WRRM1 and WRRM2: Implementations in GoldSim of Unit Process Models and IWA Benchmark Models (BSM1 and BSM2) for Nutrient Removal

Townley, Lloyd R.*, Jiang, Huanhuan* and Tang, Jinquan*
*Nanjing University Yixing Environmental Research Institute, Yixing, Jiangsu, China, townley@njuyi.cn

Abstract: New simulation software has been developed at the Nanjing University Yixing Environmental Research Institute, for use in training, and to facilitate the use of simulation software for improving the performance of water resource recovery facilities (WRRFs) in China. Computer simulation of WRRFs (formerly known as wastewater treatment plants or WTTPs) is useful for (i) design of new WRRFS, (ii) design of modifications to existing WRRFs, (iii) diagnostic analysis to understand the behaviour of existing WRRFs, (iv) design of new control strategies to improve the performance of WRRFs, and (v) training of operators, professionals and students. The new implementations are the first complete implementations in many years. This is also the first time that GoldSim has been used to simulate WRRFs. Rigorous comparison with the original benchmarks has allowed the developers to have confidence in their ability to represent all biochemical processes perfectly, and therefore to have confidence in their ability to customise models for individual WRRFs in China, with the same or similar unit processes.

Keywords: benchmark; BSM1; BSM2

Background and relevance

When challenged to improve the performance of municipal "wastewater treatment plants" (WWTPs) in China, the research team set out to understand the state-of-the-art in process-based modelling of WWTPs, as a precursor to exploring data-based and hybrid approaches. Systematic searches for industry benchmarks led to the discovery of a vast number of papers describing the evolution of component unit process models such as ASM1, ASM2, ASM2d, ASM3, ADM1 and ultimately the benchmark models BSM1 and BSM2. The team learned that in 2014, IWA and the Water Environment Foundation (WEF) recommended that WWTPs should be called "water resource recovery facilities" (WRRFs), to emphasise the importance of liquid and solid waste streams as resources. The team also learned about the history of evolution of commercial software packages, and the extent to which these are consistent with industry benchmarks.

The initial plan was to utilise existing commercial software, to initiate collaborative efforts with operators of WRRFs, and to set out to improve the performance of existing facilities. However, each of the existing software packages is different and has limitations. Each package has a graphical user interface, which of course facilitates the configuration of the software to simulate new facilities. But the fact that simulations must be performed within the graphical user interface generally limits the ability of researchers to develop new methodologies, such as model predictive control (MPC), external to the process-based model itself. Optimisation that requires many simulations is inherently parallelisable, but this requires a standalone executable that can be launched by calls from an external control program. This requirement led the team to decide to develop new implementations of the IWA benchmarks, BSM1 and BSM2. A significant benefit of developing new implementations was that a deep understanding has been gained of all aspects of the benchmark models.

There are more than 4,500 municipal WRRFs in China. Relatively few of these have been designed using commercial software. This reflects a difference in approach and perhaps experience between designers in China and in other countries. The authors believe that there is a huge opportunity to improve the performance of WRRFs in China, based on consideration of system dynamics. Furthermore, process-based modelling is the only defensible methodology for predicting the dynamic response of WRRFs, hours and days ahead. These beliefs lead us to continue our efforts to simulate WRRFs in China.

While some researchers have developed simulation models in China, most are based on open source implementations in MATLAB, or perhaps OpenModelica The authors have found theses and papers that include equations with minor errors, which of course casts doubt on subsequent implementations in MATLAB, and on the accuracy of predictions. The authors' experience developing WRRM1 and WRRM2, during a period of about eight months, has shown how sensitive the models are to every mistake in coding and in data. There is an opportunity and perhaps a need for more researchers and professionals in China to join the global community of specialists in simulation modelling, to promote the benefits of modelling.

Materials and Methods

We ride on the shoulders of giants (Table 1). Our efforts would not have been possible without the efforts of dozens of experts in the past 30 years, culminating in the development and publication of BSM1 and BSM2 under the guidance of the IWA Task Group on Benchmarking of Control Strategies for Wastewater Treatment Plants.

Table 1 Key references that describe the development of BSM1 and BSM2

Reference	Comments
Alex et al. (2008a)	Report on development of BSM1. Revised in 2018. See www.iwa-mia.org/benchmarking/.
Alex et al. (2008b)	Report on development of BSM2. Revised in 2018. See www.iwa-mia.org/benchmarking/.
Copp et al. (2008)	Conference paper at time of release of benchmark models.
Gernaey et al. (2014)	Final report of the IWA Task Group on Benchmarking of Control Strategies for Wastewater Treatment Plants. Contains a list of 15 technical reports of the Task Group, not all of which have been finalised.

Rather than choosing to write new software in traditional programming languages such as C++ or Python, we chose to use a graphical development environment known as GoldSim (GoldSim Technology Group, 2018), largely because of the first author's experience using GoldSim for integrated water management in the mining sector. This is the first time that GoldSim has been used for simulating the conventional activated sludge (CAS) process, let alone anaerobic digestion or a Takács secondary clarifier. GoldSim always steps forwards in time, so it is naturally suited for solving Monod-type equations. A very nice feature of GoldSim is the fact that units are automatically checked and converted. GoldSim can read data from and write results to Excel files; it can call embedded models saved as dynamic linked libraries (DLLs). Most importantly, a free GoldSim Player can be used to execute GoldSim models, saved as .gsp files, so that many models can be executed in parallel.

Results and Discussion

BSM1 and BSM2 have been implemented in GoldSim. The new implementations are known as "water resource recovery models", WRRM1 and WRRM2, respectively. Each model exists in two forms.

WRRM1-Validation and WRRM2-Validation are identical to the MATLAB benchmarks. The only detail not implemented in WRRM2-Validation is the analysis of risk of filamentous bulking, based on fuzzy logic. Each model includes influent data identical to that used in the benchmarks. The benchmarks were run using MATLAB, and the results were imported and saved within WRRM1-Validation and WRRM2-Validation; this allows us to demonstrate that the new models produce identical results to the MATLAB benchmarks, to several significant figures. WRRM1-Validation and WRRM2-Validation have many graphical screens and allow users to explore the rates of biochemical reactions, with a level of detail that is not possible in MATLAB without considerable additional programming.

WRRM1-Control and WRRM2-Control allow users to modify control handles, to attempt to improve the performance of the benchmark facilities using standard influent data. After completing the implementation of WRRM1, the authors learned that the developers of BSM1 intended the benchmark facility to be overloaded (undersized). As a result, it is difficult to improve the performance of the facility. For this reason, WRRM1-Control allows users to modify the sizes of activated sludge reactors, and other components of the facility, thereby providing more degrees of freedom in the model. Similarly, WRRM2-Control allows more degrees of freedom than BSM2, although it still allows only the standard influent data.

Rigorous comparison with the original benchmarks has allowed the developers to have confidence in their ability to implement the equations representing biochemical processes, and therefore to have confidence in their ability to customise models for individual WRRFs in China, with the same or similar unit processes.

The next phase of development of WRRM1 and WRRM2 will focus on customisation of models for specific plants. The software can be modified to simulate any number of activated sludge reactors, in common configurations such as A^2/O, A/O, oxidation ditch etc. Following the example set by the IWA Task Group on Benchmarking of Control Strategies for Wastewater Treatment Plants, current efforts are focused on developing methods to estimate the influent characteristics based on typical measured data.

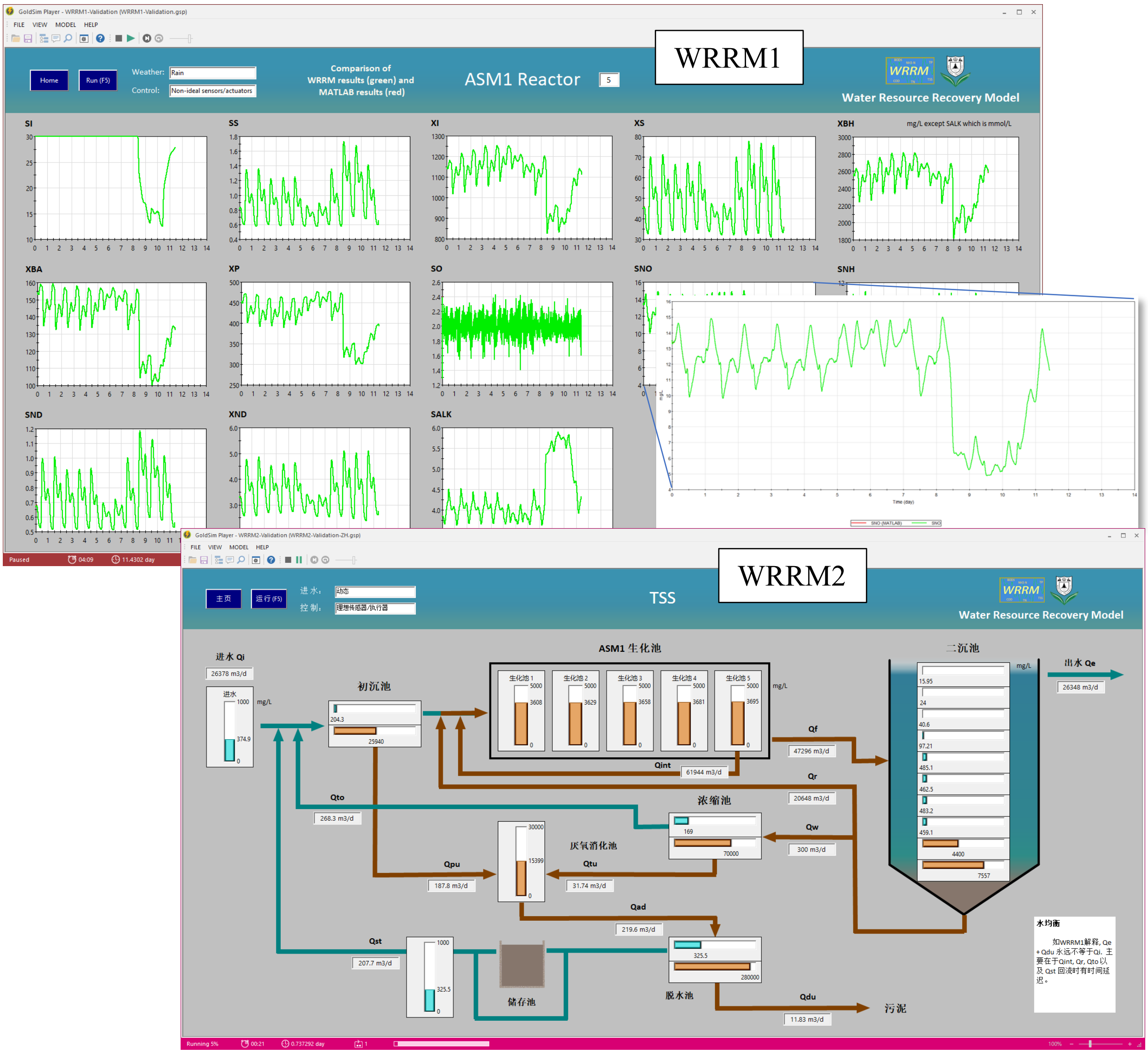

Figure 1 Example graphical screens from WRRM1 and WRRM2, in English and Chinese

Acknowledgements

The authors are grateful for financial support from the Nanjing University Yixing Environmental Research Institute and ongoing assistance from the Environmental Science and Technology Park (ES&TP) in Yixing. The first author is grateful to the Jiangsu Industrial Technology Research Institute (JITRI) for support as a JITRI Researcher. We are grateful to Prof. David Waite of the University of New South Wales (UNSW) for supporting the first author as a Senior Visiting Fellow, to Rick Kossik and his team at GoldSim Technology Group for their support, to Prof. Ulf Jeppsson of Lund University in Sweden for his continued support of the MATLAB versions of the IWA benchmark simulation models and to Dr Xavier Flores-Alsina of the Technical University of Denmark (DTU) for his assistance and encouragement.

References

Alex, J., Benedetti, L., Copp, J., Gernaey, K.V., Jeppsson, U., Nopens, I., Pons, M.N., Steyer, J.P. & Vanrolleghem, P. (2008a) *Benchmark Simulation Model no.1 (BSM1)*. IWA Report.

Alex, J., Benedetti, L., Copp, J., Gernaey, K.V., Jeppsson, U., Nopens, I., Pons, M.N., Rosen, C., Steyer, J.P. & Vanrolleghem, (2008b) *Benchmark Simulation Model no.2 (BSM2)*. IWA Report.

Copp, J.B., Jeppsson, U. & Vanrolleghem, P.A. (2008) *The Benchmark Simulation Models – A Valuable Collection of Modelling Tools*. Proceedings, iEMSs 2008: International Congress on Environmental Modelling and Software, International Environmental Modelling and Software Society.

Gernaey, K.V., Jeppsson, U., Vanrolleghem, P.A. & Copp, J.B. (2014) *Benchmarking of Control Strategies for Wastewater Treatment Plants*. IWA Publishing, London.

GoldSim Technology Group (2018) *GoldSim User's Guide*, Version 12.1, 1191 pp. See www.goldsim.com.