WATER RESEARCH COMMISSION REPORT TT800-19

APPENDIX 3

PLANT PERFORMANCE EVALUATION TOOL

USER MANUAL

PPET

Plant performance evaluation tool

USER MANUAL

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Acronyms and abbreviations

AD	Anaerobic Digester
BABE	Bio-Augmentation Batch Enhanced
BNR	Biological Nutrient Removal
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DSVI	Diluted Sludge Volume Index
EQI	Effluent Quality Index
JHB	Johannesburg
MLE	Modified Ludzack-Ettinger
OCI	Operational Cost Index
PPET	Plant Performance Evaluation Tool
PS	Primary Sludge
SRT	Sludge Retention Time
TSS	Total Settleable Solids
UCT	University of Cape Town
$V_{aerobic}$	Volume of the Aerobic Reactor (m^3)
$V_{anaerobic}$	Volume of Anaerobic Reactor (m^3)
V_{anoxic}	Volume of Anoxic Reactor (m^3)
WAS	Waste Activated Sludge
WW	Wastewater
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

This user manual is one of three deliverables that were submitted at the end of a study on the impact return dewatering liquor on the overall plant performance in the South African context; the other deliverables being a Plant Performance Evaluation Tool (PPET) and a Detailed Report. PPET was developed with the aim of converting complex plant-wide steady-state models into simple evaluation tools with the intent of evaluating the plant performance (i.e. effluent quality and cost).

The main objectives of PPET are to:

- Evaluate the impact of return dewatering liquor on the overall plant performance (cost and effluent);
- Provide a recommendation for a suitable side-stream treatment process for best effluent quality and lowered operational costs; and
- Educate the user about treatment processes and how different decisions affect the overall plant performance.

<u>Due to the complex processes running in the background, PPET requires a strong computer with a fast CPU for it to function.</u>

2. USER MANUAL

2.1 Home

Upon opening PPET, the home page is displayed. A brief introduction to the tool is provided.

- Please click on the Start button to proceed with this tool.

- By Clicking on the Start button, you will be taken to the Input Parameters tab.

2.2 Input parameters

This page entails entering all raw and settled wastewater (WW) inputs. It has been colour-coded such that the user can easily follow the instructions given. It is recommended that a value within the given range should be chosen, where input parameters are not known.

- A reset button has been provided for clearing all inputs, if needed.

Step 1: General input

Please enter the "blue" values (either for raw or settled wastewater) for the different parameters as shown in *Table **1***. Please select a value within the given range of the parameter, in the case that the input value of a parameter is not known.

Table 1: General inputs

General Input					
Parameter	**Abbreviation**	**Value @ 20 °C**		**Range**	**Unit**
		Raw WW	**Settled WW**		
Design Sludge Age, SRT	SRT	10	10	15 to 25	d
factor of safety	Sf	1.25	1.25	1.1 to 1.5	Constant
Number of Anaerobic Reactors in Series	N_{ana}	2	2	-	-
Population	Popn	5000	5000	-	-
Energy cost		62.03	62.03	-	c/kWh
System Temperature	Design Temp	18	18	15 to 25	°C
Aeration power	P_O2	1.2	1.2	-	kgO_2/kWh
Diluted Sludge Volume Index	DSVI	160	160	150 to 250	mL/g
peak factor (PWWF/ADWF)	fq	2.0	2.0	2 to 4	-

Note:

- Sludge retention time (SRT) is the length of time (in days) that sludge remains in the reactor. It is given by:

$$\text{SRT} = \frac{\text{Total reactor volume}}{\text{Waste flowrate}}$$

- There are different tests that are used to measure sludge settleability.
  - The traditional test for measuring sludge settleability is **Sludge Settleability Test (SVI)**, however, it does not provide the best measurement due to variation in the test results with respect to sludge concentration and stirring effects, the dependency of the test on the cylinder diameter and depth, etc.
  - **Diluted Sludge Volume Index (DSVI)**, is an improved test for measuring sludge settleability. It is the volume (ml) occupied by 1 g of sludge after 30 minutes settling in a one-litre measuring cylinder. DSVI falls within the 150 to 250 ml/l range.

Step 2: Biological Reactor Sizing

Please enter the blue parameters as shown in *Table **2***.

Table 2: Biological reactor sizing parameters

Biological Reactor Sizing Parameters					
Parameter	**Abbreviation**	**Input**		**Range**	**Unit**
		Raw WW	**Settled WW**		
Anoxic Vol.	V_ax	2376	2376	-	m^3
Anaerobic Vol.	V_an	1010	1010	-	m^3
Total Aerobic	V_aer	2554	2554	-	m^3
Aerobic fract.	f_Xaer	0.43	0.43	0 to 1	-
Anoxic fract.	f_Xd	0.4	0.4	0 to 1	-
Anaerobic fract.	f_Xana	0.17	0.17	0 to 1	-
SST Area	AST	1414	1414	-	m^2
anoxic to anaerobic recycle ratio	r_recy	1.00	1.00	0.5 to 5	:1 w.r.t influent flow
mixed liquor recylce ratio	a_recy	4.00	4.00	1 to 10	:1 w.r.t influent flow
Sludge underflow recylce ratio	S_recy	1.00	1.00	1 to 11	:1 w.r.t influent flow
Fraction of influent flowrate (Qi) to Module 1	f_Qi_Mod 1	0.24	0.24	0 to 1	-

- The anaerobic (f_{xana}), anoxic (f_{xd}) and aerobic mass fractions (f_{xaer}) can be calculated using the formulae below:

$$f_{xana} = \frac{V_{anaerobic}}{\text{Total volume}}$$

$$f_{xd} = \frac{V_{anoxic}}{\text{Total volume}}$$

$$f_{xaer} = \frac{V_{aerobic}}{\text{Total volume}}$$

Where:

$V_{anaerobic}$ = Volume of anaerobic reactor (m^3)

V_{anoxic} = Volume of anoxic reactor (m^3)

$V_{aerobic}$ = Volume of the aerobic reactor (m^3)

<u>The sum of the different mass fractions should equal to 1.</u>

- a-recy stands for the recycle ratio from the aerobic reactor to the anoxic reactor. The other recycle ratios (i.e. the r and s) have been assumed to be equal to 1.

Step 3: Anaerobic Digestion (AD)

The primary sludge (PS) and waste activated sludge (WAS) are treated in the anaerobic digester (AD) to reduce the fraction of active biodegradable organics in them before disposal.

➢ Please enter the blue parameters as shown in Table 3.

Table 3: Anaerobic digestion inputs

Anaerobic Digestion (AD)					
Parameter	**Abbreviation**	**Input**		**Range**	**Unit**
		Raw WW	**Settled WW**		
Fraction of primary sludge fed to AD	f_QPS_AD	1	1	0 or 1	-
Fraction of secondary waste fed to AD	f_QW_AD	1	1	0 or 1	-
Thickening effect on Primary Sludge (PS)	f_PS	100%	100%	0 to 100	%
Required Sludge Age for Anaerobic Digestion (AD)	Rs_AD_min	60	60	-	Days
Selected Total Suspended Solids (TSS) Concentration	AD_TSS	50000	50000	-	mg/l
pH		8.0	8.0	See Step 3	-
Alkalinity		500	500	See Step 3	mg $CaCO_3$/l
Volatile fatty acids	VFA	0.00	0.00	See Step 3	mg/l

Note:

It is recommended that the pH, alkalinity and VFA concentration of WAS and PS sludge should be measured. Figure 1 shows typical values for treating WAS or PS separately.

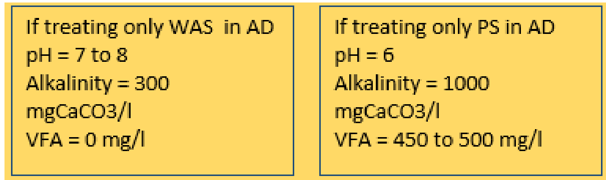


Figure 1: Typical values of pH, alkalinity and VFA concentration.

Step 4: Effluent Quality Criteria

- Please enter the plant's effluent quality criteria as shown in Table 4.

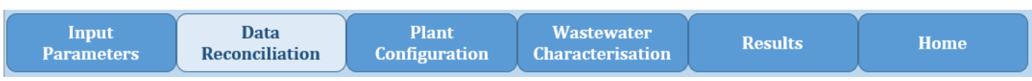
Table 4: Effluent quality criteria inputs

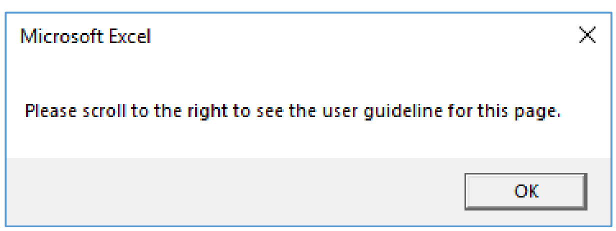
Effluent Quality Criteria				
Parameter	**Abbreviation**	Special limit	Default	unit
Chemical Oxygen Demand	COD	30	30	mgCOD/l
Free and Saline Ammonia	FSA	2	2	mgN/l
Ortho-Phosphate	OP	2.5	2.5	mgP/l
Nitrates	NO_3	1.5	1.5	mgN/
Total Suspended Solids	TSS	10	10	mgTSS/l

Note:

- If no special permission has been granted with respect to having a different effluent criterion, use the defaults special limit values.

- Please click on the Data Reconciliation tab to go to the next step.





2.3 Data Reconciliation

This section requires adding influent measurements that have been made on a yearly, monthly basis or diurnally. The data provided is used to estimate the missing influent measurements through the interpolation and fitting processes (see steps 2 and 3 below). Once this process is complete, the generated influent measurements are combined to characterise the wastewater.

This tool is limited to not more than one-year plant data.

Step 1: Please click on the reset button to empty the data cell, then enter the available plant measurements.

Note:

- **<u>All measurements inputs should have a flow rate measurement.</u>**
- Flowrate and COD are the most important measurements. It is recommended that many successive blanks of COD measurements should be avoided as much as possible to avoid skewed results from the interpolation and fitting processes.
- It is recommended that a considerable amount of data should be entered for more accurate influent wastewater characterisation. The richer the influent data measurements, the more accurate the wastewater characterisation will be.

<u>Please note that Excel will be frozen during the execution of steps 2 to 4.</u>

Step 2: Please click on the "INTERPOLATE" button.

Note:

- This process takes several minutes to complete.
- The interpolation process is for interpolating values to fill in the missing gaps in the measurements.

Step 3: Please click on the "FIT" button.

Note:

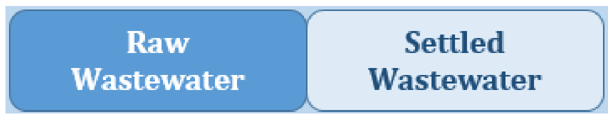
- This process takes about **<u>2 hours</u>** to complete.
- The fitting process is used for calculating the actual values where the interpolated COD and influent flowrate values were estimated.

After the fitting process is complete, you will be taken to the plant configuration tab.

2.4 Plant Configuration

This section consists of selecting the biological nutrient removal plant layout and the type of influent wastewater.

Step 1: Please select between Raw or Settled Wastewater by click on either of the buttons. By selecting the Settled Wastewater, the button will be highlighted as shown below.



Step 2: Please click on one of the buttons to select the biological nutrient removal layout of your choice.

Four configurations have been given. Figure 2 shows the selection of the UCT layout.

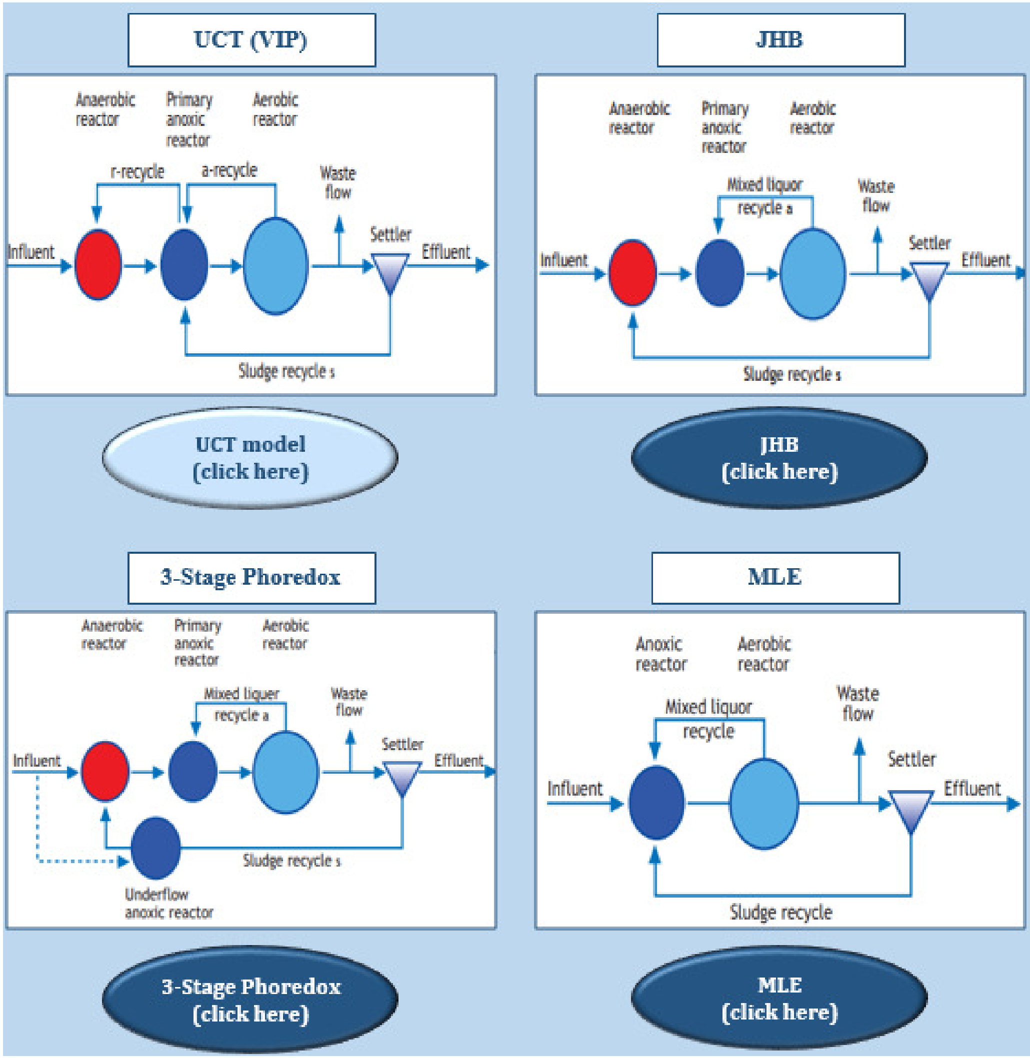


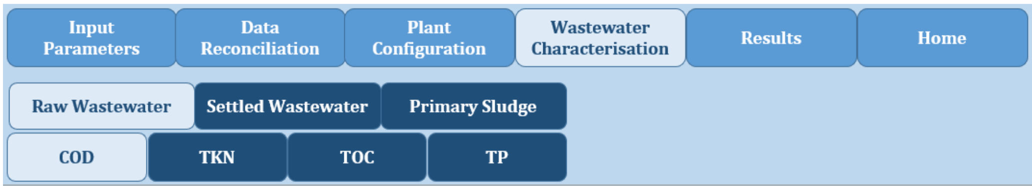
Figure 2: Plant Configuration

By click on any of the buttons, in this case, the UCT layout, the model will take several minutes to run after which you will be taken to the Wastewater Characterisation tab.

2.5 Wastewater Characterisation

The main aim of this page is for educational purposes. The resulting influent wastewater characteristics are used as inputs for the biological nutrient removal models.

Detailed wastewater characterisation (COD, TKN, TOC and TP) is provided under this tab.



The buttons have been colour-coded to make this page easier to navigate. Click on the different button combinations to look at different results.

For example, to view the raw wastewater characterisation of COD, Click on the Raw Wastewater button, then the COD button. The raw and COD button will be highlighted as shown below.

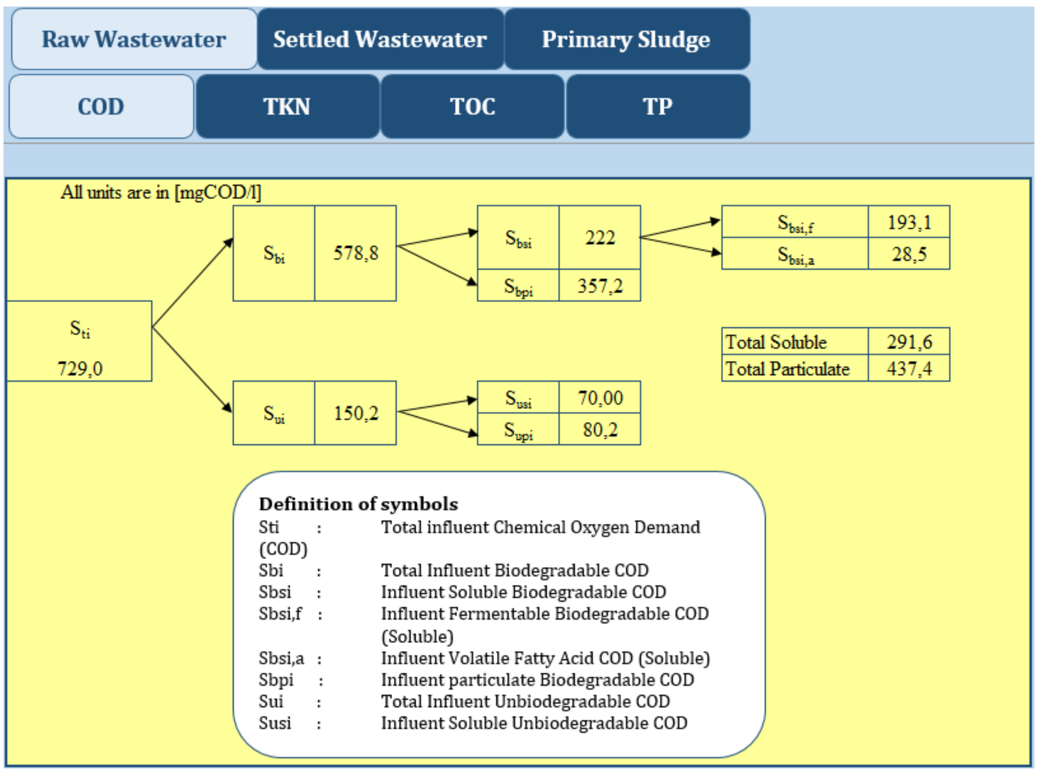


Figure 3: Raw wastewater COD characterisation

2.6 Results

Data from a South African wastewater treatment plant has been used for this demonstration. Several results, based on the inputs, for different biological reactor layouts (i.e. UCT, JHB, MLE and 3-Stage Phoredox) have been summarised.

Figure 4 shows the results' interface once the UCT model has completed running. To view, any of the results click on the buttons.

Figure 4: Interface for the results section

Please choose which results to view by clicking on the respective button.

For example, by clicking on the Biological Reactor button the results will be displayed as shown in *Table* ***5***, and the results will be displayed.

Table 5: Biological reactor results

Biological Reactor | Dewatering Liquor | Effluent Quality | Plant Performance | Recommendation

Parameter	Units	No side-stream treatment	Struvite precipitation	BABE process
Minimum sludge age for nitrification	days	8,35	8,35	8,24
Carbonaceous Oxygen demand	KgO/d	7459	7459	7459
Nitrification oxygen demand	KgO/d	5265	4812	4771
Peak oxygen demand	KgO/d	9766	9552	9501
Aeration Power Requirements	kW	488	478	475
Secondary Sludge produced	kgTSS/d	7647	6784	7561
PolyP produced in WAS (excess P removal)		301	42	283

Note:

- **Effluent Quality**

  The effluent quality results highlighted in red (see *Table* ***6***) are those that exceed the effluent quality limit (see *Table* ***4***).

Table 6: Effluent quality results

Biological Reactor | Dewatering Liquor | Effluent Quality | Plant Performance | Recommendation

Parameter	Units	No side-stream treatment	Struvite precipitation	BABE process
Effluent COD concentration	mgCOD/l	70,00	70,00	70,00
Effluent Ammonia	mgN/l	2,20	2,20	2,20
Effluent NO_3 conc (denitrification)	mgN/l	5,10	4,75	4,76
PO4	mgP/l	0,89	0,91	1,07

- **Plant Performance**
  - The plant performance was evaluated based on two indices, namely the Effluent Quality Index (EQI) and the Operational Cost Index (OCI).
  - The impact of returning dewatering liquor at the different percentage on the EQI and OCI has been summarized in several graphs as shown in Figure 5.

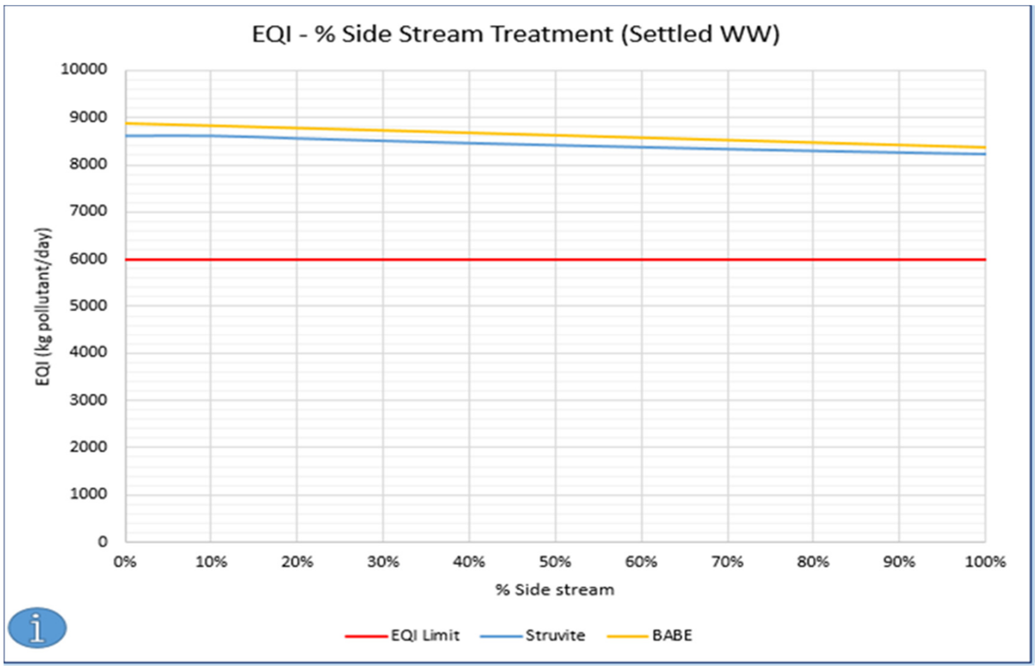
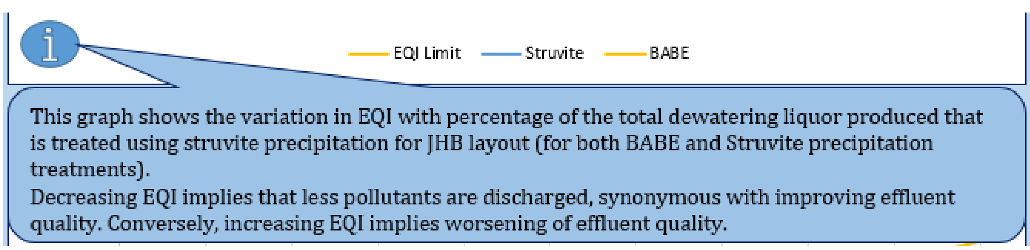


Figure 5: Example EQI graph

Please click on the info button for more information about interpreting the graph.



3. TOOL DEMO

PPET will be used primarily for evaluating the impact of the return liquors on the effluent quality and operational cost of the plant. The tool's results are estimates and are not to be used as the final figures. For a demonstration, the impact of return dewatering liquors on the wastewater treatment plant was analysed using three South African wastewater treatment plants. Table 7 summarises the plant's information.

Table 7: Plant information

Parameter	Plant A	Plant B	Plant C	Unit
Reactor Layout	UCT	3-Stage Phoredox	JHB	-
Raw WW Flowrate	40.00	23.6	4.02	Ml/d
Settled WW Flowrate	39.6	23.36	4.02	Ml/d
Primary Sludge Flowrate	0.4	0.24	0.0	Ml/d
Influent COD Load	17 386.0	17 736.0	1 886.0	kgCOD/d
Influent TKN Load	1915.0	1 539.0	218.9	kgN/d
Influent TP Load	515.7	533.5	36.7	kgP/d
Volume of anaerobic reactor	1 010.0	6 656.0	405.0	m^3
Volume of anoxic reactor	2376.0	15 660.0	1 158.0	m^3
Volume of aerobic reactor	2554.0	16 835.0	4 225.0	m^3

It was found that there is an added benefit of better effluent quality when a side-stream process is used. The high the percentage of dewatering liquor treated in the side-stream process before being returned to the reactor, the better the effluent quality. Struvite precipitation process achieved lower phosphorus concentration while the BABE process led to lower nitrate concentration in the effluent. The operational cost varied for the different plants based on their influent characteristics and operational parameters. For more information about the tool's results please refer to section 5.6 of the Detailed Report.