Annex: Modelling as a Tool for Wastewater Treatment Optimisation, Policy and Planning

Wastewater modelling is a powerful tool which may be used in the planning, design and operation of wastewater facilities. However, without a sound understanding of much of the theory behind modelling, models can quickly fall into disuse as the users fail to understand how to extract best value from this tool.

Wastewater modelling was first introduced to the ACEDP Lake Tai Project following a visit to China in October 2009. During this visit, experts on eutrophication concluded that nitrogen was a limiting nutrient in the promotion of algae growth in Lake Tai, and tours of six (6) WWTPs in Huzhou and Suzhou suggested that nitrogen removal at these facilities could probably be increased. Wastewater modelling was proposed as a tool to assist in assessing the extent to which N removal could be increased and in 2010 & 2011 demonstrations using BioWin were conducted at Suzhou and Huzhou. Summaries of these demonstrations and their results are presented below.

Case Study 1: Wuzhong Wastewater Treatment Plant, Suzhou

The Wuzhong WWTP is located in Wuzhong District, Suzhou. It has an inflow of about 20,000 tons per day of domestic wastewater serving a current population of approximately 60,000 people.

A summary process flow diagram is provided in Figure 1.

Initial construction of the WWPT was completed in 1998 (Stage 1) and consisted of primary screens and grit chamber (for coarse and dense solids removal) and oxidation ditches (a type of biological treatment process). The mixed liquor (biological sludge) in the oxidation ditches (referred to as activated sludge) is separated from the effluent using secondary clarifiers, before being thickened by gravity (in a thickener) and dewatered by a belt press. Stage 2 was constructed in 2005, and consists of a single oxidation ditch preceded by an anaerobic (biological) reactor. An anaerobic reactor was also added upstream of the Stage 1 oxidation ditches, and additional secondary clarifiers and belt presses were installed to separate the sludge. The Stage 2 upgrades enhanced the potential for biological nitrogen and phosphorus removal.

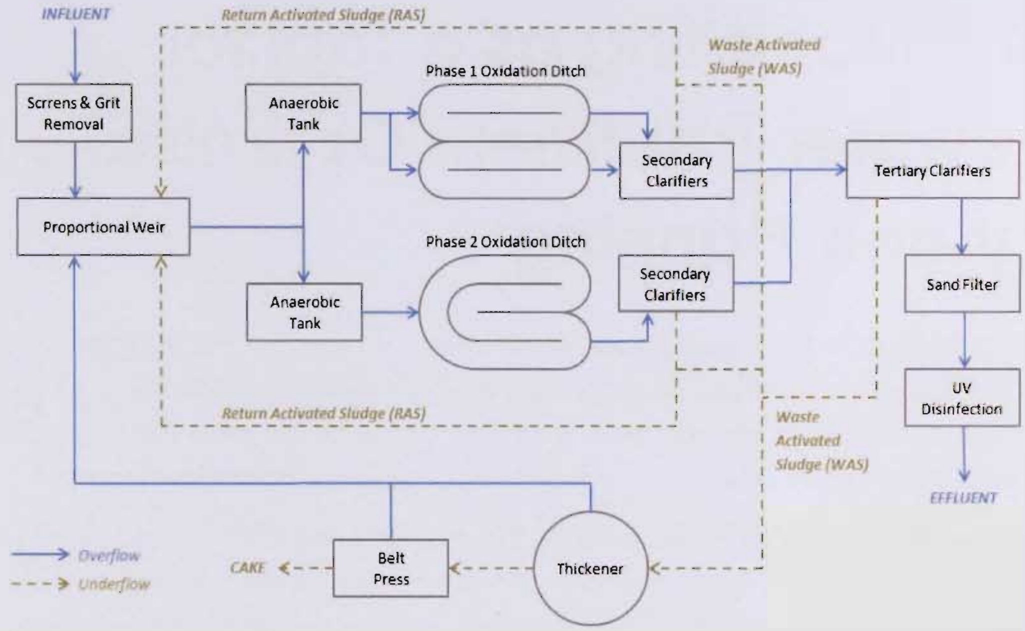

Figure 1: Simplified process flow diagram for Wuzhong WWTP, Suzhou. Overflow is shown as a blue solid line and underflow is shown as a brown dashed line.

More recent plant upgrades were commenced in 2008 in order to meet effluent quality requirements for the Lake Tai basin. The upgrades consisted of tertiary clarifiers (with chemical flocculants addition to assist with solids settling), a sand filter with the potential for residual nitrogen removal (by adding methanol) and ultraviolet (UV) disinfection. The recent plant upgrades were targeted at achieving Class 1A effluent water quality.

In August 2011, a pilot scale biological treatment process was installed with a higher degree of process control relative to the oxidation ditches.

Median influent average daily COD and Total nitrogen in 2010 were 300 mg COD /L and 36 mg N/L. The median effluent average daily COD and Total Nitrogen were 38 mg COD/L and 10.2 mg N/L.

Modelling for plant operation optimisation

A steady-state spreadsheet model was developed for the Stage 2 anaerobic/oxidation ditch circuit. Influent and effluent water quality, influent flow rate, plant geometry and operational parameters were used to define and calibrate the model to achieve an acceptable steady-state mass balance. Where data was not available, assumptions were made based on typical and likely values.

Changes in influent water chemistry and quantity were made to demonstrate how these changes can have major impacts on plant performance. Similarly, changes in plant operating parameters (e.g. recycle ratios, sludge age) were made to demonstrate the effects of these changes and more importantly, that these effects could be estimated easily and rapidly using the steady-state spreadsheet.

The steady-state spreadsheet model indicated that the Stage 2 circuit has the theoretical potential to achieve effluent water quality of approximately 5 mg TN/L and approximately 0.7 mg Ammonia-N/L; and that the high return activated sludge (RAS) recycle ratio used in the biological process does not have any theoretical advantage for nutrient removal, which suggests that there is potential for energy savings from reduced pumping requirements.

A dynamic model was developed using BioWin software[1]. Similarly to the steady state model, the Stage 2 anaerobic/oxidation ditch circuit was modelled. A simplified BioWin model was constructed initially to provide an initial indication of process capabilities prior to development of a more detailed model (see Figure2) that consisted of separate objects representing various zones within the oxidation ditch and for the anaerobic reactor. For the purposes of the demonstration assumptions were made where data were not available.

The dynamic models were manipulated by changing the internal recycle ratios and RAS ratio to demonstrate the theoretical response of the treatment biological processes to these changes. For demonstration purposes, the model was set up for optimum nutrient removal and the influent temperature varied to demonstrate the theoretical response of the biological processes to changes in environmental conditions.

The results from the dynamic-state BioWin model identified that there could be improvements made to decrease effluent nitrogen concentration. When the RAS recycle ratio was reduced to a typical value, the predicted effluent TN concentration improved significantly. This is thought to be due to a reduction in residual oxygen being delivered to the anaerobic zone in the recycled sludge, which enhances the nitrogen removal.

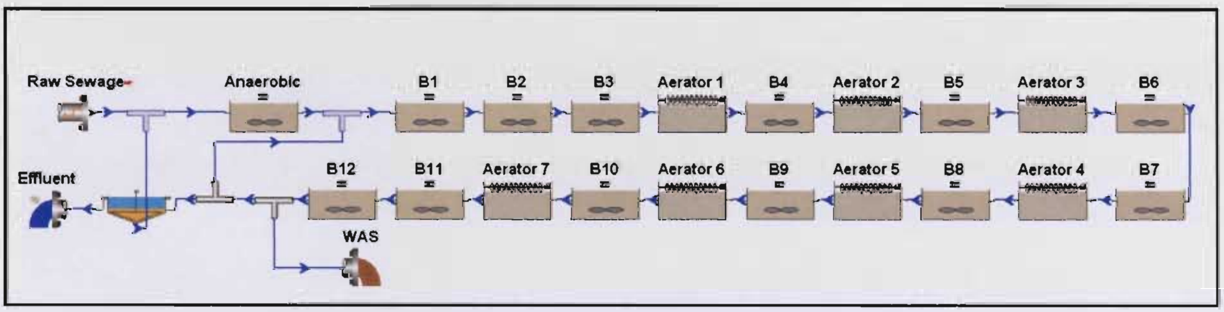

Figure 2 BioWin model screenshot depicting the detailed model constructed for the Stage 2 anaerobic and oxidation ditch processes.

The theoretical effect of wastewater temperature on the process is depicted in Figure 3 - showing that a decrease in wastewater temperature has a detrimental effect on denitrification due to the decreased rate of activity of the microorganisms involved. Nitrification was maintained by increasing the sludge age from 9 to 14 days. From an operational perspective, these results indicate that denitrification in winter is more difficult and confirms the importance of increasing the sludge age in winter.

[1] BioWin by EnviroSim Associates Ltd. is a dynamic state waste water treatment plant modelling package for PC (www.envirosim.com). Similar software packages include GPS-X by Hydromantis (www.hydromantis.com/GPS-X.html) and STOAT by WRc (http://www.wrcplc.co.uk/stoat.aspx).

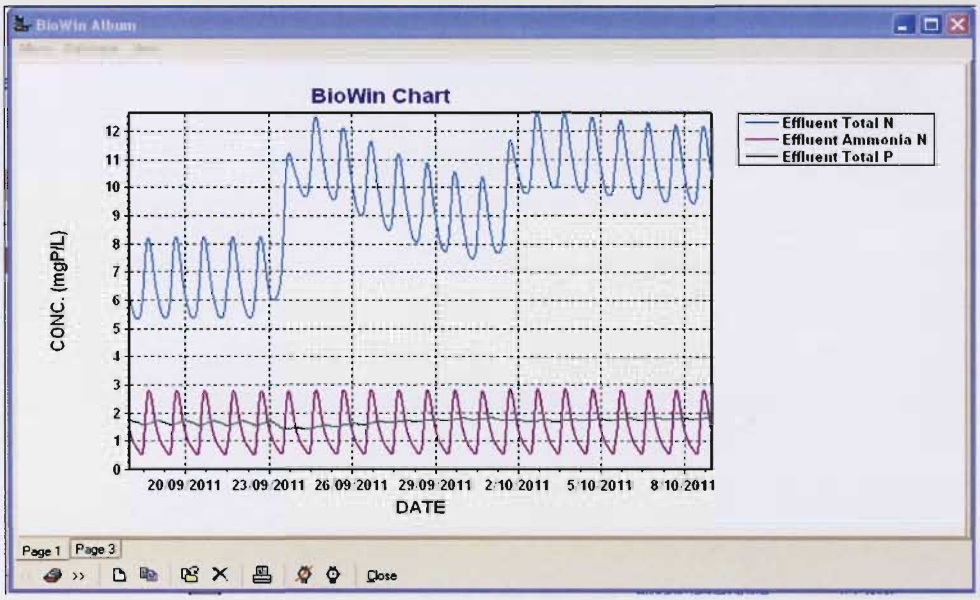

Figure 3: BioWin model output showing the increase in total nitrogen concentration after the wastewater temperature in the model was decreased in two stages from 20°C to 15 °C and to 13 °C.

Modelling for plant design (and upgrade)

To demonstrate the use of modelling as a technical design and planning tool, an alternative plant configuration using existing infrastructure with the addition of membrane bioreactors (MBR's) was modelled to indicate the theoretical throughput that the plant could achieve.

The spreadsheet model suggested that the aeration energy currently provided is theoretically adequate to match the calculated oxygen requirements for water treatment; however there is little room for increasing plant capacity without upgrading the aeration system. If the plant were to be upgraded with a more efficient aeration system and MBR technology, the plant has the theoretical capacity to double its throughput using existing infrastructure.

Demonstration conclusions

The conclusions from the demonstration exercise at Wuzhong WWTP were:

- The steady-state model can assist with identifying what data is important to better understand plant behaviour.
- The steady-state mass balance is a critical part of model development. The process of developing the mass balance can assist with identifying data quality issues (eg. errors in laboratory analysis or instrumentation) and also areas of the plant that are not performing as required or expected.
- The pilot plant at Wuzhong has excellent potential to be used to determine the maximum treatment efficiency achievable with the Wuzhong sewage.

- The plant has significant potential for increased throughput with appropriate infrastructure upgrades such as conversion to an MBR with augmented aeration capacity and the construction of a membrane tank.

Case Study 2: Shibei Wastewater Treatment Plant, Huzhou

The Shibei WWTP was the first WWTP constructed in Huzhou and is located in Jinsuo Village, Huanzhu County. Plant operation commenced in March 2000. The design plant capacity is 30 ML/day and services a current population of 84,000 people and a dyeing dominated industry that contributes approximately 30% to the influent flow. The plant also receives septage (the residue from septic tanks) that is delivered by truck.

A simplified process flow diagram is provided in Figure 4. The primary treatment process consists of a grit chamber (which receives the combined domestic and industrial wastewater and septage, which is the residual material from septic tanks) and primary settling tanks. Secondary treatment consists of two sets of biological treatment processes. Stage 1 comprises two oxidation ditches followed by two secondary clarifiers. Stage 2 comprises two carousel oxidation ditches followed by two secondary clarifiers. After secondary treatment, the overflow from Stage 1 and 2 are sent to tertiary clarifiers where coagulant (metal salt) flocculant (polymer) is added for chemical phosphorus removal and turbidity removal. A suspended media process and sand filter are also available for tertiary treatment, followed by chlorine disinfection.

The oxidation ditches are aerated using conventional brush aerators powered by fixed speed motors. Aeration is currently controlled by turning individual brush aerators on or off. Influent and effluent mean Total Nitrogen concentrations are 25.6 and 14 mg N/L and Influent and effluent mean COD concentrations are 270 and 55.4 mg COD/L.

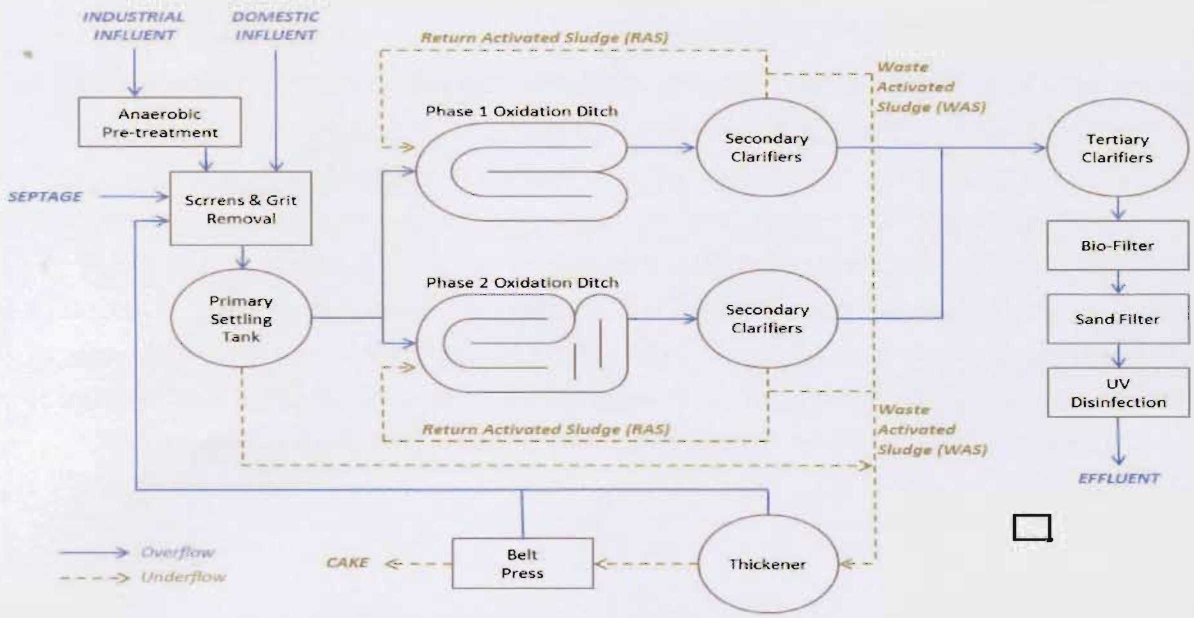

Figure 4: Simplified process flow diagram for Shibei WWTP, Huzhou. Overflow is shown as a blue solid line and underflow is shown as a brown dashed line.

Modelling for plant operation optimisation

A steady-state spreadsheet model was developed for the Stage 1 anoxic/aerobic oxidation ditch circuit (see Figure 9) to identify the theoretical potential for nitrogen reductions. Influent and effluent water quality, influent flow rate, plant geometry and operational parameters were used to define and calibrate the model to achieve an acceptable steady-state mass balance. Where data were unavailable, assumptions were made based on typical and likely values for the purposes of model demonstration.

The steady-state model for the Stage 1 oxidation ditch suggested that: a) there is an excess of aeration in the process; b) greater theoretical potential exists for nitrogen removal (potentially due to the excess aeration); and c) the plant has the potential to treat significantly higher volumes of wastewater with only operational changes. The clarifier capacity seems to be the limiting process.

Guided by the results from the steady-state modelling, a BioWin model was developed for the Stage 1 anoxic/aerobic oxidation ditch circuit (see Figure 5).

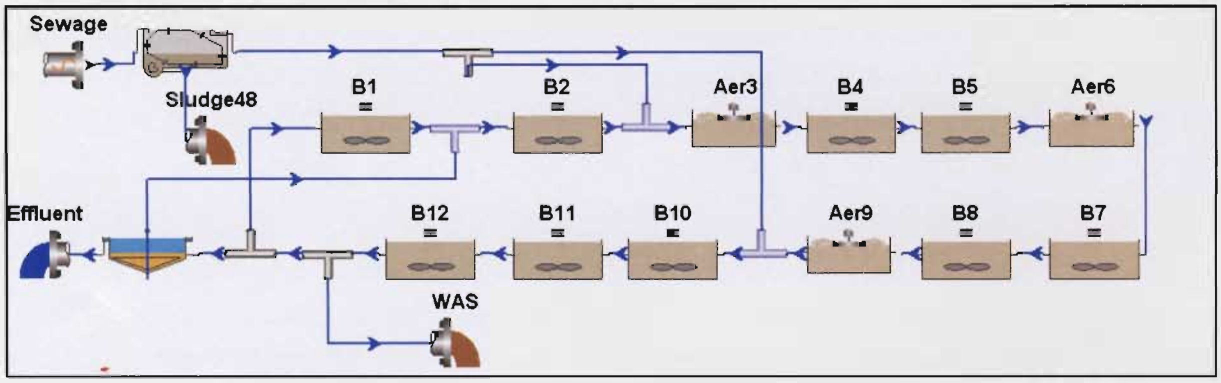

Figure 5: BioWin model construction for the Stage 1 oxidation ditch at Shibei WWTP. The model includes the primary settling tanks and three surface aerators.

The BioWin model was manipulated by changing the aerator power to demonstrate the theoretical response of the biological processes. The results indicated that the theoretical potential exists for increased nitrogen removal as well as energy savings by reducing the aeration in the Stage 1 oxidation ditch (see Figure 6). The initial period shows the modelled plant performance similar to current operation. The first reduction is by about 15% of the aerator power and reduces the total nitrogen in the effluent to approximately 5 mg/L. It should be noted that the total nitrogen is made up mainly of un-biodegradable nitrogen with very little (approximately 1 mg/L) of nitrate nitrogen. The second reduction is by about 20% of the aerator power and results in an oxygen deficit which causes the effluent ammonia to increase.

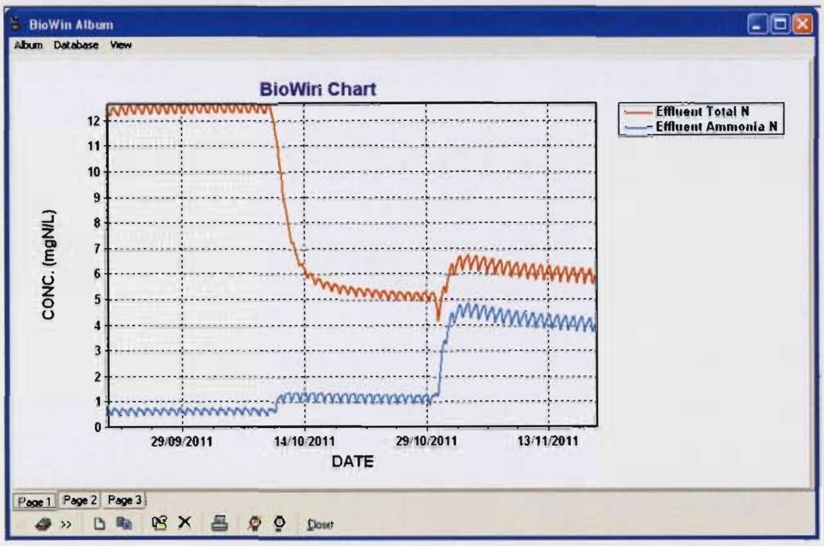

Figure 6: Ammonia and total nitrogen versus time for a 60 day BioWin simulation.

Demonstration conclusions

The conclusions from the demonstration exercise at Shibei WWTP were:

- There appears to be scope to reduce the effluent total nitrogen by adjusting the rate of surface aeration – currently the system appears to have the potential to over-aerate. This could also potentially provide substantial energy savings by adapting the plant with conventional technologies.
- The existing plant has the capacity to treat a much greater flow than is currently received, with clarification likely to be the limiting process step.
- The aeration capacity appears to be sufficient to treat the full load entering the plant with the primary sedimentation tanks being bypassed. The impact of this would be to reduce the total nitrogen in the effluent however as a consequence there would be a decrease in the cake solids concentration from the belt presses since only WAS will be being dewatered.
- The effluent discharge criteria based on COD may be difficult to achieve due to the un-biodegradable COD fraction. Infrastructure upgrades to achieve reductions in un-biodegradable COD would be very expensive with little (if any) benefit to the receiving water environment.