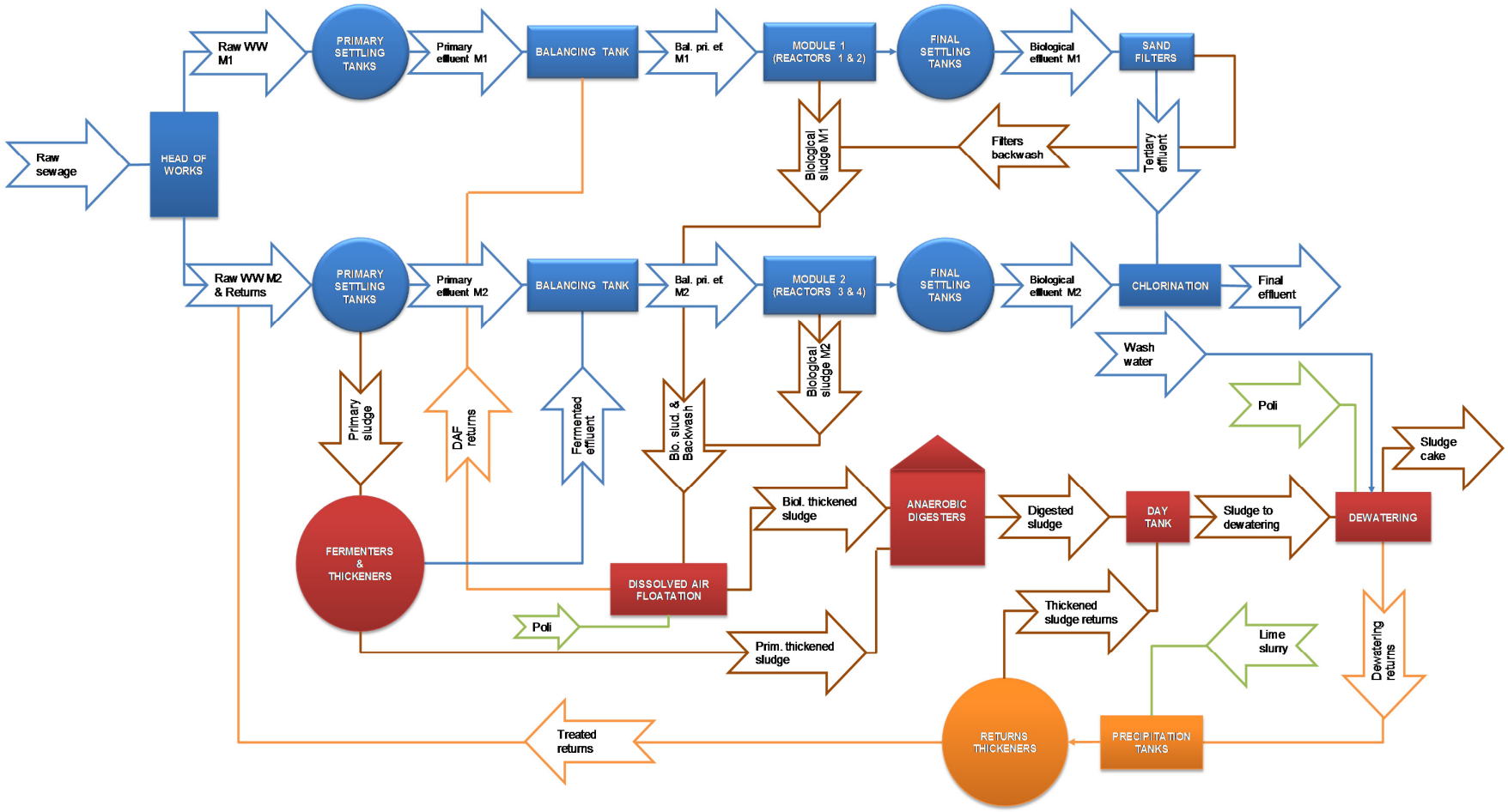

Figure 13: 'Z' WWTP Process Flow Diagram

2.2 Impact of SRL on the Influent Characteristics on Module 2 at 'Z' WWTP

The influent characteristics impacted on by sludge return flows are:

- Influent flow rate
- Influent COD load
- Influent ammonia load
- Influent PO_4 load

The impact of SRL on each of the above influent characteristics is summarised here and Figure 14 illustrates the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line of Module Influent Flow Rate 2.

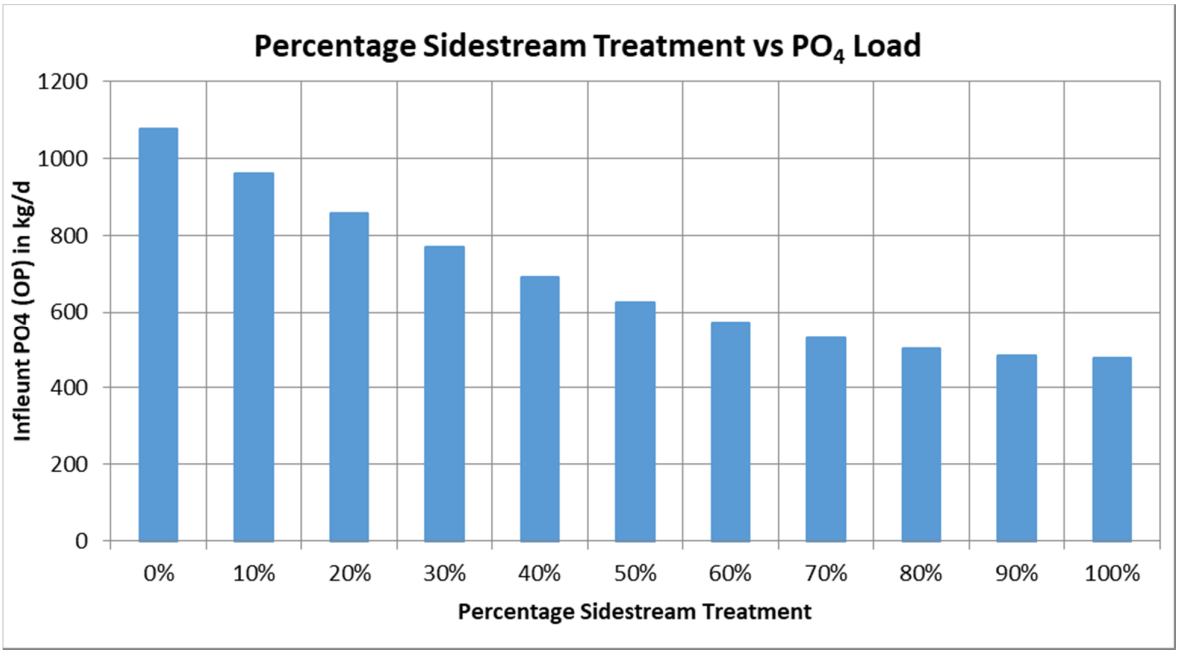

Figure 14: Impact of side-stream treatment on Module 2 influent phosphate at 'Z' WWTP

The impact of percentage side-stream treatment on the flow rate is illustrated below in Figure 15. Without side-stream treatment, i.e. 0% side-stream treatment, 100% of return sludge liquors flow back to the AS system and the treated SRL is discharged to the final effluent. The flow to Module 2 decreases along with side-stream treatment from 63 Mℓ/d to 58 Mℓ/d.

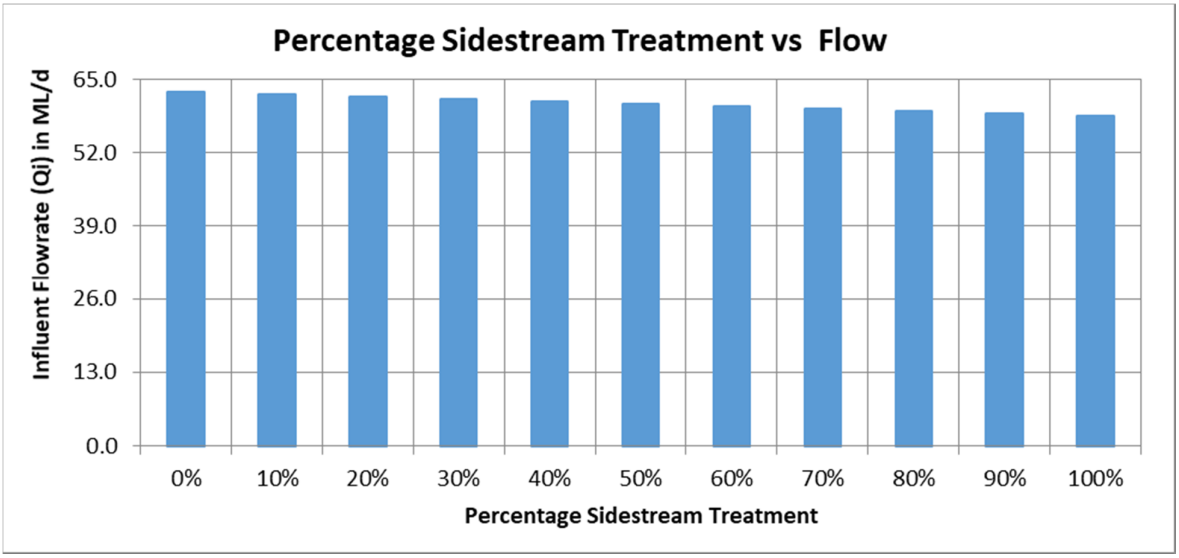

Figure 15: Impact of side-stream treatment on Module 2 influent flow at 'Z' WWTP

2.2.1 *Influent COD Load*

The impact of percentage side-stream treatment on the total influent COD load to the AS system is illustrated in Figure 16 below. Influent COD load to Module 2 decreases from 26 512 mgCOD/ℓ to 26 284 kgCOD/d.

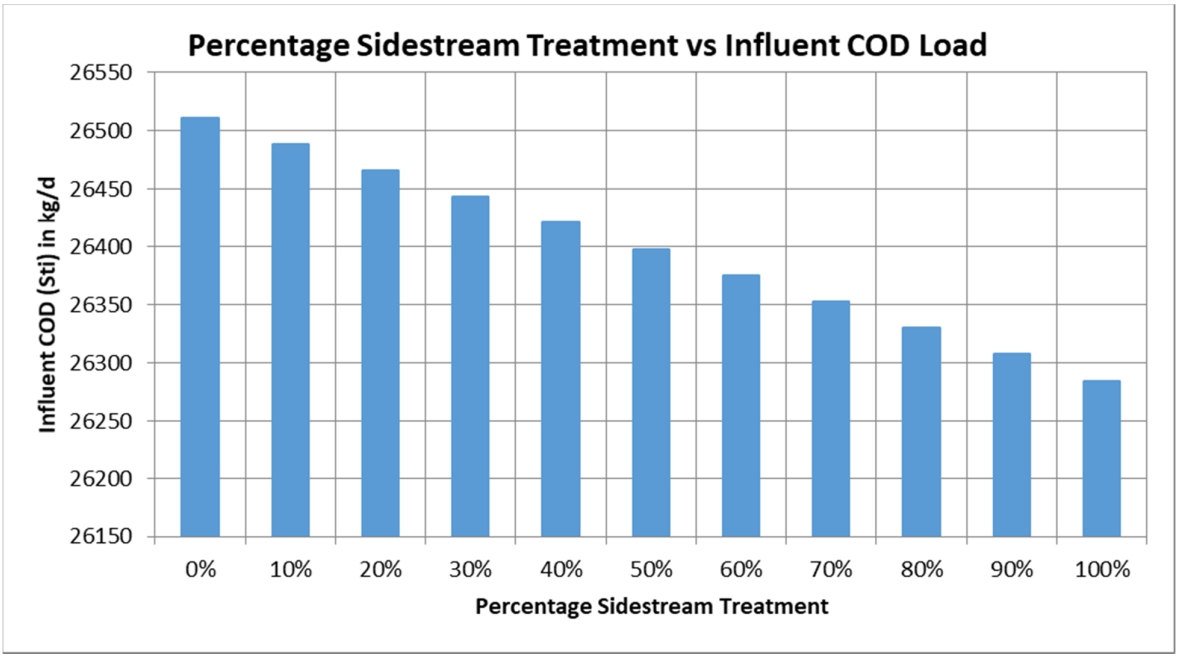

Figure 16: Impact of side-stream treatment on Module 2 influent COD at 'Z' WWTP

2.2.2 *Influent Ammonia Load*

The impact of percentage side-stream treatment on the influent ammonia load to the AS system is illustrated below in Figure 17 below. Influent ammonia load to Module 2 decreases from 2 926 kgN/d to 2,529 kgN/d, this trend is similar to the model predictions for the other plants.

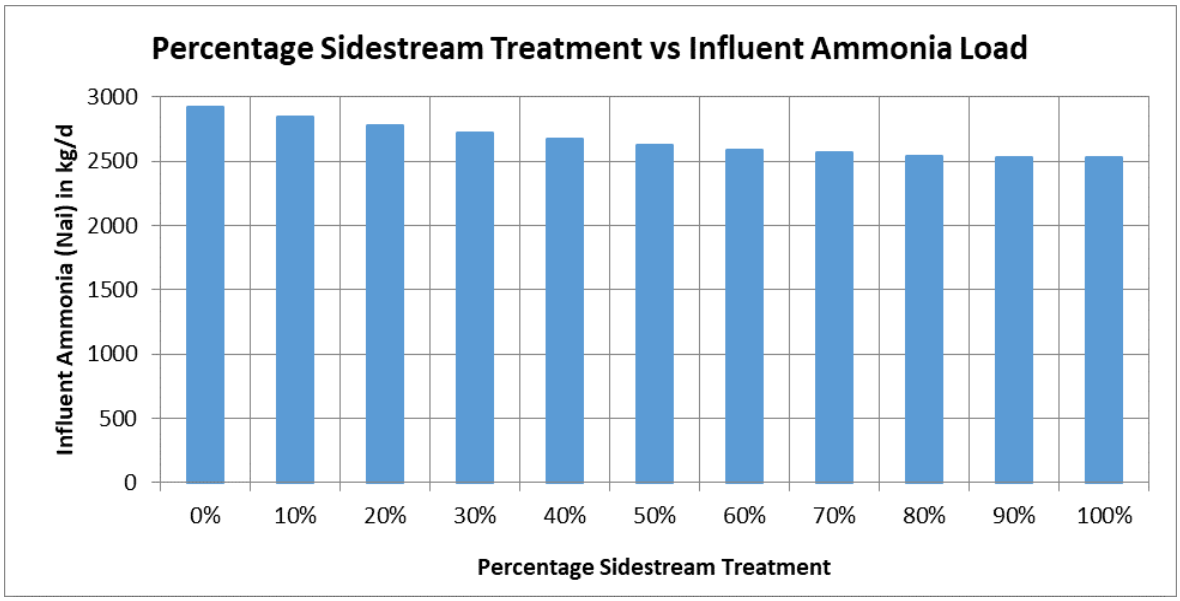

Figure 17: Impact of side-stream treatment on Module 2 influent ammonia at 'Z' WWTP

2.2.3 Influent Phosphate Load

The impact of percentage side-stream treatment on influent phosphate load to the AS system is illustrated in below in Figure 18.

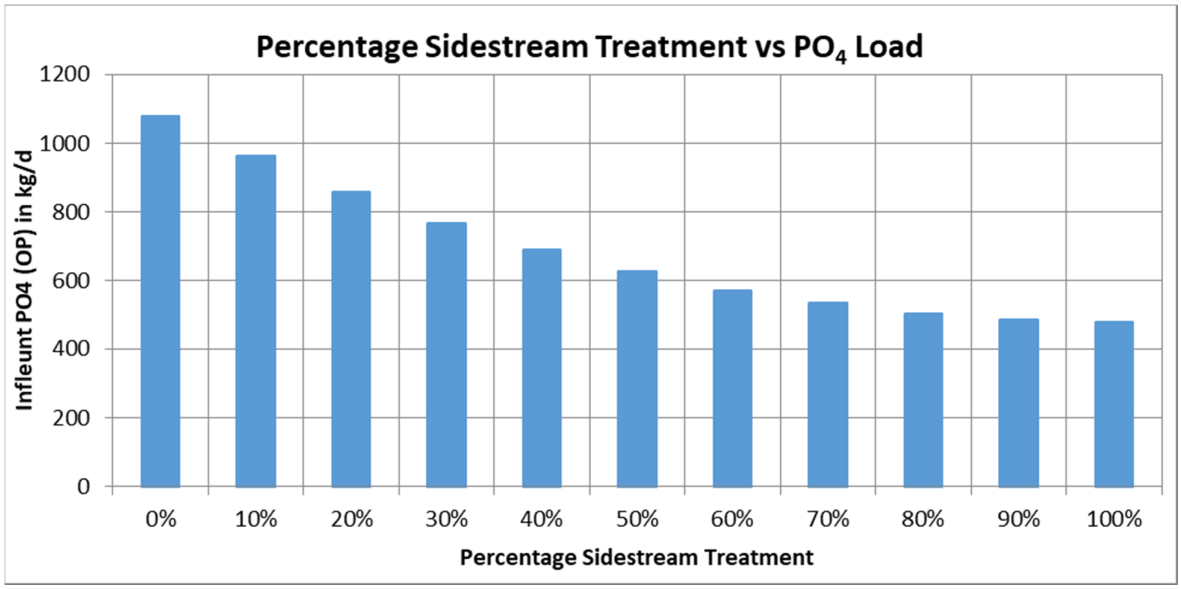

Figure 18: Impact of side-stream treatment on Module 2 influent phosphate at 'Z' WWTP

Influent phosphate load to Module 2 decreases from 1 077 kgP/d to 479 kgP/d. This trend is similar to the model predictions for the other plants. It is important to note that Module 2 at Plant 'Z' receives all the SRL from sludge treated for both modules.

2.3 Impact of SRL on Biological Treatment Capacity on 'Z' WWTP Module 2 AS System

The biological treatment capacity parameters impacted on by sludge return flows are:

- A-recycle
- Total oxygen demand
- Secondary sludge production

The impact of SRL on each of the above biological treatment capacity parameters is summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

2.3.1 A-recycle

The impact of percentage side-stream treatment on the a-recycle to the AS system is illustrated below in Figure 19. The a-recycle ratio for Module 2 increases from 3.68 Mℓ/d to 7.51 Mℓ/d. This trend is similar to that observed in the other plants.

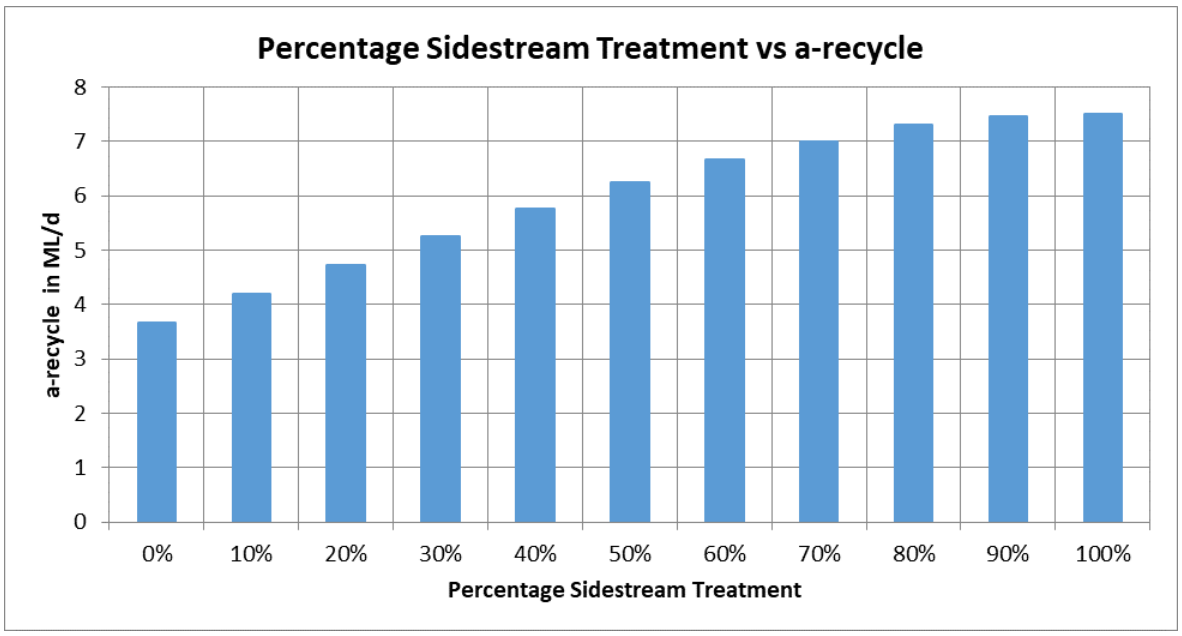

Figure 19: Impact of side-stream treatment on Module 2 a-recycle at 'Z' WWTP

2.3.2 Total Oxygen Demand

The impact of percentage side-stream treatment on the total oxygen demand (FOt) for the AS system is illustrated below in Figure 20. The FOt for Module 2 decreases along with side-stream treatment capacity from 22 569 kgO/d to 21 607 kgO/d.

The aeration power requirement for each module decreases along with side-stream treatment. Aeration power requirement for Module 1 decreases from 96 kW to 93 kW, Module 2's decreases from 496 kW to 474 kW. Similar trend is observed in the other plants.

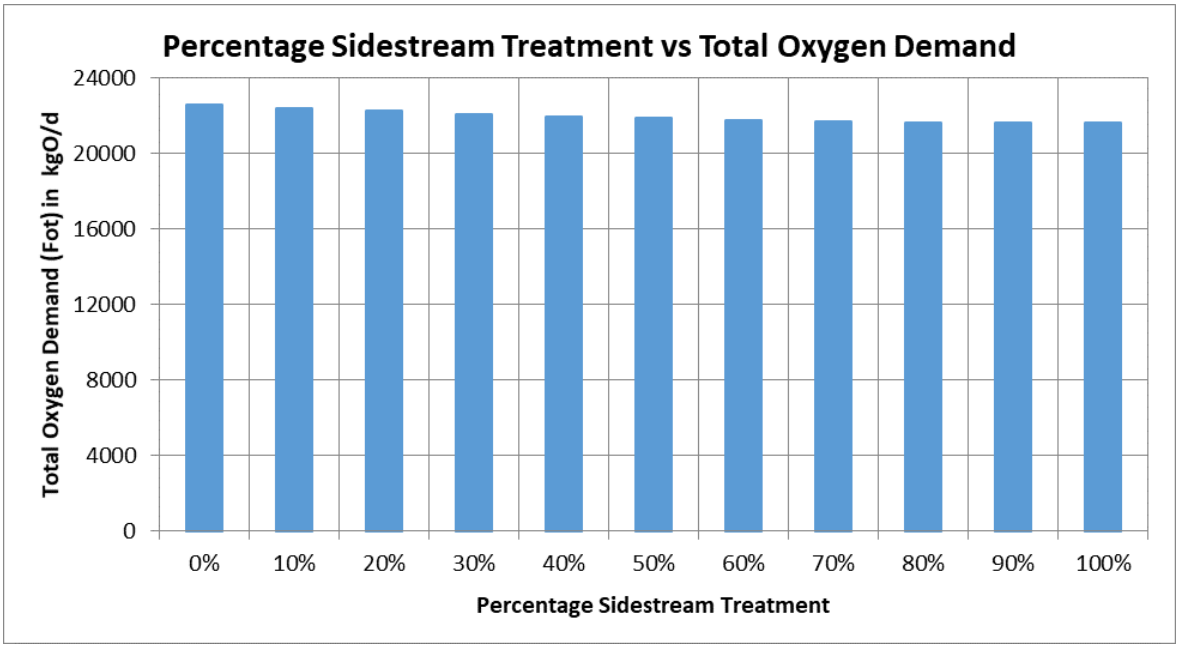

Figure 20: Impact of side-stream treatment on Module 2 total oxygen demand at 'Z' WWTP

2.3.3 Secondary Sludge Produced

The impact of percentage side-stream treatment on secondary sludge production in the AS system is illustrated below in Figure 21. Secondary sludge production in Module 2 AS system decreases marginally along with side-stream treatment from 7 174 kgTSS/d to 7 171 kgTSS/d.

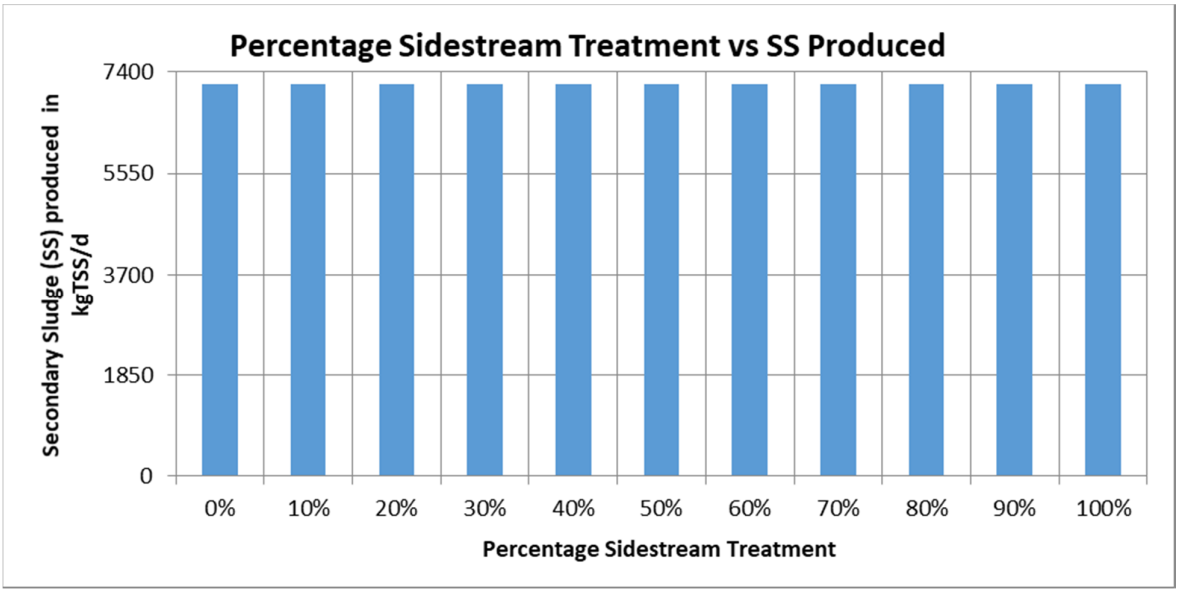

Figure 21: Impact of side-stream treatment on Module 2 secondary sludge production at 'Z' WWTP

2.4 Impact of SRL on Biological Effluent Quality from Module 2 at 'Z' WWTP

The biological effluent quality parameters impacted on be sludge return flows are:

- COD Concentration
- Ammonia Concentration
- Nitrates Concentration
- Phosphate Concentration

The impact of SRL on each of the above biological effluent parameters is summarised in this section. Figures below illustrate the impact of sludge return flows on biological effluent quality for a given percentage side-stream treatment (0% to 100% side-stream treatment).

2.4.1 Effluent COD Concentration

The impact of percentage side-stream treatment on the effluent COD from the AS system is illustrated below in Figure 22. The effluent COD concentration remains constant at 52 mgCOD/ℓ. This is the unbiodegradable soluble organics COD that is ideally the sole organic component found in the AS. This trend is similar in to other plants.

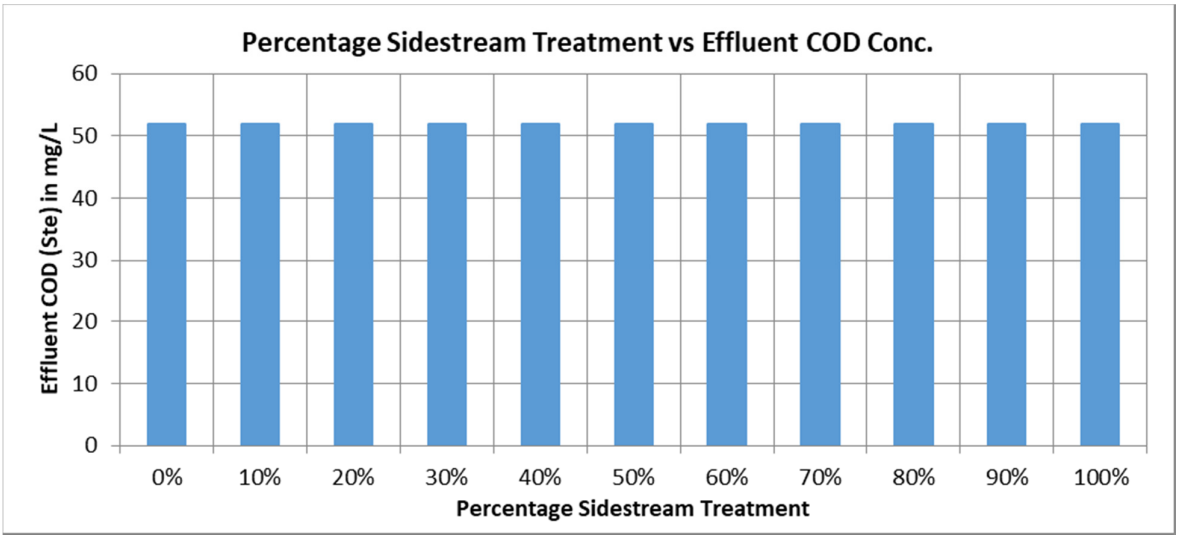

Figure 22: Impact of side-stream treatment on Module 2 effluent COD at 'Z' WWTP

2.4.2 Effluent Ammonia Concentration

The impact of percentage side-stream treatment on the effluent ammonia from the AS system is illustrated below in Figure 23. The effluent ammonia concentration remains constant at 0.66 mgN/ℓ. This trend is similar to trends in other plants.

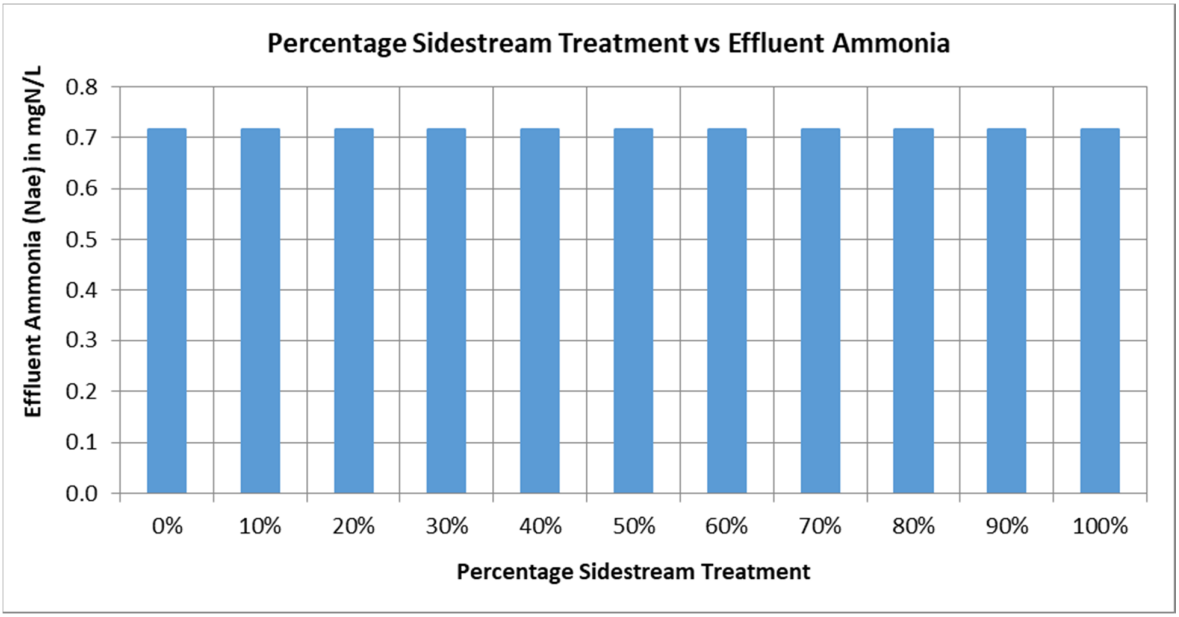

Figure 23: Impact of side-stream treatment on effluent ammonia at 'Z' WWTP

2.4.3 Effluent Nitrate Concertation

Figure 24 illustrates the effluent nitrate concentration which decreases marginally, from around 11.1 mgN/ℓ to 10.2 mgN/ℓ. A high effluent nitrate can contribute significantly to poor effluent quality, directly or indirectly. The trend is similar to other plants.

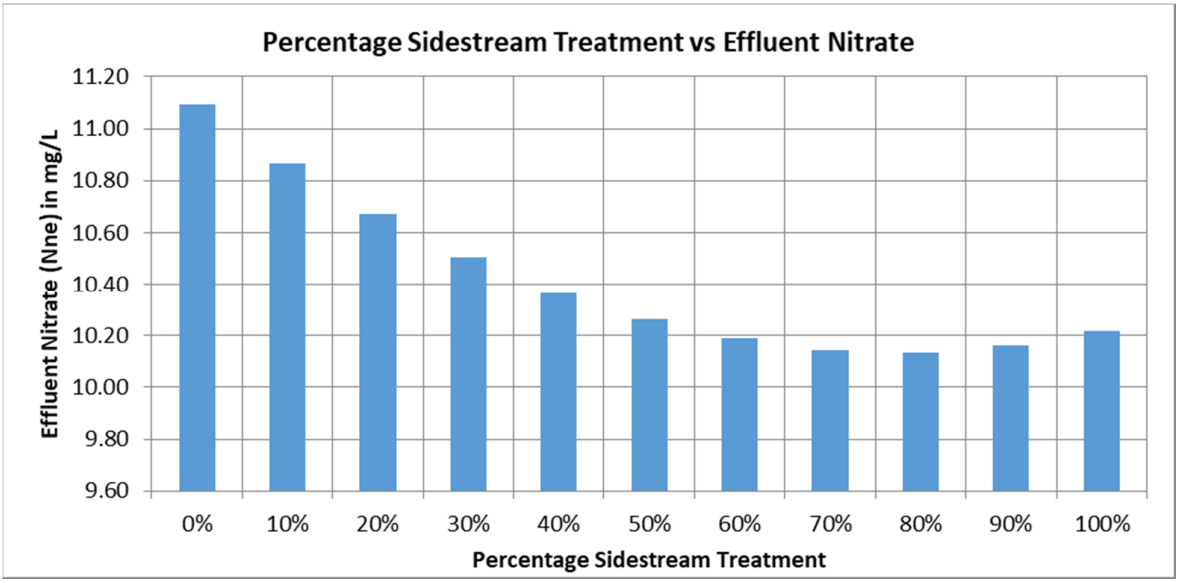

Figure 24: Impact of side-stream treatment on effluent nitrates at 'Z' WWTP

2.4.4 Effluent Phosphate Concentration

The impact of percentage side-stream treatment on the effluent phosphate from the secondary settling tank is illustrated below in Figure 25. The effluent phosphate concentration from Module 2 decreases from 11 mgP/ℓ to 1 mgP/ℓ. The results are as indicated because flux of phosphates into the system is beyond the removal capacity of the PAO biomass generated in the. Hence, the influent *P* that is not removed, i.e.

used as nutrients for biomass growth or as PP accumulated by PAOs, reflects in the effluent. The trend is similar to other plants.

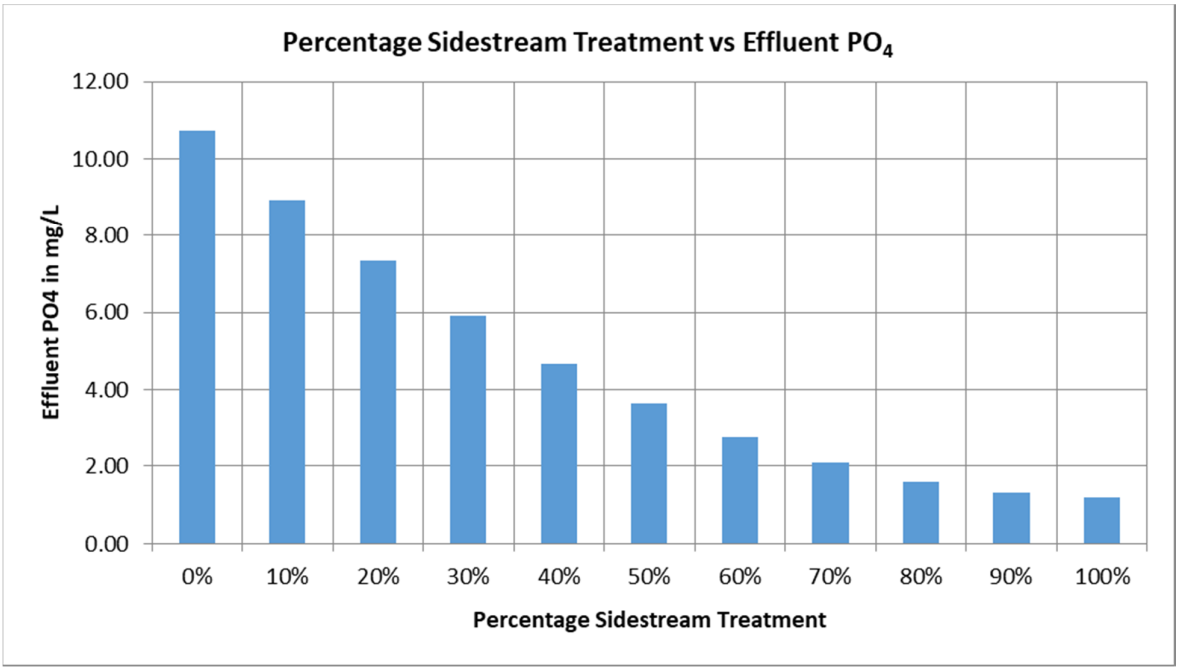

Figure 25: Impact of side-stream treatment on effluent phosphate at 'Z' WWTP

2.5 Summary of Impacts of SRL on the 'Z' WWTP AS System

Table 6 below summarises the percentage impact at a given percentage side-stream treatment starting from 0% to 100% side-stream treatment at 'Z' WWTP.

Table 6: Percentage impact at given percentage side-stream treatment

Percentage Impact at given Percentage Side-stream Treatment at 'Z' WWTP							
Parameters		0%	20%	40%	60%	80%	100%
Influent	Flow rate	7.5%	6.0%	4.5%	3.0%	1.5%	0.0%
	COD	0.9%	0.7%	0.5%	0.3%	0.2%	0.0%
	Ammonia	15.7%	10.0%	5.6%	2.5%	0.6%	0.0%
	PO_4	124.8%	79.3%	44.3%	19.6%	4.9%	0.0%
Biological Reactor	a-recycle	-51.0%	-37.1%	-23.2%	-11.3%	-2.6%	0.0%
	Total Oxygen Demand	4.5%	2.9%	1.6%	0.7%	0.2%	0.0%
	Power Requirement	4.5%	2.9%	1.6%	0.7%	0.2%	0.0%
	SS Produced	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Effluent	COD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	NO_3	8.5%	4.4%	1.5%	-0.3%	-0.8%	0.0%
	PO_4	790.1%	508.7%	288.4%	129.5%	32.8%	0.0%

Figure 27 below shows the SRL impact on 'Z' WWTP at 0% side-stream treatment. The major impact was observed for influent PO_4 load and effluent PO_4 were the impact was 125% and 790% respectively.

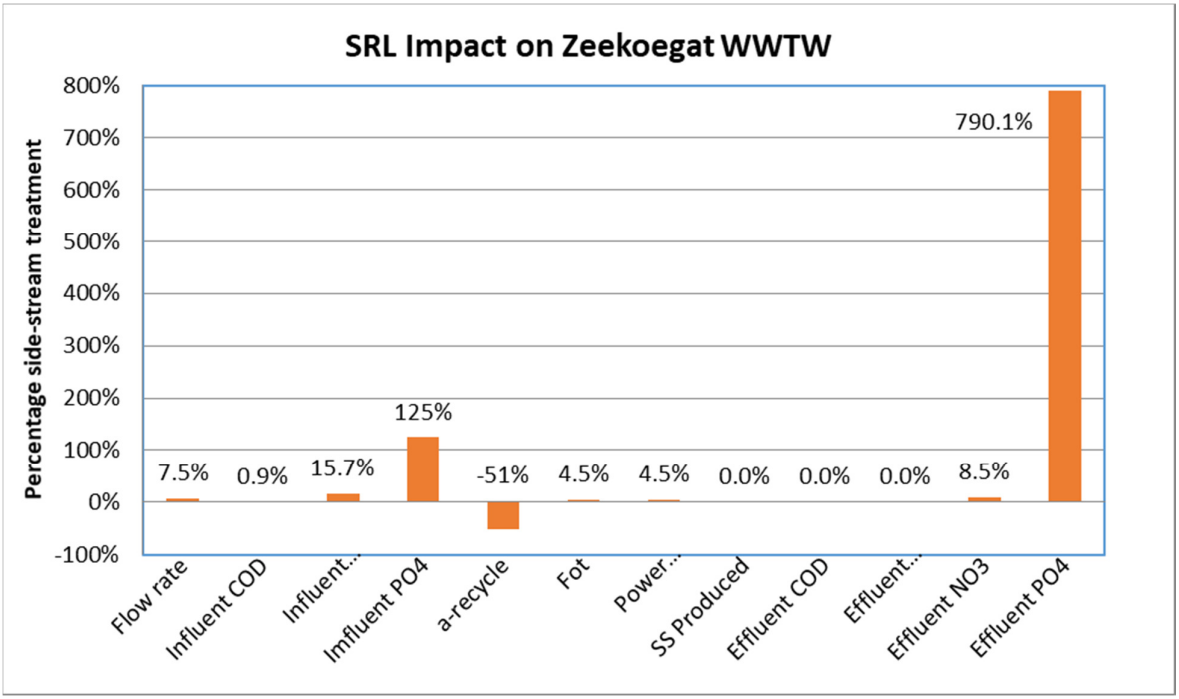

Figure 26: SRL impact on 'Z' WWTP at 0% side-stream treatment.

CHAPTER 3: 'P' WWTP

The results of the impact of return sludge liquors at 'P' WWTP are presented in this section. The impact of the sludge return flows was determined on:

- Influent Characteristics
- Biological Treatment Capacity
- Biological Effluent Quality

3.1 Process Description

A description of the 'P' WWTP is indicated below as per information found in the operation and maintenance manuals. Table 7 and Table 8 give a summary of the unit operations and process data. The general process flow diagram of the works in indicated below in Figure 27, 'P' WWTP has a design capacity of 25 Mℓ/d.

Table 7: 'P' WWTP Unit Operations and Processes

Key Unit Operations and Processes	AS System
Primary Settling Tanks	Yes
BNR System	Yes
Secondary Settling Tanks	Yes
Dissolved Air Flotation	No
Anaerobic Digesters	Yes
Dewatering	Yes

The pertinent data for the above unit operations and processes is summarised in Table 8.

Table 8: 'P' WWTP Data Summary

Key Unit Operations and Processes	AS System
Primary Settling Tanks diameter	4 Units
BNR System Volume (m³)	25 000
Secondary Settling Tank Diameter	6 Units
Anaerobic Digesters	2 × 2 600m³ + 3 × 510m³ (secondary digesters) + 5 380m³

SRL treatment consists of:

- Dewatering sludge return liquors recycles upstream of the primary settling tanks.

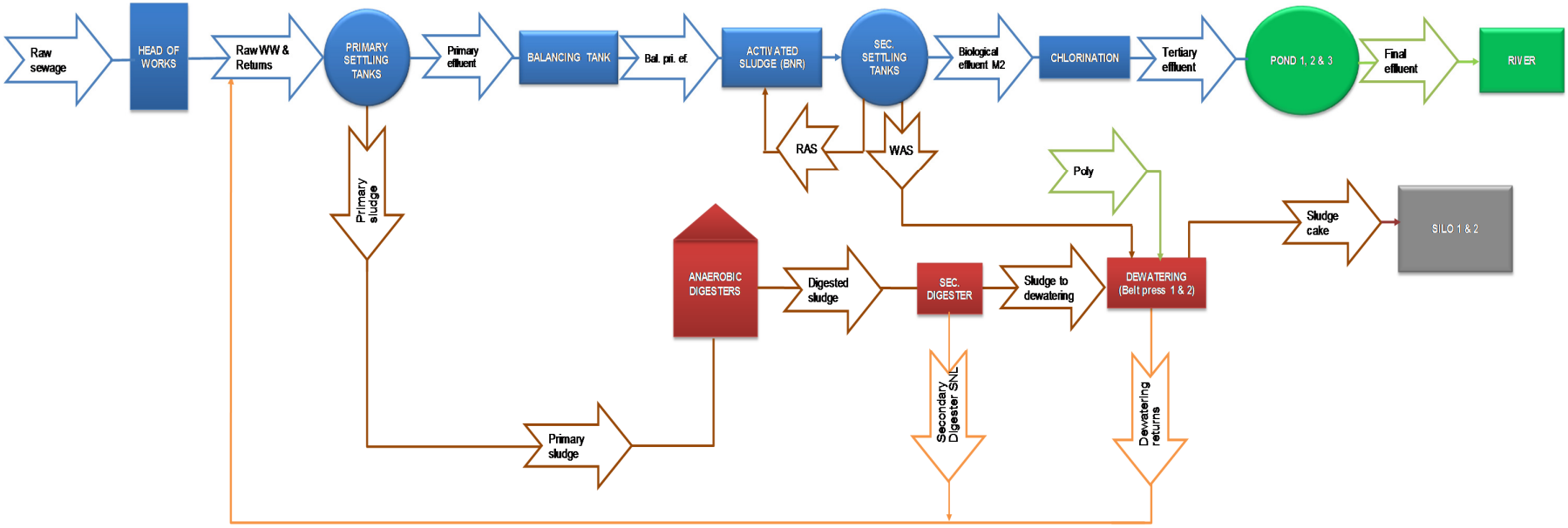

Figure 27: 'P' WWTP Process Flow Diagram

3.2 Influent Characteristics

The influent characteristics impacted on by sludge return flows are:

- Influent flow rate
- Influent COD Load
- Influent Ammonia Load
- Influent PO_4 Load

The impact of SRL on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

3.2.1 Influent Flow rate

The impact of percentage side-stream treatment on the flowrate is illustrated below in Figure 28. Without side-stream treatment, i.e. 0% side-stream treatment, means that 100% of return sludge liquors flow back to the AS system. The flow to the water line module decreases along with side-stream treatment from 25 Mℓ/d to 24 Mℓ/d.

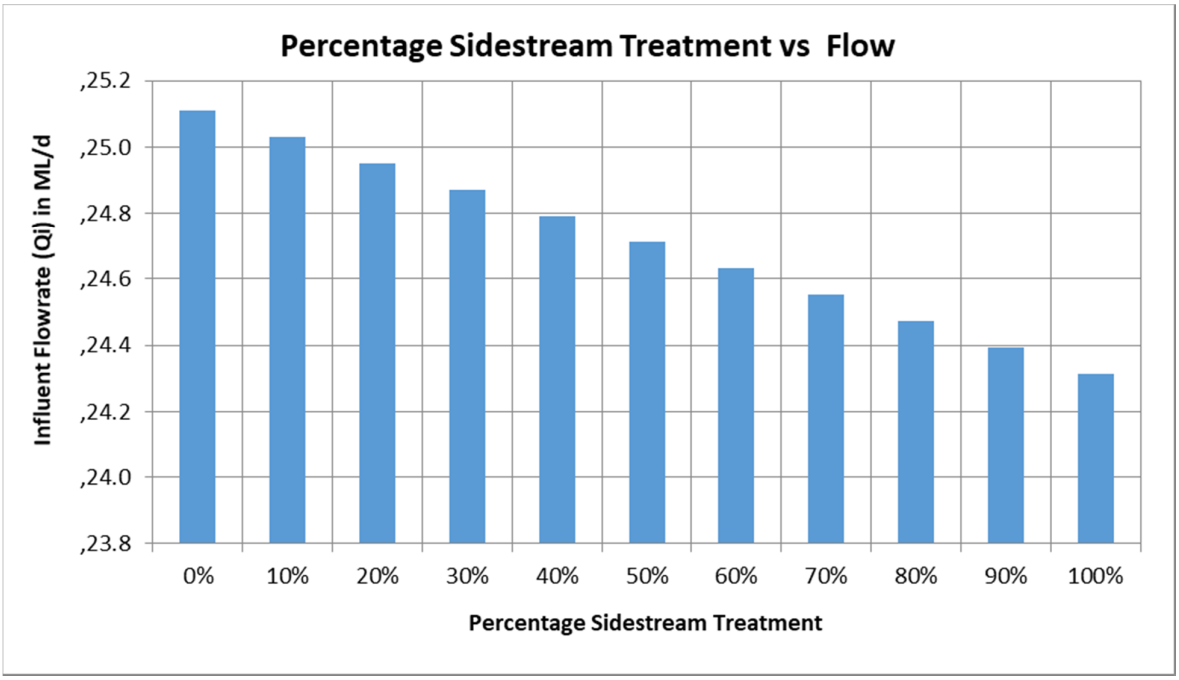

Figure 28: Impact of side-stream treatment on influent flow rate at 'P' WWTP

3.2.2 Influent COD Load

The impact of percentage side-stream treatment on the influent COD load to the AS system is illustrated below in Figure 29. Influent COD load to the AS system decreases from 10 733 to 10 694 kgCOD/d.

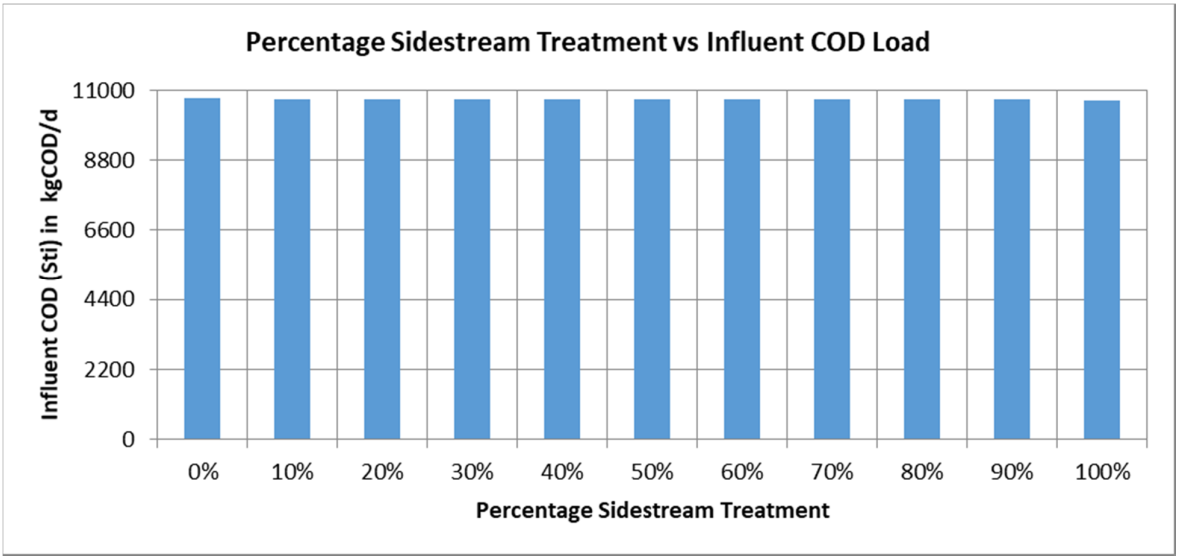

Figure 29: Impact of side-stream treatment on influent COD load at 'P' WWTP

3.2.3 Influent Ammonia Load

The impact of percentage side-stream treatment on the influent ammonia load to the AS system is illustrated below in Figure 30. Influent ammonia load to AS system decreases from 1 149 kgN/d to 1 041 kgN/d.

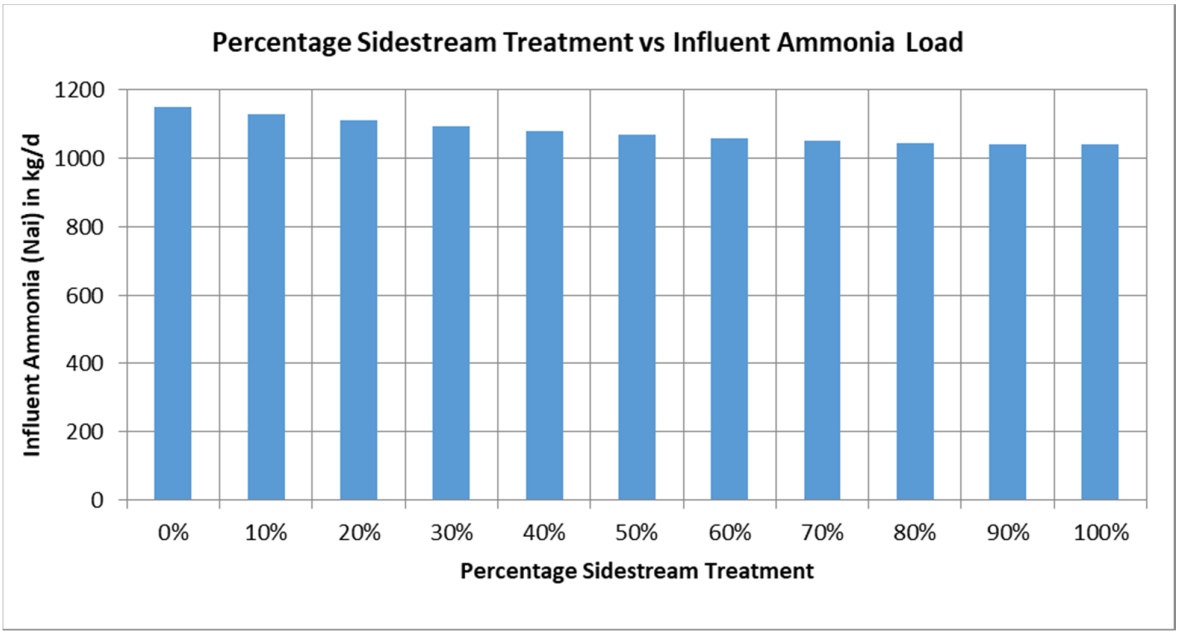

Figure 30: Impact of side-stream treatment on influent ammonia load at 'P' WWTP

3.2.4 Influent Phosphate

The impact of percentage side-stream treatment on influent phosphate to the AS system is illustrated below in Figure 31. The influent phosphate load to the AS system decreases marginally from 110 kgP/d to 109 kgP/d.

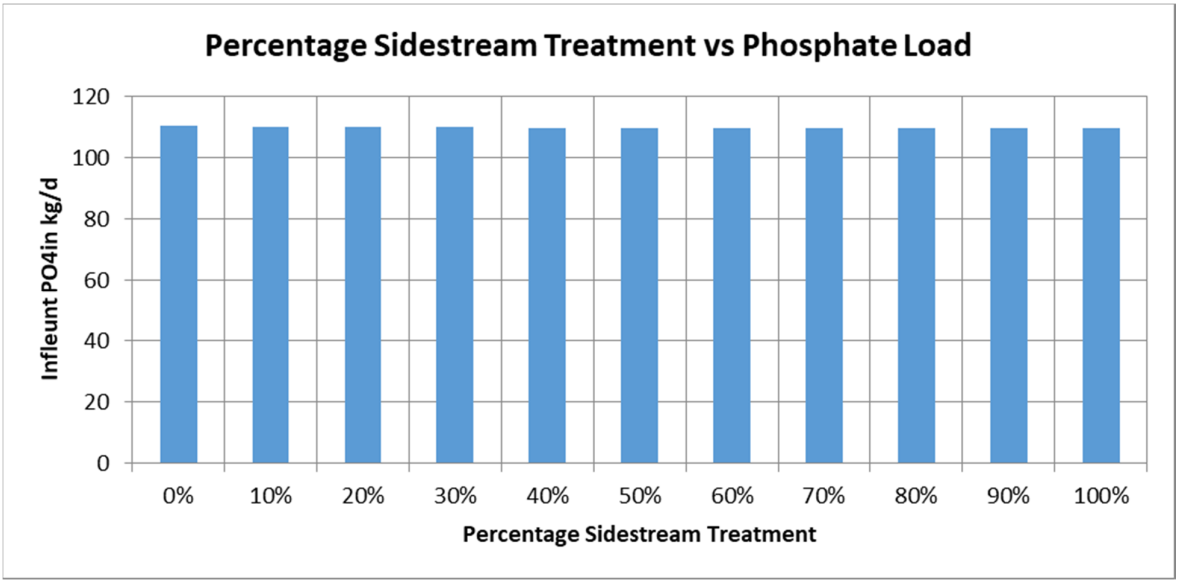

Figure 31: Impact of side-stream treatment on influent phosphate load at 'P' WWTP

3.3 Impact of SRL on Biological Treatment Capacity at 'P' WWTP

The biological treatment capacity parameters impacted on by sludge return flows are:

- A-recycle
- Total oxygen demand
- Secondary sludge production

The impact of sludge return flows on each of the above biological treatment capacity parameters is summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

3.3.1 A-recycle

The impact of percentage side-stream treatment on the a-recycle to the AS system is illustrated below in Figure 32. The a-recycle ratio increases from 0.74 to 1.19.

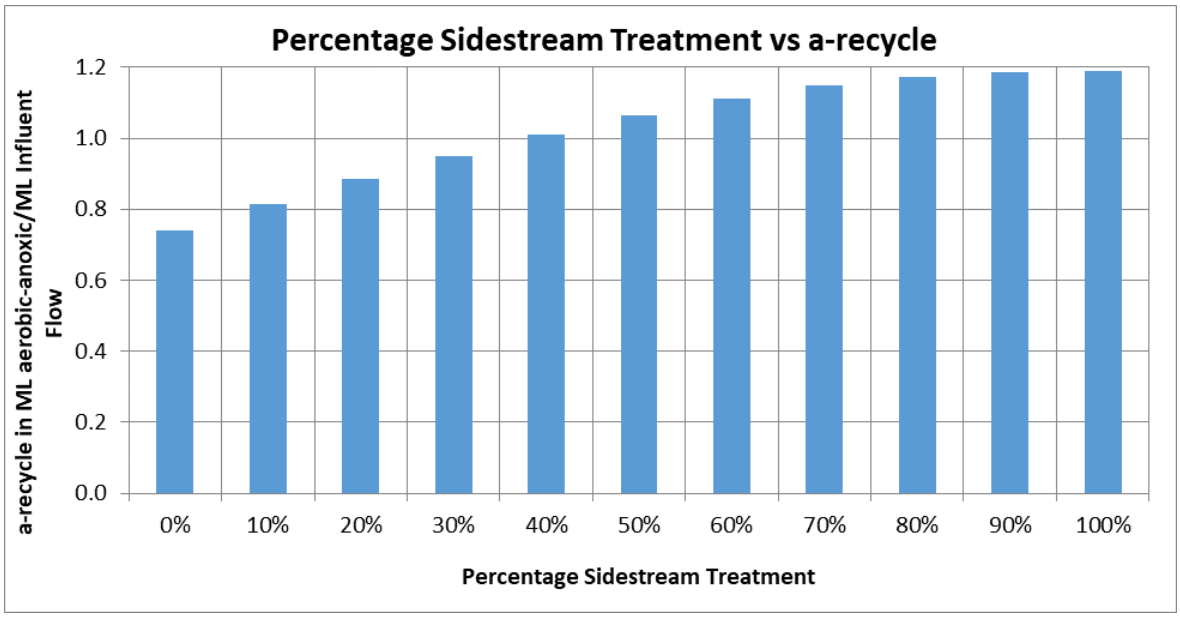

Figure 32: Impact of side-stream treatment on a-recycle at 'P' WWTP

3.3.2 Total Oxygen Demand

The impact of percentage side-stream treatment on the total oxygen demand (FOt) of the AS system is illustrated below in Figure 33. The FOt for the AS system decreases along with side-stream treatment capacity. The total oxygen demand for Plant 'P's AS system decreases from 9 514 kgO/d to 9 248 kgO/d.

The aeration power requirement for the AS system decreases along with side-stream treatment, from 209 kW to 203 kW.

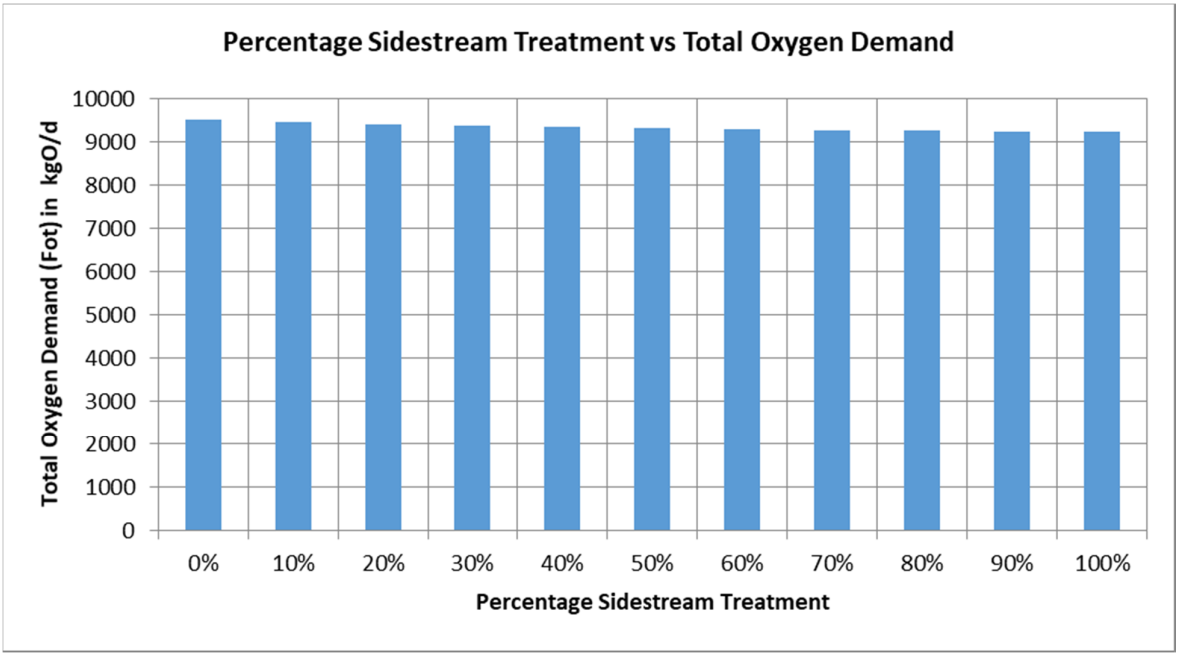

Figure 33: Impact of side-stream treatment on total oxygen demand at 'P' WWTP

3.3.3 Secondary Sludge Produced

The impact of percentage side-stream treatment on secondary sludge production from the AS system is illustrated below in Figure 34. Secondary sludge production in the AS system decreases along with side-stream treatment. Secondary sludge production for the AS system decreases from 2 432 kgTSS/d to 2 429 kgTSS/d.

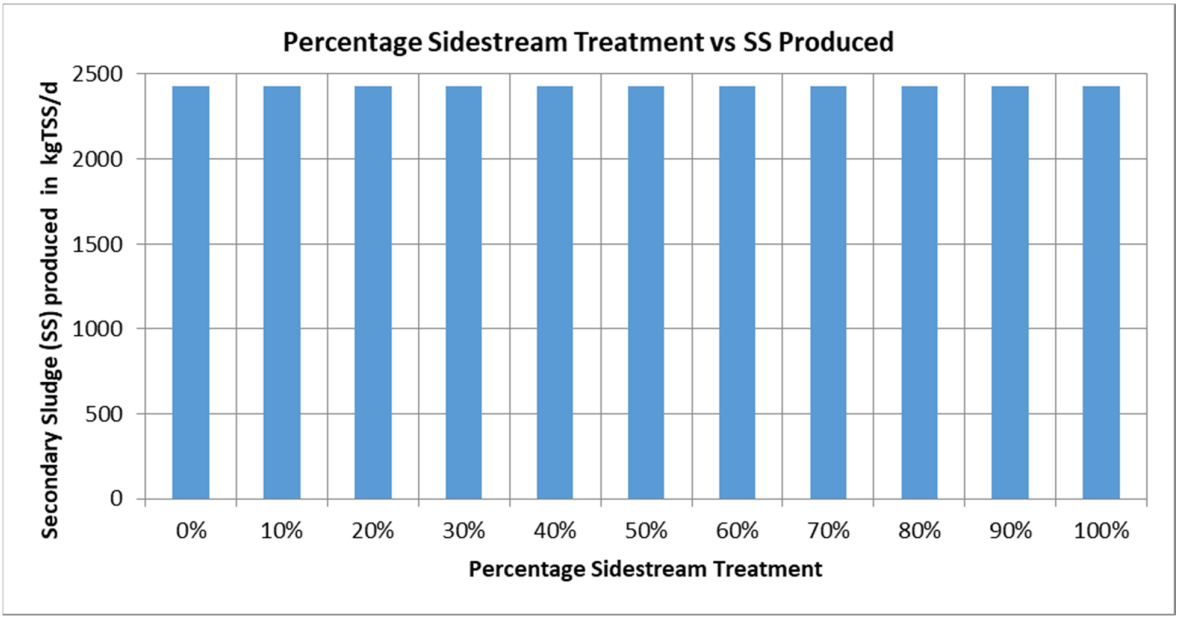

Figure 34: Impact of side-stream treatment on secondary sludge production at 'P' WWTP

3.4 Biological Effluent Quality

The biological effluent quality parameters impacted on be sludge return flows are:

- COD concentration
- Ammonia concentration
- Phosphates concentration

The impact SRL on each of the abovementioned effluent parameters is summarised in this section. Figures below illustrate the impact of sludge return flows on biological effluent quality for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

3.4.1 Effluent COD Concentration

The impact of percentage side-stream treatment on the effluent COD from the AS system is illustrated below in Figure 35. The effluent COD concentration is constant at 49 mgCOD/ℓ.

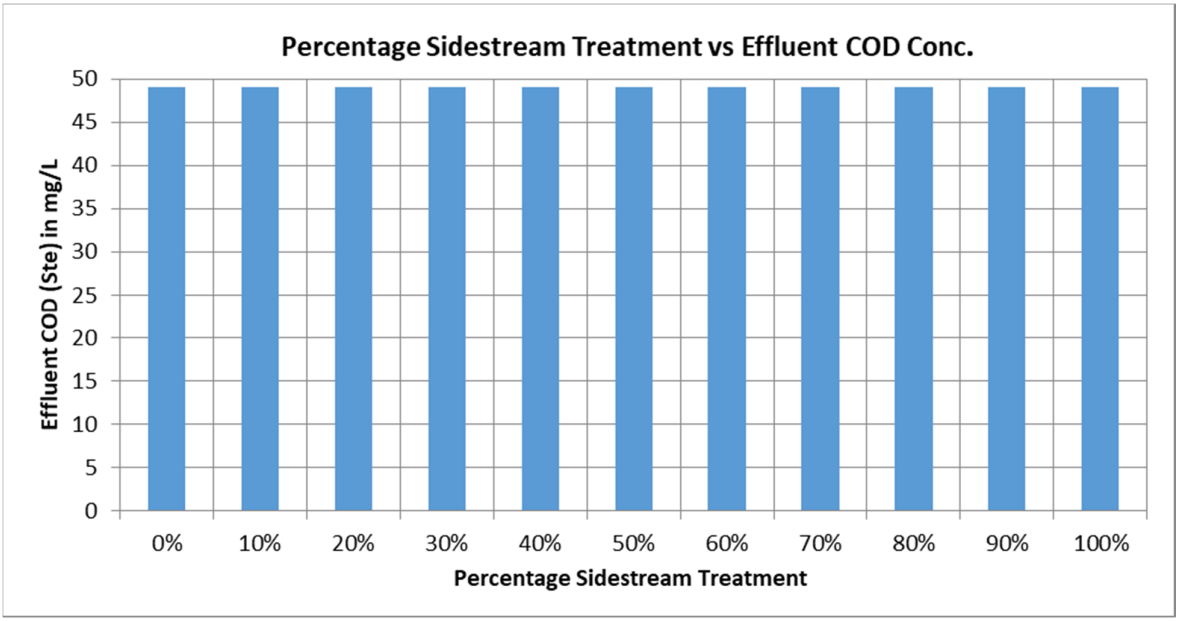

Figure 35: Impact of side-stream treatment on effluent COD concentration at 'P' WWTP

3.4.2 Effluent Ammonia Concentration

The impact of percentage side-stream treatment on the effluent ammonia from the AS system is illustrated below in Figure 36. The effluent ammonia concentration from the AS system remains constant at 0.37mgN/ℓ.

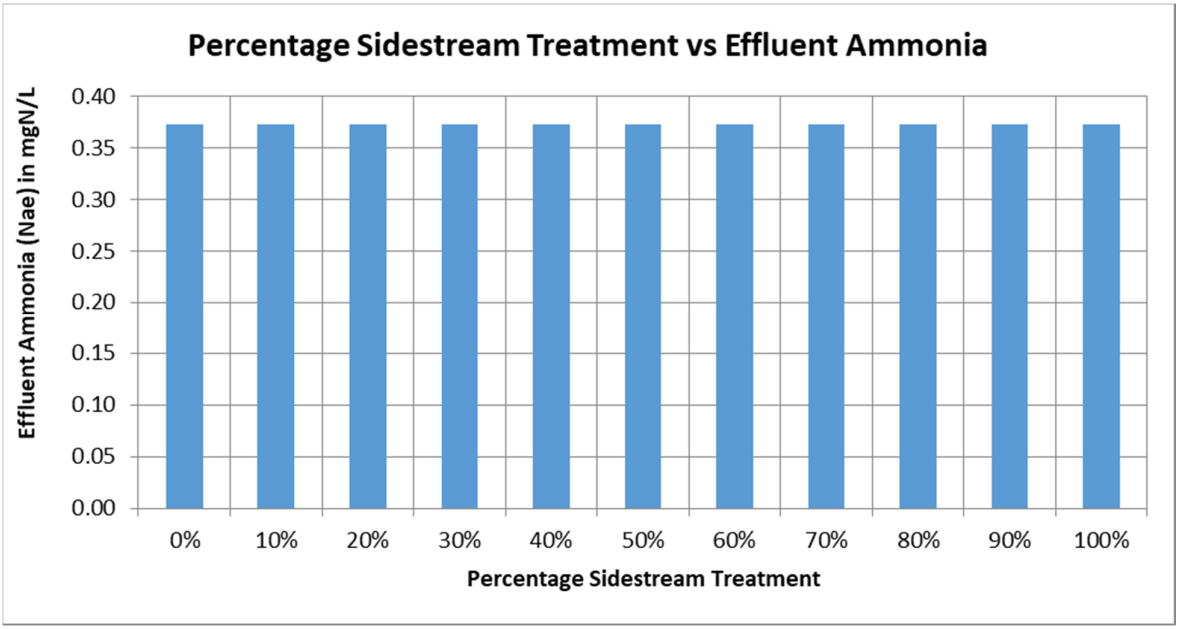

Figure 36: Impact of side-stream treatment on effluent ammonia at 'P' WWTP

3.4.3 Effluent Nitrate Concentration

The effluent nitrate concentration decreases with decrease in nitrification capacity, when the aeration for conversion of ammonia to nitrates is not limited (see Figure 37 – the effluent nitrate concentration decreases marginally from around 13.9 mgN/ℓ to 12.4 mgN/ℓ).

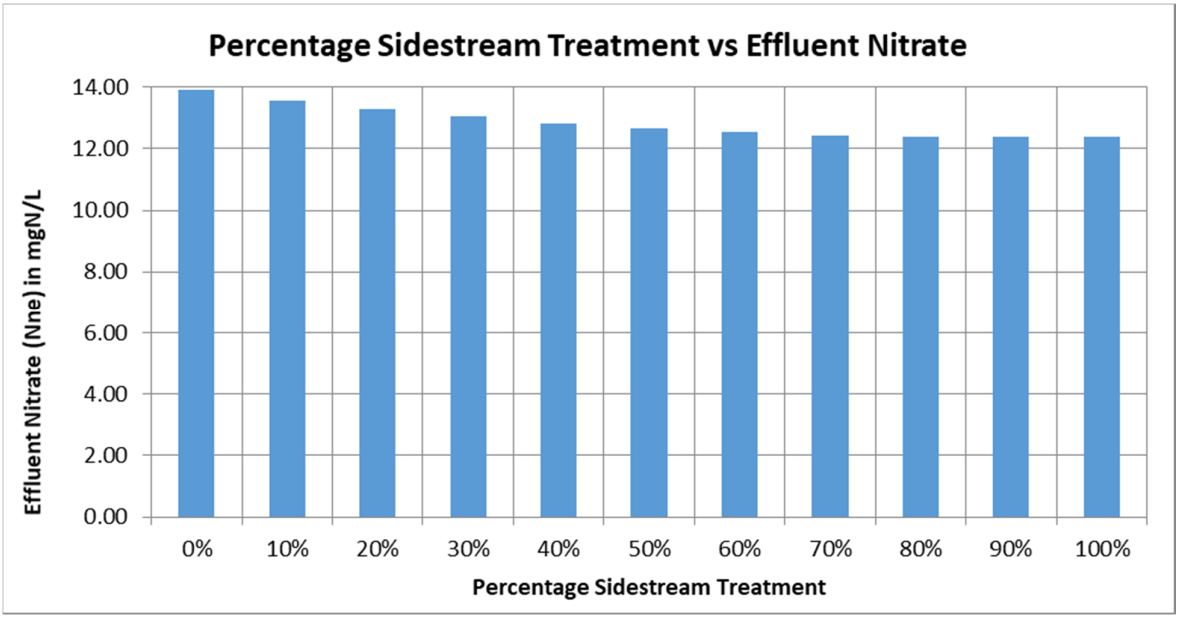

Figure 37: Impact of side-stream treatment on effluent nitrate concentration at 'P' WWTP

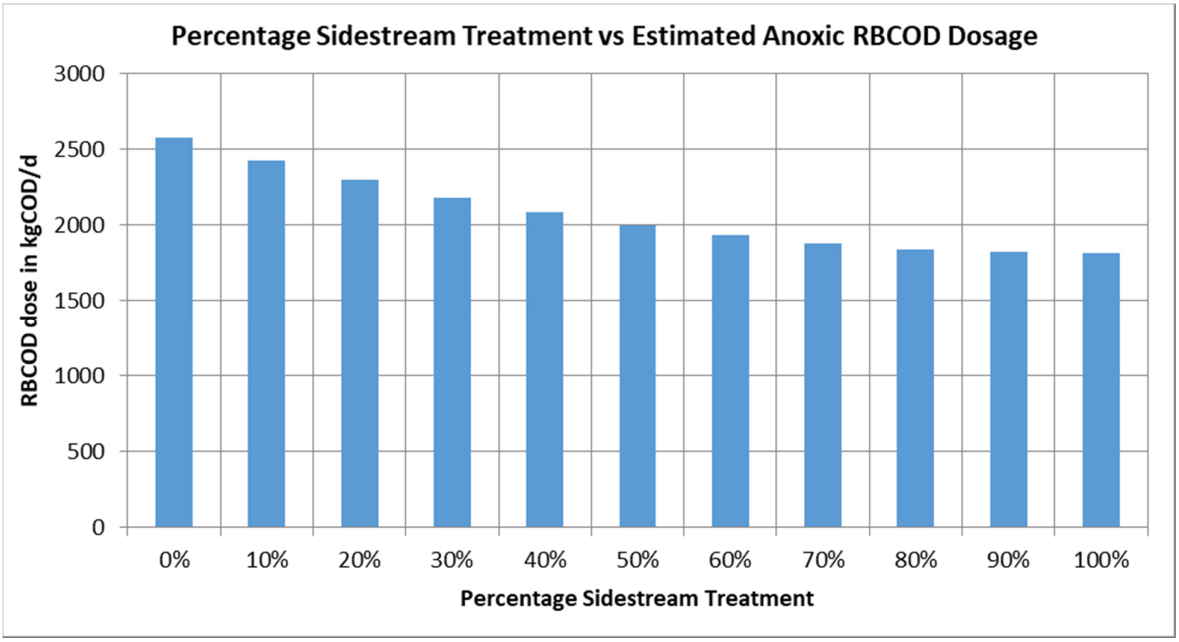

Figure 38: Impact of side-stream on estimated readily biodegradable organics COD to be dosed anoxically towards obtaining minimum effluent nitrate concentration at 'P' WWTP

3.4.4 Effluent Phosphate Concentration

The impact side-stream treatment has no predicted impact on the effluent phosphates as the effluent OP remains at 0 mgP/ℓ. However, there are chances that, for non-ideal scenarios, the effluent OP would increase with increased flux of SRL. The possible causes are inefficient metabolism of PAOs due to high nitrates, recycled anaerobically and utilization of organics by OHOs. In the steady state model, the system is assumed to be functioning under ideal conditions, with up to the maximum (0.35 mgP/mgPAOVSS) of P storage capacity by PAOs.

3.5 Summary of Impacts of SRL on Influent Characteristics at 'P' WWTP

Table 9 below summarises the percentage impact at a given percentage side-stream treatment starting from 0% to 100% side-stream treatment at 'P' WWTP.

Table 9: Percentage impact of SRL at given side-stream treatment at 'P' WWTP

Percentage Impact at given Percentage Side-stream Treatment at 'P' WWTP							
Parameter		0%	20%	40%	60%	80%	100%
Influent	Flow rate	3.3%	2.6%	2.0%	1.3%	0.7%	0.0%
	COD	0.4%	0.3%	0.2%	0.1%	0.1%	0.0%
	Ammonia	10.4%	6.7%	3.8%	1.7%	0.4%	0.0%
	PO_4	0.8%	0.5%	0.3%	0.1%	0.0%	0.0%
Biological Reactor	a-recycle	-37.8%	-25.7%	-15.0%	-6.6%	-1.4%	0.0%
	Total Oxygen Demand	2.9%	1.8%	1.0%	0.5%	0.1%	0.0%
	Aeration Power Requirement	2.9%	1.8%	1.0%	0.5%	0.1%	0.0%
	SS Produced	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
Effluent	COD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	NO_3	12.2%	7.3%	3.6%	1.1%	0.0%	0.0%
	PO_4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 39 below shows the SRL impact on 'P' WWTP at 0% side-stream treatment. The major impact was observed for influent ammonia load and effluent nitrate were the impact was 10.4% and 12.2% respectively.

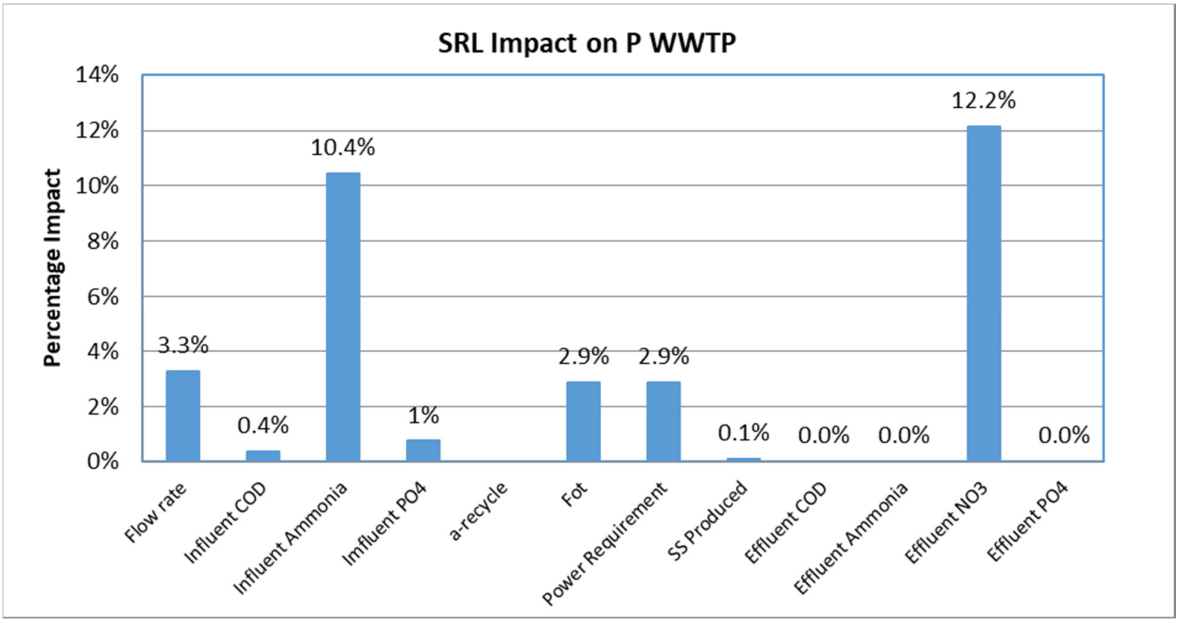

Figure 39: SRL Impact on 'P' WWTP at 0% side-stream treatment

CHAPTER 4: 'K' WWTP

The results of the impact of return sludge liquors at 'K' WWTP are presented in this section. The impact of the sludge return flows was determined on:

- Influent Characteristics
- Biological Treatment Capacity
- Biological Effluent Quality

4.1 Process Description

A description of the 'K' WWTP is indicated below as per information found in the operation and maintenance manuals. Table 10 and Table 11 give a summary of the unit operations and process data. A general process flow diagram of the works in indicated below in Figure 40, 'K' WWTP has a design capacity of 65 Mℓ/d.

Table 10: 'K' WWTP Unit Operations and Processes

Key Unit Operations and Processes	AS System
Primary Settling Tanks	Yes
Aerobic AS System	Yes
Secondary Settling Tanks	Yes
Gravity Thickeners	Yes
Dissolved Air Flotation	Yes
Anaerobic Digesters	Yes
Dewatering	Yes

The pertinent data for the above unit operations and processes is summarised in Table 11.

Table 11: 'K' WWTP Data Summary

Key Unit Operations and Processes	AS System
Primary Settling Tanks diameter	6 Units
BNR System Volume (m³)	65 000
Secondary Settling Tank Diameter	8 Units
Dissolved Air Flotation	1
Anaerobic Digesters	4 × 2 000m³ + 2 × 2 310m³ (secondary digesters) + 5 380m³

SRL treatment consists of

- All SRL from gravity thickener, DAF unit, secondary digester and mechanical dewatering are returned to upstream of the PSTs included in the AS treatment

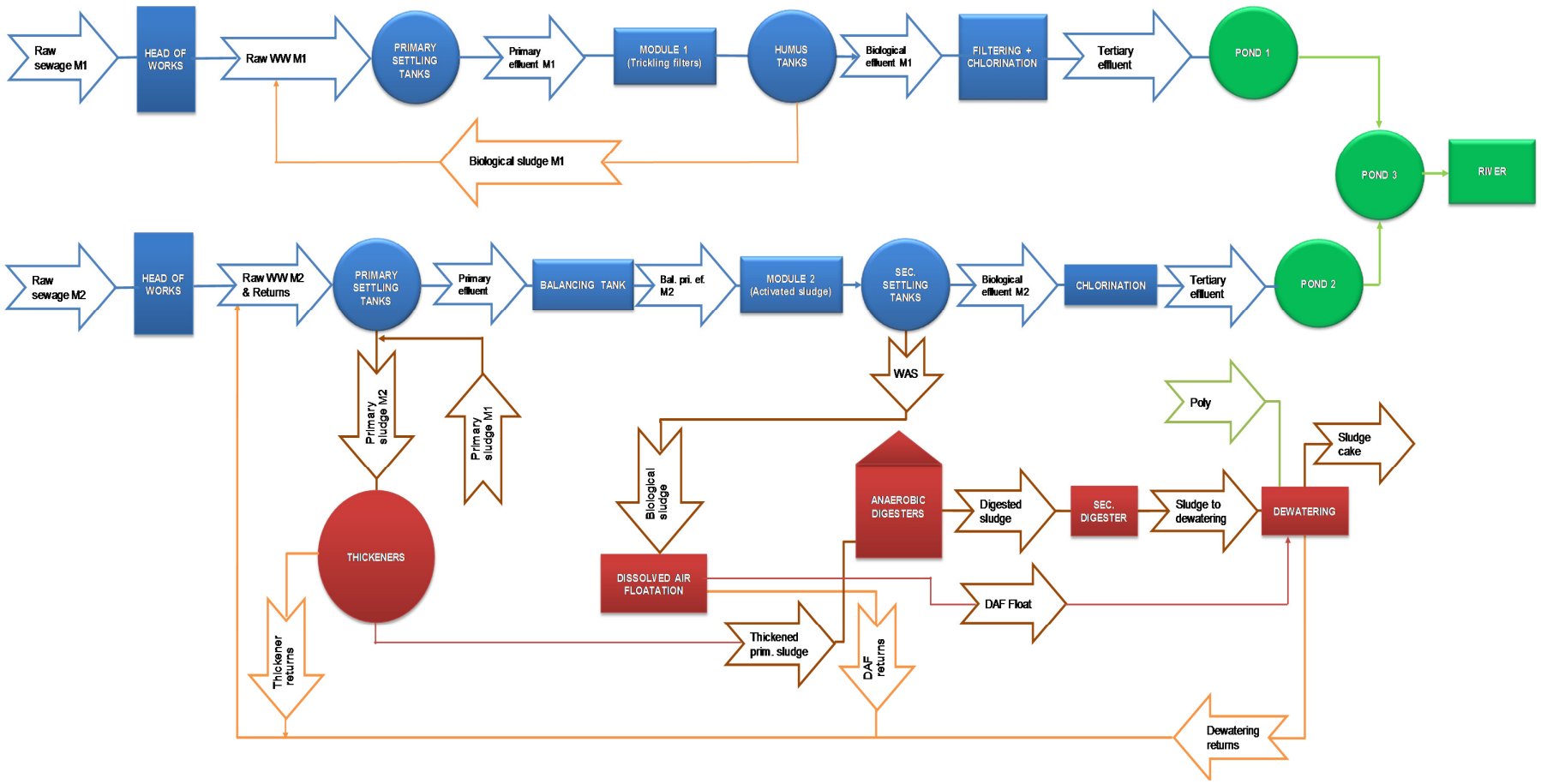

Figure 40: 'K' WWTP Process Flow Diagram

4.2 Impact of SRL on Influent Characteristics at 'K' WWTP

The influent characteristics impacted on by sludge return flows are:

- Influent Flow rate
- Influent COD Load
- Influent Ammonia Load
- Influent PO_4 Load

The impact of SRL on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

4.2.1 Influent Flow rate

The impact of percentage side-stream treatment on the flow rate is illustrated below in Figure 41. Without side-stream treatment, i.e. 0% side-stream treatment, means that 100% of return sludge liquors flow back to the AS system. The flow to the AS system decreases along with side-stream treatment causing the flow to decrease from 55 Mℓ/d to 52 Mℓ/d.

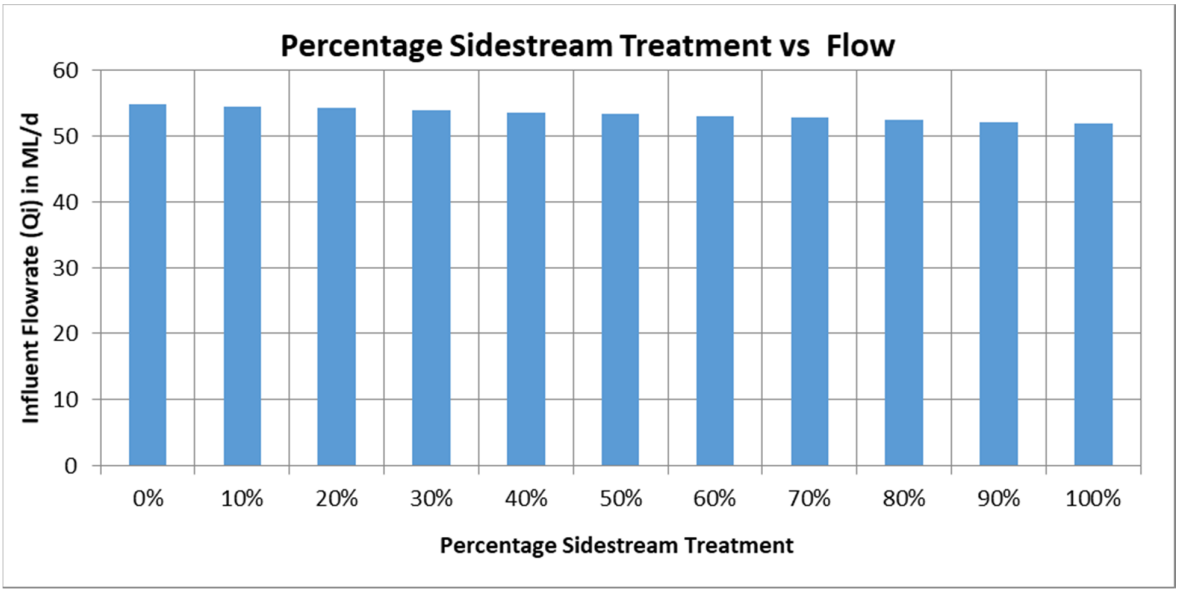

Figure 41: Impact of side-stream treatment on influent flow rate at 'K' WWTP

4.2.2 Influent COD Load

The impact of percentage side-stream treatment on the total influent COD load to the AS system is illustrated below in Figure 42. Influent COD load concentration to the AS system decreases from 31 236 kgCOD/d to 31 093 kgCOD/d.

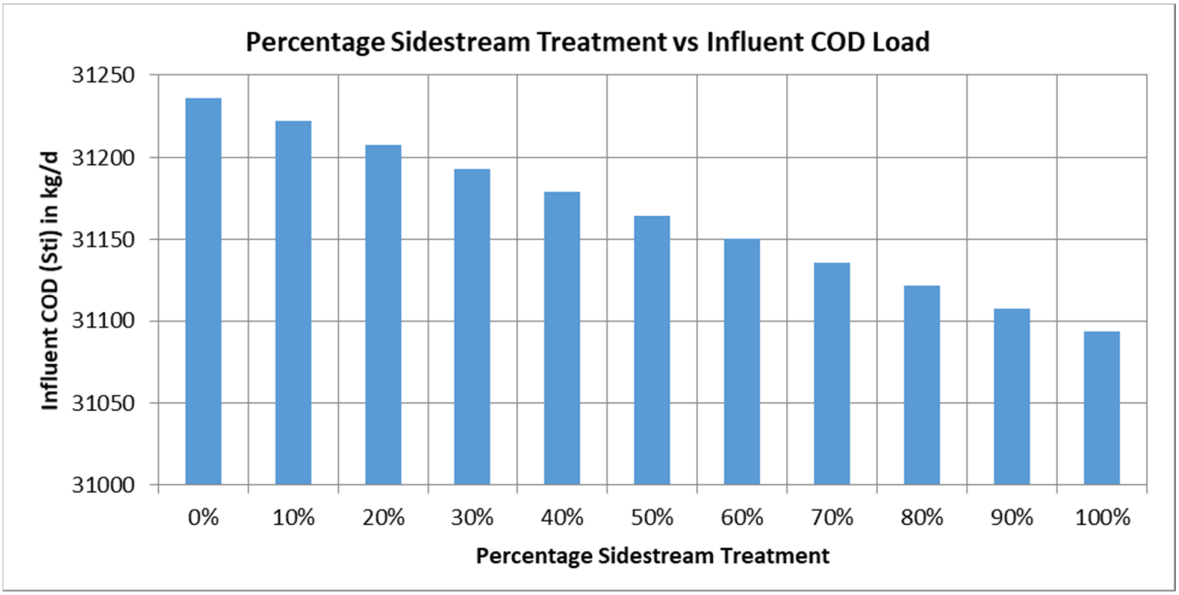

Figure 42: Impact of side-stream on influent COD at 'K' WWTP

4.2.3 Influent Ammonia Load

The impact of percentage side-stream treatment on the influent ammonia load to the activated sludge system is illustrated below in Figure 43. Influent ammonia load to AS system decreases from 1 525 kgN/d to 1 349 kgN/d.

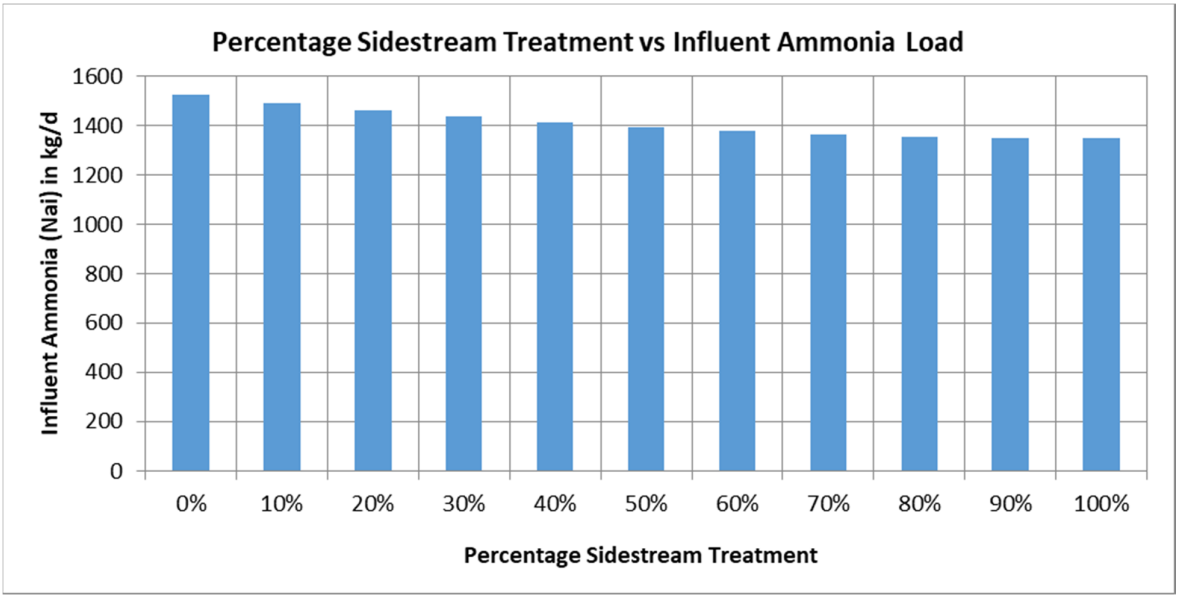

Figure 43: Impact of side-stream treatment on influent ammonia load at 'K' WWTP

4.2.4 Influent Phosphate Load

The impact of percentage side-stream treatment on influent phosphate load to the AS system is illustrated below in Figure 44. Influent phosphate load to the AS system increases from 178 kgP/d to 171 kgP/d.

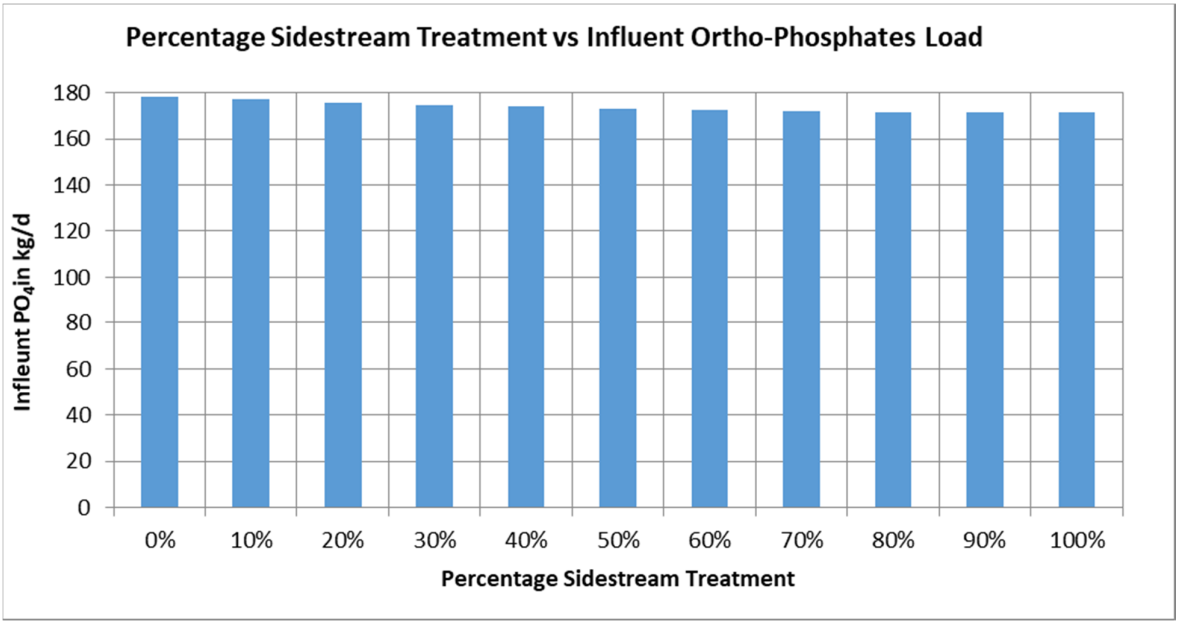

Figure 44: Impact of side-stream treatment on influent phosphate load at 'K' WWTP

4.3 Impact of SRL on Biological Treatment Capacity at 'K' WWTP

The biological treatment capacity parameters impacted on by sludge return flows are:

- Total oxygen demand
- Aeration power requirement
- Secondary sludge production

The impact of SRL on each of the above biological treatment capacity parameters is summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

4.3.1 Total Oxygen Demand

The impact of percentage side-stream treatment on the total oxygen demand (FOt) of the AS system is illustrated below in Figure 45. The FOt for each module decreases along with side-stream treatment capacity. The total oxygen demand for the AS system decreases from 27 614 kgO/d to 27 188 kgO/d.

The aeration power requirement for each module decreases along with side-stream treatment. Aeration power requirement decreases from 606 kW to 597 kW.

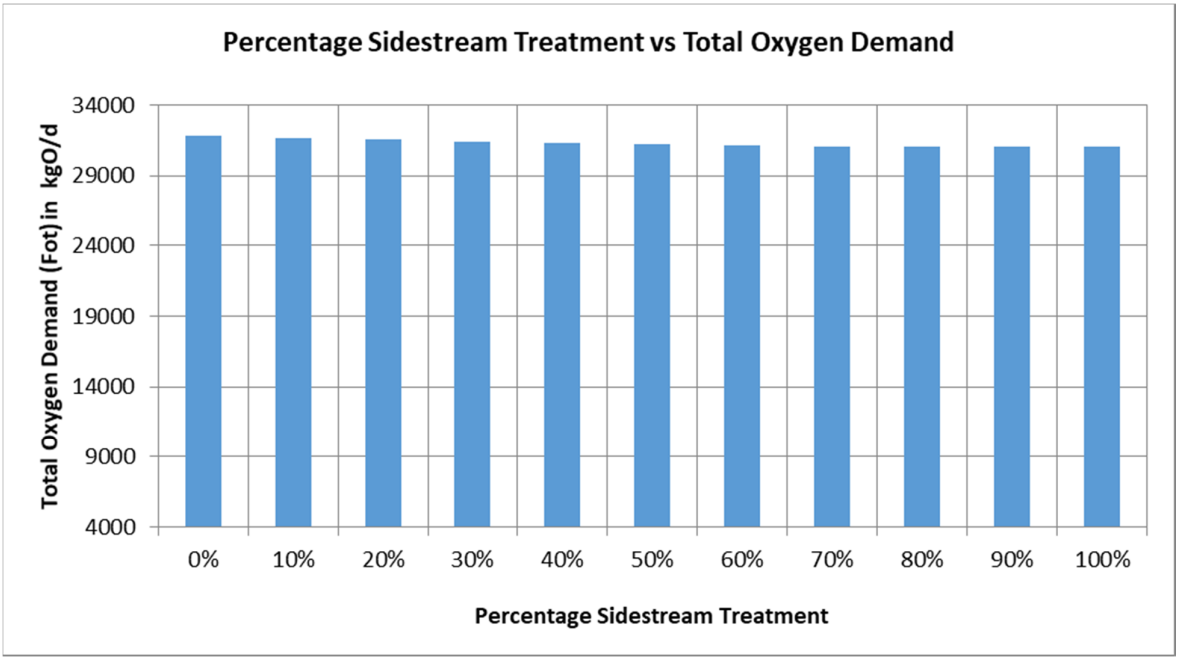

Figure 45: Impact of side-stream treatment on total oxygen demand at 'K' WWTP

4.3.2 Secondary Sludge Produced

The impact of percentage side-stream treatment on secondary sludge production from the AS system is illustrated below in Figure 46. The secondary sludge production decreases along with side-stream treatment from 4 918 kgTSS/d to 4 865 kgTSS/d.

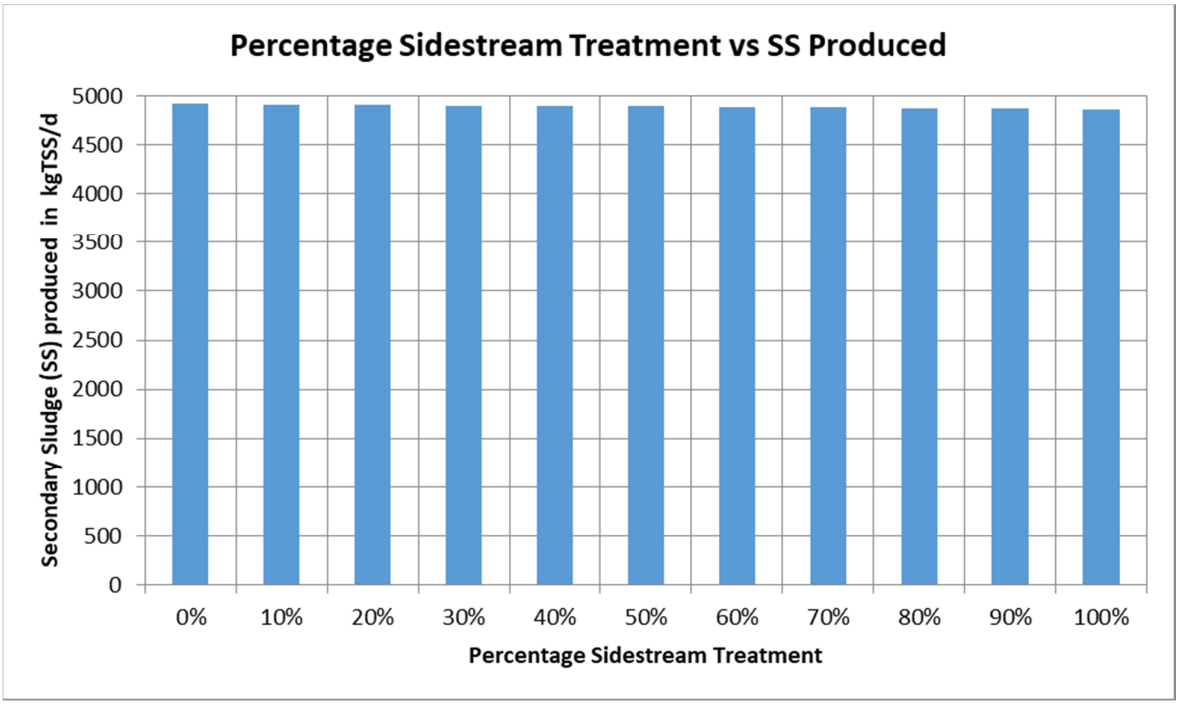

Figure 46: Impact of side-stream treatment on secondary sludge production at 'K' WWTP

4.4 Impact of SRL on Biological Effluent Quality at 'K' WWTP

The biological effluent quality parameters impacted on be sludge return flows are:

- COD concentration
- Ammonia concentration
- Phosphates concentration

The impact of SRL flows on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of sludge return flows on biological effluent quality for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

4.4.1 Effluent COD Concentration

The impact of percentage side-stream treatment on the effluent COD from the AS system is illustrated below in Figure 47. The effluent COD concentration for the AS system is 48 mg/ℓ.

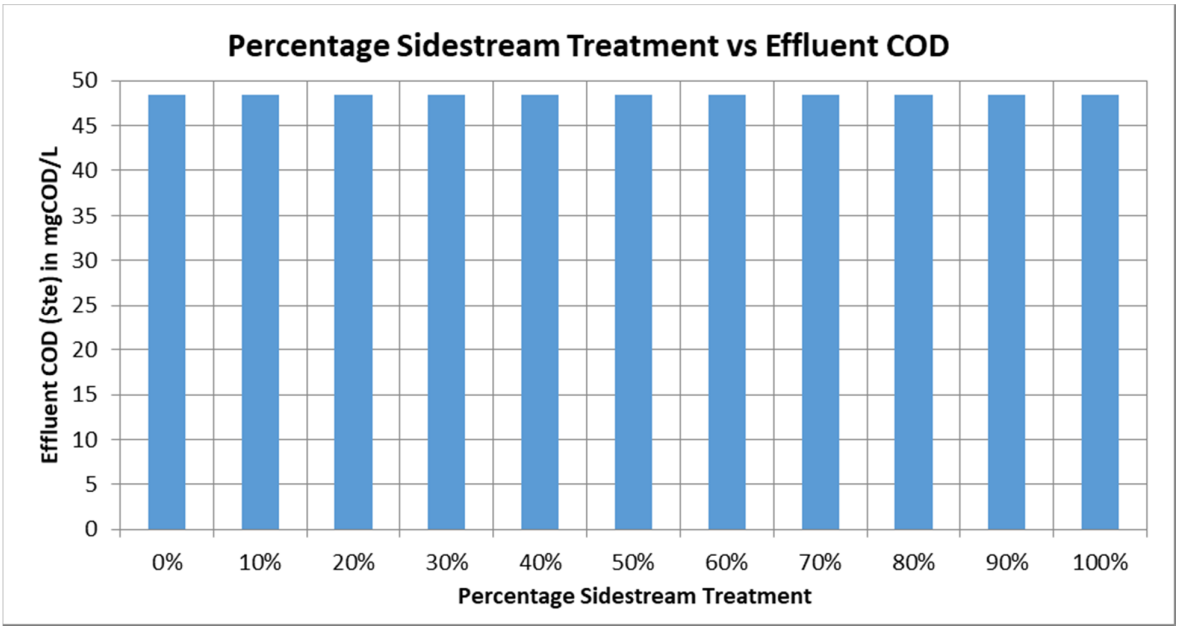

Figure 47: Impact of side-stream treatment on effluent COD at 'K' WWTP

4.4.2 Effluent Ammonia Concentration

The impact of percentage side-stream treatment on the effluent ammonia concentration from the SST is illustrated below in Figure 48. If aeration is limited, the effluent ammonia concentration from the AS system remains constant at 0.11 mgN/ℓ.

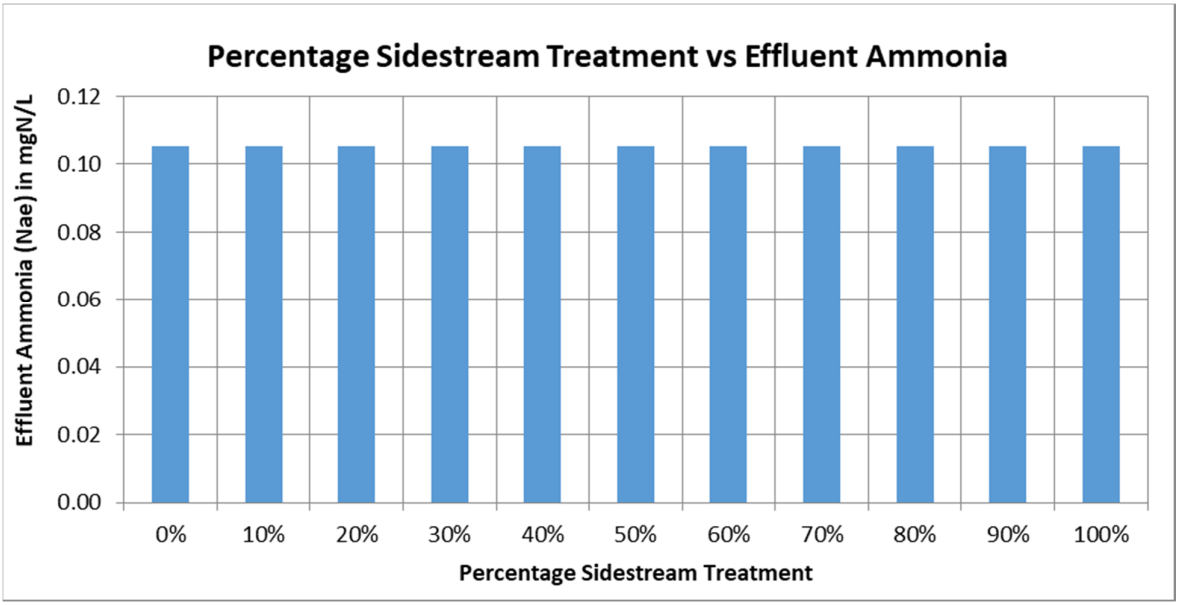

Figure 48: Impact of side-stream treatment on effluent ammonia at 'K' WWTP

4.4.3 Effluent Nitrate Concentration

The 'K' WWTW has no anoxic zone, hence has no capacity for denitrification, resulting in high effluent nitrates concentration. However, the effluent nitrate concentration decreases with decrease in nitrification capacity, when the aeration for conversion of ammonia to nitrates is not limited (see Figure 49 – the effluent nitrate concentration decreases from 35.8 mgN/ℓ to 34.4 mgN/ℓ).

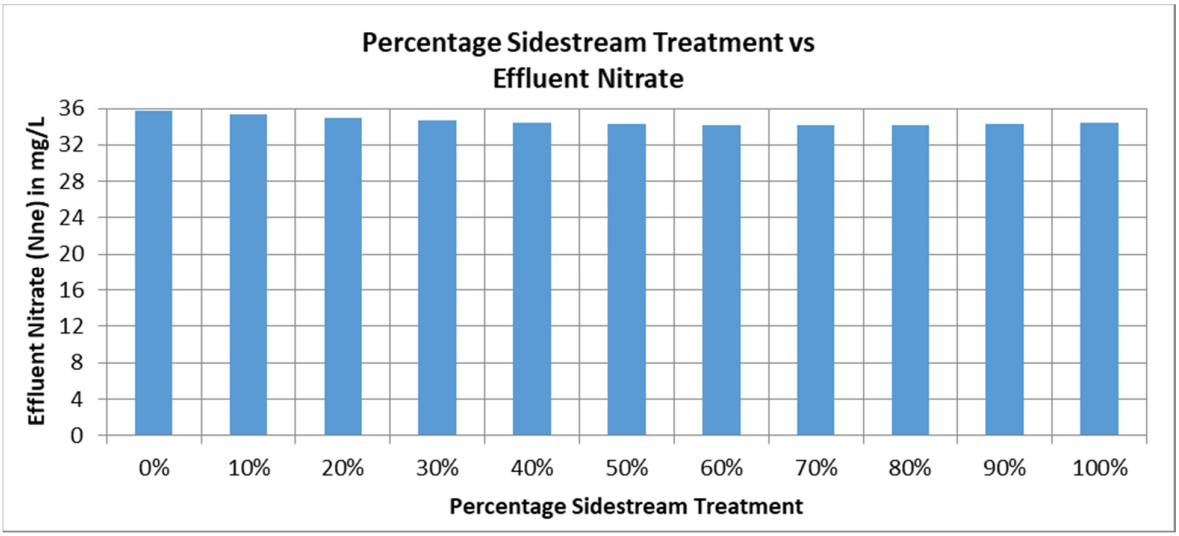

Figure 49: Impact of side-stream treatment on effluent nitrates at 'K' WWTP

4.4.4 Effluent Phosphates Concentration

The impact of percentage side-stream treatment on the effluent phosphate from the SST is illustrated in Figure 50. The effluent phosphate concentration from the AS system decreases marginally from 2.01 to 1.99 mg/ℓ. The presence of predicted effluent OP is due to Plant 'K' being fully aerated and not having the

capacity for excess biological P removal (EBPR) – hence the influent OP is solely as nutrient requirement for biomass.

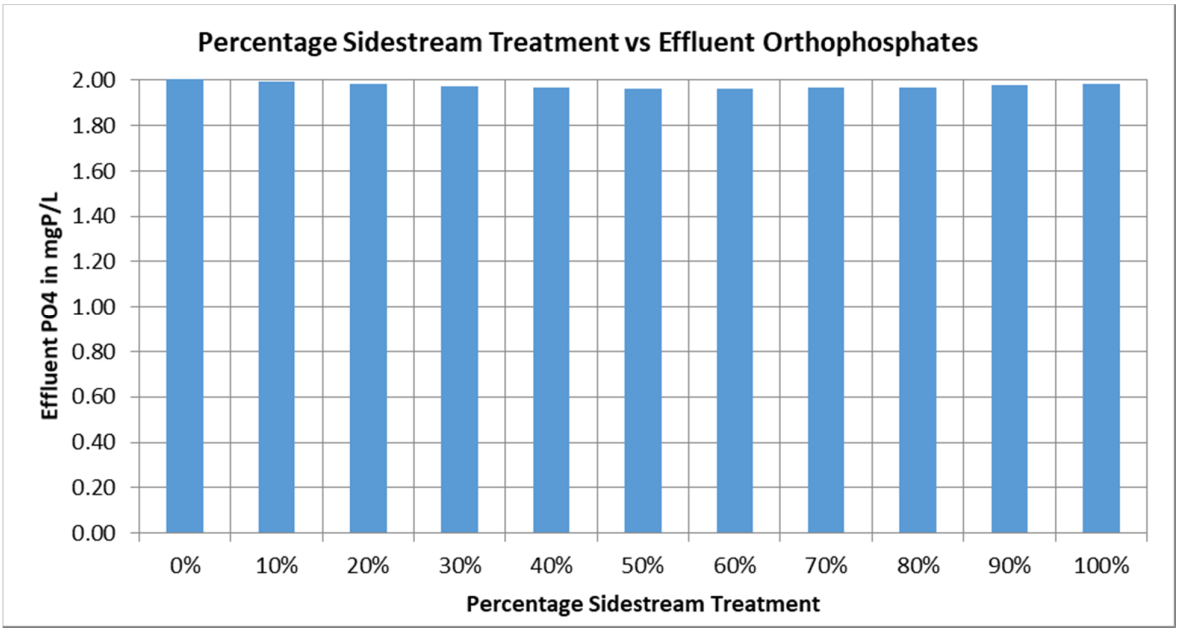

Figure 50: Impact of side-stream treatment on effluent phosphate at 'K' WWTP

4.5 Summary of Impacts of SRL Return Liquors at 'K' WWTP

Table 12 below summarises the percentage impact at a given percentage side-stream treatment starting at 0% side-stream treatment at 'K' WWTWP

Table 12: Percentage impact of SRL for given side-stream treatment at 'K' WWTP

Percentage Impact at given Percentage Side-stream Treatment at 'K' WWTP							
Parameter		0%	20%	40%	60%	80%	100%
Influent	Flow rate	5.7%	4.6%	3.4%	2.3%	1.1%	0.0%
	COD	0.5%	0.4%	0.3%	0.2%	0.1%	0.0%
	Ammonia	13.1%	8.4%	4.7%	2.1%	0.5%	0.0%
	PO_4	4.2%	2.7%	1.5%	0.7%	0.2%	0.0%
	Total Oxygen Demand	2.6%	1.7%	0.9%	0.4%	0.1%	0.0%
	Aeration Power Requirement	2.6%	1.7%	0.9%	0.4%	0.1%	0.0%
Effluent	SS Produced	1.1%	0.9%	0.6%	0.4%	0.2%	0.0%
	COD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	NO_3	4.0%	1.7%	0.1%	0.0%	0.0%	0.0%
	PO_4	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 51 below shows the SRL impact on 'K' WWTP at 0% side-stream treatment. The major impact was observed for influent ammonia load were the impact was 13.1%.

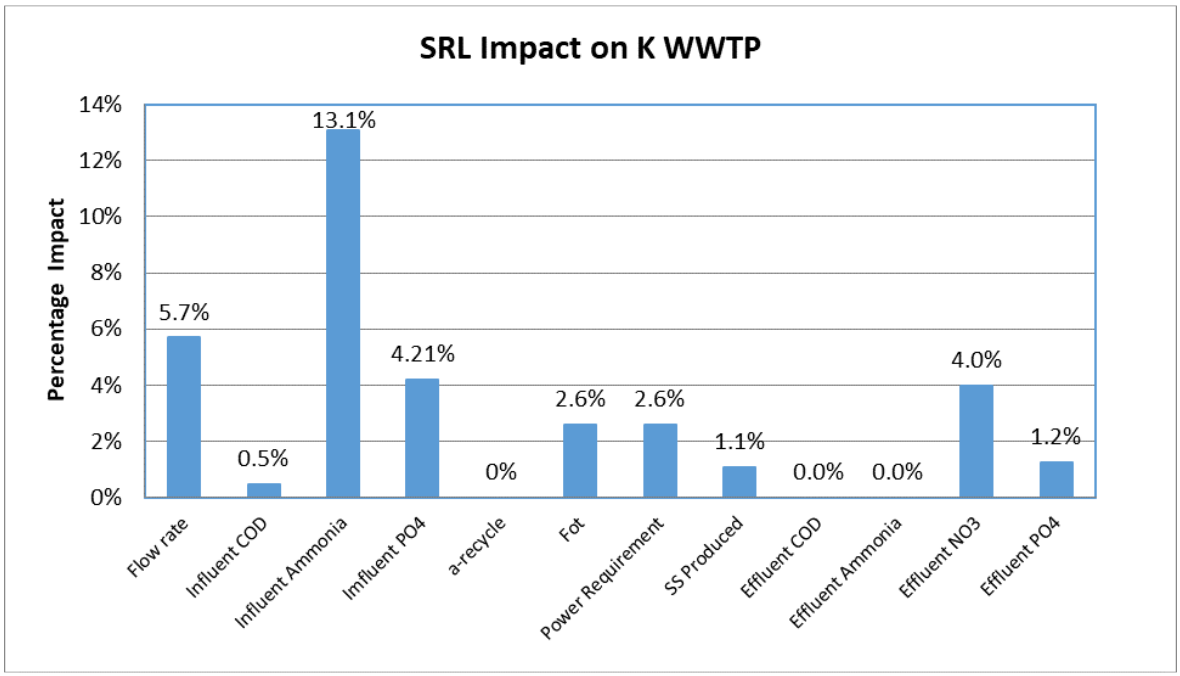

Figure 51: SRL Impact on 'K' WWTP at 0% side-stream treatment

CHAPTER 5: 'C' WWTP

The results of the impact of SRL at 'C' WWTP are presented in this section. The impact of the sludge return flows was determined on:

- Influent Characteristics
- Biological Treatment Capacity
- Biological Effluent Quality

5.1 Process Description

A description of the 'C' WWTP is indicated below as per information found in the operation and maintenance manuals. Plant 'C' has a 5-Stage Bardenpho configuration. Table 13 and Table 14 give a summary of the unit operations and process data. A general process flow diagram of the works in indicated below in Figure 52. 'C' WWTP has a design capacity of 198 Mℓ/d.

Table 13: 'C' WWTP Unit Operations and Process

Key Unit Operations and Processes	Module
Primary Settling Tanks	Yes
BNR System	Yes
Secondary Settling Tanks	Yes
Gravity Thickeners	Yes
Dissolved Air Flotation	Yes
Anaerobic Digesters	Yes
Dewatering	Yes

The pertinent data for the above unit operations and processes is summarised in Table 14.

Table 14: 'C' WWTP Data

Key Unit Operations and Processes	AS System
Primary Settling Tanks diameter	8 × 23 m
Diameter (m)	25
BNR System Volume (m³)	29 696
Secondary Settling Tank Diameter	22 × 26 m + 4 × 31m
Gravity Thickeners	3 Units
DAF Units Diameter of ea. Unit (m)	2 Units
Anaerobic Digesters	6 × 5 380 m³

SLR:

- Return liquors from gravity thickening and dissolved air flotation 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 returned to the treatment works

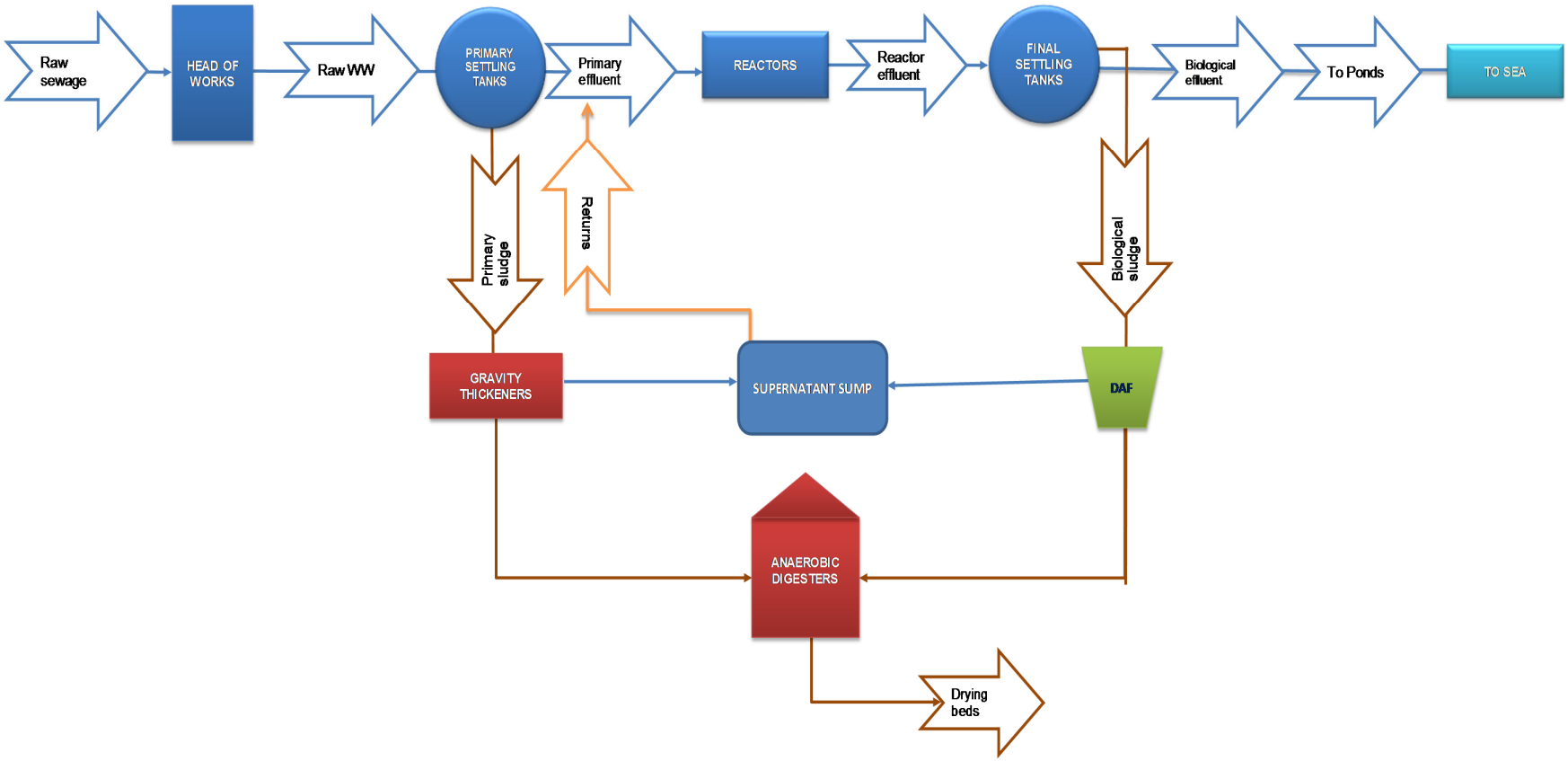

Figure 52: 'C' WWTP Process Flow Diagram

5.2 Impact of SRL on Influent Characteristics at 'C' WWTP

The influent characteristics impacted on by SRL are:

- Influent flow rate
- Influent COD Load
- Influent Ammonia Load
- Influent PO_4 Load

The impact of SRL on each of the above influent characteristics is summarised in this section. Figure 53 to Figure 56 illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

5.2.1 Influent Flow rate

The impact of percentage side-stream treatment on the flow rate is illustrated below in Figure 53. Without side-stream treatment, i.e. 0% side-stream treatment, 100% of SRL flows back to the activated sludge system. The flow to the AS system decreases along with side-stream treatment from 206 Mℓ/d to 198 Mℓ/d.

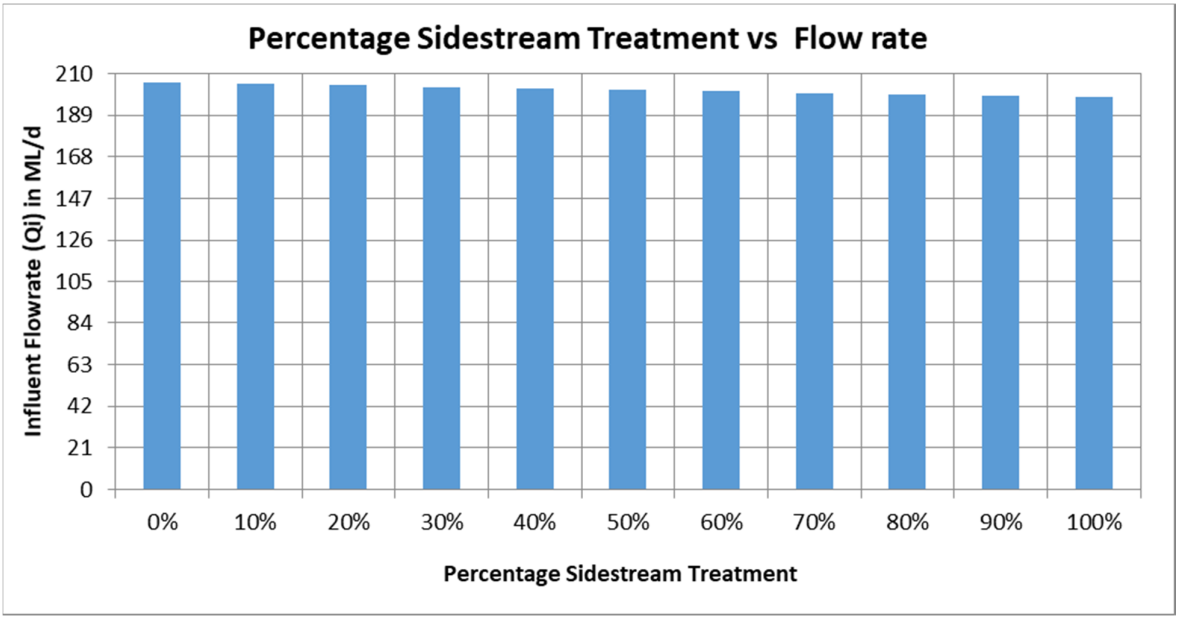

Figure 53: Impact of side-stream treatment on influent flow at 'C' WWTP

5.2.2 Influent COD Load

The impact of percentage side-stream treatment on the total influent COD load to the AS system is illustrated below in Figure 54. Influent COD load to the plant increases from 84 911 kgCOD/d to 84 348 kgCOD/d. This trend is similar to the model predictions for the other plants.

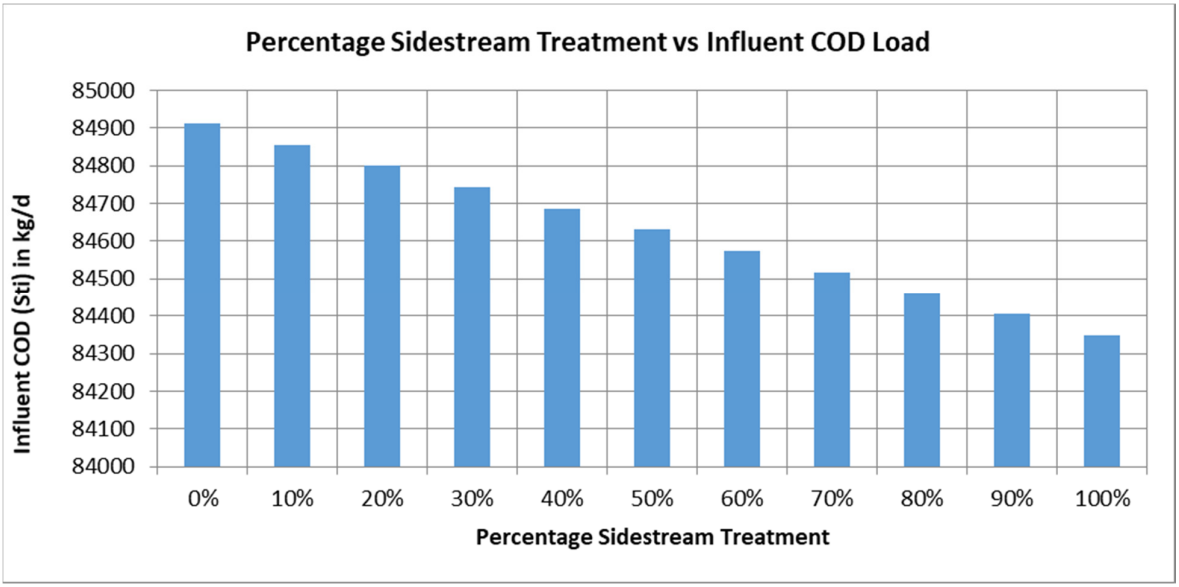

Figure 54: Impact of side-stream treatment on influent COD Load at 'C' WWTP

5.2.3 Influent Ammonia Load

The impact of percentage side-stream treatment on the influent ammonia load to the activated sludge system is illustrated below in Figure 55. Influent ammonia load to the AS system decreases from 7 875 kgN/d to 6 613 kgN/d.

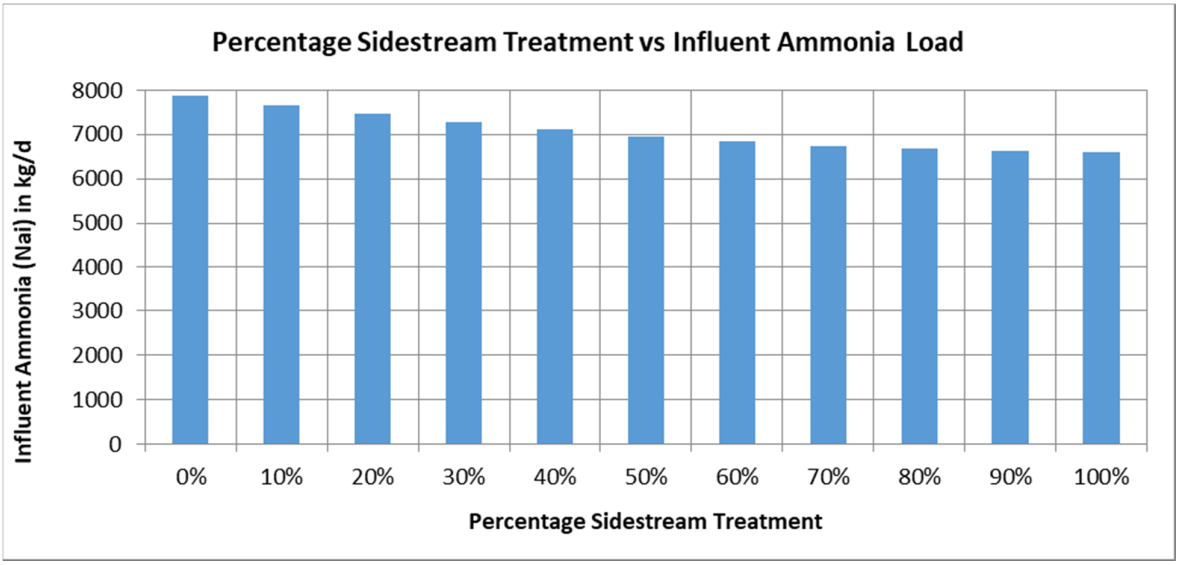

Figure 55: Impact of side-stream treatment on influent ammonia load at 'C' WWTP

5.2.4 Influent Phosphate Load

The impact of percentage side-stream treatment on the influent orthophosphate load to the AS system is illustrated below in Figure 56. Influent orthophosphate load to the AS system decreases from 1 614 kgP/d to 705 kgP/d.

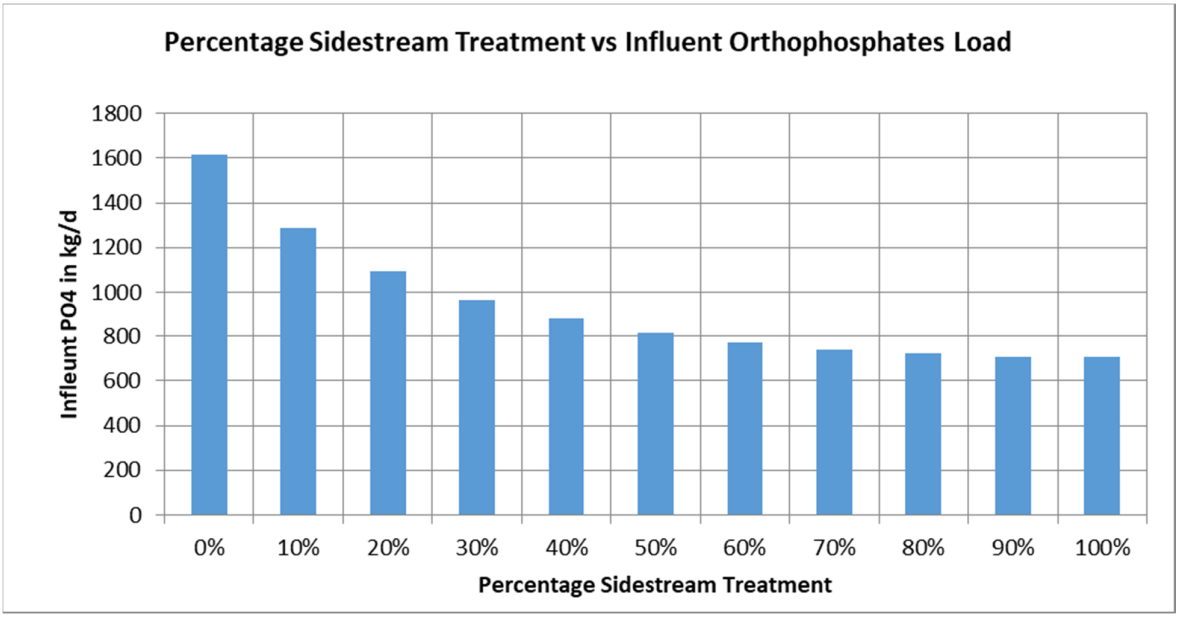

Figure 56: Impact of side-stream treatment on influent phosphate load at 'C' WWTW

5.3 Impact of SLR on Biological Treatment Capacity at 'C' WWTP

The biological treatment capacity parameters impacted on by SRL flows are:

- A-recycle
- Total oxygen demand
- Secondary sludge production

The impact of SRL on each of the above biological treatment capacity parameters is summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

5.3.1 A-recycle

The impact of percentage side-stream treatment on the a-recycle of the AS system is illustrated below in Figure 57. The a-recycle ratio flow to the anoxic reactors increases along with side-stream treatment from 0.15 to 0.64.

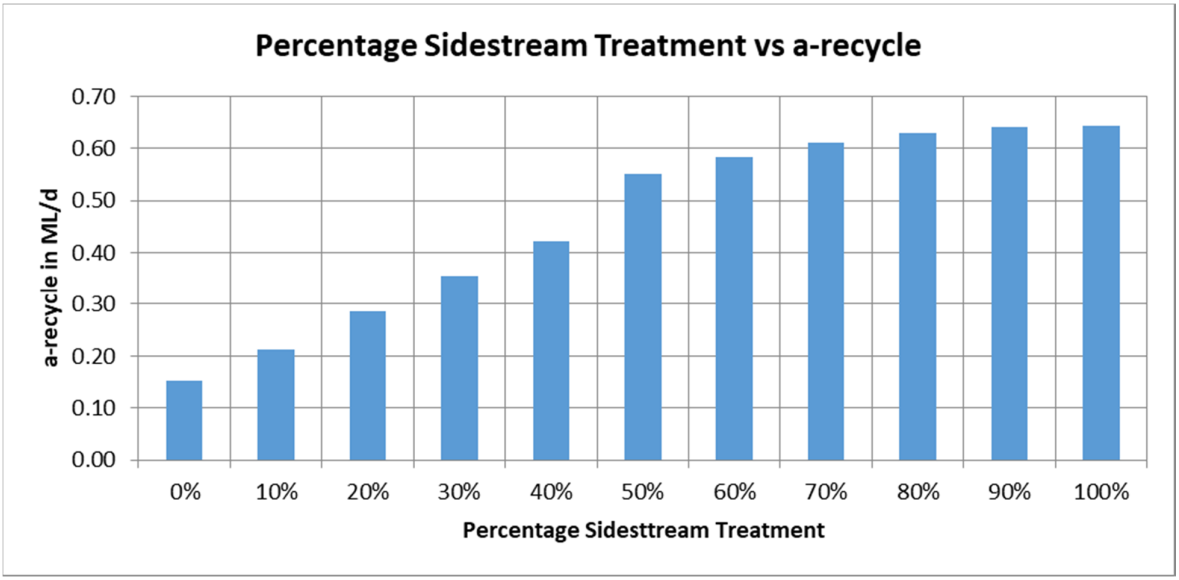

Figure 57: Impact of side-stream treatment on a-recycle at 'C' WWTP

5.3.2 Total Oxygen Demand

The impact of percentage side-stream treatment on the total oxygen demand (FOt) for the AS system is illustrated in Figure 58. The FOt for the AS system decreases along with side-stream treatment capacity from 64 599 kgO/d to 61 815 kgO/d.

Aeration power requirement for the AS system decreases along with side-stream treatment, seen in the decrease from 1 418 kW to 1 357 kW.

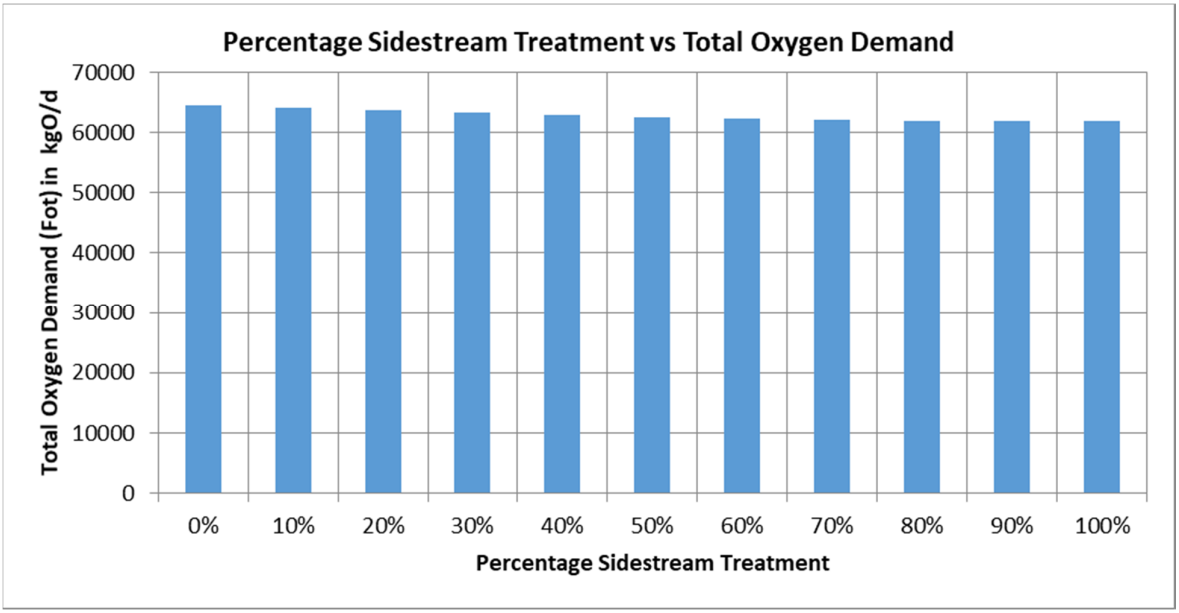

Figure 58: Impact of side-stream treatment on total oxygen demand at 'C' WWTP

5.3.3 Secondary Sludge Produced

The impact of percentage side-stream treatment on secondary sludge production from the AS system is illustrated in Figure 59. Secondary sludge production in the AS system decreases along with side-stream treatment 27 731 kgTSS/d to 24 502 kgTSS/d.

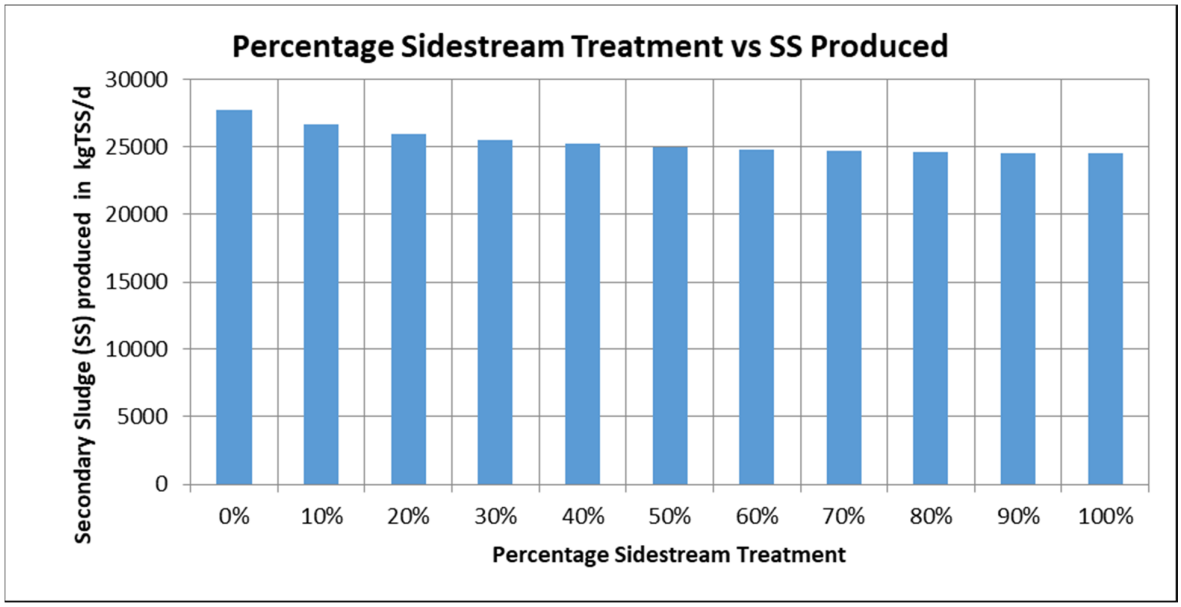

Figure 59: Impact of side-stream treatment on secondary sludge production at 'C' WWTP

5.4 Impact of SLR on Biological Effluent Quality at 'C' WWTP

The biological effluent quality parameters impacted on be sludge return flows are:

- COD Concentration
- Ammonia Concentration
- Nitrate Concentration
- Phosphates Concentration

The impact of SRL on each of the above biological effluent parameters are summarised in this section. Figures below illustrate the impact of sludge returns for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

5.4.1 Effluent COD Concentration

The impact of percentage side-stream treatment on the effluent COD from the AS system is illustrated below in Figure 60. The effluent COD concentration from the AS system remains constant at 75 mgCOD/ℓ.

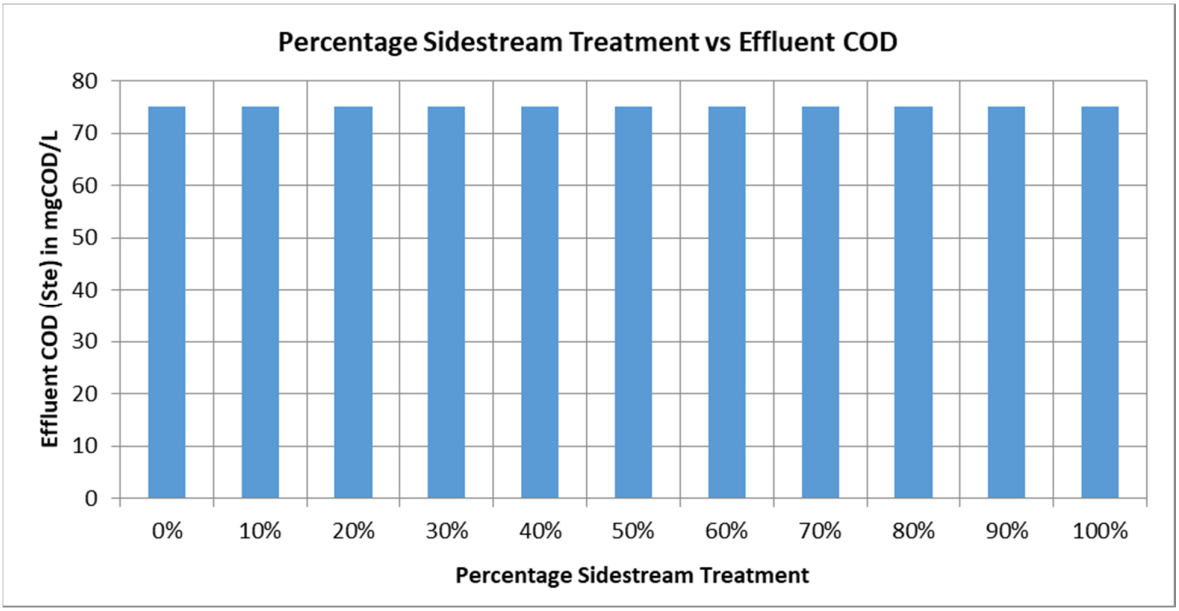

Figure 60: Impact of side-stream treatment on effluent COD at 'C' WWTP

5.4.2 Effluent Ammonia Concentration

The impact of percentage side-stream treatment on the effluent ammonia from the AS system is illustrated below in Figure 61. The effluent ammonia concentration remains constant 0.42 mgN/ℓ.

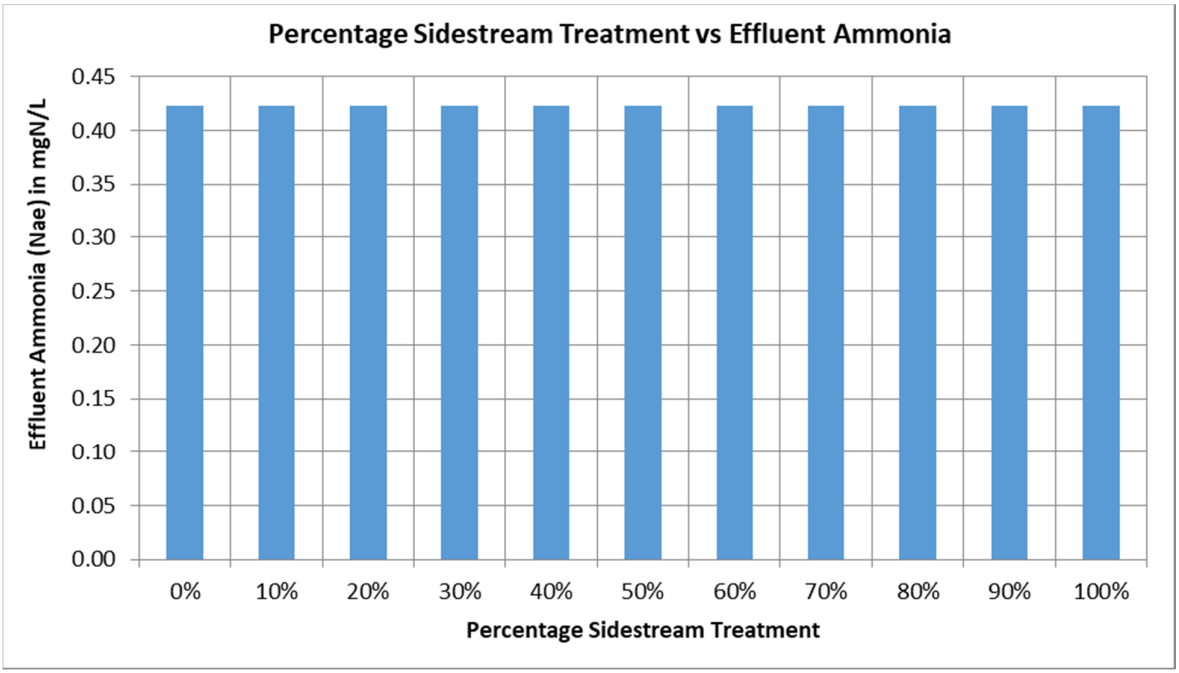

Figure 61: Impact of side-stream treatment on effluent ammonia (with limited aeration capacity) at 'C' WWTP

5.4.3 Effluent Nitrate Concentration

The effluent nitrate concentration decreases with decrease in nitrification capacity. Figure 62 illustrates the effluent nitrate concentration decreases marginally from around 8.5 mgN/ℓ to 6.9 mgN/ℓ.

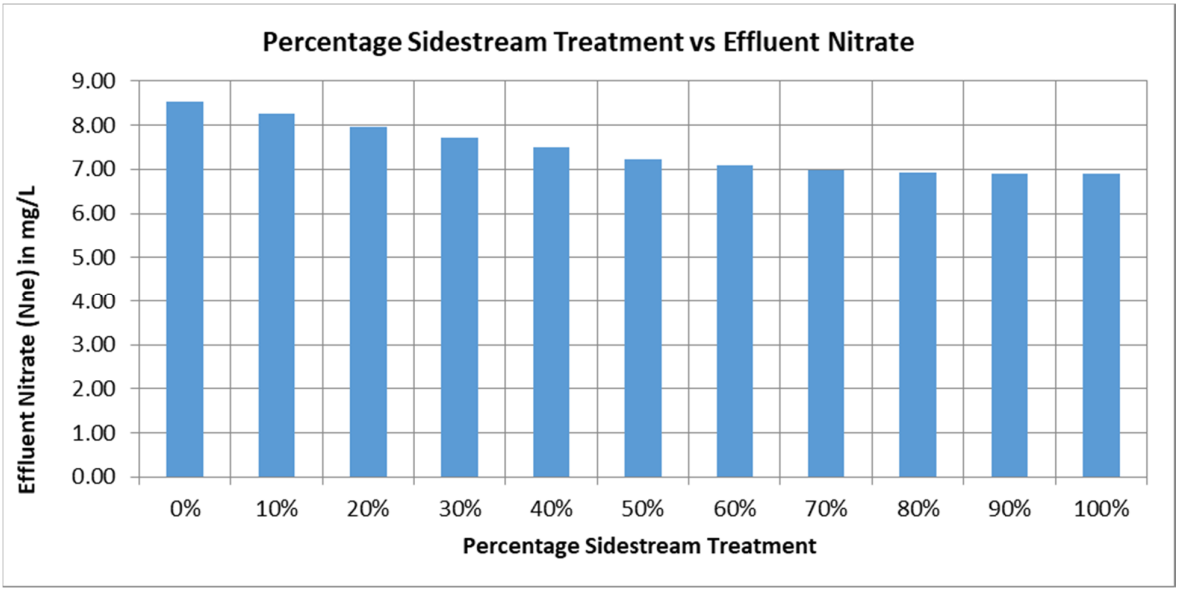

Figure 62: Impact of side-stream treatment on effluent nitrate concentration at 'C' WWTP

Figure 63 shows the estimated readily biodegradable COD load to the anoxic zone that could be used to increase the denitrification potential of the plant to ensure minimum effluent nitrate concentrations (the trend observed is with decreasing SRL to the AS system).

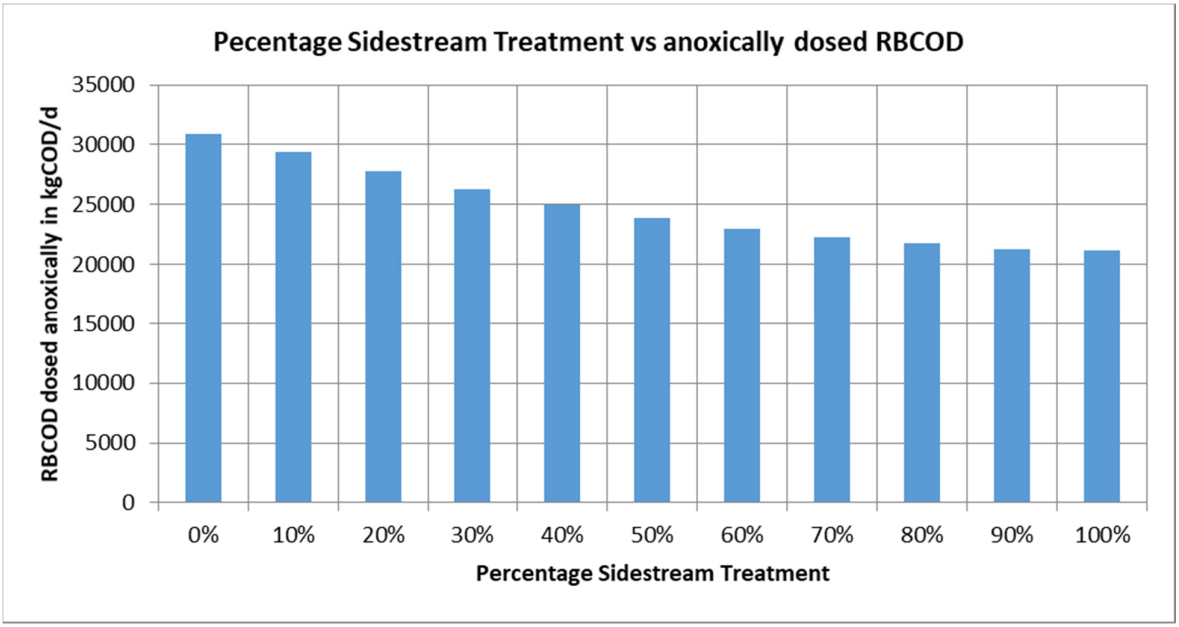

Figure 63: Impact of side-stream treatment on requirements of readily biodegradable organics to be dosed in anoxic zone for reduction of effluent nitrates to minimum concentration at 'C' WWTP

5.4.4 Effluent Phosphorus Concentration

The effluent phosphate concentration from the AS system remains constant at 0.00 mg/ℓ.

5.5 Summary of Impacts of SRL on 'C' WWTP AS System

Table 15 below summarises the percentage impact at a given percentage side-stream treatment at 'C' WWTP.

Table 15: Percentage impact for selected side-stream treatment at 'C' WWTP

Percentage Impact at given Percentage Side-stream Treatment at 'C' WWTP							
Parameter		0%	20%	40%	60%	80%	100%
Influent	Flow rate	3.8%	3.0%	2.3%	1.5%	0.8%	0.0%
	COD	0.67%	0.53%	0.40%	0.27%	0.13%	0.00%
	Ammonia	19.1%	12.9%	7.4%	3.3%	0.8%	0.0%
	PO_4	129.0%	55.0%	24.5%	9.5%	2.2%	0.0%
Biological Reactor	a-recycle	-76.1%	-55.5%	-34.5%	-9.1%	-2.1%	0.0%
	Total Oxygen Demand	1.7%	3.1%	1.8%	0.8%	0.2%	0.0%
	Aeration Power Requirement	4.5%	3.1%	1.8%	0.8%	0.2%	0.0%
	SS Produced	13.2%	6.0%	2.9%	1.3%	0.4%	0.0%
Effluent	COD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	NO_3	5.7%	5.3%	4.4%	3.2%	1.7%	0.0%
	PO_4 (Average)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 64 below shows the SRL impact on 'C' WWTP at 0% side-stream treatment. The major impact was observed for influent phosphate load were the impact was 129%.

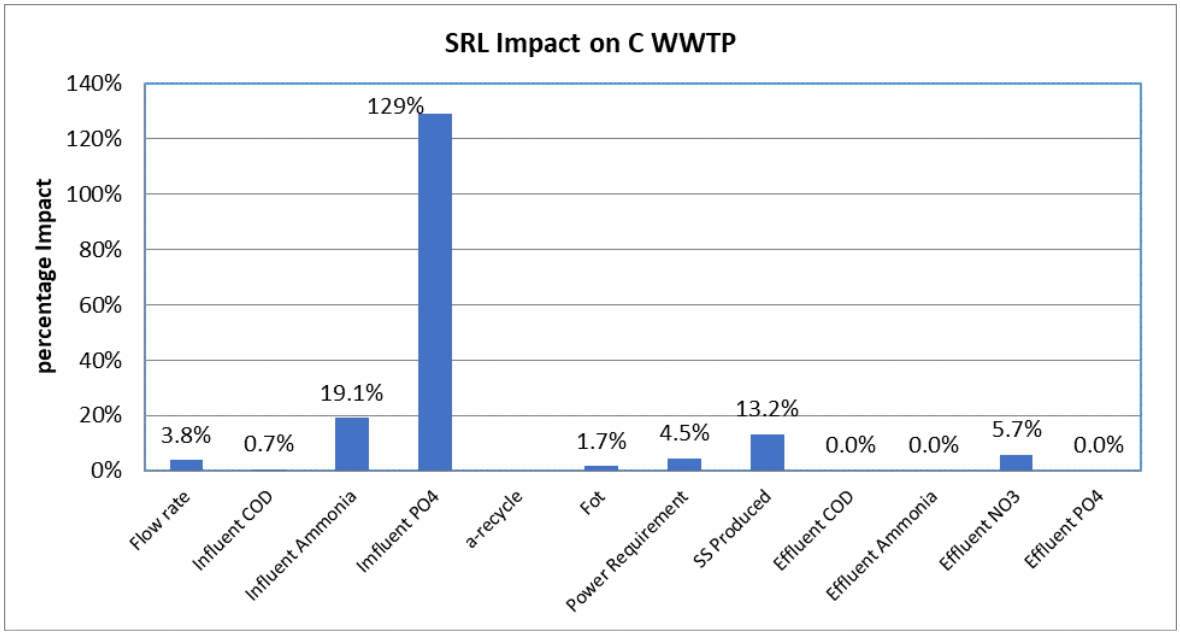

Figure 64: SRL Impact on 'C' WWTW at 0% side-stream treatment

CHAPTER 6: 'D' WWTP

The results of the impact of return sludge liquors at 'D' WWTP are presented in this section. The impact of the sludge return flows was determined on:

- Influent Characteristics
- Biological Treatment Capacity
- Biological Effluent Quality

6.1 Process Description

A description of the 'D' WWTP is indicated below as per information found in the operation and maintenance manuals. Table 16 and Table 17 give a summary of the unit operations and process data. The general process flow diagram of the works in indicated below in Figure 65. 'D' WWTP has a design flow capacity of 4.25 Mℓ/d.

Table 16: 'D' WWTP Unit Operations and Processes

Key Unit Operations and Processes	AS System
Primary Settling Tanks	Yes
BNR System	Yes
Secondary Settling Tanks	Yes
Dissolved Air Flotation	Yes
Anaerobic Digesters	Yes
Dewatering	Yes

The pertinent data for the above unit operations and processes is summarised in Table 17.

Table 17: 'D' WWTP Data

Key Unit Operations and Processes	AS System
Diameter (m)	25
Volume (m³)	5 940
Diameter	30
Diameter of ea. Unit (m)	10
Volume of each unit (m³)	424
Anaerobic Digesters	4

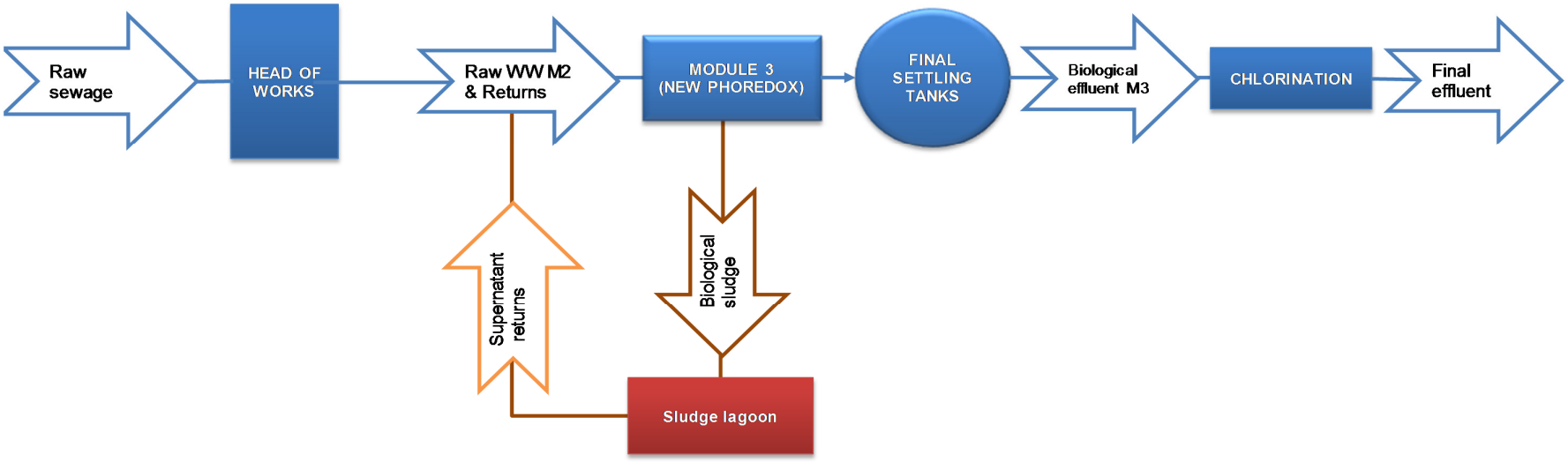

Figure 65: 'D' WWTP Process Flow Diagram

6.2 Influent Characteristics

The influent characteristics impacted on by sludge return flows are:

- Influent Flow rate
- Influent COD Load
- Influent Ammonia Load
- Influent PO_4 Load

The impact of sludge return flows on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of SRL for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

6.2.1 Influent Flow rate

The impact of percentage side-stream treatment on the flow rate is illustrated below in Figure 66. Without side-stream treatment, i.e. 0% side-stream treatment, means that 100% of SRL flow back to the AS system. The flow to the AS system decreases along with side-stream treatment from 4.10 Mℓ/d to 4.02 Mℓ/d.

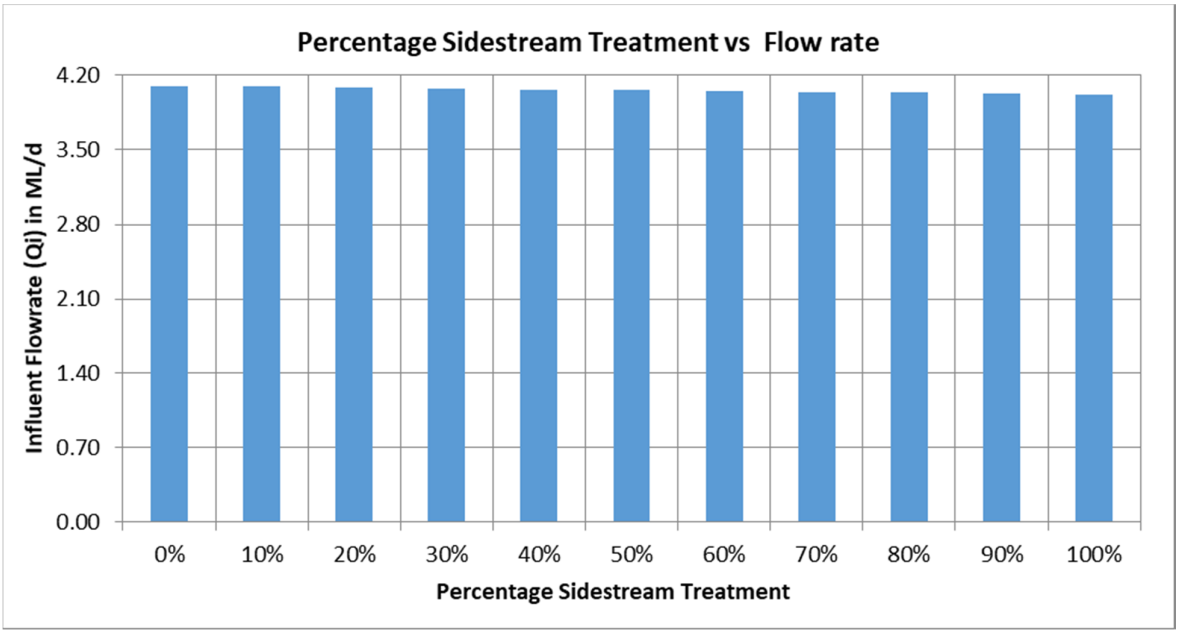

Figure 66: Impact of side-stream treatment on influent flow at 'D' WWTP

6.2.2 Influent COD

The impact of percentage side-stream treatment on the total influent COD load to the AS system is illustrated below in Figure 67. Influent COD load to the AS system decreases from 1 884 kgCOD/ℓ to 1 881 kgCOD/ℓ.

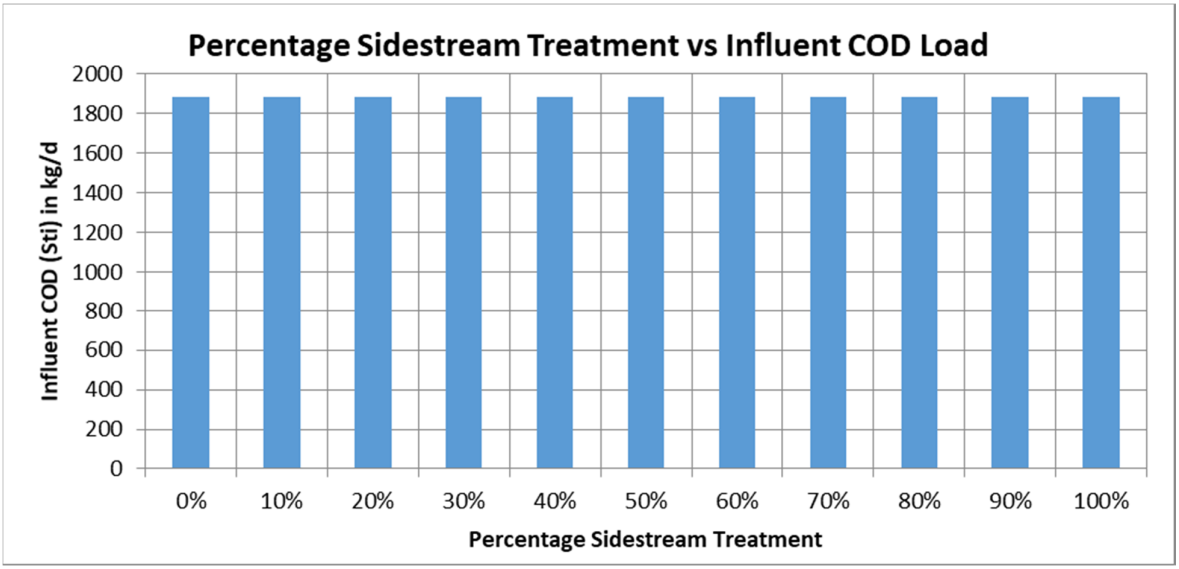

Figure 67: Impact of side-stream treatment on COD Load at 'D' WWTP

6.2.3 Influent Ammonia Load

The impact of percentage side-stream treatment on the influent ammonia load to the activated sludge system is illustrated below in Figure 68. The influent ammonia load to the AS system remains constant at 169 kgN/d to 169 kgN/d.

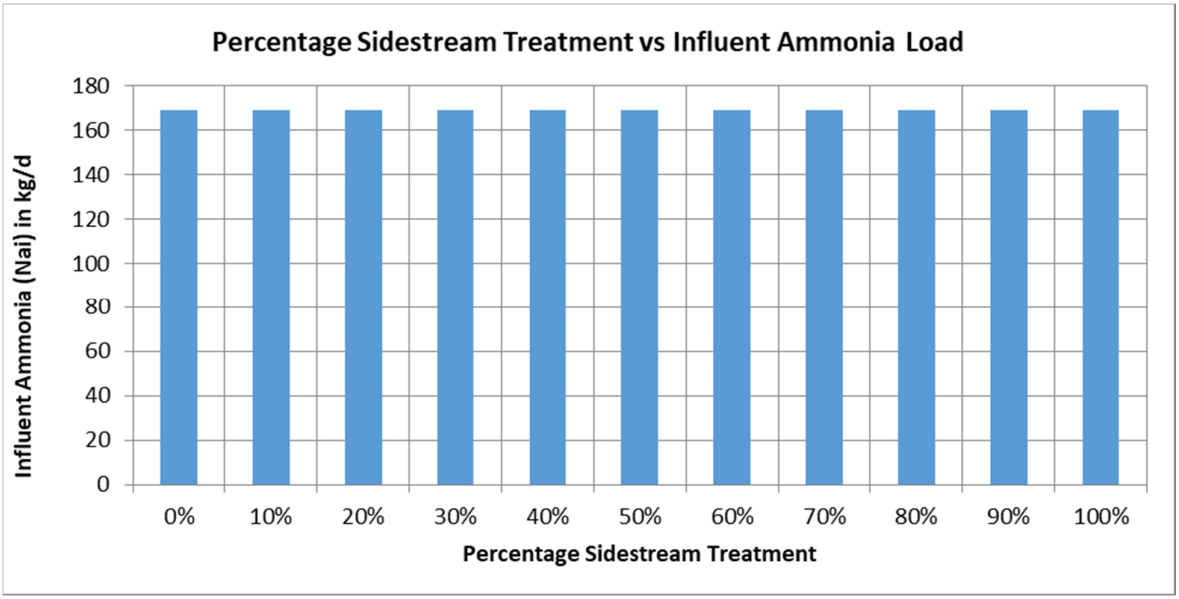

Figure 68: Impact of side-stream on influent ammonia load at 'D' WWTP

6.2.4 Influent Phosphate Load

The impact of percentage side-stream treatment on influent phosphate load to the AS system is illustrated below in Figure 69. Influent orthophosphate load to the AS system is constant at 17 kgP/d to 17 kgP/d.

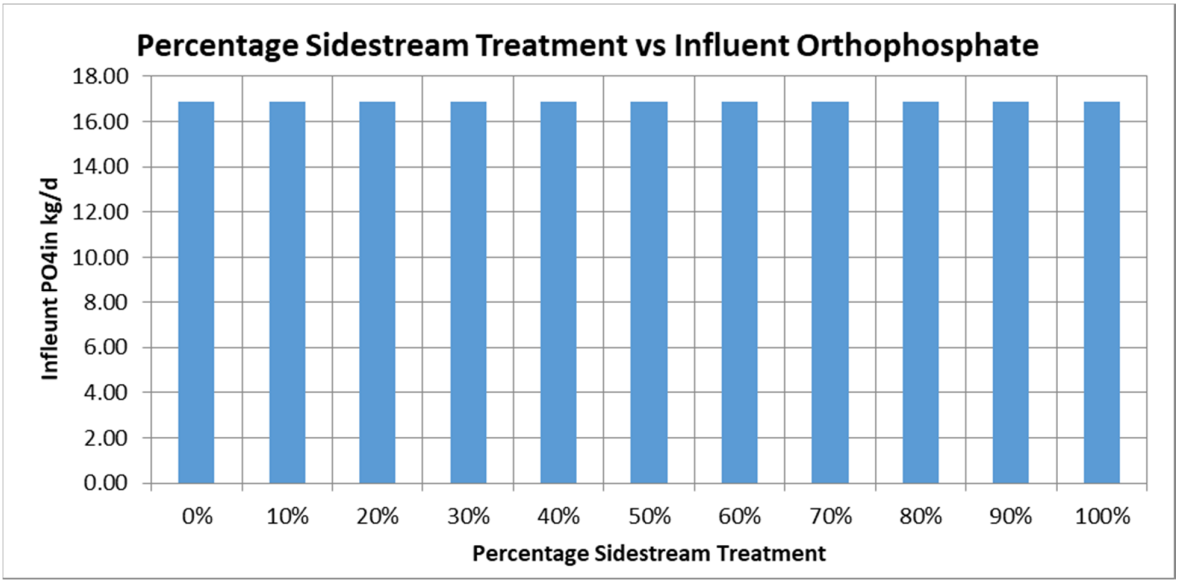

Figure 69: Impact of side-stream treatment on influent phosphate load at 'D' WWTP

6.3 Impact of SRL on Biological Treatment Capacity at 'D' WWTP

The biological treatment capacity parameters impacted on by sludge return flows are:

- A-recycle
- Total oxygen Demand
- Secondary sludge production

The impact of SRL on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of SRL for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

6.3.1 A-recycle

The impact of percentage side-stream treatment on the a-recycle for the AS system is illustrated below in Figure 70. The a-recycle ratio for the AS system decreases from 0.06 Mℓ/d to 0.04 Mℓ/d.

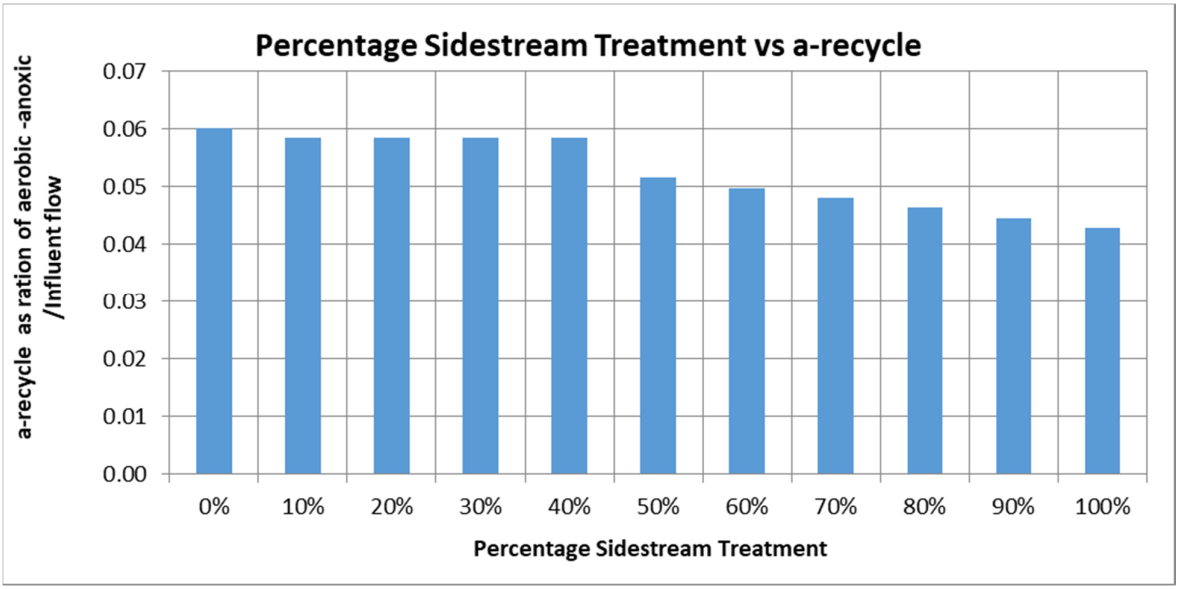

Figure 70: Impact of side-stream treatment on a-recycle at 'D' WWTP

6.3.2 Total Oxygen Demand

The impact of percentage side-stream treatment on the total oxygen demand (FOt) of the AS system is illustrated below in Figure 71. The FOt for the AS system decreases marginally along with side-stream treatment capacity from 1 501 kgO/d to 1 502 kgO/d.

Aeration power requirement for the AS system remains constant at about 33 kW.

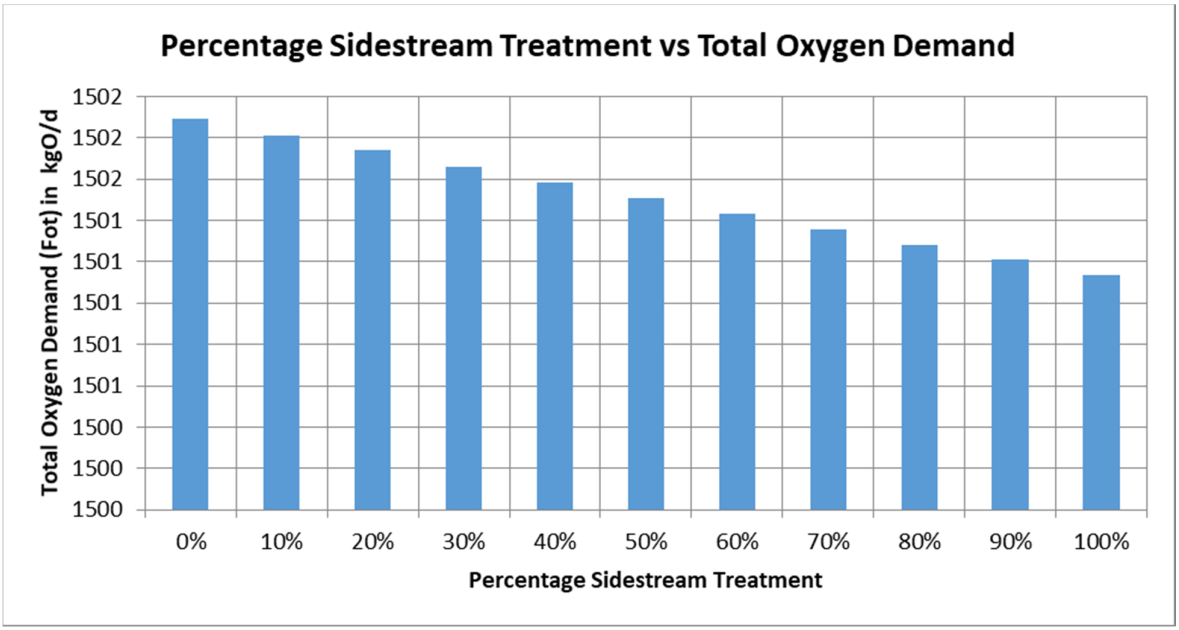

Figure 71: Impact of side-stream treatment on total oxygen demand at 'D' WWTP

6.3.3 Secondary Sludge Produced

The impact of percentage side-stream treatment on secondary sludge production in the AS system is illustrated below in Figure 72. Secondary sludge production in the AS system decreases marginally along with side-stream treatment from 764 kgTSS/d to 760 kgTSS/d.

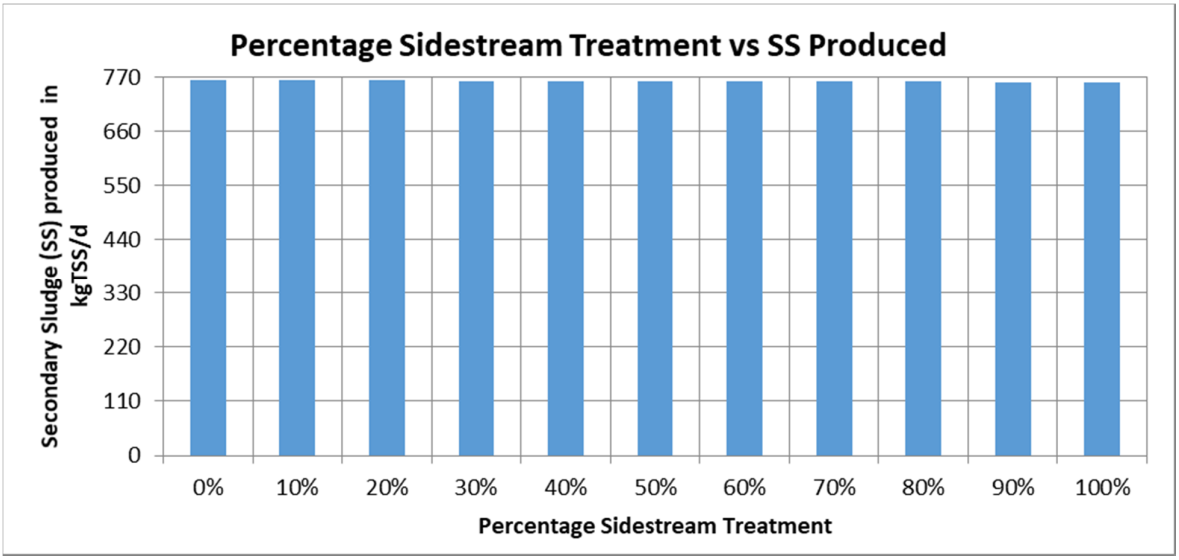

Figure 72: Impact of side-stream treatment on secondary sludge production at 'D' WWTP

6.4 Biological Effluent Quality

The biological effluent quality parameters impacted on be sludge return flows are:

- COD Concentration
- Ammonia Concentration
- Nitrate Concentration
- Phosphate Concentration

The impact of SRL on each of the above influent characteristics is summarised in this section. Figures below illustrate the impact of sludge return flows on biological effluent quality for a given percentage side-stream treatment (0% to 100% side-stream treatment) prior to return to the main water line.

6.4.1 Effluent COD Concentration

The impact of percentage side-stream treatment on the effluent COD from the AS system is illustrated below in Figure 73.

The effluent COD concentration from the AS system is constant at 33 mgCOD/ℓ.

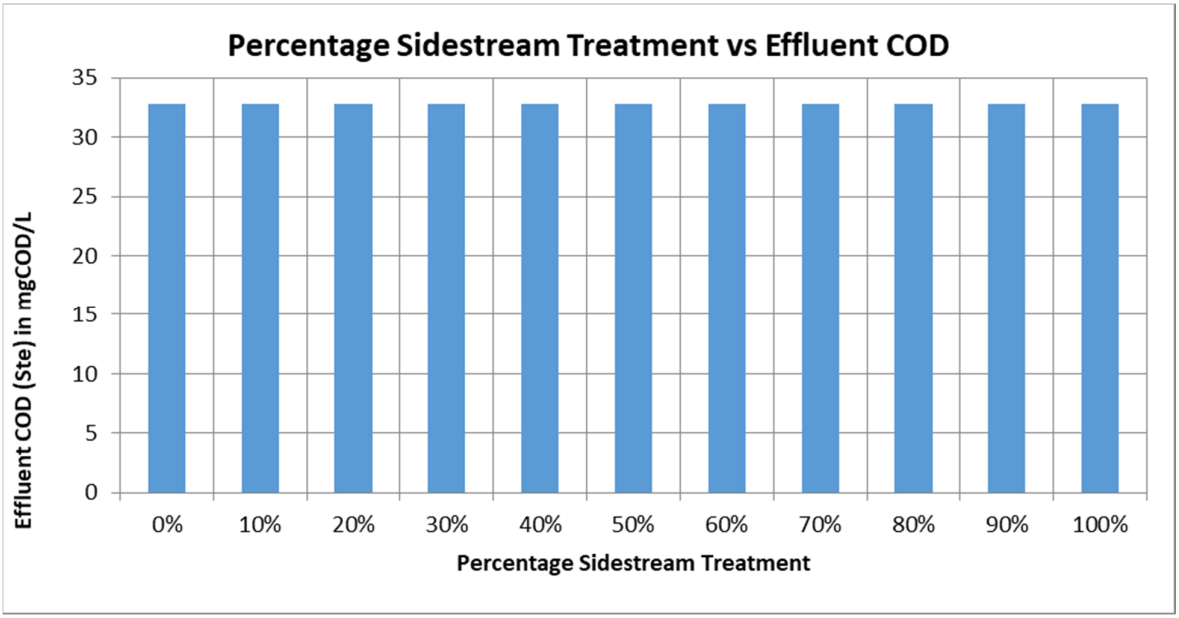

Figure 73: Impact of side-stream treatment on effluent COD concentration at 'D' WWTP

6.4.2 Effluent Ammonia Concentration

The impact of percentage side-stream treatment on the effluent ammonia from the AS system is illustrated below in Figure 74. The effluent ammonia concentration from the AS system remains constant at 0.18 mgN/ℓ.

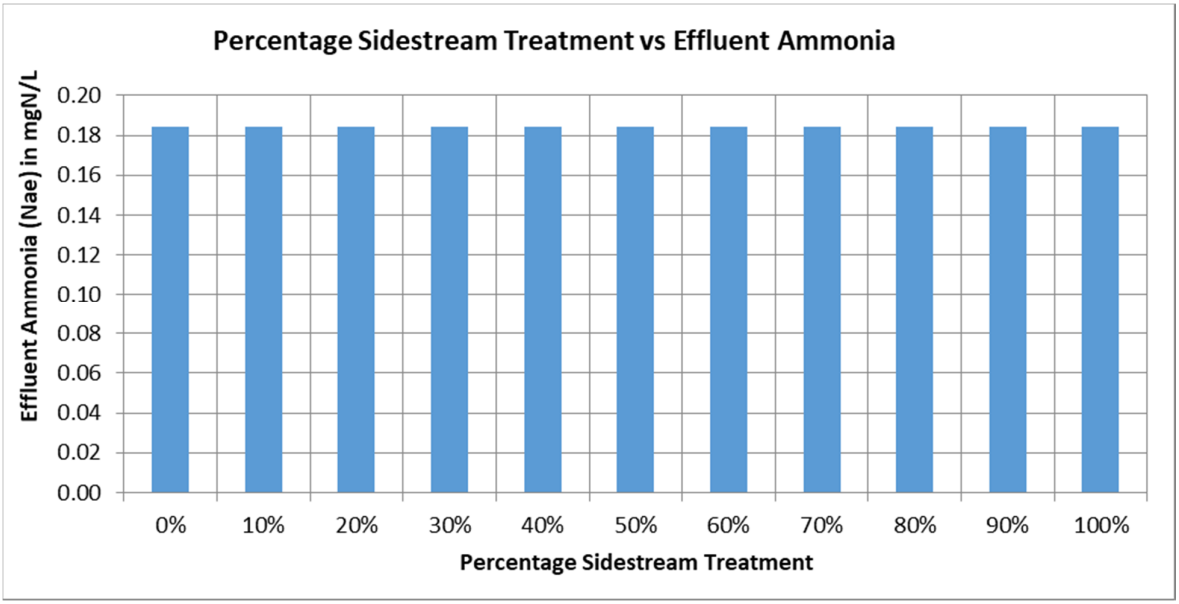

Figure 74: Impact of side-stream treatment on effluent ammonia concentration at 'D' WWTP

6.4.3 Effluent Nitrate Concentration

The effluent nitrate concentration increases with increase in nitrification capacity (see Figure 75, the increase is marginal, from around 13.6 mgN/ℓ to 13.9 mgN/ℓ).

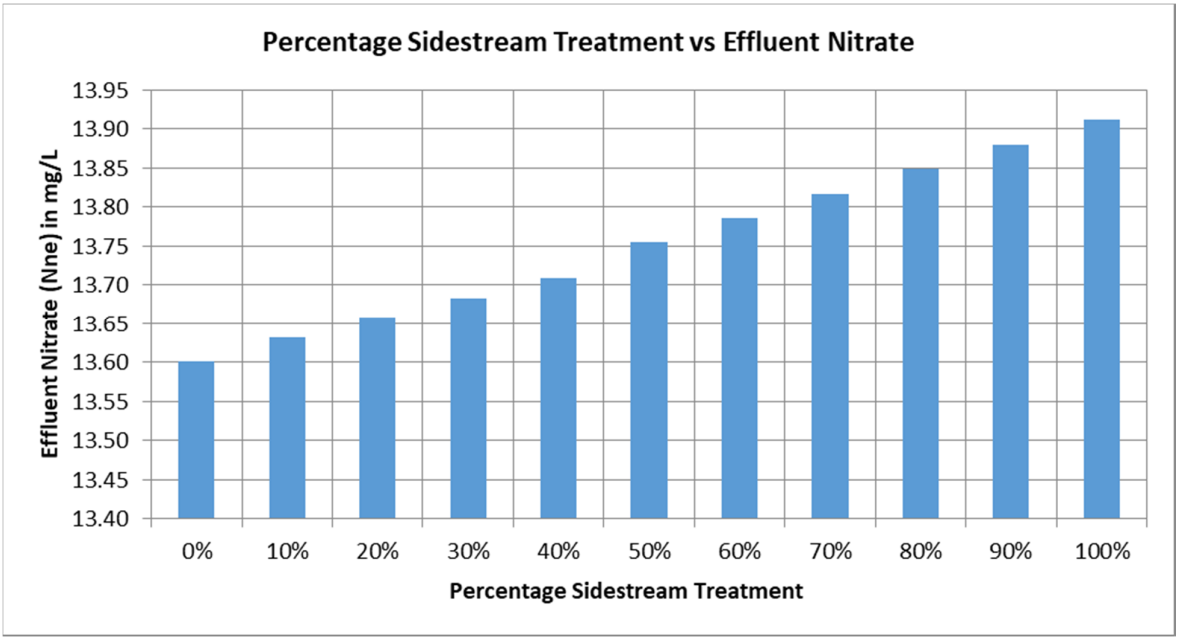

Figure 75: Impact of side-stream treatment on effluent nitrate when aeration is not limited at 'D' WWTP

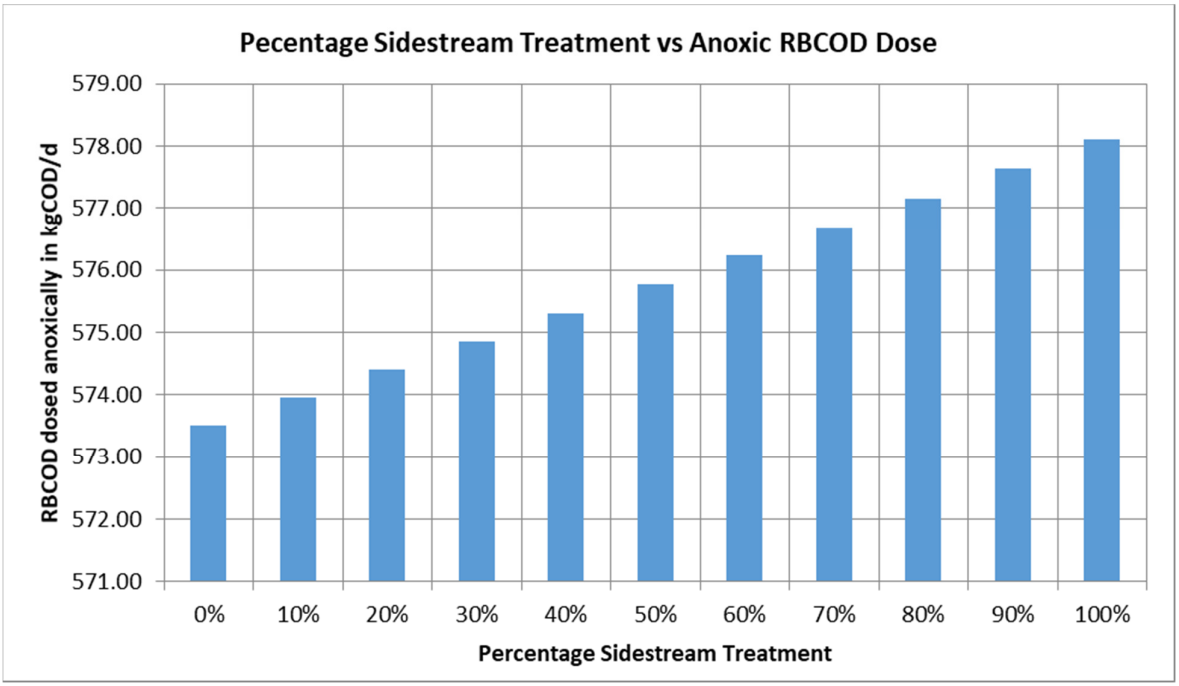

Figure 76: Impact of side-stream treatment on required RBO for use in anoxic zone, for NO_3 removal at 'D' WWTP

6.4.4 Effluent Ortho-Phosphates Concentration

The impact of percentage side-stream treatment on the effluent TP from the SST is illustrated below in. The effluent phosphate concentration from the AS system remains constant at 0.00 mg/ℓ.

6.5 Summary of Impacts of SRL on Influent Characteristics at 'D' WWTP

Table 18 below summarises the percentage impact at a given percentage side-stream treatment at 'D' WWTP.

Table 18: Percentage impact of SRL for given side-stream treatment at 'D' WWTP

Percentage Impact at given Percentage Side-stream Treatment at 'D' WWTP							
Parameter		0%	20%	40%	60%	80%	100%
Influent	Flow rate	1.9%	1.6%	1.2%	0.8%	0.4%	0.0%
	COD	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	PO4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biological Reactor	a-recycle	40.4%	36.3%	36.3%	16.2%	8.2%	0.0%
	Total Oxygen Demand	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	Aeration Power Requirement	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	SS Produced	1.1%	0.4%	0.3%	0.2%	0.1%	0.0%
Effluent	COD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ammonia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	NO_3	-2.2%	-1.8%	-1.5%	-0.9%	-0.5%	0.0%
	PO4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Figure 77 below shows the SRL impact on 'D' WWTP at 0% side-stream treatment. The highest impact was observed for a-recycle at 40%.

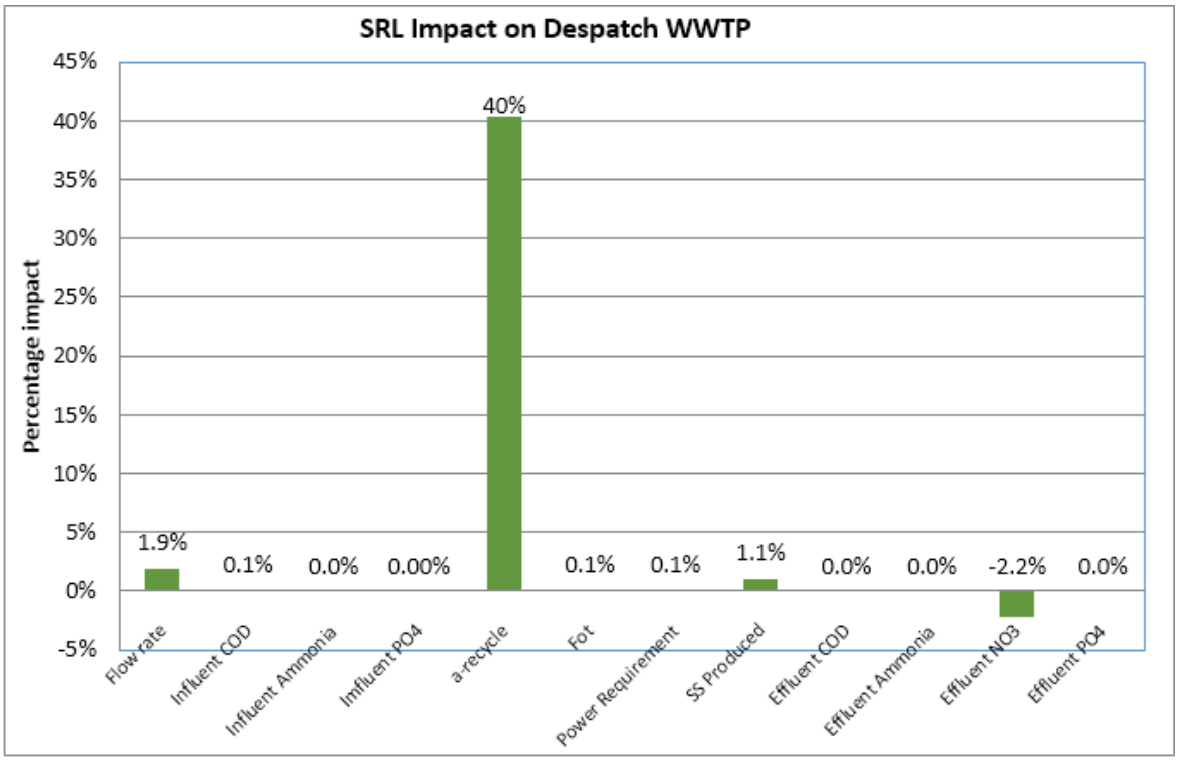

Figure 77: SRL impact on 'D' WWTP at 0% side-stream-treatment