INNOVATION OF ACTIVATED SLUDGE MODEL DEVELOPED BY IWA

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ABSTRACT

TMG (Tokyo Metropolitan Government) needs to remove nitrogen and phosphorus to meet the regulatory requirements and mitigate the eutrophication of Tokyo Bay, which is the receiving waters of the effluents. It has to be done efficiently under the tight budget. For this purpose, efficient operation of the biological nutrients removal processes is needed. TMG built new software to innovate Activated Sludge Model developed by International Water Association for its practical use. The new software is now under use at wastewater treatment plants in the downtown of Tokyo.

KEYWORDS

Activated Sludge Model (ASM), nitrogen removal, phosphorus removal, simulation

INTRODUCTION

Water pollution of enclosed Tokyo bay has been problematic, in spite of the achievement of full coverage of sewage system in Tokyo 23 wards in 1994, which is downtown of Tokyo and the most urbanized area in Japan. Especially in summer period, there occurs red tide phenomenon frequently. This phenomenon is considered to be eutrophication caused by pollution of nitrogen and phosphorus. These nutrients are partly coming from wastewater treatment plants (WWTPs). In order to meet public request and new strict regulation of nitrogen and phosphorus to WWTPs, TMG has to deal with the problem efficiently under the tight budget control.

Removal of nitrogen and phosphorus at WWTPs is commonly carried out with advanced biological treatment processes. However, they need longer hydrodynamic retention time (HRT) than conventional activated sludge processes. It is difficult to find extra-sites for introducing advanced treatment processes at WWTPs in urbanized areas such as Tokyo 23 wards.

TMG is now experimenting new technologies to remove nitrogen and phosphorus efficiently, while constructing full scale new advanced WWTPs using verified technologies. One of the new technologies is practical use of ASM (developed by IWA in 1993), which is referred in this article. ASM is applicable not only to advanced biological treatment processes but also to conventional activated sludge processes, if aeration is restricted at the beginning part of aeration tanks or if nitrification is enhanced.

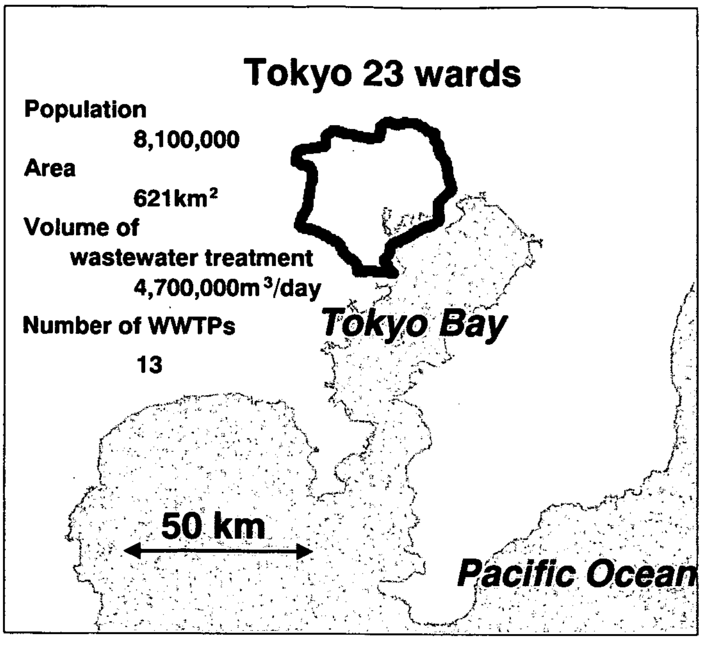


Figure 1 Outline of Tokyo 23 wards

At first, TMG regarded that practical use of ASM was impossible because of its complexity. However, ASM can be useful tool for efficient and effective removal of nitrogen and phosphorus because it enables operators to predict effluent water qualities by setting data on structures of bioreactors, water qualities of influent, and operational conditions. Therefore, TMG decided to adopt it by making innovation with new software for adaptation to the local and practical use.

METHODS

In order to utilize ASM at WWTPs regularly for operational purposes, the following requirements have to be satisfied.

The new software needs to be,
- (i) operated in Japanese,
- (ii) handled be operators with no knowledge about ASM,
- (iii) based on the measured daily water qualities data,
- (iv) and compatible with personal computers.

For the first requirement, graphical user interface (GUI) was developed. It evokes process control to the operators in a schematic way. Many commercial available software products based on ASM adopt CUI (character user interface) or poor GUI. This is one reason to avoid ASM software to be used by general engineers at WWTP.

Another reason for preventing practical use of ASM was the technical difficulties of ASM for ordinary operators of WWTPs. Operators have to understand and interpret the meanings of various equations and parameters and enter values in order to predict effluent qualities when they use commercially available software of ASM. It is impractical for operators to do so. These equations and parameters are incorporated into the software. Therefore, operators of WWTPs are free from setting of complicated parameters. All operators have to do is to enter measured water qualities and operational conditions. For advanced operators, functions to set the detailed parameters remain optional.

TMG have carefully considered in detail to establish the third requirement. The index for the organic components used in ASM is COD_{Cr}. However, COD_{Mn} and BOD are usually monitored as the index of organic compounds in Japan. The method for measuring COD_{Cr} can detect almost all of organic compounds while COD_{Mn} and BOD only detect readily degradable compounds. Moreover, COD_{Cr} has to be fractionated to six organic variables defined in ASM. In order to obtain the variables from COD_{Mn} or BOD, influent samples are examined through two steps. The first step is to convert measured COD_{Mn} or BOD into COD_{Cr}. The second step is the fractionation of COD_{Cr} to six organic variables. Some of investigated ways to convert measured data into ASM variables are taken in by the software.

The fourth strategy is also needed to be used the software widely in Tokyo 23 wards for improvement of water quality. As the performance of general purpose personal computers has been improved in a recent few years, special technologies are not needed for developing the software.

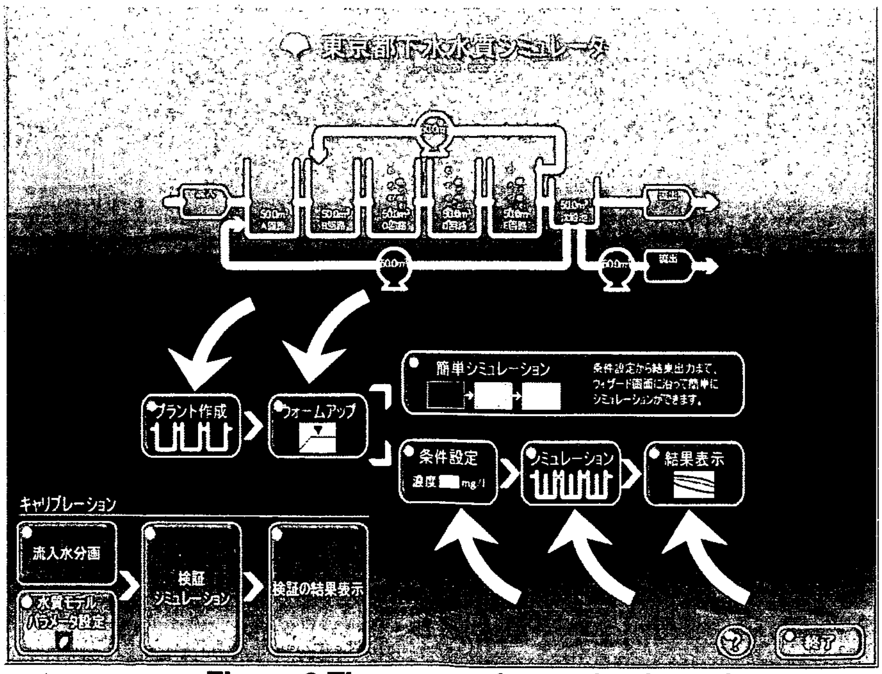
The simulation software predicting water quality of treated wastewater was built. Characteristic functions of the software are described in RESULTS section.

RESULTS

Characteristic functions and user-friendly operation screen equipped with the software are described below. These functions were built so that they are associated with demands of job sites. Comparisons between actual data and calculated data about WWTP are carried out to enhance the predictive accuracy.

The outline of the software operation method

The software has been built so that the general sewage engineers can operate easily only by watching its screen. The screenshot at the time of starting is shown in Figure 2. Pushing buttons can start each simulated processes, such as setting up, start-up and operation of an imaginary WWTP. The data needed for the simulation are promoted to input and the simulation is suspended if data are blanked. Thus, the simulation can be completed without any operational difficulties.



The arrows show buttons to start each simulated processes.

Figure 2 The screenshot at the time of starting

Figure 3 is a screenshot of an imaginary WWTP set up. The operation is very easy just like graphic software. It is possible to not only recreate actual WWTP but also design new type of WWTP which does not exist.

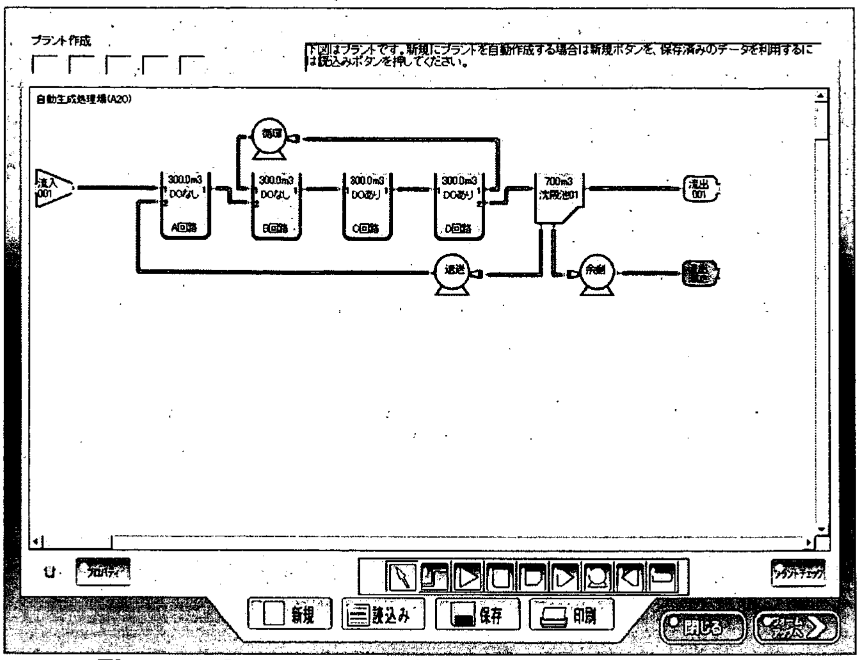


Figure 3 A screenshot of an imaginary WWTP

The data of water quality of influents and operational conditions can be input in spreadsheet form.

The simulation proceeds with calculated water qualities displayed. Once a certain condition of simulation is finalized, the required parts of the predicted water qualities as spreadsheet form can be retrieved.

If predicted data is far from actual data, recalculation is required with adjusted ASM parameters. However, much knowledge about ASM is needed to estimate what parameters should be adjusted and how much the numerical values of parameters should be increased or decreased. This software has a function that calibrates the parameters automatically for ordinary users. It is required just to input the measured data of effluent additionally.

The way converting measured data to ASM variables

In order to predict water quality of the effluent based on the daily measuring influent such as COD_{Mn} or BOD, it is needed to clarify the relationship between COD_{Cr} and COD_{Mn} or BOD and to establish the way to convert COD_{Mn} or BOD into COD_{Cr}. As results of studies of many samples at various WWTP, five ways to enter measured water qualities are provides to the software. The ways set up are as follows:

If measured data are COD_{Mn}, BOD or TOC, it is needed to convert these values into COD_{Cr}. As a result of the investigation at some WWTPs, conversion factors from COD_{Mn}, BOD and TOC to COD_{Cr} were obtained. According to the calculated results, these factors are applicable at WWTPs in Tokyo 23 wards.

Measured or converted COD_{Cr} has to be fractionated to six ASM variables at the next step. As the easiest way for users, fraction coefficients to six variables were established by the result of the investigation at some WWTPs. Just input of measured COD_{Mn}, BOD or TOC is needed in this way. Contrary, the function to enter six ASM variables directly was also prepared. And the third way was equipped. This way has high accuracy same as entering ASM variables directly although the data needed to input is measured easily. The method is modified one of STOWA's. The fractionation method proposed by STOWA (Stichting Toegepast Onderzoek WAterbeheer, English name is "Dutch acronym for the Foundation for Applied Water Research") is the method of not performing the complicated OUR (oxygen usage rate) measurement. The new method eliminates some measurements from STOWA method to use practically. Only the input of COD_{Mn}, s-COD_{Mn}, BOD and concentration of acetic acid can obtain the prediction results with high accuracy by the modified method of STOWA's.

Thus, five input methods have been finally equipped, i.e. input of COD_{Mn}, BOD, TOC or ASM variables directly and the modified method of STOWA's.

The estimation of aeration rate for cost reduction

ASM model only deals with biological treatment processes. Other reliable models can be introduced additionally into the ASM software. The models for sedimentation tank are often introduced. The model to estimate the aeration rate was introduced considering the demands of job site, the accuracy of the model and the increase in calculation time after some studies of already confirmed models.

Since actual oxygen requirement (AOR) is calculated from ASM, defined value of either oxygen-solution rate or dissolved oxygen (DO) can yield another one. Comparing these values at WWTPs with calculated ones, the calculated aeration rate almost corresponded with the actual value in case of DO control. On the contrary, DO did not agree well with measured data in case DO is not controlled. As a result of these studies, the function to estimate the aeration rate was equipped, while the investigation to estimate DO has been continuing. An example of the calculation of the aeration rate will be shown at latter section.

Other functions of the software

Two more functions of the software will be described. The first one is the setting of "anoxic zone" at aerobic stage. More excess denitrification than theoretical calculation is often observed. If this phenomenon has occurred, the predicted result becomes less accurate. Because the phenomenon is probably caused by unevenness of DO observed occasionally at aerobic stage, the concept of "anoxic zone" can reproduce more accurate calculation.

The another one is the setting the concentration of nitrate reduced in return sludge. Denitrification at final sedimentation tank often occurs even though the phenomenon has been rarely regarded. This leads to more release of phosphate at anaerobic stage and sequential more ingestion at aerobic stage. This function can enhance accuracy for prediction of phosphorus removal.

TMG is still trying to introduce other functions to enhance the prediction accuracy.

Reproduced examples to improve water quality

Practical use of this software has been just started all WWTPs in Tokyo 23 wards. Therefore, there are no practical examples to change operational conditions and to improve the water quality of effluent on the basis of simulation results. Reproduced examples of the actual improvement with this software are shown in this section.

Phosphorus removal is difficult even with A^2/O process when the concentration of soluble organic compounds in influent to bioreactor is low. Actually, phosphorus concentration of effluent was found relatively high at a certain WWTP with A^2/O process in Tokyo 23 wards. The observed and calculated phosphates in a certain period are shown in Figure 4. The calculated data are nearly in agreement with the measured ones. The average concentration is approximately 1.0 mg-P/L in this period. However, the desirable maximum concentration is also 1.0 mg-P/L. Some operational conditions have been changed for efficient phosphorus removal as a result after various attempts; those are the ratio of recycled nitrate, the ratio of return sludge, the volume of excess sludge to be excluded and the HRT at each stage. The ratio of recycled nitrate has been reduced, while the ratio of return sludge, the volume of excess sludge and the HRT at anaerobic stage have been increased. The calculated data using current average operational conditions is also shown in Figure 4. The predicted data are dramatically improved by changing operational conditions. Current water qualities are also around this level.

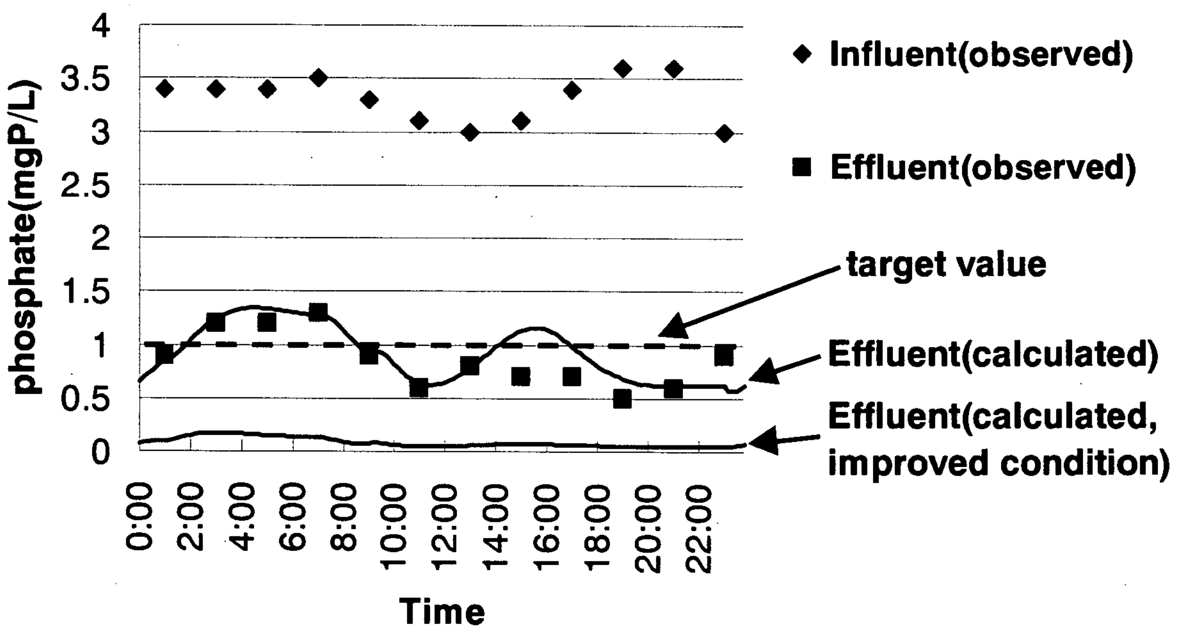


Figure 4 The observed and calculated phosphates

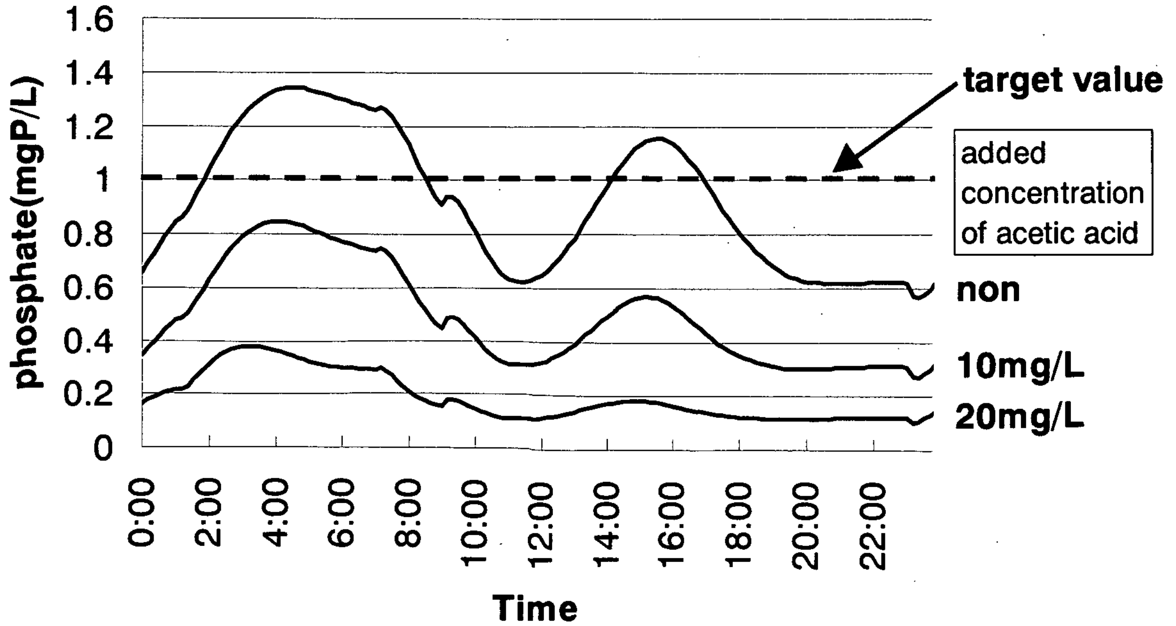


Figure 5 Predicted effect of acetic acid addition

The optimum operational condition can be also estimated when removal of both phosphorus and nitrogen is required. Water quality of ammonium is not so good in the improved case shown in Figure 4. If 1.0mg/L is demanded as maximum concentration about both phosphorus and ammonium, the software can confirm that medium condition of improved and unimproved conditions is recommended.

Another attempt can be also reproduced. Figure 5 shows the predicted data in case acetic acid is added at the inlet of the bioreactor. Addition of acetic acid at a concentration of only 10mg/L is also recommended when acetic acid is readily available.

This software also can be used to attempt cost reduction. The predicted and measured aeration rate at another WWTP is shown in Figure 6.

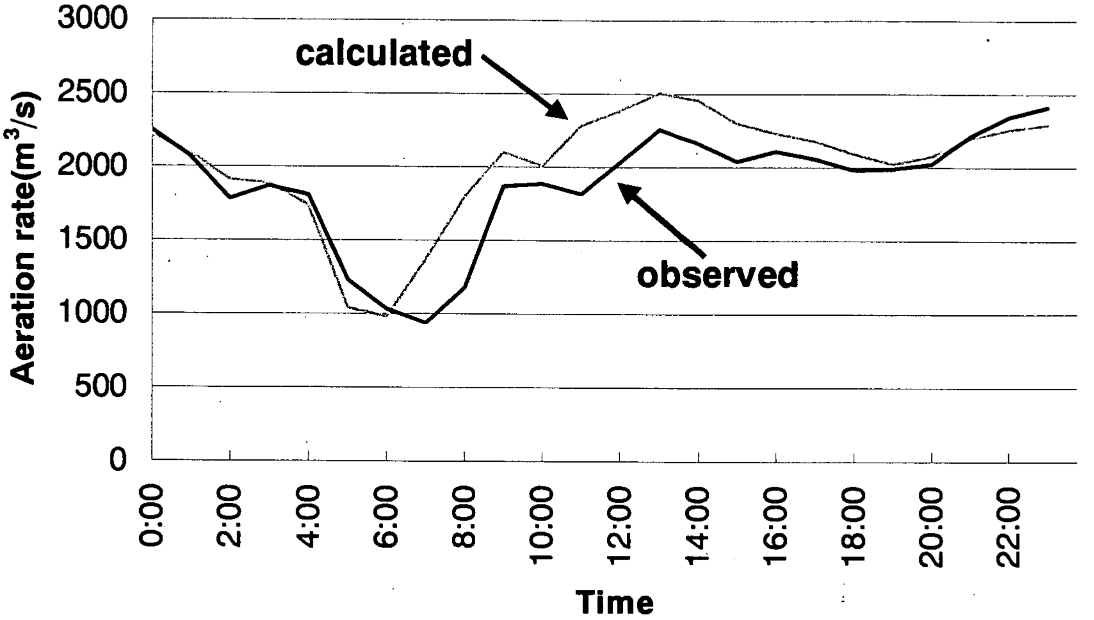


Figure 6 An example of aeration rate simulation

Additional calculation can be done at the WWTP for another challenge. The calculation results of various DO are shown in Table 1.

Table 1 Calculation results for cost reduction

DO (mg/L)	ratio of aeration rate	total nitrogen in effluent (mg/L)	phosphate in effluent (mg/L)
4.3	1	16.3	0.32
3.5	0.82	16.3	0.29
2.5	0.67	16.2	0.26

The results suggest that it is possible to reduce cost of aeration hugely by lowering DO without deterioration of nitrogen and phosphorus in effluent. This is because of lower actual oxygen-solution rate at higher DO.

It is not checked that all of these calculation results are right. However, the results described in this section indicate that the actual improved water qualities and the calculated ones with the software are very resemblance.

DISCUSSION

The outline of the software of innovated ASM of IWA for practical use and the way of forthcoming practical use are described in this article. The newly developed software has fewer functions. For example, the software does not equip the models for sedimentation tank, program languages, and so on. However, the functions of the software are enough for daily practical use at WWTPs. Other functions should be rather equipped, such as the function to predict appropriate volume of excess sludge in order to maintain desirable MLSS, DO of each tanks in case of no DO control and the concentration of denitrified nitrogen at sedimentation tank. These functions have been studied for introduction into the updated version of the software.

European countries have been utilizing ASM actively for designing and optimizing of WWTPs. Especially in the Netherlands, over 100 WWTPs have been optimized in detail. However, ASM has not been utilized by average operators for daily practical use at WWTPs. TMG led to build the software which can be used for the operators because TMG manages a lot of job sites by itself. TMG will face the extensive and unprecedented challenge to utilize ASM practically.

CONCLUSIONS

TMG have built the software for general engineers at WWTPs to predict water quality in effluent after bio-treatment. This software has functions to provide the information to improve water quality of nitrogen and phosphorus concentration. TMG has just started daily practical use of the software and enhances use of this software for daily management at WWTPs.

ACKNOWLEDGMENTS

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REFERENCES

The IWA Task Group on Mathematical Modeling for Design and Operation of Biological Wastewater Treatment (2000) Activated Sludge Models, International Water Association