# Activated sludge modelling in practice: an international survey

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

## ABSTRACT

The Good Modelling Practice Task Group (GMP-TG) of the International Water Association (IWA) is developing guidelines for the use of Activated Sludge Models (ASM). As part of this work the group created and sent out a questionnaire to current and potential activated sludge model users in 2007. The objectives of the questionnaire were (i) to better define the profile of ASM users, (ii) to identify the tools and procedures that are actually used and (iii) to highlight the main limitations while building and using ASM-type models. Ninety-six answers were received from all over the world, from several types of organisation. The results were analysed to identify the modellers' perceptions of models depending on their profile. The results also highlighted the main topics of interest for improving modelling procedures which are standardisation of the available modelling guidelines and better experience and knowledge transfer.

**Key words** | ASM, good modelling practice, modelling guidelines, questionnaire, survey

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## INTRODUCTION

Activated Sludge Models (ASM) are now widely used for Wastewater Treatment Plant (WWTP) design, optimisation, operation and training. The decisions used in the design and optimisation of WWTPs have significant financial and environmental impacts; therefore they should be based on high quality models. Reaching the correct level of quality is thus a key topic for all model users.

A general framework for building and using activated sludge plant models is needed to increase the quality and efficiency of modelling projects. To this aim, the International Water Association (IWA) formed a Task Group on *Good Modelling Practice–Guidelines for Use of Activated Sludge Models* (GMP-TG) (www.modeleau.org/GMP_TG/). Their assignment is to prepare a Scientific and Technical Report

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that proposes simple and effective procedures in the use of ASM-type models. The ultimate goal is to promote the correct use of ASM-type models by practitioners, and to overcome any major obstacles that prevent widespread use of Activated Sludge Modelling in practice.

A questionnaire was prepared by the GMP-TG and sent out in 2007 to benchmark and collect relevant information on the practical use of modelling. The objectives were threefold: (i) to better define the profile of ASM users, (ii) to identify the tools/procedures that are used (models, guidelines, protocols…) and (iii) to highlight the main limitations encountered while building and using ASM-type models.

## METHODOLOGY

### The questionnaire

The questionnaire was divided into three main parts:

1. *Profile of the respondents*: the educational background of respondents, the type of organisation they are working for, etc.
2. *Questions to ASM users* (including 17 multiple choice and open questions): (i) biological models employed, procedures and platforms used; (ii) motivation for using models and typical pitfalls; and (iii) expectations for the IWA report.
3. *Questions to non-ASM users* (on the basis of 6 multiple choice and open questions): (i) reasons for not using ASMs; (ii) the main obstacles encountered; and (iii) expectations for model improvements.

For the analysis of this questionnaire, the answers of ASM users and non-users on the limitations of modelling projects and expectations were evaluated together.

### The answers and the response rate

The questionnaire was sent out via several means: by e-mail lists, hand-outs in conferences and seminars, and downloads from partners' websites. 96 completed questionnaires were received but due to the open procedure used for distributing the questionnaire, it was impossible to calculate the response rate. 80% of the respondents were ASM users.

The representativeness of the answers is also unknown, because it is difficult to estimate the number of Activated Sludge Model users worldwide and different user categories may have responded at different rates. Two methods have been used to estimate the total number of ASM modellers worldwide:

- One of the questions referred to the number of ASM users in the company. Using this information alone it would be estimated that there are about 635 ($\pm 55$) modellers, which is certainly less than the total in the world, since not every company or university has answered the questionnaire. It is difficult for people to know exactly how many people are using ASM models in their company.
- Numbers of sold licences of the latest versions of simulators were provided by some of the software companies. Summing those numbers led to a rough estimation of between 3,000 and 5,000 modellers worldwide.

### The encoding

To analyse the results of this questionnaire, it was necessary to encode the answers. In fact the structure of the questionnaire was not appropriate to perform a simple analysis, due to the number of questions allowing free form responses, and because the respondents were allowed to answer several items for each multiple choice question.

The multiple choice question items were considered as a yes/no (coded with 1/0) question: yes if the item has been ticked. Items were created for the proposed topics in open questions. Then the questions were analysed as if they were multiple choice questions.

Several question and answer items were found to be similar among the questions asked to users and non users. As a result, several questions could be gathered into two main areas of concern: what are the obstacles in using wastewater treatment models and what are the expectations for improving modelling.

### The statistics

Simple statistics were obtained by dividing the number of answers by the number of respondents to the question (96 for general questions, 76 for ASM user questions and 20 for non-ASM user questions). As discussed above, the respondents were allowed to tick several items per question which

explains the overlaps in the histograms. To find correlations between the respondents' profiles (continent, organisation type) and their answers, the percentages of answers were calculated for each profile.

The confidence intervals on proportions were calculated with the Wilson interval (Brown *et al.* 2001), that relies on only one approximation (Central Limit Theorem). According to Brown *et al.* (2001), for this type of questionnaire with few answers, the Wilson interval provides a more suitable interval than the more commonly used Wald interval, that relies on two approximations (CLT and observed proportion is used as an approximation of the true proportion in the population). Nevertheless, due to the number of answers, the confidence intervals are quite large. Also, they are represented only on the graphs that merge all types of respondents to keep the graphs readable.

It is not possible to conclude on the significance of the results because of several shortcomings:

- the number of respondents is limited;
- the way the survey was sent out was not controlled to ensure a randomly sampled pool of respondents;
- the encoding of free answer question may have introduce some bias.

Nevertheless this study provides qualitative information on the trends in modelling.

## RESULTS AND DISCUSSION

The results are presented in three parts according to the three main objectives of the questionnaire:

- Profile of Respondents
- Practical Use of ASMs
- Obstacles and Expectations for Use of ASMs

The discussion about each part follows the presentation of the results.

### Profile of respondents

#### Results

Among the 96 responses, 65% were returned from European countries and 20% from North America (see Figure 1). Other continents were under-represented, and South America, Africa, Asia and Australia have been merged during the evaluation of responses. Thus, the study focuses primarily on the differences between those North-American and European model users who responded.

Figure 2 is split into two parts. On the left is shown the distribution of the organisation types among respondents, and on the right the extrapolated distribution among the number of model users, calculated based on the given number of ASM users in the organisations. The respondents are mainly from universities and public research centres and from private companies. The distribution of the organisation type differs depending on whether the respondents are ASM users or non-users and on their continent (Figure 2). One should notice that:

- A greater proportion of non ASM users are from WWTPs and private companies compared to ASM users
- One third (33) of the total respondents are from European universities, which represents more than half of European respondents
- Two thirds of North American respondents are from private companies
- A similar proportion of modellers are seen in each category when comparing actual respondents (a) to the estimated number of modellers (b).
- The predominance of private companies in North America and of universities in Europe is even more important in the extrapolated distribution based on all model users within the organisations.

Since there is only one ASM user from WWTPs, that response is not taken into account when comparing response rates between organisation types.

About 86% of the respondents have an engineering background, and their knowledge about modelling is acquired predominantly from self training (78%).

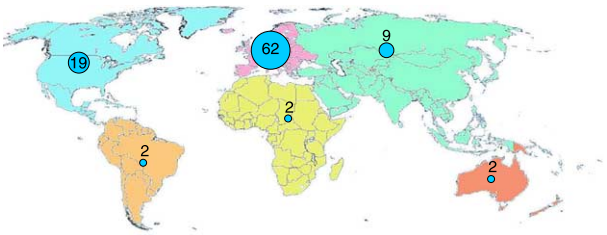


**Figure 1** | Number of answers per continent.

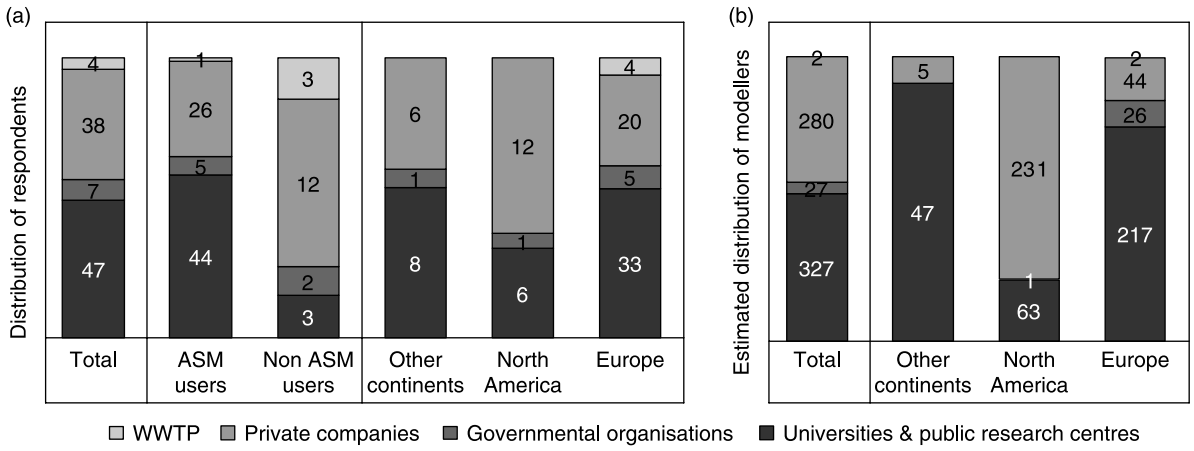


**Figure 2** | Distribution of organisation types among (a) the respondents and (b) the estimated number of model user.

Figure 3 reveals that the source of knowledge varies among the organisation types. The portion of respondents who answered only one of the four items is indicated in black. Self training is always the main source of knowledge, and for a great proportion of people it is quoted as being their only source of knowledge. Private companies take much more advantage of training offered by software suppliers. Governmental employees using models are different in that they acquire their modelling of knowledge at university and employee training.

## Discussion

The proportion of respondents from WWTPs and industry among non-ASM users reveals that they are interested in WWTP models since they have also answered the questionnaire but for several reasons (discussed below) they do not use them.

The large number of European respondents and especially those from universities is probably due to several factors: the way the questionnaire was distributed, the level of interest in the GMP-TG and the workload. The difference

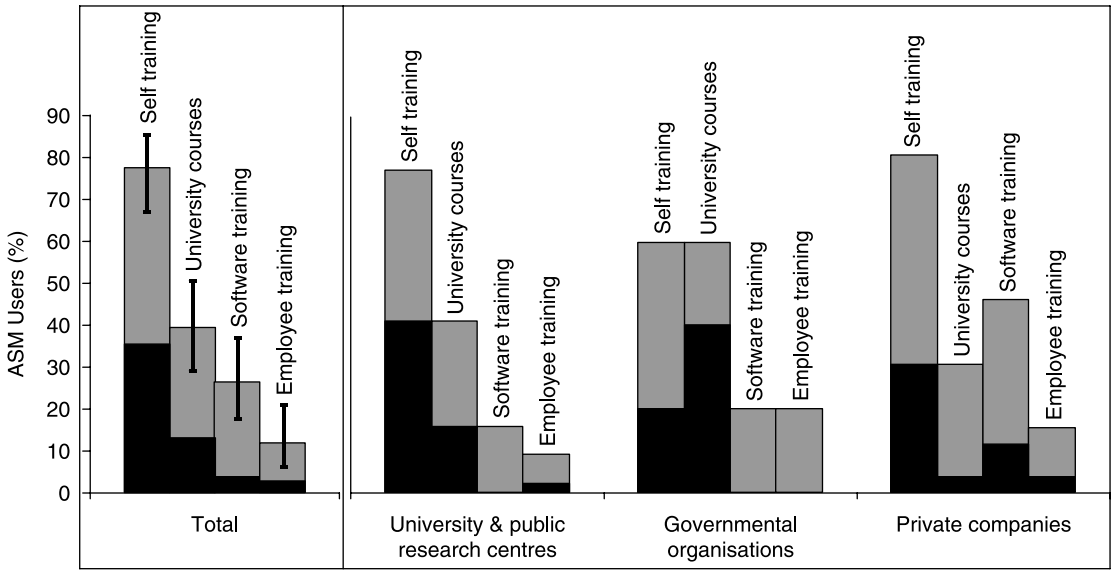


**Figure 3** | Source of knowledge of ASM users per organisation type.

in proportion of European and North-American responses between private companies and universities can be interpreted that in Europe models are mostly a research subject whereas in North America they are predominantly used as an engineering tool in practice.

The engineering background of most of the respondents seems to confirm the hypothesis that wastewater treatment plant modelling is increasingly becoming an engineering tool. However, self training as main source of knowledge reveals a lack of university training and continuing education programs. Self training also includes knowledge transfer into work teams and learning by doing. Thus the proportion of respondents who have answered only one item is relevant. It shows that self training is the only source of knowledge for 31% of commercial ASM users. With limited opportunities in university courses, software providers seem to play an important role in transfer of modelling technology, especially among private companies.

## Practical use of ASMs

### Results

The main objectives cited for building and using a model are: optimisation (59%), design (42%) and prediction of future operations (21%). As shown in Figure 4, the modelling tasks differ depending on the organisation type:

- Optimisation (daily plant operation, control…) is the main objective regardless of the organisation type.
- Private companies use models for design (new plant design and expansion) more than any other organisation types.
- Universities are the only ones having a significant use of models for educational purposes.

North-American and European users are using models in a slightly different way. Europeans are more concerned with daily plant operation and control strategies, while North-Americans use models more for plant design (and re-design).

Respondents were asked to state the time allocated to different modelling steps. Following the Good Modelling Practice protocol (www.modeleau.org/GMP_TG/UP.htm), the modelling steps that have been considered were:

1. Project definition
2. Data collection and reconciliation
3. Plant model set-up
4. Calibration/validation
5. Simulation & results interpretation

The results presented in Figure 5 highlight the three most time consuming steps: data collection and reconciliation, calibration and validation, and simulation and results interpretation (including reporting). Time allocation for governmental organisations and universities is quite similar. Private and public organisations diverge most in the time spent on the calibration and validation step which is more important for public organisations, and on the simulation and result interpretation step, for which private companies spend more time than any other step.

To meet the modelling objectives (Figure 6):

- The most used biokinetics models are 1)ASM1 (Henze *et al.* 1987) (57%) and 2) ASM2d (Henze *et al.* 1999) (32%).
- ASM3 (Gujer *et al.* 1999) is used equally by each organisation type.

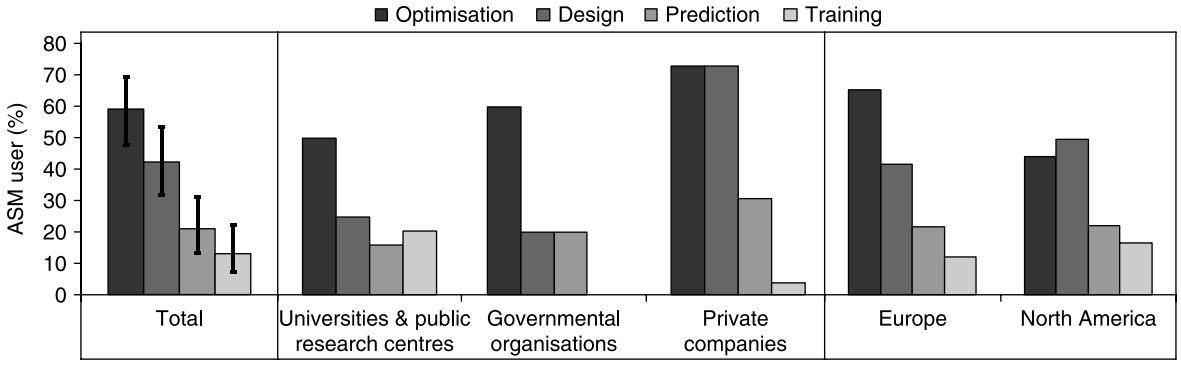


**Figure 4** | Main modelling objectives per organisation type.

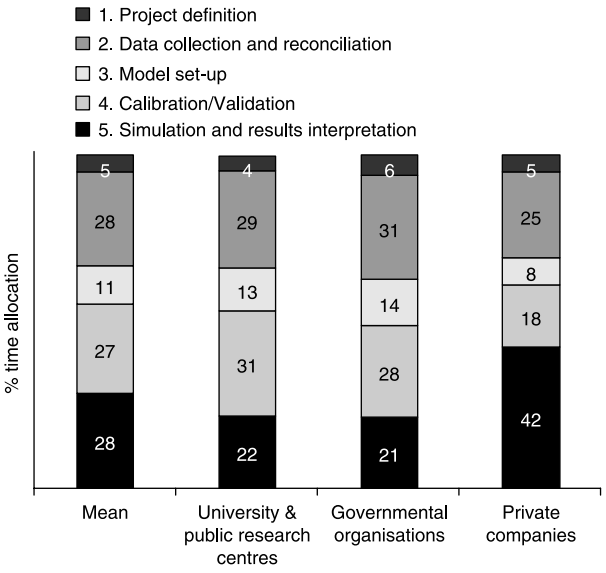


**Figure 5** | Time allocation of protocol steps for each organisation type.

- ASM2d, TUD (Smolders *et al.* 1995) and New General (Barker & Dold 1997) are used much more by governmental organisations.
- Universities use mainly ASM1, whereas the preference for one particular model is less important among private companies.
- ASDM (BioWin) and Mantis (GPS-X) are much more used by governmental organisations and private companies than in universities.

## Discussion

Consultants are mainly called upon for plant design studies and plant modifications, which is confirmed by these results. The difference between European and North-American model use - that corresponds to the difference between universities and private companies–could be explained by the fact that in Europe the use of models by consultants is not widespread (see Figure 2) since design rules may be imposed (e.g.: the German design guideline ATV-DVWK-A 131E 2000). On the contrary ASM-type modelling is often involved in the North-American WWTP design by consultants. Researchers are actually more concerned with optimisation, prediction and training. Many researchers often use virtual WWTPs as research tools, such as the IWA benchmarks models (COST/IWA benchmark, Jeppsson & Pons 2004), as this is a relatively inexpensive way to carry out experiments.

The differences in time allocation between organisation types can be mostly explained by their aim in using models. Consultants are mainly using models in a practical way for design and optimisation, thus their major task is to deliver a report with reliable results to their customers. Universities and public research centres mainly use models for research, thus they aim for more detailed models and therefore spend more time on the data collection and reconciliation step and on calibration and validation. Also private companies likely spend less time on model set up, calibration and validation steps thanks to their modelling proficiency and use of typical modelling tasks developed through multiple modelling projects. Finally, consultants mainly use models for design and plant modifications, which do not require an extensive calibration step, as they use parameter sets from their modelling experience.

Another explanation for the limited use of ASM-type models in European engineering practice could be the typically small size of European consulting firms (with the UK as an exception) in comparison to the large and internationally operating North-American firms. The small

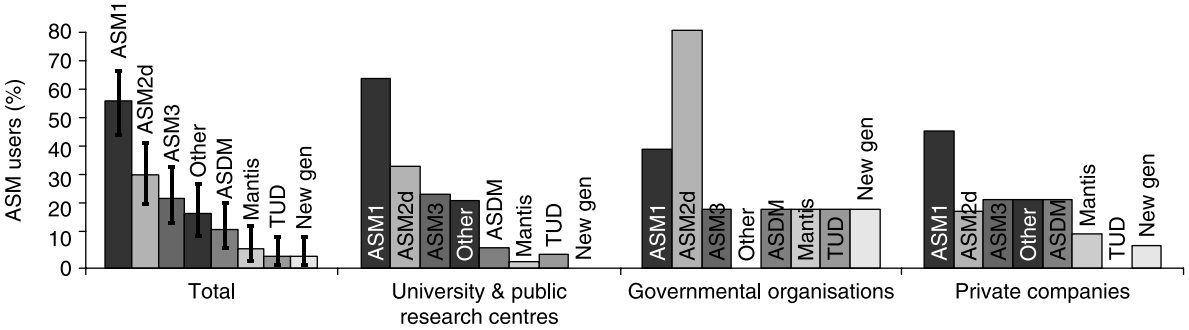


**Figure 6** | Models utilisation per organisation type (ASDM in BioWin, New Gen: New General).

size does not allow them to maintain critical level of modelling experience in-house. Since modelling is not a standard task yet, very few companies specialized in modelling exist in Europe.

The Mantis and New General models have a similar basis as ASM1. Mantis includes assimilative denitrification, whereas New General includes the Wentzel *et al.* (1992) Bio-P module. Consequently, these results show that ASM1 is the most used model type and many of its adaptations are used for specific processes.

## Obstacles and expectations for use of ASMs

### Results

Modelling projects are limited by a number of obstacles. To cope with these obstacles, respondents expressed several requests to facilitate the use of ASM-models in practice (see Figure 7). To keep the figure readable, only the proportion of all respondents is shown. The variation between profile types were included in the study, but are not shown.

The items can be split into 4 topics:

- Cost (17% of respondents) and time (16% of respondents) are issues that could be seen as a related problem (not shown on Figure 7 for clarity). These obstacles are particularly strong among non-users and respondents from WWTPs.
- The topic of model structure is related to the theoretical and mathematical part of modelling. The obstacles expressed are the complexity of the models, the problems of reliability and non-adequacy of the model to simulate the behaviour of the plant (for example they

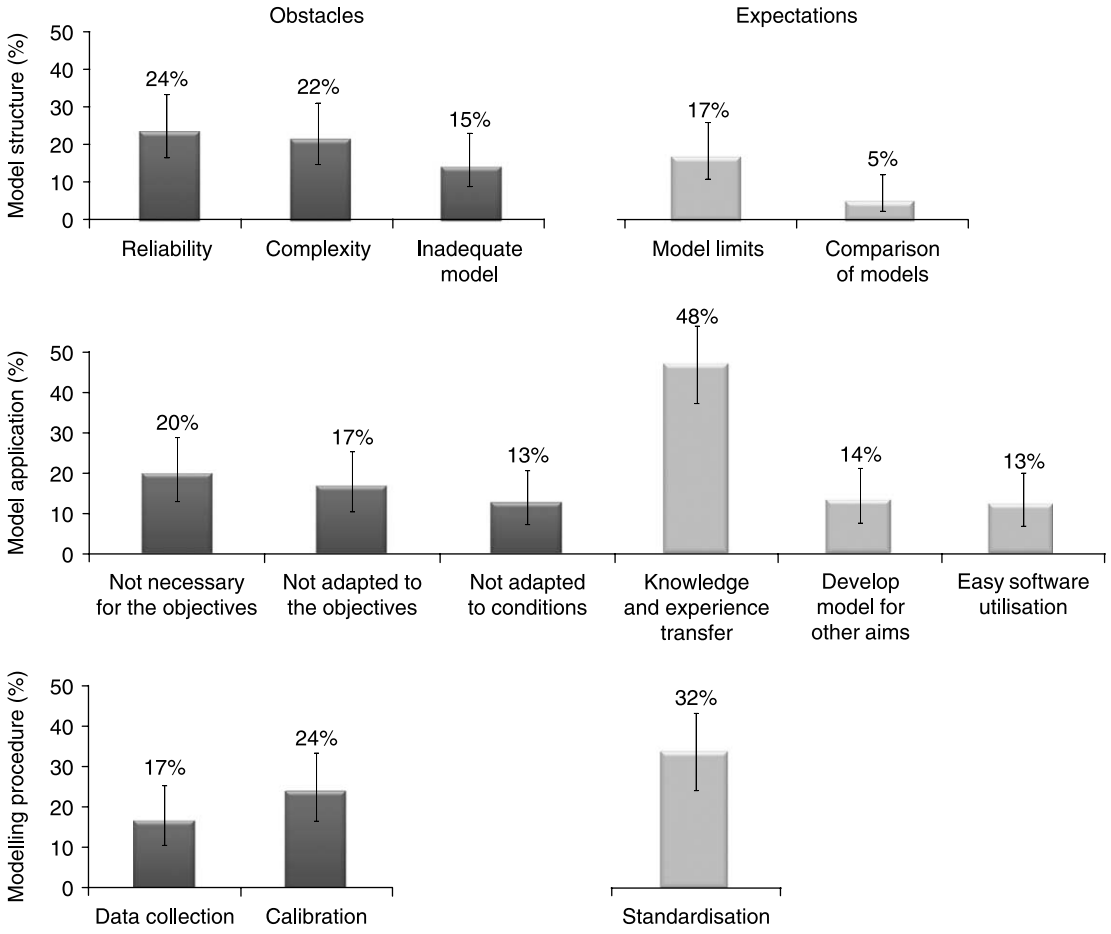


**Figure 7** | Obstacles and expectations.

do not include precipitation phenomena or other specific processes).

The expectations to overcome these obstacles are concerned with the definition of model limits and comparison of models. The problem of model reliability and the expectation to clearly state model limitations are quoted by both users and non-users. Comparison of models is not a high expectation among the respondents, but it is relevant to note that it is often requested by governmental organisations and universities, and not by private companies. Model complexity and inadequate models are considered problematic for all.

- Model application deals with the practical use of models and their implementation in software. This theme contains the most obstacles. For 20% of the respondents models are not required to reach their objectives. On the other hand, about 15% of the respondents claim that available models are not adapted to their objectives (i.e. the particular questions they want answers for). Furthermore, available models are sometimes not adapted to the operational conditions of the plant (for example higher temperature ranges). Consequently respondents, and especially non-ASM users (about 50% of them), are asking for the development of new models and strongly request better knowledge transfer (48%), including sharing case studies. Non-ASM users and respondents from WWTPs expect improvements in software to help carry out modelling steps.
- In the modelling procedure, data collection and calibration effort are the main obstacles. The three other modelling steps were not quoted by the respondents. Calibration effort is problematic for ASM users and represents an obstacle for using models among non-users. To solve these problems, people ask for a standardization of the procedures (32%). This expectation is quite important for all respondents, but especially for governmental organisations.

## Discussion

Non-users, respondents from WWTPs and the category "other continents" (including South America, Africa and Asia) are more sensitive to the problems of cost, time demand and complexity of the models. That reveals a bias against models or a lack of knowledge on modelling. Actually, people have to be aware of the benefits of using models to accept the associated cost. However, modelling requires a certain educational background which is difficult and time consuming to acquire after university studies. The high recurrence of the reliability problem and the expectation of clearer stated model limits show the lack of published technical studies on modelling results. Real and detailed examples would help to determine a realistic model prediction quality.

The reported obstacle by some that models are not required to reach the objectives reveals that these people prefer simpler methods over ASM-type models to meet their objectives. Non-ASM users particularly request the development of models for other aims but also for easier software. As the first statement is far less mentioned by other respondents, it seems that non-ASM users could have some bias or misinformation on model applications. As respondents from WWTPs also ask for more user-friendly software, this could reveal that currently available software is not straightforward for non-experienced people. But a contradiction remains between the wish to have models that cover an even larger number of processes and more user-friendly software despite the increased number of parameters and variables.

The questionnaire indicated that some users and non-users of the models (24%, see Figure 7) reservations about the usefulness and accuracy of models. Two main misuses could be observed and corroborated by the results:

- Spending too much time on calibration without ensuring high quality data. For ASM users this is reflected by the time allocated to calibration. It is also a misconception from non-ASM users that calibration should be a big effort, although data collection does not seem to be a problem for them.
- Lacking methodology for the validation step. Modellers tend to use the independent validation data set for what is in effect a second calibration and not a validation at all. Consultants even often neglect the validation step altogether. The result is a model with a limited or unknown prediction capability, which could subsequently lead to a general mistrust in models.

## CONCLUSION

This survey provided useful insights into the use of activated sludge models. It also pointed out the main limitations of modelling and the expectations of users for improvements.

Generally speaking, the majority of North-American and European modellers are using models in different ways. In Europe, models are most often used by researchers for optimisation purposes, while in North America most modellers are employed by private companies and carry out design studies. Modelling is an engineering tool, but a lack of relevant training has been highlighted. This study also reveals that models are sometimes not properly applied, probably due to a lack of knowledge and standardised procedures.

The development of standardised modelling procedures and better knowledge transfer by making some practical case studies available should address such obstacles as:

- the complexity (apparent or actual) of the model theories and modelling procedures,
- the time consuming steps and therefore the cost of modelling and
- the modellers' appreciation of the reliability of the models.

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