

Activated sludge modelling: development and potential use of a practical applications database

H. Hauduc, L. Rieger, T. Ohtsuki, A. Shaw, I. Takács, S. Winkler, A. Héduit, P. A. Vanrolleghem and S. Gillot

ABSTRACT

This study aims at synthesizing experiences in the practical application of ASM type models. The information is made easily accessible to model users by creating a database of modelling projects. This database includes answers to a questionnaire that was sent out to model users in 2008 to provide inputs for a Scientific and Technical Report of the IWA Task Group on *Good Modelling Practice – Guidelines for use of activated sludge models*, and a literature review on published modelling projects. The database is analysed to determine which biokinetic model parameters are usually changed by modellers, in which ranges, and what values are typically used for seven selected activated sludge models. These results should help model users in the calibration step, by providing typical parameter values as a starting point and ranges as a guide. However, the proposed values should be used with great care since they are the result of averaging practical experience and not taking into account specific parameter correlations.

Key words | ASM, database, good modelling practice, parameter ranges, parameter sets, survey

H. Hauduc

A. Héduit

S. Gillot (corresponding author)

Cemagref, UR HBAN, Parc de Tourvoie,
BP 44, F-92163 Antony Cedex, France
E-mail: Sylvie.gillot@cemagref.fr

H. Hauduc

L. Rieger

P. A. Vanrolleghem

modelEAU, Département de génie civil,
Université Laval, Pavillon Adrien-Pouliot,
1065 av. de la Médecine, Quebec (QC) G1V 0A6,
Canada

L. Rieger

EnviroSim Associates Ltd.,
McMaster Innovation Park, 175 Longwood Rd S,
Suite 114A, Hamilton, ON L8P 0A1, Canada

T. Ohtsuki

Kurita Water Industries Ltd, 4-7, Nishi-Shinjuku
3-Chome, Shinjuku-Ku, Tokyo 160-8383, Japan

A. Shaw

Black & Veatch, 8400 Ward Parkway,
Kansas City, MO, 64114 USA

A. Shaw

Department of Civil,
Architectural, and Environmental Engineering,
Illinois Institute of Technology,
Alumni Memorial Hall, Room 228,
3201S. Dearborn St., Chicago, IL 60616, USA

I. Takács

EnviroSim Europe., 15 Impasse Fauré,
Bordeaux 33000, France

S. Winkler

Institute for Water Quality and Waste Management,
Vienna Technical University, Karlsplatz 13/E 226,
1040 Vienna, Austria

INTRODUCTION

The International Water Association (IWA) Task Group on *Good Modelling Practice – Guidelines for use of activated sludge models* (GMP-TG, <https://iwa-gmp-tg.cemagref.fr/>) is collecting knowledge and experience on how to use activated sludge (AS) models in engineering practice. The group developed and sent out a first questionnaire to current and potential users of activated sludge models to better define

the profile of ASM users and to identify the tools and procedures used. Ninety-six answers were received that provided useful insights into the use of activated sludge models and highlighted the main limitations of modelling and the expectations of users for improvements (Hauduc *et al.* 2009). The calibration step was pointed out especially as one of the most time-consuming steps and is considered as an obstacle

for widespread model use. Respondents also asked for better knowledge transfer.

A second, more detailed, questionnaire was sent out in 2008 to provide inputs for the GMP-TG report regarding typical parameter values and case studies from several countries and for different wastewater treatment conditions. In addition and as a second source of information, a literature review was carried out on published modelling projects. The objective of this work was to collect available experiences of practical applications using AS models. A database was constructed to synthesise the answers from the second questionnaire and literature data.

The database includes parameters for seven published activated sludge models: (1) ASM1 (Henze *et al.* 2000a); (2) ASM2d (Henze *et al.* 2000b); (3) ASM3 (Gujer *et al.* 2000); (4) ASM3 + BioP (Rieger *et al.* 2001); (5) ASM2d + TUD (Meijer 2004); (6) Barker & Dold model (Barker & Dold 1997); (7) UCTPHO + (Hu *et al.* 2007). In order to keep this paper readable, these references will not be repeated each time. Prior to this parameter study, all models were analysed for typos and errors (Hauduc *et al.* 2010).

METHOD

Source of data

Questionnaire

In order to completely describe each modelling study, the questionnaire asked for the objectives of the project, the description of the wastewater treatment plant (WWTP) and the parameter set used for the biokinetic model. The questionnaire was sent out in 2008 to the respondents of the first survey, to the attendees of the WWTmod2008 seminar in Mont-St-Anne, QC, Canada, and could be downloaded from GMP-TG sponsor websites.

Probably due to the higher complexity of this questionnaire, only 28 answers were received, among which 17 were usable for this study (i.e. at least one model parameter set provided).

Literature review

In order to have a homogeneous database, only published modelling projects applied to full-scale WWTPs or pilot plants with a major domestic wastewater influent were selected. The review includes 50 articles containing 59 parameter sets.

Database description

Structure

In order to store all the information in an efficient way, a database composed of three main tables was constructed:

1. **Parameter sets:** model, country, temperature, parameter values
2. **WWTP description:** information on influent, wastewater characteristics, processes and environmental conditions
3. **Model users:** user information

To facilitate parameter comparison, a new standardised notation (Corominas *et al.* 2010) was used.

Classification of parameter sets

Two classes of model parameter sets were distinguished:

- **Optimised parameter sets** obtained for a specific modelling project. These parameter sets were provided with the description of the WWTP under study. Parameter values may have different sources (see below).
- **Proposed new default parameter sets** based on personal expertise. These parameters were used as starting points for the calibration step during the project and given with an approximate number of WWTPs on which this experience was gained.

Sources of parameter values

- **Original:** value given in the original publication of the model;
- **New Default:** value given in a proposed new default parameter set;
- **Measured:** value is obtained using a dedicated experimental protocol;
- **Calibrated:** value is changed either using a manual or an automatic procedure to fit simulation results to the data collected on the WWTP.

Temperature adjustment

For comparison purposes, the parameter values were standardised at 20°C. The correction factor was either provided with the dataset or extracted from the original publication. For instance, in the original ASM1 and ASM2d publications, the kinetic parameters only are given at 10°C and 20°C. The correction factor θ_{pow} has thus been recalculated following the equation $k_{10^{\circ}\text{C}} = k_{20^{\circ}\text{C}} * \theta_{pow}^{10-20}$.

Database analysis

The database was analysed for the three topics:

Original vs. proposed new default parameter sets: The parameter sets were compared and differences identified and discussed.

Parameters changed in modelling projects: Most often changed parameters (in more than 50% of the projects) are highlighted.

Parameter ranges and statistics: For each model, the following variables have been calculated:

- The median values, which should not be misinterpreted as new default parameters, because the median values are not from a single parameter set and some parameters may be correlated (e.g. growth and decay rate),
- The 25th and 75th percentiles. These percentiles have been chosen to exclude extreme values and to obtain a representative range of the typical parameter values,
- The variability (V), the difference between the two percentiles divided by the median.

These results are discussed and confronted to the knowledge on parameter values and parameter ranges of other published overview studies.

RESULTS

Modelling project characteristics

The database contains 76 parameter sets, which can be differentiated into 57 optimised parameter sets and 19 proposed new default parameter sets, and distributed as shown in

Figure 1. ASM1 and ASM2d are the most represented models in the database.

The following paragraphs describe the main information extracted from the current database for ASM1 and ASM2d. An insufficient number of modelling studies is available for the other models, thus no comments are given on the results for these models. However, synthesis tables are presented in the appendix for ASM3, ASM3 + BioP and Barker & Dold model. Concerning ASM2d + TUD and UCTPHO+, no additional modelling projects than those in the original publication were found, the tables are thus not presented.

ASM1

Data description

The database contains 31 parameter sets for ASM1, of which 9 are "proposed new default parameter" sets and 22 are "optimised parameter sets" from specific modelling projects. The modelling studies were mainly carried out at full scale WWTPs (19) mostly in Europe (18), with only 1 application in North-America and 3 in Asia. The sludge ages of the specific modelling projects are between 4 and 40 days.

Table 1 presents the main results extracted from the database including the original and the proposed new default parameter sets. Basic statistics for optimised parameter sets comprise the number of values for each parameter (n), if the parameter has been modified in more than 50% of the cases (Modif. > 50%), the median value (Med.), the 25th and 75th percentiles and the variability (V). The proposed new default parameter sets are by definition based on several simulation studies and therefore present more experience than single

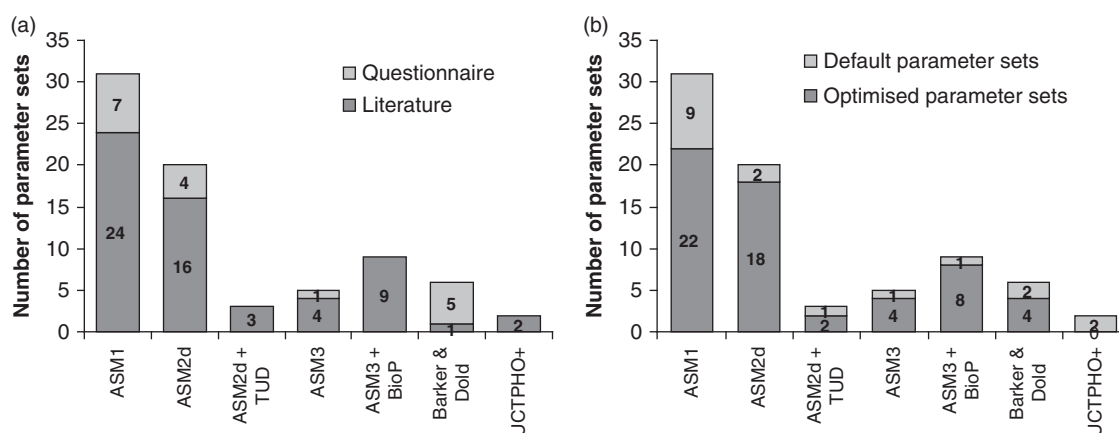


Figure 1 | Distribution of parameter sets per model: a) per source; b) per class of parameter set.

Table 1 | Synthesis of database results for ASM1, only modified parameters are mentioned. Parameter values are standardised at a temperature of 20 °C

Parameter*	Unit	Description	Original parameter set			Optimised parameter sets			Proposed new default parameters		
			Notation	Value (a)	n	Modif > 50%	Med.	Perc. 25%	Perc. 75%	V (%)	Parameter sets: b/c/d/e/f/g/h/i
Stoichiometric parameters											
Y_{OHO}	g X_{OHO} g X_{CB}^{-1}	Yield for X_{OHO} growth	Y_{H}	0.67	26	X	0.67	0.62	0.67	7	0.6(c);i) $Y_{\text{OHO,OX}}$: 0.67 and $Y_{\text{OHO,AX}}$: 0.54 (b);f;h)
Conversion coefficient											
$i_{\text{N_XBio}}$	g N g X_{Bio}^{-1}	N content of biomass (X_{OHO} , X_{ANO})	$i_{\text{X,B}}$	0.086	31		0.086	0.079	0.086	8	0.08(c;g)
Kinetic parameters											
Hydrolysis											
$q_{\text{XCB,SB,hyd}}$	g X_{CB} g $X_{\text{OHO}}^{-1} \text{d}^{-1}$	Maximum specific hydrolysis rate	k_{h}	3	31		3	2.2	3	26	2(c)/2.21(i)/5.2(g)
$\theta_{q_{\text{XCB,SB,hyd}}}$	-	Temperature correction factor for $q_{\text{XCB,SB,hyd}}$	θ_{kh}	1.116	11	X	1.116	1.072	1.12	4	1.072(f)
$K_{\text{XCB,hyd}}$	g X_{CB} g X_{OHO}	Half-saturation coefficient for $X_{\text{CB}}/X_{\text{OHO}}$	K_{X}	0.03	30		0.03	0.03	0.03	0	0.02(c)/0.17(g)/0.15(i)
$\theta_{K_{\text{XCB,hyd}}}$	-	Temperature correction factor for $K_{\text{XCB,hyd}}$	θ_{KX}	1.116	10	X	1.116	1.116	1.12	0	1(f)
$\eta_{\text{qhyd,AX}}$	-	Correction factor for hyd. under anoxic cond.	η_{h}	0.4	31		0.4	0.4	0.5	25	0.5(g)/ 0.6(d) $\eta_{\text{qhyd,AX}}$: 0.75(d)
Ordinary Heterotrophic Organisms											
$\mu_{\text{OHO,Max}}$	d^{-1}	Maximum growth rate of X_{OHO}	μ_{H}	6	31		6	5.7	6	6	4(d)/5.7(g)
$\theta_{\mu_{\text{OHO,Max}}}$	-	Temperature correction factor for $\mu_{\text{OHO,Max}}$	$\theta_{\mu\text{H}}$	1.072	11	X	1.072	1.071	1.09	2	
$\eta_{\mu_{\text{OHO,AX}}}$	-	Reduction factor for anoxic growth of X_{OHO}	η_{g}	0.8	31		0.8	0.8	0.8	0	0.6(c)

$K_{S_{B,OHO}}$	$g\ S_B\ m^{-3}$	Half-saturation coefficient for S_B	K_S	20	31	20	10	20	50	5(d)/10(g)
b_{OHO}	d^{-1}	Decay rate for X_{OHO}	b_H	0.62	31	0.62	0.61	0.62	2	0.4(d)/0.41(i)/0.5(c)/0.53(g)
θ_{bOHO}	-	Temperature correction factor for b_{OHO}	θ_{bH}	1.12	11	1.1	1.029	1.12	8	1.029(f)/1.071(c,d)
$K_{O_2,OHO}$	$g\ SO_2\ m^{-3}$	Half-saturation coefficient for SO_2	K_{OH}	0.2	31	0.2	0.2	0.2	0	0.05(f)/0.1(i)
$K_{NO_x,OHO}$	$g\ S_{NO_x}\ m^{-3}$	Half-saturation coefficient for S_{NO_x}	K_{NO}	0.5	31	0.5	0.1	0.5	80	0.1(f)/0.2(i)
Autotrophic Nitrifying Organisms										
$\mu_{ANO,Max}$	d^{-1}	Maximum growth rate of X_{ANO}	μ_A	0.8	30	0.8	0.66	0.9	30	0.77(i)/0.82(g)/0.85(c)/0.9(b; d)
$\theta_{\mu_{ANO,Max}}$	-	Temperature correction factor for $\mu_{ANO,Max}$	$\theta_{\mu A}$	1.103	14	1.103	1.059	1.11	5	1.059(f; h)/1.072(b)
b_{ANO}	d^{-1}	Decay rate for X_{ANO}	b_A	0.5-0.15	30	0.1	0.08	0.15	70	0.07(g)/0.096(i)/0.17(b; f; h)
θ_{bANO}	-	Temperature correction factor for b_{ANO}	θ_{bA}	1.072	12	1.07	1.029	1.072	4	1.027(f; h)/1.083(d)/1.103(c)
q_{am}	$m^3\ g\ X_{CB,d}^{-1}\ d^{-1}$	Rate constant for ammonification	k_a	0.08	29	0.08	0.07	0.08	12	0.05(g)/0.16(i)
θ_{qam}	-	Temperature correction factor for q_{am}	θ_{ka}	1.072	11	1.07	1.07	1.07	0	1.071(d; c)
$K_{O_2,ANO}$	$g\ SO_2\ m^{-3}$	Half-saturation coefficient for SO_2	K_{OA}	0.4	31	0.4	0.4	0.4	0	0.2(f)/0.5(c)/0.75(i)
$K_{NH_x,ANO}$	$g\ S_{NH_x}\ m^{-3}$	Half-saturation coefficient for S_{NH_x}	K_{NH}	1	31	1	0.75	1	25	0.1(f)/0.5(d)

a: Henze et al. (2000a); b, c: 2 answers from the questionnaire; d: Bornemann et al. (1998); e: Hulsbeek et al. (2002); f: Marquot (2006); g: Sparijers et al. (1998); h: Choubert et al. (2009b); i: Grady et al. (1999).
 *Standardised notation from Corominas et al. (2010) is used. n: number of parameter values in the database. Please refer to the appendix for the parameter definitions.

studies. Consequently, they are presented on the same level as the median of all the optimised parameter sets.

Original vs. proposed new default parameter set: Only 3 parameters (out of 26) have not been changed compared to the original value: the autotrophic growth yield (Y_{ANO}), the fraction of particulate unbiodegradable organics generated in biomass decay ($f_{XU_Bio,lys}$) and the nitrogen content of unbiodegradable organics generated in biomass decay (i_{N_XUE}).

A change in ASM1 model structure for the ordinary heterotrophic yield (Y_{OHO}) value by introducing an ordinary heterotrophic yield under anoxic conditions is suggested in three of the proposed new default parameter sets.

Parameters changed in modelling projects (compared to original values): for each parameter set, a majority of parameters are kept at their default values. Only the autotrophic growth yield (Y_{ANO}) is always kept at its original value. Nine parameters were changed in more than half of the modelling studies: 6 temperature correction factors, the heterotrophic yield (Y_{OHO}) and the autotrophic growth and decay rate pair ($\mu_{ANO,Max}$, b_{ANO}).

Only a few parameter sets contain measured parameters (Stamou *et al.* 1999; Makinia & Wells 2000; Petersen *et al.* 2002; Nuhoglu *et al.* 2005). Most of the measured values are close to the values used in other modelling projects, except for Stamou *et al.* (1999) who determined very low values for the heterotrophic and autotrophic growth related parameters.

Parameter ranges and statistics: All median values are the same as in the original parameter set. The variability is quite narrow (<33%), except for the half-saturation coefficients for substrate ($K_{SB,OHO}$) and nitrate ($K_{NOx,OHO}$) and the autotrophic decay rate (b_{ANO}).

Discussion

Original vs. proposed new default parameter sets: The need to change the ASM1 model structure by introducing a heterotrophic yield under anoxic conditions ($Y_{OHO,Ax}$) to properly model the nitrate and COD consumption was experimentally proven by Orhon *et al.* (1996). A new default value of $0.54 \text{ g } X_{OHO} \text{ g } X_{CB}^{-1}$ is proposed by Choubert *et al.* (2009a), based on full-scale modelling studies.

The change of the maximum autotrophic growth rate ($\mu_{ANO,Max}$) and decay rate (b_{ANO}) is discussed in Dold *et al.* (2005). The authors showed that it was no longer necessary to modify $\mu_{ANO,Max}$ when the sludge retention time (SRT) varies if a higher b_{ANO} value is used (experimentally measured to $0.19 \pm 0.4 \text{ d}^{-1}$). Choubert *et al.* (2009b) proposed the values of $\mu_{ANO,Max} = 0.8 \text{ d}^{-1}$ and $b_{ANO} = 0.17 \text{ d}^{-1}$ at 20°C as new default values validated on 13 full-scale WWTPs in France.

Parameters changed in modelling projects (compared to original values): Similar to the proposed new default parameter sets a reduced heterotrophic growth rate (Y_{OHO}) is often associated with plants with anoxic and/or anaerobic zones. This confirms the need to differentiate aerobic and anoxic growth yields.

The couple ($\mu_{ANO,Max}$, b_{ANO}) is modified in most studies. However, in the analysed modelling projects a high maximum growth rate was not always compensated by a high decay rate.

In addition, the temperature correction factor values are sometimes re-evaluated in the course of a project. They are deduced from the parameter determination at a different temperature and therefore include measurement uncertainties.

Parameter ranges and statistics: The ranges provided by the 25th and 75th percentiles of the database are generally in agreement with other overview studies, which ranges were not included in the database (Weijers & Vanrolleghem 1997; Bornemann *et al.* 1998; Hulsbeek *et al.* 2002; Cox 2004; Sin *et al.* 2009). However, the ranges from the database differ from these studies for the following parameters:

- $\mu_{OHO,Max}$ and b_{OHO} ranges proposed by Weijers & Vanrolleghem (1997) are wider (respectively $2\text{--}10 \text{ d}^{-1}$; $0.1\text{--}1.5 \text{ d}^{-1}$);
- $K_{SB,OHO}$, b_{OHO} and $K_{NHx,ANO}$ in Bornemann *et al.* (1998) have different and not overlapping ranges (respectively $1\text{--}5 \text{ g } S_B \text{ m}^{-3}$; $0.3\text{--}0.5 \text{ d}^{-1}$; $0.1\text{--}0.7 \text{ g } S_{NHx} \text{ m}^{-3}$);
- The median values provided by Cox (2004) are quite different from the database ones (up to 100% of relative difference); whereas the 25th and 75th percentiles are in agreement. An exception is for the heterotrophic growth and decay rates ($\mu_{OHO,Max}$, b_{OHO}) and the half-saturation coefficient for substrate ($K_{SB,OHO}$), for which the ranges provided by Cox (2004) are not overlapping the database ones (respectively $2.06\text{--}4.69 \text{ d}^{-1}$; $0.2\text{--}0.6 \text{ d}^{-1}$; $2.54\text{--}7.06 \text{ g } S_B \text{ m}^{-3}$);
- Sin *et al.* (2009) provided “uncertainties” (or better variabilities) based on expert knowledge. Two parameter variabilities ($\mu_{ANO,Max}$, b_{ANO}) are narrower than the observed variability in this study (respectively 5% and 25%) and 8 much wider (50% of variability for i_{N_XBio} , $K_{O2,OHO}$, q_{am} , $K_{NHx,ANO}$; 25% of variability for $K_{XCB,hyd}$, $\mu_{OHO,Max}$, $\eta_{\mu_{OHO,Ax}}$, $K_{O2,ANO}$).

It is noticeable that the above mentioned parameters correspond to the ones with the greatest variability in Table 1 and/or to those modified in more than 50% of the cases, although the observed variations of these parameters are often lower than those provided in these studies.

Finally, all of the overview studies present a parameter range or an “uncertainty” for the autotrophic yield (Y_{ANO}), whereas its value was modified in none of the 22 modelling projects.

Conclusion

Regarding ASM1, six parameters have been pointed out as subject to changes: Y_{OHO} , $K_{SB,OHO}$, $K_{NOx,OHO}$, $\mu_{ANO,Max}$, b_{ANO} and $K_{NHx,ANO}$. In addition to the variability of Y_{OHO} , $\mu_{ANO,Max}$ and b_{ANO} already discussed, the three other parameters are half-saturation coefficients, suspected to depend on environmental conditions. These results are supported by the literature data although the chosen 25th and 75th percentiles provide a narrower range for some of the parameters than specified in literature.

ASM2d

Data description

The database contains 20 parameter sets for ASM2d, of which 2 are “proposed new default parameter sets” and 18 are “optimised parameter sets” from specific modelling projects. The modelling studies were mainly carried out in Europe (16), with only two applications in Asia; and mainly on full scale WWTPs (12). Table 2 synthesises the main results for ASM2d. The sludge ages of the specific modelling projects are between 7 and 22 days.

Original vs. proposed new default parameter sets: Only the original parameter set is presented. A new default parameter set was proposed by Cinar *et al.* (1998) but it concerns in fact ASM2 and not ASM2d.

Parameters changed in modelling projects (compared to original values): The majority of the parameters are kept at their original values, from which 33 (of the 83 parameters) have never been changed:

- 4 of the 11 stoichiometric parameters: the inert fractions generated in hydrolysis and biomass decay processes ($f_{SU_XCB,hyd}$, $f_{XU_Bio,lys}$); the yield of polyphosphate storage per organic stored compound used (Y_{PHA_PP}) and the autotrophic growth yield (Y_{ANO}).
- 7 of the 15 conversion coefficients: i_{N_SF} , i_{N_XBio} , i_{P_SF} , i_{P_SU} , i_{TSS_XCB} , $i_{TSS_XPAO,PHA}$ and $i_{TSS_XPAO,PP}$.
- 22 of the 57 kinetic parameters: the alkalinity half-saturation parameters ($K_{Alk,OHO}$, $K_{Alk,PAO}$, $K_{Alk,ANO}$); heterotrophic half-saturation parameters for nutrients ($K_{NHx,OHO}$, $K_{PO4,OHO}$); autotrophic half-saturation parameters for

nutrients ($K_{PO4,ANO}$); 5 phosphorus accumulating organism half-saturation parameters (K_{S,IPP_PAO} , $K_{O2,PAO}$, $K_{NOx,PAO}$, $K_{NHx,PAO}$, $K_{PO4,PAO,upt}$); the half-saturation parameters for dissolved oxygen and nitrates in the hydrolysis process ($K_{O2,hyd}$, $K_{NOx,hyd}$); 6 of the 12 temperature correction factors ($\theta_{q_XCB_SB,hyd}$, $\theta_{\mu_OHO,Max}$, $\theta_{q_SF_Ac,Max}$, θ_{b_OHO} , $\theta_{\mu_ANO,Max}$, θ_{b_ANO}); and the chemical phosphorus precipitation parameters ($q_{P,pre}$, $q_{P,red}$, $K_{Alk,pre}$).

Two types of modelling studies could be distinguished:

- Studies with a calibrated parameter subset (12 studies). These are mainly composed of kinetic parameters;
- Studies with measured parameters (6 studies), among which 4 studies use the calibration protocol of [Penya-Roja *et al.* \(2002\)](#) ([Penya-Roja *et al.* 2002](#); 2 by [Ferrer *et al.* 2004](#); [Garcia-Usach *et al.* 2006](#)). This protocol is based on batch tests that allow the measurement of many stoichiometric and kinetic coefficients for autotrophs, ordinary heterotrophs and phosphorus accumulating organisms.

Among the 18 modelling studies, 8 parameters - all of which are kinetic parameters - were changed in more than half of the cases: the heterotrophic and autotrophic maximum growth rates ($\mu_{OHO,Max}$, $\mu_{ANO,Max}$), the autotrophic half-saturation coefficient for ammonia ($K_{NHx,ANO}$), the rate constants for volatile fatty acids (VFA) uptake (q_{PAO,VFA_Stor}) and for polyphosphate storage ($q_{PAO,PO4_PP}$) of the PAO and their storage pools' decay (m_{PAO} , b_{PP_PO4} , b_{Stor_VFA}).

Parameter ranges and statistics: The median values are the same as the original publication values except for the rate constant for VFA uptake (q_{PAO,VFA_Stor}). The ranges of kinetic parameter values between 25th and 75th percentiles are quite narrow (< 33%), except for the reduction factor for hydrolysis under anaerobic conditions ($\eta_{qhyd,A\eta}$), for the rate constants for VFA uptake (q_{PAO,VFA_Stor}) and polyphosphate storage ($q_{PAO,PO4_PP}$) and the half-saturation coefficient for ammonia ($K_{NHx,ANO}$).

Discussion

Parameters changed in modelling projects (compared to original values): Among the eight parameters that were changed most, two have a particularly wide range of values: the rate constants for VFA uptake (q_{PAO,VFA_Stor}) and polyphosphate storage ($q_{PAO,PO4_PP}$). Furthermore, the users of the [Penya-Roja *et al.* \(2002\)](#) protocol observed large parameter ranges for PAO growth and polyphosphates storage yields (Y_{PAO} , $Y_{PP_Stor,PAO}$). This could indicate a problem in the ASM2d model structure, such as the simplification of not

Table 2 | Synthesis of database results for ASM2d model, only modified parameters are mentioned. Parameter values are standardised at a temperature of 20°C

Parameter*	Unit	Description	Original notation	Original parameter set	Optimised parameter sets				V (%)	
				j	n	Modif. > 50%	Median	Perc. 25%		Perc. 75%
Kinetic parameters										
Hydrolysis										
$\eta_{\text{qhyd,Ax}}$	-	Correction factor for hydrolysis under anoxic conditions	η_{NO_3}	0.6	20		0.6	0.6	0.8	33
$\eta_{\text{qhyd,A}\eta}$	-	Correction factor for hydrolysis under anaerobic conditions	η_{fe}	0.4	20		0.4	0.2	0.4	50
Ordinary Heterotrophic Organisms										
$\mu_{\text{OHO,Max}}$	d^{-1}	Maximum growth rate of X_{OHO}	μ_{H}	6	20	X	6	4	6	33
$\eta_{\mu\text{OHO,Ax}}$	-	Reduction factor for anoxic growth of X_{OHO}	η_{NO_3}	0.8	20		0.8	0.8	0.8	0
Phosphorus Accumulating Organisms										
$q_{\text{PAO,VFA,Stor}}$	$\text{g } X_{\text{Stor}} \text{ g } X_{\text{PAO}}^{-1} \text{ d}^{-1}$	Rate constant for S_{VFA} uptake rate ($X_{\text{PAO,Stor}}$ storage)	q_{PHA}	3	20	X	3.4	3	6	90
$q_{\text{PAO,PO}_4\text{,PP}}$	$\text{g } X_{\text{PP}} \text{ g } X_{\text{PAO}}^{-1} \text{ d}^{-1}$	Rate constant for storage of $X_{\text{PAO,PP}}$	q_{PP}	1.5	20	X	1.5	1.5	3.3	120
$\mu_{\text{PAO,Max}}$	d^{-1}	Maximum growth rate of X_{PAO}	μ_{PAO}	1	20		1	1	1.04	4
$\theta_{\mu\text{PAO,Max}}$	-	Temperature correction factor for $\mu_{\text{PAO,Max}}$	$\theta_{\mu\text{PAO}}$	1.041	3		1.041	1.0-41	1.0-58	2
m_{PAO}	d^{-1}	Endogenous respiration rate of X_{PAO}	b_{PAO}	0.2	20	X	0.2	0.15	0.2	25
$b_{\text{PP,PO}_4}$	d^{-1}	Rate constant for lysis of $X_{\text{PAO,PP}}$	b_{PP}	0.2	20	X	0.2	0.15	0.2	25
$b_{\text{Stor,VFA}}$	d^{-1}	Rate constant for respiration of $X_{\text{PAO,Stor}}$	b_{PHA}	0.2	20	X	0.2	0.15	0.2	25
Autotrophic Nitrifying Organisms										
$\mu_{\text{ANO,Max}}$	d^{-1}	Maximum growth rate of X_{ANO}	μ_{AUT}	1	20	X	1	1	1.15	15
b_{ANO}	d^{-1}	Decay rate for X_{ANO}	b_{AUT}	0.15	20		0.15	0.15	0.16	7
$K_{\text{NH}_x,\text{ANO}}$	$\text{g } S_{\text{NH}_x} \text{ m}^{-3}$	Half-saturation coefficient for S_{NH_x}	K_{NH_4}	1	20	X	1	0.5	1	50

j: Henze *et al.* (2000b). Please refer to the appendix for the parameter definitions.

*Standardised notation from Corominas *et al.* (2010) is used. n: number of parameter values in the database.

taking into account glycogen storage and glycogen accumulating organisms in ASM2d (Penya-Roja *et al.* 2002).

Another explanation could be that the ASM2d model describes polyphosphate uptake and the growth of PAOs as

two independent kinetic processes. However, experimental results show that oxidation of organic stored compounds provides energy for both PAO growth and polyphosphate storage (Wentzel *et al.* 1989). Consequently, PAO growth and

polyphosphate storage yield are linked and depend on the oxidation of organic stored compounds. Therefore some models link both yields to energy production (in metabolic models, e.g.: Meijer 2004) or model PAO growth and polyphosphate storage as a single process (Barker & Dold model, UCTPHO +). Fixing the ratio between growth and phosphate storage would then assist ASM2d calibration.

Parameter ranges and statistics: Based on expert knowledge, Brun *et al.* (2002) assigned an uncertainty to each parameter. The database is in agreement with the low uncertainties (between 5% and 20%) attributed to stoichiometric parameters and conversion coefficients parameters by Brun *et al.* (2002). In Brun *et al.* (2002), high uncertainty is attributed to kinetic parameters (between 20% and 50% of uncertainty), which are overestimated based on the database results for all the parameters, except for the reduction factors for hydrolysis under anoxic and anaerobic conditions ($\eta_{\text{qhyd,An}}$, $\eta_{\text{qhyd,An}}$), the rate constants for VFA uptake ($q_{\text{PAO,VFA_Stor}}$) and polyphosphate storage ($q_{\text{PAO,PO}_4\text{_PP}}$).

Conclusion

The main potential pitfalls in calibrating ASM2d seem to come from the determination of the rate constants for VFA uptake ($q_{\text{PAO,VFA_Stor}}$) and polyphosphate storage ($q_{\text{PAO,PO}_4\text{_PP}}$). These two parameters are used in organic compound storage and consumption processes, and their high variability could indicate a problem in the model structure leading to difficulties in the calibration process.

GENERAL DISCUSSION

Inter-model comparison

In both ASM1 and ASM2d, few parameters have been changed in more than half the cases considered. This shows that either model users are in most cases relying on the original values, or that the model outputs are not sensitive to these parameters. In an inter-model comparison taking into account the results for other models presented in the appendix (ASM3, ASM3 + BioP, ASM2d + TUD, Barker & Dold), the following parameters are most often modified:

- growth and decay rates of autotrophs,
- PAO storage processes rates,
- Heterotrophic half-saturation coefficients for substrate and oxygen
- Autotrophic half-saturation coefficient ammonia.

The half-saturation coefficients are thought to be dependent on specific environmental conditions.

Several modelling protocols suggest measuring some kinetic and stoichiometric parameters: WERF (Melcer *et al.* 2003), BIOMATH (Vanrolleghem *et al.* 2003) and HSG (Langergraber *et al.* 2004). However, in current practice few, if any, biokinetic parameters are measured.

Limitations of modelling project articles

The large literature review on modelling projects revealed that important information is often missing from these articles to enable them to be fully used. Lacking information included:

- information on plant: tank configuration, tank dimensions, aeration time;
- information on environmental conditions: temperature, rain events, diurnal variations;
- information on measurement campaign: duration, number of samples, measurement methods;
- information on influent characteristics and characterisation method used;
- method used for data validation and reconciliation;
- method used to optimise the parameter set: protocol, parameters set to original value;
- temperature for which the optimised parameter set is provided.

This lack of information prevents further analysis of the database, such as an investigation of correlations. It also makes it difficult to evaluate the quality of the modelling projects. Thus, the modelling projects included in the database had to be considered to be of equal quality. The differences within parameter values therefore are supposed to be linked to the WWTP conditions and not to a wrong calibration or poor data quality.

It should also be noted that there seems to be a lack of (published) experimental data with respect to parameter values. If parameters were measured it is often difficult to evaluate the results due to missing information on the measurement method.

Potential use of the database

A number of correlations were searched for in the database including: correlations between parameters; between changed values; between parameters and WWTP conditions (Food/Microorganism ratio, nitrogen loads, Sludge Retention Time). No significant correlations were found which is probably due to the limited number of datasets.

The database has been designed to allow future extensions with new data sets. A larger database could allow further analysis to:

- determine model parameter ranges and typical values to define current practice and help model users in the calibration step for the commonly used models;
- provide a synthesis of practical modelling experiences that could help model users to find appropriate case studies similar to their simulation project;
- examine correlation between parameters and analyse its impact on calibration practice (e.g. b_{ANO} and μ_{ANO});
- examine correlations between changes in parameter values and WWTP conditions;
- determine practical model limits from various modelling experiences;
- identify research needs.

CONCLUSION

This study synthesises the practical knowledge of activated sludge models through a database that combines experience from modelling projects and expert knowledge. For now, this database provides parameter ranges for ASM1 and ASM2d. These values should help model users in the calibration step, by showing typical practice in model calibration. However, these parameters should be used with great care since they are the result of averaging practical experience without taking into account parameter correlations or specific environmental conditions.

These results contribute to the knowledge transfer on activated sludge modelling that was requested by respondents of the first survey. This database can be expanded with more modelling projects which would enable further analysis to be carried out. The authors would like to make this database accessible to the AS modelling community and several solutions are currently under study.

The questionnaire provides further information that has not been presented in this study, but will be included in the Scientific and Technical Report of the *Good Modelling Practice – Guidelines for use of activated sludge models* (GMP-TG), such as typical ratios and key numbers currently measured at WWTPs.

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Peter A. Vanrolleghem holds the Canada Research Chair in Water Quality Modelling.

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APPENDIX

Parameter definitions

Table 3 | Parameter definitions and original notation of the studied models

Description	Parameter*	Unit	ASM1	ASM2d	ASM3	ASM3+ BioP	Barker & Dold
State Variables							
COD soluble							
Soluble biodegradable organics	S_B	g COD m ⁻³	S_S		S_S	S_S	
Fermentable organic matter	S_F	g COD m ⁻³		S_F			S_{BSC}
Fermentation product (volatile fatty acids)	S_{VFA}	g COD m ⁻³		S_A			S_{BSA}
Soluble undegradable organics	S_U	g COD m ⁻³	S_I	S_I	S_I	S_I	S_{US}
Dissolved oxygen	S_{O_2}	-g COD m ⁻³	S_O	S_{O_2}	S_O	S_O	S_O
COD particulate and colloidal							
Particulate biodegradable organics	X_{CB}	g COD m ⁻³	X_S	X_S	X_S	X_S	S_{ENM}
Adsorbed slowly biodegradable substrate	X_{Ads}	g COD m ⁻³					
Particulate undegradable organics	X_U	g COD m ⁻³		X_I	X_I	X_I	
Particulate undegradable organics from the influent	$X_{U,Inf}$	g COD m ⁻³	X_I				S_{UP}
Particulate undegradable endogenous products	$X_{U,E}$	g COD m ⁻³	X_P				Z_E
Nitrogen and Phosphorus							
Ammonium and ammonia nitrogen (NH ₄ + NH ₃)	S_{NHx}	g N m ⁻³	S_{NH}	S_{NH4}	S_{NH}	S_{NH}	N_{H3}
Nitrate and nitrite (NO ₃ + NO ₂) (considered to be NO ₃ only for stoichiometry)	S_{NOx}	g N m ⁻³	S_{NO}	S_{NO3}	S_{NO}	S_{NO}	N_{O3}
Particulate biodegradable organic N	$X_{CB,N}$	g N m ⁻³	X_{ND}				N_{BP}
Soluble biodegradable organic N	$S_{B,N}$	g N m ⁻³	S_{ND}				N_{BS}
Soluble inert organic N	$S_{U,N}$	g N m ⁻³					N_{US}
Soluble inorganic phosphorus	S_{PO_4}	g P m ⁻³		S_{PO_4}		S_{PO_4}	P_{O_4}
Biomasses							
Ordinary heterotrophic organisms	X_{OHO}	g COD m ⁻³	X_{BH}	X_H	X_H	X_H	Z_H
Autotrophic nitrifying organisms (NH ₄ to NO ₃)	X_{ANO}	g COD m ⁻³	X_{BA}	X_{AUT}	X_A	X_A	Z_A
Phosphorus accumulating organisms	X_{PAO}	g COD m ⁻³		X_{PAO}		X_{PAO}	Z_P
Organisms (biomass)	X_{Bio}	g COD m ⁻³					
Storage compound in OHOs	$X_{OHO,Stor}$	g COD m ⁻³			X_{STO}	X_{STO}	
Storage compound in PAOs	$X_{PAO,Stor}$	g COD m ⁻³		X_{PHA}		X_{PHA}	S_{PHB}
Stored glycogen in PAOs	$X_{PAO,Gly}$	g COD m ⁻³					
Stored polyphosphates in PAOs	$X_{PAO,PP}$	g P m ⁻³		X_{PP}		X_{PP}	

Table 3 | (continued)

Description	Parameter*	Unit	ASM1	ASM2d	ASM3	ASM3+ BioP	Barker & Dold
Stoichiometric parameters							
Yield for X_{OHO} growth	Y_{OHO}	$\text{g } X_{\text{OHO}} \text{ g } X_{\text{CB}}^{-1}$	Y_{H}				
Yield for X_{OHO} growth per $X_{\text{OHO,Stor}}$ (Aerobic)	$Y_{\text{Stor_OHO,Ox}}$	$\text{g } X_{\text{OHO}} \text{ g } X_{\text{Stor}}^{-1}$			$Y_{\text{H,O2}}$		
Yield for X_{OHO} growth per $X_{\text{OHO,Stor}}$ (Anoxic)	$Y_{\text{Stor_OHO,Ax}}$	$\text{g } X_{\text{OHO}} \text{ g } X_{\text{Stor}}^{-1}$			$Y_{\text{H,NOX}}$		
Yield for $X_{\text{OHO,Stor}}$ formation per S_{B} (Aerobic)	$Y_{\text{SB_Stor,Ox}}$	$\text{g } X_{\text{Stor}} \text{ g } S_{\text{B}}^{-1}$			$Y_{\text{STO,O2}}$		
Yield for $X_{\text{OHO,Stor}}$ formation per S_{B} (Anoxic)	$Y_{\text{SB_Stor,Ax}}$	$\text{g } X_{\text{Stor}} \text{ g } S_{\text{B}}^{-1}$			$Y_{\text{STO,NOX}}$		
Conversion coefficient							
N content of S_{U}	$i_{\text{N_SU}}$	$\text{g N g } S_{\text{U}}^{-1}$					$f_{\text{N,SEP}}$
N content of X_{U}	$i_{\text{N_XU}}$	$\text{g N g } X_{\text{U}}^{-1}$			$i_{\text{N,XI}}$		
N content of X_{CB}	$i_{\text{N_XCB}}$	$\text{g N g } X_{\text{CB}}^{-1}$			$i_{\text{N,XS}}$		
N content of X_{OHO}	$i_{\text{N_OHO}}$	$\text{g N g } X_{\text{OHO}}^{-1}$					$f_{\text{N,ZH}}$
N content of biomass ($X_{\text{OHO}}, X_{\text{PAO}}, X_{\text{ANO}}$)	$i_{\text{N_XBio}}$	$\text{g N g } X_{\text{Bio}}^{-1}$	$i_{\text{X,B}}$				
N content of products from X_{OHO}	$i_{\text{N_XUE,OHO}}$	$\text{g N g } X_{\text{UE}}^{-1}$					$f_{\text{N,ZEH}}$
N content of products from X_{PAO}	$i_{\text{N_XUE,PAO}}$	$\text{g N g } X_{\text{UE}}^{-1}$					$f_{\text{N,ZEP}}$
N content of products from X_{ANO}	$i_{\text{N_XUE,ANO}}$	$\text{g N g } X_{\text{UE}}^{-1}$					$f_{\text{N,ZEA}}$
Kinetic parameters							
Hydrolysis							
Maximum specific hydrolysis rate	$q_{\text{XCB_SB,hyd}}$	$\text{g } X_{\text{CB}} \text{ g } X_{\text{OHO}}^{-1} \text{ d}^{-1}$	k_{h}		k_{H}		
Temperature correction factor for $q_{\text{XCB_SB,hyd}}$	$\theta_{q_{\text{XCB_SB,hyd}}}$	-	$\theta_{k_{\text{h}}}$				
Half-saturation coefficient for $X_{\text{CB}}/X_{\text{OHO}}$	$K_{\text{XCB,hyd}}$	$\text{g } X_{\text{CB}} \text{ g } X_{\text{OHO}}^{-1}$	K_{X}				
Temperature correction factor for $K_{\text{XCB,hyd}}$	$\theta_{K_{\text{XCB,hyd}}}$	-	$\theta_{K_{\text{X}}}$				
Correction factor for hydrolysis under anoxic conditions	$\eta_{q_{\text{hyd,Ax}}}$	-	η_{h}	η_{NO3}			η_{gro}
Correction factor for hydrolysis under anaerobic conditions	$\eta_{q_{\text{hyd,A}\eta}}$	-		η_{fe}			
Ordinary Heterotrophic Organisms							
Rate constant for $X_{\text{OHO,Stor}}$ storage	$k_{\text{SB_Stor}}$	$\text{g } X_{\text{CB}} \text{ g } X_{\text{OHO}}^{-1} \text{ d}^{-1}$			k_{STO}		
Maximum growth rate of X_{OHO}	$\mu_{\text{OHO,Max}}$	d^{-1}	μ_{H}	μ_{H}	μ_{H}		
Temperature correction factor for $\mu_{\text{OHO,Max}}$	$\theta_{\mu_{\text{OHO,Max}}}$	-	$\theta_{\mu_{\text{H}}}$				
Reduction factor for anoxic growth of X_{OHO}	$\eta_{\mu_{\text{OHO,Ax}}}$	-	η_{g}	η_{NO3}	η_{NOX}		
Half-saturation coefficient for S_{B}	$K_{\text{SB,OHO}}$	$\text{g } S_{\text{B}} \text{ m}^{-5}$	K_{S}		K_{S}		
Half-saturation coefficient $X_{\text{OHO,Stor}}/X_{\text{OHO}}$	$K_{\text{Stor_OHO}}$	$\text{g } X_{\text{Stor}} \text{ g } X_{\text{OHO}}^{-1}$			K_{STO}		
Decay rate for X_{OHO}	b_{OHO}	d^{-1}	b_{H}				

Table 3 | (continued)

Description	Parameter*	Unit	ASM1	ASM2d	ASM3	ASM3+ BioP	Barker & Dold
Temperature correction factor for b_{OHO}	$\theta_{b\text{OHO}}$		$\theta_{b\text{H}}$				
Endogenous respiration rate of X_{OHO} (Aerobic)	$m_{\text{OHO,Ox}}$	d^{-1}			$b_{\text{H,O2}}$		
Endogenous respiration rate of X_{OHO} (Anoxic)	$m_{\text{OHO,Ax}}$	d^{-1}			$b_{\text{H,NOX}}$		
Endogenous respiration rate of $X_{\text{OHO,Stor}}$ (Aerobic)	$m_{\text{Stor,Ox}}$	d^{-1}			$b_{\text{STO,O2}}$		
Endogenous respiration rate of $X_{\text{OHO,Stor}}$ (Anoxic)	$m_{\text{Stor,Ax}}$	d^{-1}			$b_{\text{STO,NOX}}$		
Reduction factor for anoxic endogenous respiration of X_{OHO}	$\eta_{m\text{OHO,Ax}}$	-				$\eta_{\text{NO,end,H}}$	
Half-saturation coefficient for S_{O2}	$K_{\text{O2,OHO}}$	$\text{g } S_{\text{O2}} \text{ m}^{-3}$	K_{OH}		K_{O2}	$K_{\text{O,H}}$	$K_{\text{O,HET}}$
Half-saturation coefficient for S_{NOx}	$K_{\text{NOx,OHO}}$	$\text{g } S_{\text{NOx}} \text{ m}^{-3}$	K_{NO}				
Phosphorus Accumulating Organisms							
Rate constant for S_{VFA} uptake rate ($X_{\text{PAO,Stor}}$ storage)	$q_{\text{PAO,VFA,Stor}}$	$\text{g } X_{\text{Stor}} \text{ g } X_{\text{PAO}}^{-1} \text{ d}^{-1}$		q_{PHA}			
Rate constant for storage of $X_{\text{PAO,PP}}$	$q_{\text{PAO,PO4,PP}}$	$\text{g } X_{\text{PP}} \text{ g } X_{\text{PAO}}^{-1} \text{ d}^{-1}$		q_{PP}		q_{PP}	
Maximum ratio of $X_{\text{PAO,PP}}/X_{\text{PAO}}$	$f_{\text{PP,PAO,Max}}$	$\text{g } X_{\text{PP}} \text{ g } X_{\text{PAO}}^{-1}$				$K_{\text{max,PAO}}$	
Maximum growth rate of X_{PAO}	$\mu_{\text{PAO,Max}}$	d^{-1}		μ_{PAO}			
Temperature correction factor for $\mu_{\text{PAO,Max}}$	$\theta_{\mu\text{PAO,Max}}$	-		$\theta_{\mu\text{PAO}}$			
Endogenous respiration rate of X_{PAO}	m_{PAO}	d^{-1}		b_{PAO}			
Rate constant for lysis of $X_{\text{PAO,PP}}$	$b_{\text{PP,PO4}}$	d^{-1}		b_{PP}			
Rate constant for respiration of $X_{\text{PAO,Stor}}$	$b_{\text{Stor,VFA}}$	d^{-1}		b_{PHA}			
Half-saturation coefficient for $X_{\text{PAO,PP}}$	$K_{\text{PP,PAO}}$	$\text{g } X_{\text{PP}} \text{ m}^{-3}$					K_{XP}
Autotrophic Nitrifying Organisms							
Maximum growth rate of X_{ANO}	$\mu_{\text{ANO,Max}}$	d^{-1}	μ_{A}	μ_{AUT}	μ_{A}	μ_{A}	μ_{A}
Temperature correction factor for $\mu_{\text{ANO,Max}}$	$\theta_{\mu\text{ANO,Max}}$	-	$\theta_{\mu\text{A}}$				
Decay rate for X_{ANO}	b_{ANO}	d^{-1}	b_{A}	b_{AUT}			b_{A}
Temperature correction factor for b_{ANO}	$\theta_{b\text{ANO}}$		$\theta_{b\text{A}}$				
Endogenous respiration rate for X_{ANO} (Aerobic)	$m_{\text{ANO,Ox}}$	d^{-1}			$b_{\text{A,O2}}$		
Endogenous respiration rate for X_{ANO} (Anoxic)	$m_{\text{ANO,Ax}}$	d^{-1}			$b_{\text{A,NOX}}$		
Rate constant for ammonification	q_{am}	$\text{M}^3 \text{ g } X_{\text{CB,N}}^{-1} \text{ d}^{-1}$	k_{a}				
Temperature correction factor for q_{am}	$\theta_{q_{\text{am}}}$	-	$\theta_{k_{\text{a}}}$				
Half-saturation coefficient for S_{O2}	$K_{\text{O2,ANO}}$	$\text{g } S_{\text{O2}} \text{ m}^{-3}$	K_{OA}			$K_{\text{O,A}}$	$K_{\text{O,AUT}}$
Half-saturation coefficient for S_{NHx}	$K_{\text{NHx,ANO}}$	$\text{g } S_{\text{NHx}} \text{ m}^{-3}$	K_{NH}	K_{NH4}	$K_{\text{A,NH4}}$		K_{NH}

*Standardised notation from Corominas *et al.* (2010) is used.

ASM3

Data description. The database contains 5 parameter sets for ASM3, of which 1 is a "proposed new default parameter

sets", and 3 are "optimised parameter sets". The modelling studies were exclusively carried out in the North of Europe (Belgium, Finland, Germany) on full scale WWTPs. Table 4 synthesises the main results for ASM3.

Table 4 | Synthesis of database results for ASM3 model, only modified parameters are given

Parameter*	Unit	Original parameter set		Proposed new default parameter set	Optimised parameter sets					
		Notation	Value (k)	l	n	Modif > 50%	Median	Perc. 25%	Perc. 75%	V (%)
Stoichiometric parameters										
$Y_{Stor_OHO,Ox}$	$g\ X_{OHO}\ g\ X_{Stor}^{-1}$	$Y_{H,O2}$	0.85	0.8	5	0.80	0.80	0.80	0	
$Y_{Stor_OHO,Ax}$	$g\ X_{OHO}\ g\ X_{Stor}^{-1}$	$Y_{H,NOX}$	0.8	0.7	5	0.70	0.70	0.70	0	
$Y_{SB_Stor,Ox}$	$g\ X_{Stor}\ g\ S_B^{-1}$	$Y_{STO,O2}$	0.63	0.8	5	0.80	0.63	0.80	21	
$Y_{SB_Stor,Ax}$	$g\ X_{Stor}\ g\ S_B^{-1}$	$Y_{STO,NOX}$	0.54	0.65	5	0.65	0.54	0.65	17	
Conversion coefficient										
i_{N_XU}	$g\ N\ g\ X_U^{-1}$	$i_{N,XI}$	0.02	0.04	5	0.040	0.035	0.040	13	
i_{N_XCB}	$g\ N\ g\ X_{CB}^{-1}$	$i_{N,XS}$	0.04	0.03	5	0.030	0.030	0.030	0	
Kinetic parameters										
Hydrolysis										
$q_{XCB_SB,hyd}$	$g\ X_{CB}\ g\ X_{OHO}^{-1}d^{-1}$	k_H	3	9	5	9.0	3.0	9.0	67	
q_{SB_Stor}	$g\ X_{CB}\ g\ X_{OHO}^{-1}d^{-1}$	k_{STO}	0.1		5	12.0	10.0	12.0	17	
Ordinary Heterotrophic Organisms										
$\mu_{OHO,Max}$	d^{-1}	μ_H	2	3	5	3.0	2.0	3.0	33	
$\eta_{\mu OHO,Ax}$	-	η_{NOX}	0.6	0.5	5	0.50	0.50	0.60	20	
$K_{SB,OHO}$	$g\ S_B\ m^{-3}$	K_S	2	10	5	10.0	2.0	10.0	80	
K_{Stor_OHO}	$g\ X_{Stor}\ g\ X_{OHO}^{-1}$	K_{STO}	1	0.1	5	0.10	0.10	0.10	0	
$m_{OHO,Ox}$	d^{-1}	$b_{H,O2}$	0.2	0.3	5	0.30	0.20	0.30	33	
$m_{OHO,Ax}$	d^{-1}	$b_{H,NOX}$	0.1	0.15	5	0.15	0.10	0.15	33	
$m_{Stor,Ox}$	d^{-1}	$b_{STO,O2}$	0.2	0.3	5	0.30	0.20	0.30	33	
$m_{Stor,Ax}$	d^{-1}	$b_{STO,NOX}$	0.1	0.15	5	0.15	0.10	0.15	33	
$K_{O2,OHO}$	$g\ S_{O2}\ m^{-3}$	K_{O2}	0.2		5	0.200	0.200	0.500	150	
Autotrophic Nitrifying Organisms										
$\mu_{ANO,Max}$	d^{-1}	μ_A	1	1.3	5	X	1.00	1.00	1.30	30
$m_{ANO,Ox}$	d^{-1}	$b_{A,O2}$	0.15	0.2	5	0.20	0.15	0.20	25	
$m_{ANO,Ax}$	d^{-1}	$b_{A,NOX}$	0.05	0.1	5	0.10	0.05	0.10	50	
$K_{NHx,ANO}$	$g\ S_{NHx}\ m^{-3}$	$K_{A,NH4}$	1	1.4	5	1.40	1.00	1.40	29	

k: Gujer et al. (2000); l: Koch et al. (2000). Please refer to the appendix for the parameter definitions.

*Standardised notation from Corominas et al. (2010) is used. n: number of parameter values in the database.

ASM3 + BioP

Data description. The database contains 9 parameter sets for ASM3 + BioP, 1 original parameter set and 8 optimised parameter sets. The modelling studies were exclusively carried out in Germany. Half of them were carried out on full scale WWTPs.

Table 5 | Synthesis of database results for ASM3 + BioP model, only modified parameters are mentioned

Parameter*	Unit	Original notation	Original parameter set	Optimised parameter sets					
				m	n	Modif > 50%	Median	Perc. 25%	Perc. 75%
Kinetic parameters									
Ordinary Heterotrophic Organisms									
$\eta_{mOHO,Ax}$	-	$\eta_{NO,end,H}$	0.33	9		0.33	0.33	0.50	52
$K_{O_2,OHO}$	$g\ S_{O_2}\cdot m^{-3}$	$K_{O,H}$	0.2	9		0.200	0.200	0.500	150
Phosphorus Accumulating Organisms									
$q_{PAO,PO_4,PP}$	$g\ X_{PP}\cdot g\ X_{PAO}^{-1}\cdot d^{-1}$	q_{PP}	1.5	9	X	1.50	1.50	2.30	53
$f_{PP,PAO,Max}$	$g\ X_{PP}\cdot g\ X_{PAO}^{-1}$	$K_{max,PAO}$	0.2	9	X	1.00	0.24	1.00	76
Autotrophic Nitrifying Organisms									
$\mu_{ANO,Max}$	d^{-1}	μ_A	0.9 - 1.8	9	X	1.20	1.10	1.60	42
$K_{O_2,ANO}$	$g\ S_{O_2}\cdot m^{-3}$	$K_{O,A}$	0.5	9	X	0.18	0.13	0.50	206

m: Rieger *et al.* (2001). Please refer to the appendix for the parameter definitions.

*Standardised notation from Corominas *et al.* (2010) is used. n: number of parameter values in the database.

Barker & Dold model

The database contains 6 parameter sets for the Barker & Dold model, of which 1 is "proposed new default parameter

sets" and 4 are "optimised parameter sets". Two of the modelling studies were carried out in North-America, one in Africa and one in Oceania. The modelling studies mainly concern full scale WWTPs with domestic influent (3).

Table 6 | Synthesis of database results for Barker & Dold model, only modified parameters are mentioned

Parameter*	Unit	Original parameter set		Proposed new default parameter set	n	Optimised parameter sets				
		Notation	Value (n)			o	Modif > 50%	Median	Perc. 25%	Perc. 75%
Conversion coefficient										
$i_{N,SU}$	$g\ N\ g\ S_U^{-1}$	$f_{N,SEP}$	0.07	0.034	5		0.070	0.034	0.070	51
$i_{N,OHO}$	$g\ N\ g\ X_{OHO}^{-1}$	$f_{N,ZH}$	0.07		6	X	0.069	0.068	0.070	3
$i_{N,XUE,OHO}$	$g\ N\ g\ X_{UE}^{-1}$	$f_{N,ZEH}$	0.07	0.034	6		0.069	0.034	0.070	52
$i_{N,XUE,PAO}$	$g\ N\ g\ X_{UE}^{-1}$	$f_{N,ZEP}$	0.07	0.034	6		0.070	0.034	0.070	51
$i_{N,XUE,ANO}$	$g\ N\ g\ X_{UE}^{-1}$	$f_{N,ZEA}$	0.07	0.034	6		0.068	0.034	0.068	50

Table 6 | (continued)

Parameter*	Unit	Original parameter set		Proposed new	n	Optimised parameter sets				
		Notation	Value (n)	default parameter set		o	Modif > 50%	Median	Perc. 25%	Perc. 75%
Kinetic parameters										
Ordinary Heterotrophic Organisms										
$\eta_{\text{H,OHO,Ax}}$	-	η_{gro}	0.37		6		0.37	0.37	0.50	35
$K_{\text{O}_2,\text{OHO}}$	$\text{g S}_{\text{O}_2} \text{m}^{-3}$	$K_{\text{O,HET}}$	0.002	0.05	6		0.002	0.002	0.050	2400
Phosphorus Accumulating Organisms										
$K_{\text{PP,PAO}}$	$\text{g X}_{\text{PP}} \text{m}^{-3}$	K_{XP}	0.05	0.01	6	X	0.010	0.010	0.010	0
Autotrophic Nitrifying Organisms										
$\mu_{\text{ANO,Max}}$	d^{-1}	μ_{A}	0.6	0.9	6	X	0.73	0.60	0.90	41
b_{ANO}	d^{-1}	b_{A}	0.04	0.17	6	X	0.08	0.04	0.17	163
$K_{\text{O}_2,\text{ANO}}$	$\text{g S}_{\text{O}_2} \text{m}^{-3}$	$K_{\text{O,AUT}}$	0.5	0.25	6		0.50	0.25	0.50	50
$K_{\text{NH}_x,\text{ANO}}$	$\text{g S}_{\text{NH}_x} \text{m}^{-3}$	K_{NH}	1	0.5	6		1.00	0.50	1.00	50

n: Barker & Dold (1997); o- Questionnaire (based on > 100 modelling project studies)

*Standardised notation from Corominas et al. (2010) is used. n: number of parameter values in the database. Please refer to the appendix for the parameter definitions.

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