Performance evaluation of an activated sludge process using a personal computer spread sheet

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Abstract

The University of Cape Town's steady state model of the activated sludge process was entered into a spread sheet on a desk-top microcomputer, together with the actual analytical and operational data from a nutrient removal activated sludge plant. With the aid of this spread sheet, it was possible to conduct an in-depth evaluation of the process from both a theoretical and practical point of view, all within a few minutes. Such evaluations are especially useful when endeavouring to optimise the processes, or when investigating operational problems within the process itself.

Introduction

The general activated sludge model developed by the University of Cape Town (UCT) has been shown to correctly predict, with remarkable accuracy, the performance of both pilot (Ekama and Marais, 1978; Van Haandel and Marais, 1981) and full-scale plants (Nicholls *et al.*, 1982). Until recently the use of this model was confined to persons having access to main-frame computers. To overcome this problem, the steady state model equations were applied to a spread sheet which was used in conjunction with a microcomputer. This paper describes how this was achieved and further demonstrates how this facility can be used to optimise performance.

The spread sheet program

There are many commercially available spread sheets which all have similar facilities. The spread sheet program is a powerful program which allows easy manipulation and calculation of data without any *knowledge of programming*. The data are arranged in rows and columns, i.e. in a matrix. To distinguish between the rows and columns, the rows have numeric values from 1 to 2 000 and the columns have characters such as A, B, C, . . .Z.(;), AA, AB . . .AZ.(;), BA, BB . . .BK, etc. Each point on the matrix is therefore defined by its row and column identity. Furthermore, each point is either a *label* or a *value*. The *labels* can be characters or figures which make up headings or titles on the spread sheet. A *value* on the other hand, can either be a variable to which a specific value is given, or an equation which may or may not incorporate variable values. When an equation is inserted into a matrix point, only the value of this equation will be reflected on the screen.

The UTC general activated sludge steady state model was applied to a spread sheet, by inserting firstly, the values for all the variables, and secondly, by the equation describing the steady state activated sludge process, into the appropriate space on a spread sheet. Using a spread sheet program, all the equations were solved simultaneously, resulting in predictions of the performance of the process.

Should it be necessary to change the value of any variable, it is only necessary to change this value at the entry point, i.e. where it is defined. All other changes, for example, within equations, are then reflected automatically throughout the work sheet. This feature highlights the real power of the spread sheet program, particularly in this model application, where conditions are frequently changed to optimise the process.

In the following section, an example of how the sheet was developed is given, as well as the constants and equations used, and into which matrix points they were inserted. Once the spread sheet had been set up, the model predictions could be calculated within seconds.

Application of the UCT steady state model to a spread sheet

The spread sheet was developed for a five-stage Bardenpho process (Barnard, 1975), designed to remove both nitrogen and phosphorus biologically. With unfavourable feed sewage characteristics, consistent plant performance may be difficult to achieve, and the UCT model may be used advantageously to determine the best method of optimising plant performance.

The equations used describing the UCT model were taken from two sources:
(*) Theory, design and operation of nutrient removal activated sludge processes (Water Research Commission, 1984).
(**) Kinetics of biological phosphorus removal (Wentzel *et al.*, 1985).

The equations used in this paper have been given the same numbers as in the above publications, for easy cross-referencing. This character before the equation will refer to which of the abovementioned publications is being referenced, i.e. either * or ** above. The definitions of the various symbols used are detailed in Appendix 1.

In setting up the spread sheet, only the first three columns are used and approximately 200 rows. The first two columns (A and B) have been reserved for naming constants or variables, while in the third column the values of the corresponding constants, variables or equations are given.

The inputs into the spread sheet UCT model can be further divided into three groups:

- Kinetic constants;
- Plant and operational details; and
- Sewage characteristics.

● Kinetic constants

The kinetic constants used in the model are given in Table 1. Some of these, viz. (b_{hT}, μ_{nmT}, k_{1T} and k_{3T}) are temperature dependent and are automatically corrected for temperature when the work sheet is calculated.

The value of % volatile solids (f_i) and the specific growth

Received 19 January 1987.

rate of nitrifiers (μ_{nm20}), should be measured (Ekama and Marais, 1978), since these values can vary from plant to plant.

If these constants are used in any equation in the spread sheet, they will be referred to by this location e.g. the value of Y_h in Table 1 has a location C11 and the value of f_n a location C25.

- **Plant and operational details**

The actual operating conditions at the Johannesburg Northern Works are reflected in Table 2.

TABLE 1
KINETIC CONSTANTS

Column No.	A and B	C
8	Kinetic constants	
9		
10	f_v	1,48
11	Y_h	0,45
12	f	0,20
13	f_p	0,02
14	f_f	0,72
15	b_{h20}	0,24
16	b_{hT}	0,23
17	μ_{nm20}	0,36
18	μ_{nmT}	0,32
19	k_{120}	0,72
20	k_{1T}	0,72
21	k_{2T20}	0,1008
22	k_{2T}	0,0933
23	k_{3T20}	0,0768
24	k_{3T}	0,0746
25	f_n	0,10
26	α	0,03
27	c_{sp}	0,50
28	k_p	0,06
29	n	1,00

TABLE 2
PLANT AND OPERATIONAL PARAMETERS
JOHANNESBURG NORTHERN WORKS

	Column	
Row No.	A and B	C
31	Plant details	
32		
33	Mass fractions	
34		
35	f_{xa} Anaerobic	0,08
36	f_{x1} Primary anoxic	0,16
37	f_{x3} Secondary anoxic	0,16
38	f_{xdm} Allowable	0,32
39	No. anaerobic basins	1,00
40	Flows Mℓ/d	
41		
42	Settled sewage feed	15,00
43	Returned sludge	42,00
44	MLSS recycle	102,00
45	Waste sludge	0,78
46	Total volume	29,18
47		
48	Recycle ratios	
49		
50	s Sludge return	2,8
51	a MLSS recycle	6,8
52	R_s Sludge age	37
53	Dissolved oxygen	
54		
55	Primary aeration	2,00
56	Returned sludge	1,00
57	Total power kW.h	
58	Total kW.h	2 100
59	Temperature °C	19
60		

Note $f_{xdm} = f_{x1} + f_{x3}$ the value in location C38 would be C36 + C37.

- **Sewage characteristics**

The composition of sewage received at treatment plants can vary considerably, depending on, for example, the length of outfall sewer and the presence of industrial effluents. This means that these inputs will also vary from one plant to the next. In fact, sometimes they can vary from day tot day. As a result of this, Ekama and Marais (1978) developed a system whereby the biodegradable substrate in the feed could be assessed on a uniform basis. This required measurement of the following fractions:

- Unbiodegradable particulate COD (f_{up})
- Soluble and unbiodegradable COD (f_{us})
- Readily biodegradable COD (f_{bs})

In addition, the feed COD, TKN and total phosphorus concentrations are also required together with the nitrate concentration (N_{nr}) in the returned sludge. As the nitrate in the returned sludge is a consequence of the model predictions, the initial input value is unknown. To overcome this problem, an arbitrary value is given to effluent nitrate concentrations (N_{nr}). The model then predicts the effluent nitrate concentrations (N_{te}). This value is then used as a new value of N_{nr} and a N_{te} estimated a second time. After a number of such iterations, $N_{nr} = N_{te}$. At this stage the true input value for N_{nr} can be obtained.

The sewage characteristics entered into the spread sheet for the Johannesburg Northern Works are given in Table 3. These values can obviously be replaced by any measured values for specific sewages and operating conditions.

TABLE 3
SEWAGE CHARACTERISTICS
JOHANNESBURG NORTHERN WORKS

Row No.	Column No.	
	A and B	C
61	Sewage characteristics	
62		
63	Feed conc m/ℓ	
64	COD	584
65	TKN as N	46
66	Total P as P	20
67		
68	COD fractions	
69	f_{bs}	0,24
70	f_{up}	0,07
71	f_{us}	0,05
72		
73	Estimation of NO_3	
74	N_{nr} returned	3,17
75	N_{te} returned	3,17
76		
77	P removal MX_{ah}/Q	
78	1st MX_a/Q_h	True/False
79	MX_{ah}/Q Temporary	810
80		

With all the above input values the model can now be applied to predict plant performance.

Prediction equations

The UCT model can be subdivided into a number of sections:

- Composition of the feed COD
- Composition of the MLSS
- Nitrification
- Denitrification
- Oxygen utilisation
- Biological phosphorus removal

Since each section is not self-supporting, the order in which they are put into the whole sheet is important, because at times it is necessary to solve one equation first, and to use the data obtained in subsequent equations.

Composition of the feed COD

The UCT group divides the feed COD into a number of different fractions, which either directly or indirectly, describe the availability of COD to microorganisms (WRC, 1984).

These fractions are as follows:

Concentration of unbiodegradable inert COD in feed	(S_{ui})
Concentration of unbiodegradable particulate inert COD in feed	(S_{upi})
Biodegradable COD concentration in feed	(S_{bi})
Readily biodegradable COD concentration in feed	(S_{bsi})
Readily biodegradable COD concentration in anaerobic reactor	(S_{bsa})
Readily biodegradable COD concentration available for conversion	(S'_{bsi})
Readily biodegradable COD concentration in last anaerobic reactor	(S_{bs})

The values of all the above fractions can be calculated using the equations below. These are inserted in Column C adjacent to the appropriate text which is located in Columns A and B in the spread sheet.

$$S_{ui} = (f_{us} + f_{up})\,S_{ti} \qquad * \; 2.5$$

$$S_{upi} = f_{up}\,S_{ti} \qquad * \; 2.4$$

$$S_{bi} = S_{ti}\,(1 - f_{up} - f_{us}) \qquad * \; 2.7$$

$$S'_{bsi} = S_{bsi} - r.\,8{,}6.\,N_{nr} - s\,3{,}0 \qquad ** \; 2$$

$$S_{bsa} = (f_{bs}\,S_{bi} - S_{bs})/(1 + s) \qquad * \; 7.1b$$

$$\Delta S_{bs} = s(8{,}6\,N_{ns} + 3{,}0.0_s) + 3{,}0.0_i \qquad * \; 7.2b$$

$$S_{bsn} = \frac{S'_{bsi}/(1 + r)}{[1 + K\frac{f_{xa}}{N}\frac{MX_{ah}}{Q}/(1 + r)]^n} \qquad **9$$

Equation **2 has been modified slightly to include the dissolved oxygen concentration in the returned sludge.

To illustrate how these equations are entered into the worksheet, consider:

$$S_{ui} = (f_{us} + f_{up})\,S_{ti} \qquad * \; 2.5$$

f_{us}, f_{up} and S_{ti} are in locations C71; C70 and C64 respectively, hence the equation:

$$S_{ui} = (f_{us} + f_{up})\,S_{ti} = (C71 + C70)*C64$$

Sometimes the values determined by one equation are used in a second equation, e.g.:

$$S_{bsi} = f_{bs}\,(S_{bi}) \qquad * \; 2.8a$$

S_{bi} is determined by Eq. *2,7 located in C84 and f_{bs}, a variable, located in C69. Hence the expression entered in location C85 is

(C84*C69)

Table 4 depicts where these equations are entered into the spread sheet.

TABLE 4
CALCULATED COD CHARACTERISTICS DISPLAYED ON THE SPREAD SHEET

Row No.	Column No.	
	A and B	C
81	COD fractions	
82	S_{ui}	29
83	S_{upi}	60
84	S_{bi}	494
85	S_{bsi},	118
86	S_{bsi}	39
87	S_{bsa}	9
88	S_{bsn}	3,6
89		

Composition of the mixed liquor suspended solids

The UCT group have divided the mixed liquor suspended solids (X_t) into a number of fractions, as depicted below:

● Active mass	(X_a)
● Endogenous mass	(X_e)
● Inert mass	(X_i)
● Volatile mixed liquor	(X_v)
● Total mixed liquor	(X_t)
● Mass of non-polyP organisms in system	(MX_{ah}/Q)

Each of the above fractions may be described by equations which are either related to each other ot to the input parameters discussed earlier.

$$X_a = \frac{S_{bi}\,Y_h R_s}{(1 + b_h R_s)} \qquad * \; 4.10$$

$$X_e = f\,b_h\,R_s\,X_a \qquad * \; 4.11$$

$$X_i = \frac{f_{up}\,S_{ti}\,R_s}{f_{cv}} \qquad * \; 4.12$$

$$X_v = X_a + X_e + X_i \qquad * \; 4.13$$

$$X_t = X_v/f_i \qquad * \; 4.14$$

$$MX_{ah}/Q = \frac{[S_{bi} - (S'_{bsi} - (1 + r)S_{bsN})]Y_h\,R_s}{(1 + b_h\,R_s)} \qquad ** \; 10$$

Each of these equations is then inserted into the spread sheet as indicated below:

> *MX_{ah}/Q is estimated in conjunction with Eq. **9 (S_{bsn}) by* iteration and has been located in position C78 and C79. C78 gives MX_{ah}/Q a value of zero after which it then calculates a value for MX_{ah}/Q in location (C97) which is the same value as C79.
>
> The iteration is repeated until the value in C79 remains constant. In the spread sheet used, the values entered in C78 and C79 are @IS ERROR (C85) and @IF (C78, 0, C97). The method of iteration will depend on the type of spread sheet used.

Nitrification

The nitrogen utilised by the organisms for growth is given by Eq. 4.23 and the nitrification capacity by Eq. 5.29.

The nitrification capacity is a very useful parameter, for its magnitude can give the operator an idea of what nitrate concentration could be expected if no denitrification occurred.

TABLE 5
CALCULATED SLUDGE MASS CONCENTRATIONS DISPLAYED ON SPREAD SHEET

Row No.	Column A and B	Column C
90	Fraction of MLSS	
91		
92	X_a	854
93	X_e	1 475
94	X_i	1 512
95	X_v	3 842
96	X_t	5 336
97	$\frac{MX_{ah}}{Q}$	810
98		

$$N_s = \frac{f_n V X_v}{R_s Q} \qquad \text{derived from} \quad * \ 4.23$$

$$N_c = N_{ti} - N_{te} - N_s \qquad * \ 5.29$$

N_{te} is the total nitrogen in the effluent. In the warm weather conditions in Johannesburg, a value of 2 to 3 mg/ℓ is often obtained. Hence, for the purpose of this excercise it was assumed that
$N_{te} = 2,5$.
The insertion of the above equations into the spread sheet is given in Table 6.

TABLE 6
CALCULATION OF NITRIFICATION CAPACITY AND NITROGEN IN MLSS

Row No.	Column No. A and B	C
99	Nitrification	
100		
101	N_s	10,38
102	N_c	33,34
103		

Denitrification

The concept of denitrification potential is described in WRC(1984). This parameter estimates the capacity of the anoxic reactors to remove nitrate from the feed sewage characteristics and the plant operating conditions. Again, it is a most informative parameter when compared with the actual amount of nitrogen removed in the anoxic reactor, the difference will give an indication as to how efficiently the denitrification process is working.

The equations for calculating the denitrification potential in both the primary and secondary anoxic reactors are given below:

$$D_{p1} = S_{bi}[\alpha + K_2 f_{xi} Y_h R_s/(1 + b_h R_s)] \qquad *6.20$$

$$\alpha = f_{bs}(1 - f_{cv} Y_h)/2,86$$

$$D_{p3} = S_{bi} f_{x3} K_3 Y_h R_s/(1 + b_{hT} R_s) \qquad *6.22$$

The total denitrification capacity is given by:

$$D_p = D_{p1} + D_{p3}$$

For a Bardenpho process the nitrate in the effluent can be estimated from the equation given below. This equation takes into account the dissolved oxygen (DO) concentrations in the streams entering both the anoxic and anaerobic reactors.

$$N_{ne} = \frac{\left[\frac{N_c}{a + S + 1} + \frac{O_a}{2,86}\right]\left[a + \frac{K_{2T}}{K_{3T}}(s + 1) \frac{sO_s}{2,86}\right] - D_{pp}}{\frac{K_{2T}}{K_{3T}} + S\left[\frac{K_{2T}}{K_{3T}} - 1\right]} \qquad *6.24$$

D_{pp} is similar to Eq. 6.20 except that f_{xi} is replaced by f_{xdm}, i.e. anoxic mass fraction.

The above equations are inserted into the spread sheet as depicted in Table 7.

TABLE 7
ESTIMATION OF DENITRIFICATION POTENTIALS AND NITRATE IN THE EFFLUENT

Row No.	Column No. A and B	C
104	Denitrification pot	
105		
106	D_{p1} Primary	26,6
107	D_{p3} Secondary	9,6
108	Total	36,2
109	D_{pp} maximum	39,4
110		
111	Effluent NO_3	3,17
112		

Oxygen utilisation

The model considers three different oxygen demands viz. oxygen required for carbonaceous material $M(0_c)$; oxygen required for nitrification $M(0_n)$; oxygen "recovered" via denitrification $M(0_d)$

The total oxygen demand $M(0)_T$ may be expressed as follows:

$$M(0)_T = M(0_c) + M(0_n) - M(0_d)$$

The relevant equations for each of the above parameters are given below and their inclusion in the spread sheet is given in Table 8.

$$M(O_c) = M(S_{ti})(1 - f_{us} - f_{up})(1 - f_{cv} Y_h) + f_{cv}(1 - f)_{bh} \frac{Y_h R_s}{(1 + b_h R_s)} \qquad * \ 4.15$$

$$M(O_n) = 4,57 \, M(N_{ne}) \qquad * \ 5.39(a)$$

$$M(O_d) = 2,86 \, (N_c - N_{ne})Q \qquad * \ 6.32$$

TABLE 8
ESTIMATION OF THE OXYGEN DEMAND

Row No.	Column No. A and B	C
113	Oxygen demand	
114		
115	$M(0_c)$ Carbonaceous	6 016
116	$M(0_n)$ Nitrification	2 385
117	$M(0_d)$ Denitrification	1 294
118	$M(0)_T$ Total	7 005
119		

Biological phosphorus removal

The UCT group have developed a parametric and a kinetic model for excess biological phosphorus removal. Both of these models have been included in the spread sheet.

The parametric model (Siebritz *et al.*, 1983) requires the following values which then result in an equation which estimates the mass of phosphorus that can be removed.

S_{bi} readily biodegradable COD in influent (mg/ℓ)
S_{bsa} readily biodegradable COD conc. in anaerobic reactor (mg/ℓ)
P_f excess phosphorus removal propensity factor (mg/ℓ)
coefficient of excess phosphorus removal
P_s phosphorus removal (mg/ℓ)

The equations describing S_{bi} and S_{ba} were considered previously (C84 and C87 respectively) and those describing P_f and P_s are given below:

$$P_f = (S_{bsa} - 25)\, f_{xa} \qquad *7.5$$

$$\gamma = 0{,}35 - 0{,}29 \exp(-0{,}242\, P_f) \qquad *7.7$$

$$P_s = S_{ti}\left[\frac{(1 - f_{us} - f_{up})}{(1 + b_{hT}\, R_s)}\, Y_h\, (\gamma + f_p\, f b_{hT}\, R_s) + f_p\, \frac{f_{up}}{f_{cv}}\right] \qquad *7.6$$

The equations describing the kinetic model (Wentzel *et al.*, 1985) are given below:

The magnitude of phosphorus release in the nth reactor is given by P_n:

$$\Delta P_n = C_{sp}\, S'_{bsi}\left[\frac{1}{\left\{1 + K\dfrac{f_{xa}}{N}\dfrac{MX_{ah}}{Q}/(1+r)\right\}^{n-1}} - \frac{1}{\left\{1 + K\dfrac{f_{xa}}{N}\dfrac{MX_{ah}}{Q}/(1+r)\right\}^{n}}\right] \qquad **11$$

The magnitude of phosphorus removal in the aerobic reactor is given by:

$$P\ (\text{removal}) = (a^1 - 1)P\ (\text{release}) + P\ (\text{metabolic}) \qquad **14$$

$$P\ (\text{metabolic}) = 0{,}03\ MX_v/(Q.R_s) \qquad **15$$

a^1 could have values ranging from 1,145 to 1,198

Since the exact value of a^1 is unknown, the predicted phosphate removal concentration is inaccurate. The UCT group are working on this problem and once resolved, it will be an easy matter to include the revised equations into the spread sheet program. The format of these equations in the work sheet is given in Table 9.

At this stage all the steady state equations have been included in the spread sheet.

TABLE 9
ESTIMATION OF THE VARIOUS PARAMETERS ASSOCIATED WITH BIOLOGICAL PHOSPHATE REMOVAL

Row No.	Column No.	
	A and B	C
120	Phosphate removal (Kinetic)	
121		
122	Parametric model	
123		
124	S_{bi}	494
125	S_{ba}	9,6
126	P_f	0,00
127	γ	0,06
128	P_s	2,60
129		
130	Kinetic model	
131		
132	ΔP_n	11,1
133	P removed	6,9
134		

Check on the spread sheet UCT model

To check the spread sheet UCT model, input data given in *Theory, Design and Operation of Nutrient Removal Activated Sludge Processes* (WRC, 1984), (refer to Tables 4.3; 5.2 and 6.1), was inserted into the spread sheet. The program was iterated until N_{nr} and N_{te} (C74 and C75) had the same value and MX_{ah}/Q temporary at site C79 remained constant. The various results were then checked against the values given in Table 7.1 of this document. The agreement was excellent, indicating that this model was free of logic errors.

Incorporation of actual plant performance into the spread sheet

The next requirement was to compare plant performance with model predictions. Up to this point in the development, only the model has been entered into the spread sheet.

To improve the usefulness of the spread sheet, the actual analytical data representing the plant performance were added. The parameters considered were soluble ammonia, nitrate and phosphate in each reactor, as well as the effluent. Details of how they were entered into the work sheet are given in Table 10.

With all the analytical plant data entered, the next step was to conduct mass balances over each reactor with respect to nitrogen and phosphorus. The equations describing the mass balance were inserted in the appropriate location, as depicted in Table 11. A negative value indicates a release of phosphorus.

Reporting on plant performance

With all the information on the model and the plant entered into the work sheet what is now required is that this information be processed into a meaningful report which could then be disseminated to operators and managers. To achieve this objective a suitable report is formatted in a different area of the same work sheet. An example of a report, detailing where it is included in the work sheet is given in Appendix 2.

Relevant information is extracted automatically from Column C and inserted into the report where desired. For example, consider the actual MLSS concentration in L119 — the value inserted here would be C173, which is the value originally inserted into the spread sheet. Should additional information be required in the report this can readily be added, e.g. volatile acid concentration J84 to N84.

This section illustrates the power of the spread sheet where data processing and report writing are handled simultaneously.

Problem solving using the spread sheet model

Plant data used in case studies

Three different applications of the UCT model to solve plant problems will be discussed. Data used were obtained from the Johannesburg Bushkoppie Plant and shown in Table 12.

TABLE 10
ANALYTICAL DATA ENTERED IN THE SPREAD SHEET

Row No.	Column No.		Row No.	Colum No.	
	A and B	C		A and B	C
135	Analytical analyses		157	Re-aeration	
136			158	Ammonia	0,80
137	Anaerobic		159	Nitrate	2,10
138	Ammonia	6	160	o - P	6,40
139	Nitrate	0,30	161		
140	o - P	14	162	Effluent	
141			163	Total COD	48,00
142	Primary anoxic		164	TKN	2,00
143	Ammonia	3,40	165	Ammonia	0,80
144	Nitrate	2,30	166	Nitrate	4,00
145	o - P	11,00	167	Total P	7,00
146			168	o - P	6,20
147	Primary aeration		169	Suspended solids	25,00
148	Ammonia	0,90	170		
149	Nitrate	5,80	171	Suspended solids	
150	o - P	7,40	172	Returned sludge	6 600
151			173	MLSS	4 900
152	Secondary anoxic		174	MLVSS	3 528
153	Ammonia	1,00	175	Total P MLSS	—
154	Nitrate	3,70	176	TKN MLSS	—
155	o - P	8,00	177	SVI	190
156			178	DSVI	170
			179		

TABLE 11
MASS BALANCE CALCULATION FOR NITRATE, AMMONIA AND PHOSPHORUS

Row No.	Column No.	
	A and B	C
180	Mass balances	
181		
182	Nitrate	
183	Anaerobic	10,06
184	Primary anoxic	16,2
185	Secondadry anoxic	2,1
186		
187	Ammonia	
188	Anaerobic	- 5,50
189	Primary anoxic	33,6
190	Primary aeration	2,6
191	Secondary anoxic	- 0,10
192	Re-aeration	0,20
193		
194	Phosphorus	
195	Anaerobic	- 15,84
196	Primary anoxic	- 13,08
201	Secondary anoxic	- 0,60

Evaluation of correctness of plant data

Wentzel *et al.* (1985) have indicated that the feed sewage characteristics play a vital role in the biological phosphorus removal process. From their work and from the feed sewage characteristics measured at Bushkoppie, good nitrogen and phosphorus removal would have been expected. In practice however, as can be seen from Table 12, the nutrient removal was not acceptable, with effluent concentrations of 14 mg N/ℓ nitrate and 2 mg P/ℓ phosphate. In order to establish why the plant was not performing as expected, an in-depth evaluation of the process was conducted. All the relevant information was fed into the spread sheet and then the results calculated (Appendix 3). Arising out of this assessment, the following was noted:

- The readily biodegradable COD concentration in the feed was most favourable from a phosphorus removal point of view.
- With a TKN/COD ratio of 0,07 good nitrogen removal would be expected. This was not the case.
- The dissolved oxygen concentrations in the main aeration basin were excessively high at 4 to 6 mg/ℓ. The reason for this was inadequate oxygen control.
- The SVI and DSVI were extremely favourable.

In any evaluation of a plant the first point is always to establish that the data are correct and meaningful. Ekama *et al.*, 1979 have described methods where nitrogen and COD mass balances were estimated across the plant and recoveries between 90 and 110 % would be considered acceptable. All the relevant information to conduct these balances was incorporated into the work sheet, and it was a matter of extracting this information. Only a nitrogen balance was possible at Bushkoppie, since there were no facilities to measure the oxygen utilisation rate of the mixed liquor, and therefore, COD balance was not possible. Details of the nitrogen balance are given in Table 13.

The nitrogen recovery as shown in Table 13 was totally unacceptable.

Since all the flow meters on this plant are checked regularly and are known to have been accurate, the only source of errors could be sampling and/or the chemical analysis.

In order to locate the error, theoretical and actual nitrogen removal in the primary anoxic reactor was checked and found to be 29,4 mg N/ℓ and 23,6 mg N/ℓ of feed respectively. This agreement was considered acceptable, particularly as the theoretical value did not take into account the oxygen in the recycled mixed liquor which would decrease this value. The theoretical and actual effluent nitrate concentrations were then checked and found to be 9 mg N/ℓ and 14 mg N/ℓ respectively, which indicated that more than the measured nitrogen must have been available for nitrification i.e. 5 mg/ℓ.

TABLE 12
OPERATING CONDITIONS AND AVERAGE (1 MONTH) ANALYTICAL DATA FOR JOHANNESBURG BUSHKOPPIE PLANT

Sample Point	COD	S_{bs}	Nitrogen TKN	NH_4	NO_3	Phosphorus Total	ortho	Susp. solids
Influent ex ● Balancing tank	671	134	48,2			4,8		
Zone : Anaerobic 1				17	0,2		4	
Anoxic 2				9,7	2,2		9,1	
Aerobic 3				0,1	14,2		3,1	2 720
Final effluent	8		1,8	0,2	14,8	3,2	2,1	40

Results expressed as mg/ℓ, where applicable

TABLE 13
NITROGEN MASS BALANCE ACROSS THE JOHANNESBURG BUSHKOPPIE PLANT

	mg N/ℓ
TKN feed	48,2
TKN effluent	1,8
Nitrate effluent	14,8
Loss of N due to denitrification	35,8
Nitrogen in waste sludge	11,2
Nitrogen recovered	63,6
% nitrogen recovered	132

Furthermore, approximately 12 mg N/ℓ nitrate was removed in practice in the anaerobic reactor, whereas the model assumed that all the nitrate was removed in the anoxic reactors (this is the ideal situation). Therefore, the total unaccountable nitrate nitrogen, when compared with the model, was (5 + 12) = 17 mg N/ℓ. The only possible explanation for this difference was that the original estimate of the feed TKN was low, and instead of 48,2 mg N/ℓ, it should have been 48,2 + 17 = 65 mg N/ℓ.

In order to check the latter point, all the concentrations of the feed TKN and COD were averaged from the time the plant was commissioned and compared with the values under discussion, as depicted in Table 14.

TABLE 14
COMPARISON OF AVERAGE TKN AND COD CONCENTRATIONS WITH ACTUAL CONCENTRATIONS IN THE TEST PERIOD

	TKN (mg N/ℓ)	COD (mg/ℓ)	TKN/COD
Average for period under discussion	48	670	0,07
Overall average	66	930	0,08

The overall average value of the TKN given in Table 14 of 66 mg N/ℓ, was almost identical with the estimated value of the TKN of 65 mg N/ℓ. As the COD values could not be checked, in all probability, the measured value would also be too low.

Therefore, using the model and the spread sheet, it was not only possible to highlight an erroneous result, but also to suggest what the correct result might have been. To complete this investigation the corrected TKN and COD values were inserted into the model and the plant performance predicted, as reflected in Table 15.

TABLE 15
COMPARISON BETWEEN THE PREDICTED AND ACTUAL EFFLUENT NITRATE AND PHOSPHATE CONCENTRATIONS

	Actual	Predicted
Effluent nitrate (mg N/ℓ)	14,8	11,8
Effluent phosphorus (mg P/ℓ)	2,1	2,9

The agreement in Table 15 was within 10%, which again indicated that the estimate of TKN and COD concentrations was reasonable.

Optimisation of the Bushkoppie process

Examination of Table 12 shows that the effluent phosphorus concentration did not meet the 1 mg/ℓ effluent standard. From the work of Siebritz *et al.* (1983) there are two changes which could improve the situation, viz. to reduce the nitrate concentration in the returned sludge stream entering the anaerobic reactor; and to increase the readily biodegradable COD concentration in the feed.

To investigate these points further, a range of nitrate concentrations in the returned sludge from 0 to 7 mg N/ℓ was entered into the spread sheet and their effect on phosphate removal calculated. The results are depicted in Fig. 1.

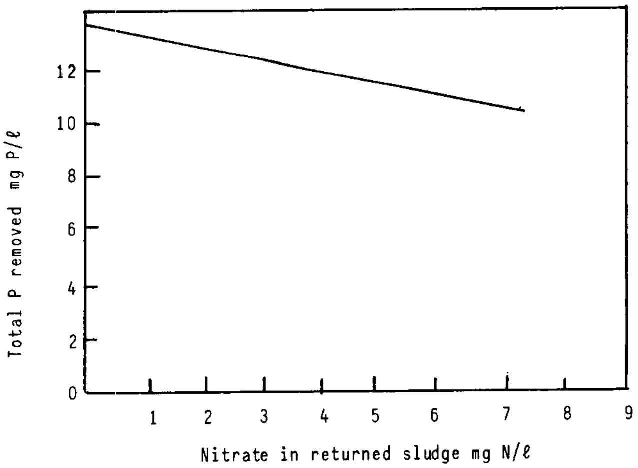

Figure 1
Theoretical concentration of nitrate in the return sludge which would result in an effluent phosphorus concentration of ±1 mg P/ℓ.

From Fig. 1 the maximum permissible nitrate concentration in the returned sludge was, theoretically, 7 mg N/ℓ. From Table 14 this concentration was 14 mg/ℓ, which meant that an additional 7 mg N/ℓ must be removed via denitrification. There were two ways of achieving this removal:

- The returned sludge could be retained in a denitrification reactor for a short period before being discharged to an anaerobic reactor (Pitman, 1986).
- The feed readily biodegradable COD concentration to the reactor could be increased by elutriating biodegradable COD from the primary sludge. This could be achieved by recycling sludge through the primary sedimentation tanks (Pitman, 1986).

The first suggestion requires structural modifications to the plant, while the second requires only pumping, which is far easier and cheaper to implement. In order to investigate how much COD had to be solubilised, a range of S_{bs} values was entered into the spread sheet and the effects on both nitrate and phosphate removal calculated.

The results are given in Fig. 2.

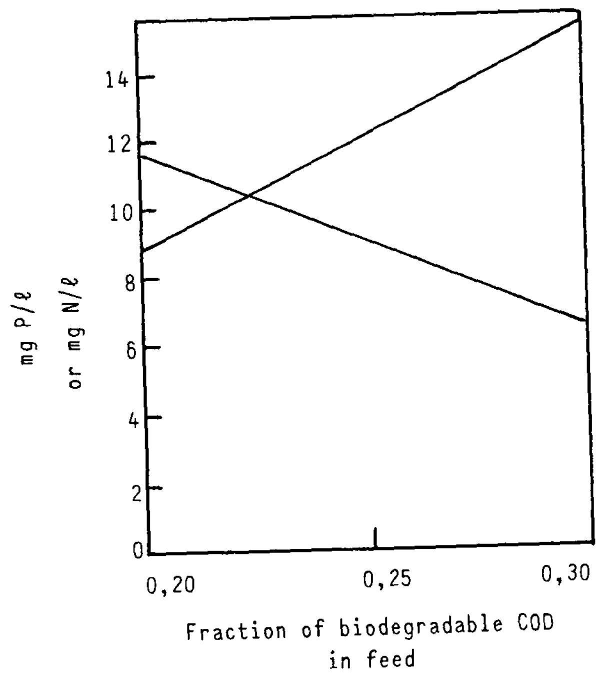

Figure 2
The theoretical relationship between effluent nitrate concentration and mass of P removed at Bushkoppie at various fractions of readily biodegradable feed COD.

As shown in Fig. 2, it was evident that the fraction of biodegradable COD in the feed should be increased from 0,20 to 0,30 if 7 mg N/ℓ were to be denitrified and an effluent phosphorus concentration of less than 1 mg P/ℓ was to be achieved.

With the aid of the model, the works manager can test the various options available, and also obtain an idea of how to achieve a certain objective, e.g. how much solubilisation of the feed COD was required. The net overall result would certainly be an improvement in effluent quality.

Comparison of a three-stage versus a five-stage option

Where there appears to be a nitrate problem as described above, a five-stage process may have been more desirable, as additional nitrate would be removed in the second anoxic reactor. Performance of the plant operated in a five-zone mode can easily be predicted by making use of the same spread sheet, as already described. In this instance, the mass fraction of MLSS in the second anoxic zone was increased from 0 to 0,17 i.e. $f_{x3} = 0,17$. The results were then calculated and are given in Appendix 3 and a summary is given in Table 16.

TABLE 16
A THEORETICAL COMPARISON BETWEEN A 3 AND 5 STAGE BUSHKOPPIE TYPE PLANT

	3-Stage process	5-Stage process
Effluent nitrate (mg/N/ℓ)	11,8	1,0
Mass of phosphorus removal (mg P/ℓ)	8,9	13,2
Total oxygen demand (kg O/d)	30 200	28 990

As can be seen in Table 16 the five-stage process with these feed characteristics would theoretically be preferable. Furthermore, the second anoxic reactor was estimated to remove approximately 14 mg N/ℓ, which would account for the lower oxygen demand. In addition, the lower effluent nitrate concentration would greatly improve the mass of phosphorus which could be removed.

This again highlights the usefulness of the model and how easily investigations can be carried out by works managers.

Conclusions

The use of the spread sheet technique has permitted the sophisticated UCT model to become available to waste-water plant management staff. Works management staff do not require to have any computer programming knowledge to make use of this facility, but must have a good working knowledge of the basic concepts involved.

Repetitive use of this system has resulted in greater confidence on the part of the Johannesburg works management team, the reliability of the model, and its usefulness in solving both day to day and future design problems.

The spread sheet version of the UCT model provides a very useful teaching medium for the training of new staff. Coupling it with interactive videos, would make an even more effective teaching aid. Using the system, the operator can make a change to one parameter in the spread sheet, and immediately see the ripple effect that this change has on other parameters and final effluent quality. A more widespread adoption of this technology will improve the working knowledge of the process by operational staff, and result in a more effectively managed works. As further technological advances are made and more accurate equations become available for the description of various unit processes, these can easily be incorporated into an updated version of the spread sheet.

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Appendix 1

List of symbols

a	Mixed liquor recycle ratio from the aerobic to the anoxic reactors. Subscript o denotes optimum
b_{hT}	Endogenous mass loss rate for heterotrophic organisms at T°C(/d) = b_{h20} (1,029) (T-20)
b_{h20}	The rate at 20°C = 0,24/d
C_{sp}	Stoichiometric ratio ($\Delta P : \Delta S_{bs}$) = 0,5 mg (PO_4-P)/mg COD converted
D_p	Denitrification potential (mg N/ℓ influent)
D_{p1}, D_{p3}	Subscripts 1 and 3 refer respectively to the primary and secondary anoxic zone
D_{pp}	Denitrification potential of the process when the maximum anoxic sludge mass fraction is all in the form of a primary anoxic reactor
f	Unbiodegradable fraction of active mass = 0,20 mg VSS/mg VSS
f_{bs}	Readily biodegradable COD fraction of the influent with respect to the biodegradable COD concentration
f_{cv}	COD to VSS ratio of the volatile sludge mass = 1,48 mg COD/mg VSS
f_i	MLVSS to MLSS concentration ratio of the mixed liquor
f_n	Nitrogen fraction of the MLVSS (mg N/mg VSS) 0,10 mg N/mg VSS
f_p	Phosphorus fraction of the inert MLVSS and endogenous residue MLVSS = 0,015 mg P/mg VSS
f_u	Unbiodegradable COD fractions in the influent (mg COD/mg COD). Additional subscripts p and s refer respectively to particulate and soluble fractions
f_x*	General parameter for sludge mass fractions
	*Additional subscriptions a, b, d, 1, 3 and m refer respectively to anaerobic, total aerobic, total anoxic, primary anoxic, secondary anoxic and maximum unaerated allowable sludge mass fraction
f_{xdm}	Additional subscripts t and m following the d subscript refer respectively to the total and maximum allowable sludge mass fractions
K	General parameter for denitrification rate (mg NO_3/mg VASS.d)
K_1,K_2,K_3	Subscripts 1 and 2 refer respectively to the 1st and 2nd rates in the primary anoxic and 3 to the rate in the secondary anoxic
	Additional subscripts T and 20 refer to T°C and 20°C respectively
K_p	First order rate constant in phosphate removal (/d)
M	Prefix denoting mass as opposed to concentration of a variable
MX_{ah}	Mass of non-poly P organisms in system (mg VASS)
N	General parameter denoting nitrogen concentration (mg N/ℓ)
n	Number of anaerobic reactors of equal volume in series
N_a,N_n	Subscripts a, n, o, t and u, refer respectively to ammonia, nitrate, biodegradable organic nitrogen, total TKN and soluble unbiodegradable organic nitrogen concentrations
N_o,N_t	Additional subscripts e, i, r, s and a refer respectively to the concentrations in the effluent, influent, r-, s- and a-recycle flows
N_c	Nitrification capacity (mg N/ℓ influent)
N_s	Nitrogen required for sludge production (mg N/ℓ influent)
O	General parameter for oxygen
O_c,O_n O_d,O_t	Subscripts c, n, d and t refer respectively to the oxygen demands for carbonaceous material degradation, nitrification, that recovered by denitrification and total oxygen demand
O_i,O_a,O_s	Subscripts i, a and s refer respectively to the dissolved concentrations in the influent a- and s-recycles
P_f	Excess P removal propensity factor (mg COD/ℓ)
ΔP_n	Phosphorus release in nth reactor per litre influent flow (mg P/ℓ)
P_s	Phosphorus in daily sludge wastage per ℓ influent flow (mg P/ℓ) i.e. the phosphorus removal from the waste water
P_t	Total phosphorus concentration (mg P/ℓ)
	Additional subscripts i and e refer respectively to influent and effluent
Q	Daily mean influent flow rate (ℓ/d)
R_s	Sludge age (d)
S	General parameter denoting COD concentration
S_b,S_u,S_t	Subscripts b, u and t refer respectively to biodegradable, unbiodegradable and total COD concentrations
S_{bs},S_{up} S_{bi},S_{bsi}	Additional subscripts i, e, s and p refer respectively to concentrations in the influent and effluent, and readily biodegradable and particulate COD
S'_{bsi}	Readily biodegradable COD available for conversion per litre influent (mg COD/ℓ)
S_{bsa}	Readily biodegradable COD concentration in the anaerobic reactor
S_{bSN}	Readily biodegradable COD concentration leaving the last anaerobic reactor (mg COD/ℓ)
S_{COD}	Substrate concentration with respect to COD
T	Temperature °C
v	Volume of waste sludge abstracted from process reactor per day

V	General parameter denoting volume. Subscripts p and r refer respectively to the total process and reactor
X	General parameter denoting sludge mass concentration. Subscripts a, e, i, v, t and n refer respectively to active, endogenous, inert, volatile, total and nitrifier sludge concentrations. Additional subscripts f and i, and a, d and b refer respectively to concentrations in effluent and influent and those in the anaerobic, anoxic and aerobic reactors
Y_h	Heterotrophic organism yield coefficient = 0,45 mg VSS/mg COD
α	Denitrification attributable to the readily biodegradable COD (mg NO_3-N/mg biodegradable influent COD)
γ	Coefficient of excess phosphorus removal (mg P/mg VASS) i.e. the proportion of phosphorus in the active mass
Δ	Prefix denoting the change in the parameter following
μ_n	Specific growth rate of nitrifiers (/d). Subscript m denotes the maximum rate Additional subscripts T and 20 refer respectively to the rate at T °C and 20 °C
2,86	Oxygen equivalent of nitrate i.e. 2,86 mg oxygen can accept as many electrons as 1 mg NO_3-N nitrate
8,6	mg mass of COD utilised per mg NO_3-N nitrate denitrified
4,57	mg mass of oxygen required for nitrifying 1 mg N nitrate

Appendix 2

EXAMPLE OF A REPORT WHICH WAS ENTERED INTO THE SPREAD SHEET

Row No.	Column number						
	J	K	L	M	N	O	P
10				**Phosphate removal studies at the Northern Works**			
11							
12							
13							
14				**July 1985**			
15							
16							
17							
18	The experiments were conducted on a five-stage Bardenpho plant						
19							
20							
21							
22				**Plant operating conditions during the test period**			
23							
24							
25							
26	All balancing tank effluent fed to the anaerobic reactor						
27	No primary sludge recycle						
28	Balancing tank not emptied each day						
29							
30	Liquid retention times (h)					Actual	Nominal
31							
32	Anaerobic reactor					1,27	3,57
33							
34	Primary anoxic reactor					0,69	7,32
35							
36	Primary aerobic reactor					2,31	24,48
37							
38	Secondary anoxic reactor					1,93	7,32
39							
40	Re-aeration reactor					1,05	4,00
41							
42	Overall						46,69
43							
44	Solids retention time						37
45							
46	Returned sludge ratio to anaerobic reactor						2,8
47							
48	Returned sludge to anoxic reactor						0,00

MLSS recycle ratio			6,8

Dissolved oxygen conc. (mg/ℓ) in primary aeration reactor

Bridge 1	1,4
Bridge 2	1,4
Bridge 3	1,6
Bridge 4	1,8
Bridge 5	1,8
Average	1,60

Power used per cubic meter treated kW.h/m^3		459
MLSS conc.	4 900	
Temperature (°C)	19	

Influent feed conditions

Average concentration (mg/ℓ)

COD	584
TKN as N	46
Total P as P	20
Ortho P as P	10,00
TKN/COD ratio	0,08

Anaerobic reactor: conditions in anaerobic reactor

Solids (mg/ℓ)	4 200
Readily biodegradable COD (mg/ℓ)	105
Volatile acids (mg CH_3 COOH/ℓ)	75

Phosphate removal or release (mg P/ℓ)

(-ve value indicated release)

Anaerobic	– 15,88	
Primary anoxic	– 13,1	
Primary aeration	3,6	
Re-aeration	0,6	
Overall	11,70	13,8

Nitrate removal (mg N/ℓ)

Anaerobic	10,1
Primary anoxic	16,2
Diluted SVI	2,1

Settling properties

SVI	150
DSVI	100

Comparison with UCT model

Constants used

113	f_{bs}	0,24		
114	f_{up}	0,09		
115	f_{us}	0,05		
116				
117	Test	Actual value	Predicted value	
118				
119	MLSS (mg/ℓ)	4 900	5 337	
120				
121	Nitrate removal			
122	(mg N/ℓ)			
123				
124				
125	Anaerobic and anoxic	26,26	26,64	(Anoxic only)
126				
127	Secondary anoxic	2,10	9,57	
128				
129	Effluent nitrate			
130	(mg/ℓ	4,00	3,17	
131				
132	Effluent phosphate	15,84	11,1	
133	(mg P/ℓ)			
134	Release in anaerobic			
135	Overall removal	13,80	7,18	
136				
137				
138	**Performance of the process**			
139				
140	Test (mg/ℓ)	Feed	Effluent	
141				
142				
143	COD	440,00	77,00	
144	TKN as N	44,0		
145	Nitrate as N	0,00	1,20	
146	Total P as P	14,00		
147	Ortho P as P	0,00	2,30	
148	Suspended solids		17,00	
149				
150				

Appendix 3

JOHANNESBURG BUSHKOPPIE PLANT
PREDICTION OF PLANT PERFORMANCE USING THE UCT MODEL AND A SPREAD SHEET

	Column		
Column No.	A and B	C	D
8	**Kinetic constants**		
9			
10	f_{cv}	1,48	
11	Y_h	0,45	
12	f	0,20	
13	f_p	0,02	
14	f_i	0,72	
15	b_{h20}	0,24	
16	b_{hT}	0,26	
17	μ_{nm20}	0,36	
18	μ_{nmT}	0,51	
19	$k_{1\ 20}$	0,72	
20	$k_{1\ T}$	0,72	
21	k_{2T20}	0,101	
22	k_{2T}	0,127	
23	k_{3T20}	0,072	
24	k_{3T}	0,078	

f_n	0,10
	0,03
c_{sp}	0,50
k_p	0,06
n	3
Plant details	
Mass fractions	
f_{xa} Anaerobic	0,09
f_{x1} Primary Anoxic	0,17
f_{x3} 2nd Anoxic	0,00
f_{xdm} Allowable	0,17
No. Anaerobic basins	3
Flows Mℓ/d	
Settled sewage feed	43,3
Returned sludge	36,7
MLSS recycle	100,00
Waste sludge	1,80
Total volume	34,20
Recycle ratios	
s sludge return	0,85
a MLSS recycle	2,30
R_s Sludge age	19
Dissolved oxygen	
Primary aeration	2,00
Return sludge	1,00
Total power kW.h	
Total kW.h	2 100
Temperature °C	23
Sewage characteristics	
Feed conc. mg/ℓ	
COD	671
TKN as N	48,2
Total P as P	11,8
COD fractions	
f_{bs}	0,20
f_{up}	0,09
f_{us}	0,07
Estimation of NO_3	
N_{nr} returned	9,07
N_{te}	9,07
P removal MX_{ah}/Q	
1st MX_a/Q_h	True/false
MX_a/Q Temp	730
COD fractions	
S_{ui}	40
S_{upi}	89
S_{bi}	541
S'_{bsi}	108
S_{bsi}	39
S_{bsa}	21
S_{bsn}	4

90	**Fraction of MLSS**		
91			
92		X_a	775
93		X_e	770
94		X_i	1 147
95		X_v	2 693
96		X_t	3 741
97		MX_{ah}/Q	730
98			
99	**Nitrification**		
100			
101		N_s	11,20
102		N_c	35,17
103			
104	**Denitrification pot**		
105			
106		D_{p1} Primary	29,4
107		D_{p3} Secondary	0,00
108		Total	29,42
109		D_{pp} maximum	29,42
110			
111	**Effluent NO_3**		9,07
112			
113	**Oxygen demand**		
114			
115		$M(O_c)$ Carbonaceous	18 226
116		$M(O_n)$ Nitrification	6 960
117		$M(O_d)$ Denitrification	3 232
118		$M(O_T)$	21 953
119			
120	**Phosphate removal (kinetic)**		
121			
122	**Parametric model**		
123			
124		S_{bi}	541
125		S_{ba}	21,5
126		P_x	0,00
127		γ	0,06
128		ΔP_s	3,96
129			
130	**Kinetic model**		
131			
132		ΔP_n	15,6
133		P removed	7,5
134			

Appendix 4

JOHANNESBURG BUSHKOPPIE PLANT
THEORETICAL COMPARISON OF A 3 AND 5 STAGE PHOREDOX PROCESS USING THE UCT MODEL AND A SPREAD SHEET

			5-Stage	3-Stage
	Column			
Column No.	**A and B**		**C**	**D**
8	**Kinetic constants**			
9				
10		f_{cv}	1,48	1,48
11		Y_h	0,45	0,45
12		f	0,20	0,20
13		f_p	0,02	0,20
14		f_i	0,72	0,72

15	b_{h20}	0,24	0,24
16	b_{hT}	0,26	0,26
17	μ_{nm20}	0,36	0,36
18	μ_{nmT}	0,51	0,51
19	$k_{1\ 20}$	0,72	0,72
20	$k_{1\ T}$	0,72	0,72
21	k_{2T20}	0,101	0,101
22	k_{2T}	0,1272	0,1272
23	K_{3T20}	0,072	0,072
24	k_{3T}	0,078	0,078
25	f_n	0,10	0,10
26		0,03	0,03
27	c_{sp}	0,50	0,50
28	k_p	0,06	0,60
29	n	3	3
30			
31	**Plant details**		
32			
33	Mass fractions		
34			
35	f_{xa} Anaerobic	0,09	0,09
36	f_{x1} Primary anoxic	0,17	0,17
37	f_{x3} 2nd Anoxic	0,17	0,00
38	f_{xdm} Allowable	0,34	0,17
39	No. Anaerobic basins	3	3
40	**Flows Mℓ/d**		
41			
42	Settled sewage feed	43,3	43,3
43	Returned sludge	36,7	36,7
44	MLSS recycle	100	100
45	Waste sludge	1,8	1,8
46	**Total volume**	34,2	34,2
47			
48	**Recycle ratios**		
49			
50	s sludge return	0,85	0,85
51	a MLSS recycle	2,3	2,3
52	R_s Sludge age	19	19
53	**Dissolved oxygen**		
54			
55	Primary aeration	2,0	2,0
56	Return sludge	1,00	1,0
57	**Total power kW.h**		
58	Total kW.h	2 100	2 100
59	**Temperature °C**	23	23
60			
61	**Sewage characteristics**		
62			
63	**Feed conc. mg/ℓ**		
64	COD	930	930
65	TKN as N	66	66
66	Total P as P	11,8	11,8
67			
68	**COD fractions**		
69	f_{bs}	0,20	0,20
70	f_{up}	0,13	0,13
71	f_{us}	0,06	0,06
72			
73	**Estimation of NO_3**		
74	N_{nr} returned	0,99	11,8
75	N_{te} returned	0,99	11,8
76			
77	**P removal MX_{ah}/Q**		
78	1st MX_a/Q_h	True/False	

79	MX_a/Q Temp	904	999
80			
81	**COD fractions**		
82	S_{ui}	55,8	55,8
83	S_{upi}	123	123
84	S_{bi}	750	750
85	S'_{bsi}	150	150
86	S_{bsi}	139	60
87	S_{bsa}	75	33
88	S_{bsn}	11,4	4,3
90	**Fraction of MLSS**		
91			
92	X_a	1 074	1 074
93	X_e	1 068	1 068
94	X_i	1 590	1 590
95	X_v	3 733	3 733
96	X_t	5 185	5 185
97	$MX_{ah/Q}$	904	999
98			
99	**Nitrification**		
100			
101	N_s	15,2	15,2
102	N_c	48,7	48,7
103			
104	**Denitrification pot**		
105			
106	D_{p1} primary	40,8	40,8
107	D_{p3} secondary	14,3	0
108	Total	55,1	40,8
109	D_{pp} maximum	0,99	11,80
110			
111	**Effluent NO_3**	64,02	40,77
112			
113	**Oxygen demand**		
114			
115	$M(0_c)$ Carbonaceous	25 261	25 261
116	$M(0_n)$ Nitrification	9 627	9 617
117	$M(0_d)$ Denitrification	5 902	4 563
118	$M(0_T)$	28 985	30 324
119			
120	**Phosphate removal** (kinetic)		
121			
122	**Parametric model**		
123			
124	S_{bi}	750	750
125	S_{ba}	75,9	33,3
126	P_{xf}	4,58	0,75
127	γ	0,25	0,11
128	ΔP_s	16,4	8,2
129			
130	**Kinetic model**		
131			
132	ΔP_n	59,4	26,5
133	P removed	13,22	8,94
134			