Wastewater Treatment Plant Optimization Using a Dynamic Model Approach

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ABSTRACT

This paper reviews plant optimization and in particular the role a dynamic model can have in assessing plant capacity and performance. A dynamic model can be used to simulate a number of "what-if" scenarios, which may be difficult to evaluate at full-scale. A well-calibrated model can be used as a "tool" in the optimization of facilities. This paper presents four case studies, which demonstrate some uses of a simulation model in plant optimization. A wastewater simulator can be used to assess capacity limitations, operational concerns and cost-benefits associated with various operating strategies.

KEY WORDS

Plant optimization, dynamic modeling, wastewater treatment

INTRODUCTION

Optimizing the operation of existing facilities is becoming more important as effluent criteria become more stringent and available funds for upgrades/expansions becomes less available. Getting more from existing facilities by either operational changes or minor upgrades is a means to meet these restraints. Optimization involves reviewing plant operations, facilities and testing to determine unit capacities and process bottlenecks. Field tests are available to diagnose unit processes, such as aeration efficiency tests (e.g. off-gas analysis) and clarifier flow profiling (i.e. dye testing). These tests can evaluate current operating limitations and lead to operational changes or upgrade requirements.

Often recommended operational changes cannot be immediately verified at full-scale. A mathematical model of the plant can be used as a tool to provide a means to evaluate different operating strategies and upgrades.

Basis of Modeling

Models are representations of the knowledge we have about a system. If we can prepare models that are accurate representations of real systems, then we can use them to conduct experiments which otherwise could not be possible. For example, we can conduct stability and sensitivity analyses, test the limits of the model and 'run' the model under conditions that would be harmful or dangerous in the real system. Using quantitative and qualitative optimization techniques, we can determine the inputs required to achieve a desired output. In practical terms, this capability would allow us to build better tools for process design operation and control. Tools for model building, calibration and simulation facilitate these tasks and are changing the manner in which process and plant analysis is performed.

Modeling and simulation has been practiced by engineers and scientists in the environmental field for many years; however, the model are often steady-state rather than dynamic. With the advent or powerful, low-cost workstations, numerical solution of large-scale dynamic models has become practical. In wastewater engineering, there has been rapid progress in the development of models for the processes used in a typical municipal or industrial plant. In 1986, the International Association on Water Quality (IAWQ) released a report outlining a general model for the activated sludge processes. This model is often referred to the ASM1 model. This was followed by a second publication in 1995, which included phosphorous removal. This model is often referred to as ASM2. Sedimentation, biofilm, anaerobic and disinfection models have also seen gradual improvement. With these developments it has become possible to consider the preparation of models for entire treatment facilities from headworks to effluent disinfection.

GPS-X provides the platform and input/output capability to utilize these powerful models and the flexibility to compute numerical solutions. These tools considerably reduce the time required to build, calibrate and simulate treatment processes.

Calibration of Models

For a simulation model to accurately evaluate the operation of a plant it needs to be developed to include the physical and process aspect of the full-scale plant. The model must include all physical processes and be operated in a similar fashion to the plant it is simulating. Most important is the calibration of the model. If operational data from a plant is being used for the calibration of the model, generally a period of equilibrium is used to establish the performance of the model and adjust the model parameters. Ideally a second period of differing operations (e.g. winter conditions) or dynamic data would be used to verify the model. The accuracy of the model predictions is entirely dependent on the degree of calibration conducted.

For a small plant in southeastern Ontario, a period of intensive monitoring, which was 3 months in duration, was used to calibrate a model of the activated sludge plant. Table 1 shows the comparison of the actual period and steady-state modeling results. For the steady-state period, the model accurately characterized the performance of the plant and the biomass in the system. A stress test was conducted to evaluate the performance of the secondary clarifiers under high solids loadings, and the testing resulted to a short period of washout from the final clarifier. This period was used to enhance the calibration of the model in terms of the final clarifier settling parameters. Figure 1 shows the result when using the optimized settling parameters. Although the solids blanket is consistently under-estimated by the model, this was felt to be due to the subjective nature of this parameter.

Table 1. Comparison of Model and Actual Effluent Concentrations

Parameter	Effluent Concentration (mg/L)	
	Model	Actual
Chemical Oxygen Demand (COD)	47	47
Biochemical Oxygen demand (BOD_5)	3	3
Suspended Solids (SS)	13	8

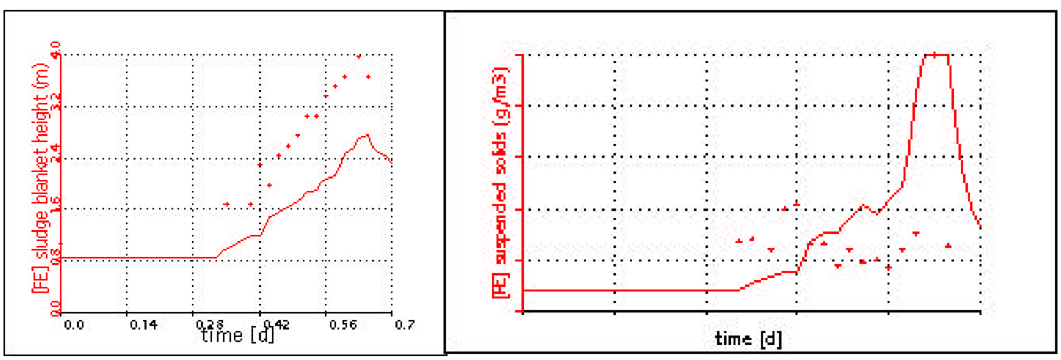

FIGURE 1 – Modeling of Final Clarifier Stress Test Results

The example stresses the importance of model calibration, such that the model can be used to make accurate simulations of the plant to reflect its capacity and operation under various operating modes.

CASE STUDIES

The following four case studies demonstrate the role modeling can play in plant optimization.

Waterdown Sewage Treatment Plant (STP)

The Waterdown STP is a 4000 m^3/d activated sludge facility. It was the site of testing alternative means to increase plant capacity, including nitrification, using a hybrid fixed film media in the aeration tank. As a result of this work both the modified part of the plant and the control side of the plant were monitored in detail. Initial modeling of the control side of the plant indicated inconsistencies in the flow metering at the plant. Subsequent review of the facility and draw-down tests on the effluent flow instrument indicated a flow meter problem. The model was instrumental in identifying this inconsistency in the data.

The facility had online instrumentation mixed liquor suspended solids (MLSS) and effluent ammonia-N. Figure 2 shows the performance of the calibrated model's ability to accurately model the effluent ammonia-N concentration at the plant.

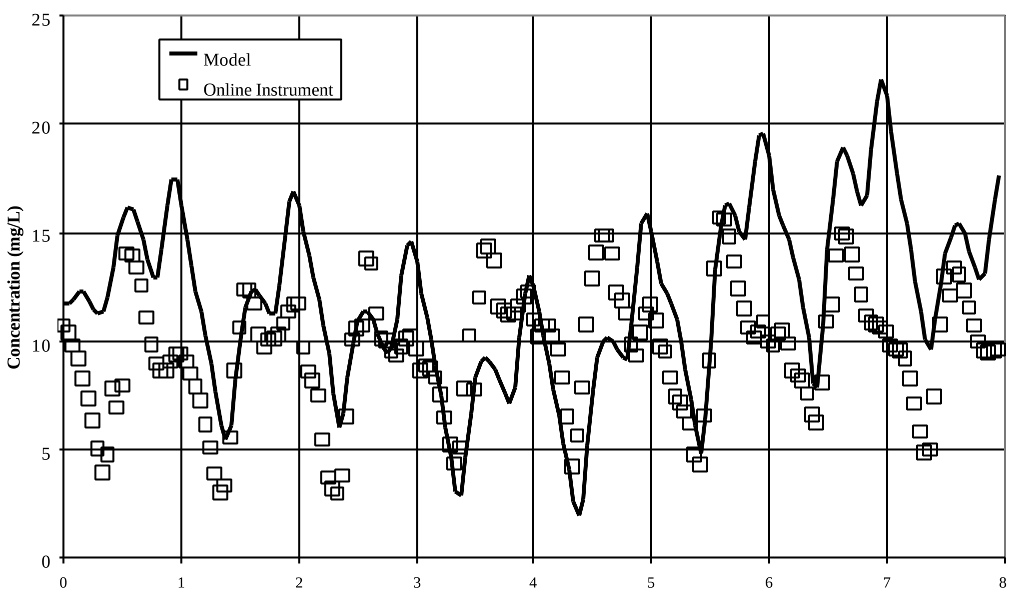

FIGURE 2 – Weekly Trend of Online Ammonia-N Instrument and Model Prediction (January 1996)

The calibrated model was used to assess the overall capacity of the control side of the plant under varying operating scenarios. Model runs were based on the operation of half of the plant. Figure 3 shows that the plant capacity on average was higher than expected, but operating at higher MLSS concentrations resulted in elevated effluent SS concentrations. Reducing the SRT and the MLSS concentration by increased wasting resulted in a loss in nitrification at winter wastewater temperatures. Further model scenarios including varying the expected settling characteristics were used to establish the plant's overall expected capacity.

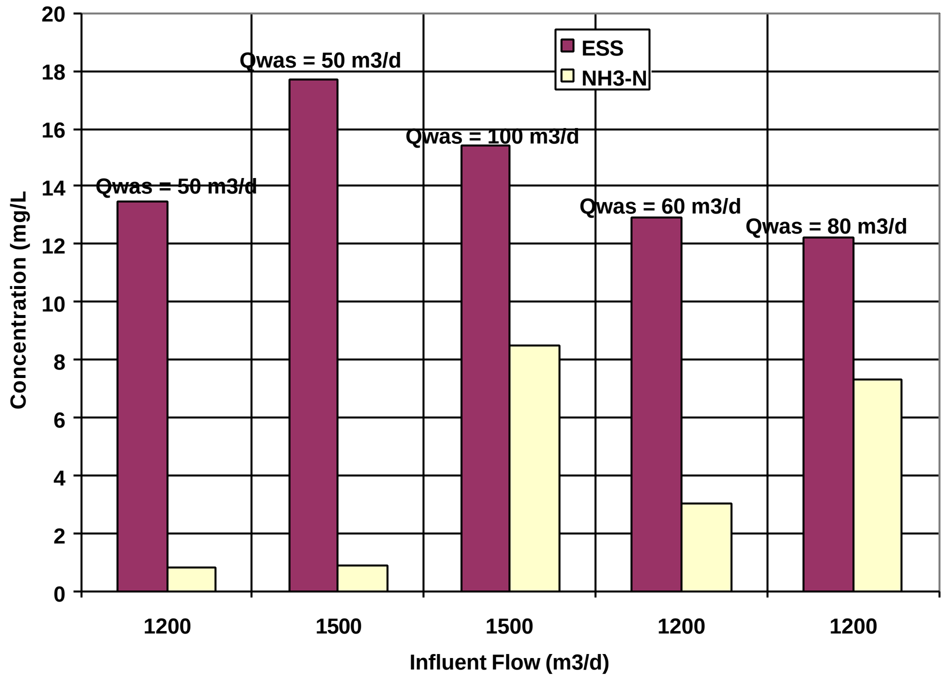

FIGURE 3 – Impact on Performance of Increased Influent Flow Rate and Wasting Practices

Little River Pollution Control Plant (PCP)

The Little River PCP is a conventional activated sludge facility, with capacity evenly split between two activated sludge plants. The plant's rated capacity is 72,000 m^3/d. A detailed model of the plant was generated in GPS-X and used to evaluate plant performance, capacity and to optimize the plant's aeration cleaning system.

Data from the Little River PCP for 1996 was reviewed. During the spring of 1996, Plant No. 1 operated under higher SVIs and with fewer final clarifiers in service. During this period effluent solids were elevated. Daily flow, SVI and MLSS concentrations were used to drive the simulation. After some minor changes to the settleability, the results are displayed in Figure 4 for a 40-day period. The model accurately predicts the performance of the clarifier, incorporating the changes in flow and settleability (i.e. sludge volume index or SVI).

The model provides a good prediction of the impact of surface overflow rate (SOR) and SVI around day 10. At this point the actual and model predicted effluent solids concentrations are 12 and 16 mg/L, respectively. Later elevated solids around day 30 and day 37 are also well characterized by the model.

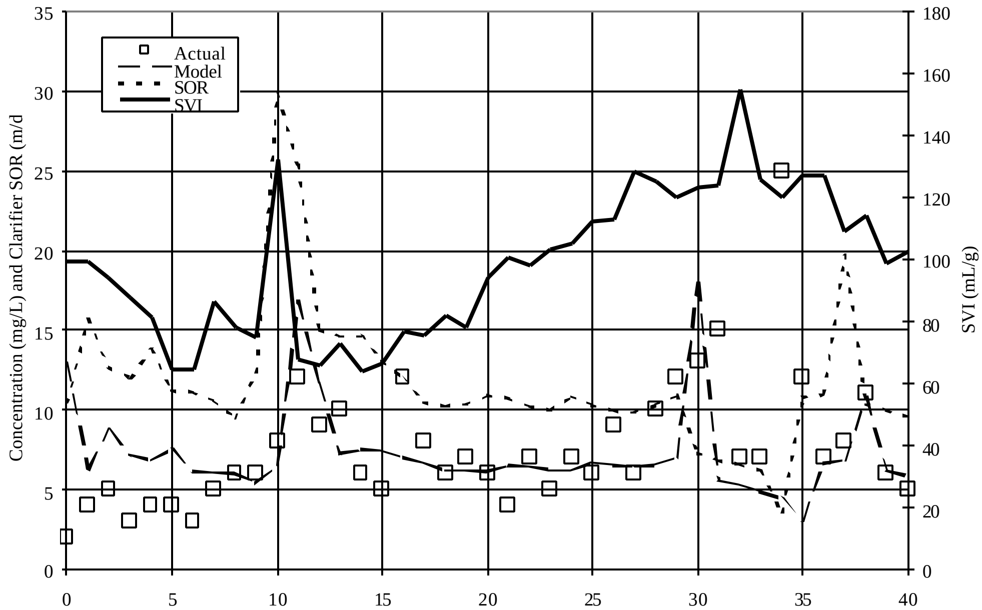

FIGURE 4 – Model Predications of Final Clarifier Performance at the Little River PCP

A dynamic model was constructed in GPS-X to evaluate the impact of various parameters on the optimal cleaning frequency of the fine pore diffuser aeration system. For this simulation actual plant data was used as input into the model. The layout consists of two activated sludge processes, each representing Plant No. 2 under different operating conditions. For the control process (scenario 1), the diffusers begin at a clean condition and the efficiency degrades over time. For scenario 2 the diffusers are cleaned at a selected interval. The main parameters for controlling the simulation are:

- Cleaning Frequency
- Cost of Cleaning
- Fouling Rate

Figure 5 shows the simulated efficiency for each scenario, the control or scenario 1 has a declining diffuser efficiency, whereas scenario 2 shows the optimal simulation, which provides yearly cleaning of the diffusers. Both scenarios are based on aeration efficiency tests conducted using the off-gas procedure.

In addition to the energy savings demonstrated by the model of yearly cleaning of the diffusers the impact on future demands was modelled. Future loadings at the plant and potential treatment of landfill leachate indicate that the yearly cleaning will be required to ensure adequate aeration capacity is available for future loadings. Figure 6 shows the impact of diffuser cleaning on the available air for the expected loadings. Without cleaning the aeration demand will exceed the available capacity from the existing blowers.

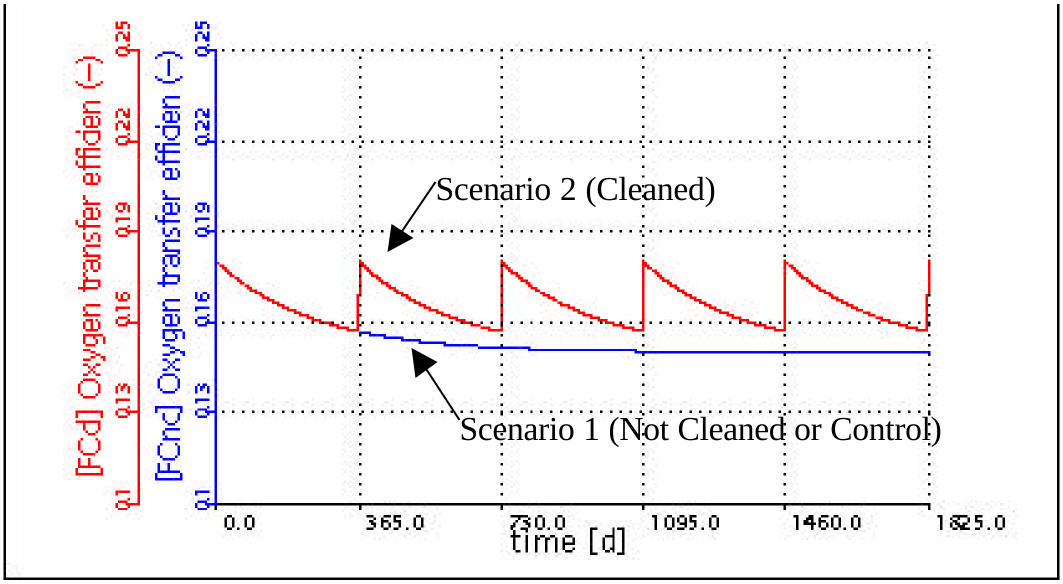

FIGURE 5 – Output From Simulation For SOTE Based On A One Year Cleaning Frequency

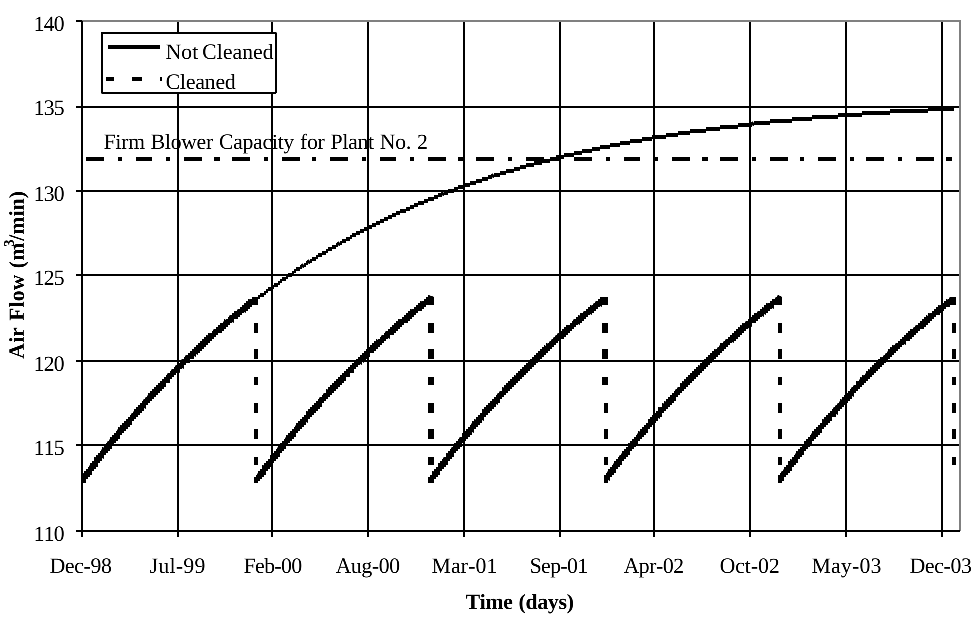

FIGURE 6 – Aeration Needs for Future Loadings to the Little River PCP

Wheatley Water Pollution Control Plant (WPCP)

The Wheatley WPCP has a rated capacity of 2750 m^3/d and treats a mixture of domestic and industrial wastes. Food and fish processing plants in the Town have increased the loading to the plant, such that the design organic loading to the plant has been reached even though the plant is treating about one-half of its design hydraulic capacity.

As a result of handling the increased organic loading and with bottlenecks in the plant's solids handling system, the plant carries a large biomass in its aeration system. Historically the MLSS concentration is greater than 11,000 mg/L. Calibration of a model for the plant was successfully made using intensive monitoring data (Table 1) and various tests at the plant (e.g. Figure 1 stress test). The model was then used to establish the plant capacity and future options.

Average capacity was determined to be greater than the plant's rated capacity, at least for the liquid train. However, the peak flow capacity was limited by the available solids loading capacity of the final clarifiers. Both the stress test and the modeling indicated that at peak hydraulic loadings, solids are washed out of the clarifier. Figure 7 shows the impact of the current operations and doubling the wasting at the plant. Under current conditions the clarifier blanket rises causing the solids to be washed out of the final clarifier. By doubling the wasting from the liquid train, the blanket level is maintained and solids remain in the system under high flow conditions. In addition, the model indicates that at increased wasting, complete organic removal and nitrification are maintained, even under cold wastewater conditions.

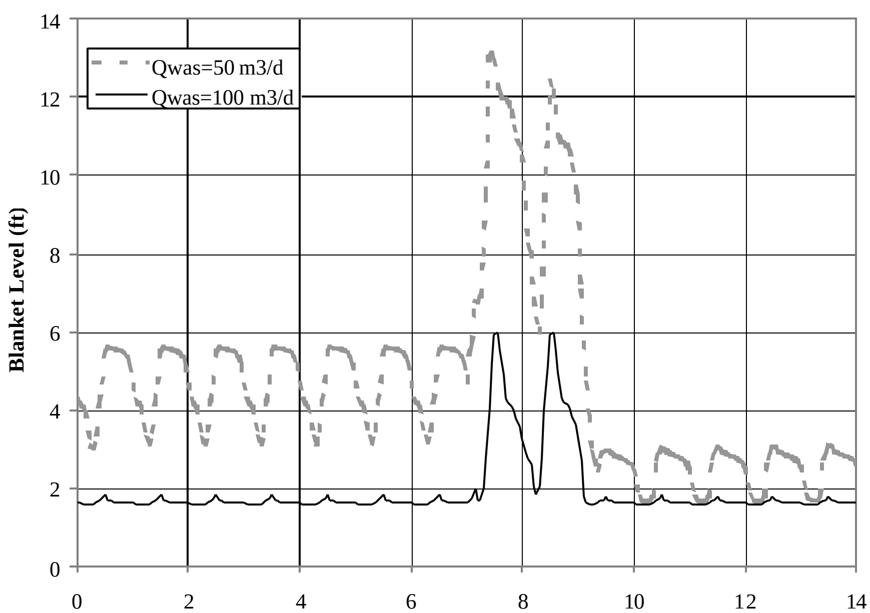

FIGURE 7 – Simulated Clarifier Blanket Level Under Two Operating Scenarios

Further simulations using the calibrated model were performed to evaluate the impact of installing a first zone anoxic zone and utilizing step-feed during wet weather conditions. The benefits for both operations were demonstrated and initial sizing/operating conditions defined using the model.

Gabal el Asfar WWTP

The first stage Gabal el Asfar Wastewater Treatment Plant in Cairo, Egypt (WWTP) is currently starting up and future expansions are proceeding. The Stage 1 plant was designed for an average flow rate of 1000 million litres per day (MLD) and will provide conventional activated sludge treatment and effluent disinfection. An extensive solids handling system will provide thickening, stabilization and dewatering.

The project scope for the modeling work included the generation of a process model of the plant to evaluate its performance under expected operating scenarios. At the time of this work the plant was still under construction. The review included an assessment of the steady-state and dynamic performance of the plant. Based on the physical description of the facility and design data for the plant, a layout of the plant was generated in GPS-X. The physical layout, process performance and influent characterization were based on information supplied.

The modeling indicated a number of issues that would potentially arise with the plant's operation including:

- Nitrification will occur at the plant and should be planned for
- Solids handling systems will be overloaded a peak loadings, and storage in the system, including the primary clarifiers, should be utilized
- The plant should be optimized to control nitrification, overloading of the solids handling systems and to reduce energy consumption

Figure 8 shows the relationship between plant operations at varying wastewater temperatures and the impact on nitrification. As indicated in the figure, nitrification is expected to occur especially under warm summer conditions. Aerator capacity is available to handle this loading. Many options were investigated to address nitrification, including employing selector technology, reducing the aeration capacity and utilizing on/off aeration.

Figure 9 shows the impact of a variety of on/off operating scenarios to reduce power consumption and control nitrification. The first demonstration is based on operating the aerators in any given tank one hour on and one hour off (i.e. 12 hours on per day). The trend indicates that there is insufficient aeration for continuous nitrification and the 4-d trend shows an increasing effluent ammonia-N concentration. This mode could be used as a procedure to inhibit nitrification. Demonstration two extends the aerator on time to three hours followed by one hour with the aerators off (i.e. four-hour cycle, aerators on for 18 hours per day). This scenario seems to maintain nitrification and improved denitrification. Denitrification may help in maintaining a good settling sludge (i.e. selector effect). The last scenario is based on varying the cycles through the tank; therefore, the first two cells are on all the time, the next two cells are on for 3 hours/off for 1 hour and the last cells are on for 2.5 hours and/off for 1.5 hours. Therefore, aerators are on an average of 19 hours per day. This results in better nitrification, but does not increase denitrification. The potential energy savings for the aerator system are shown in the Figure 9. Overall such an operation could reduce the potential for denitrification in the final clarifiers, improve settleability and reduce energy usage. Alternatively, it could be used to inhibit nitrification, but this may be difficult to control.

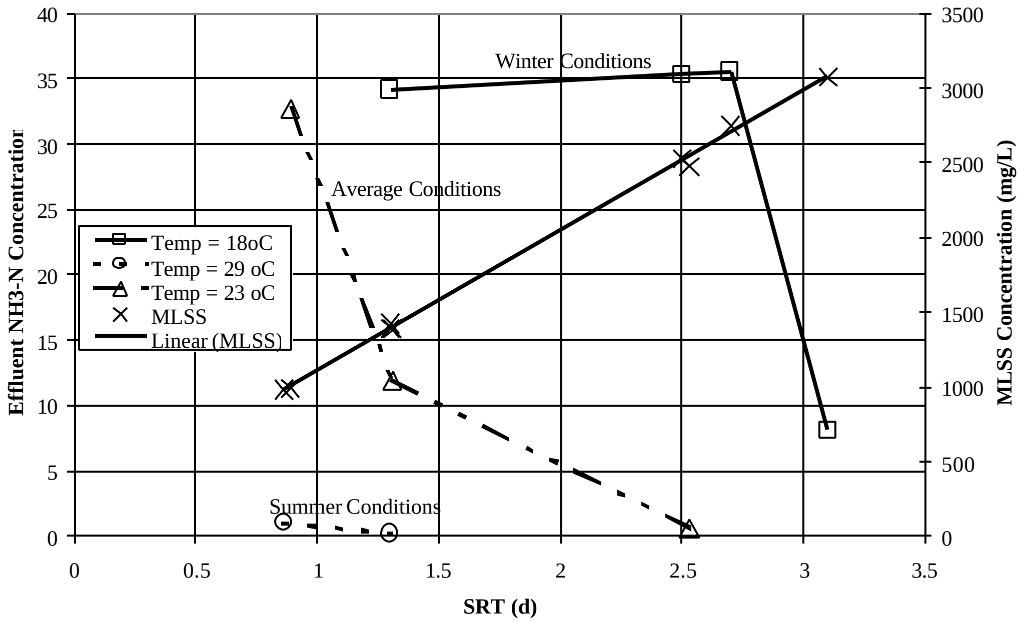

FIGURE 8 – Simulated Impact of Wastewater Temperature and SRT on Nitrification

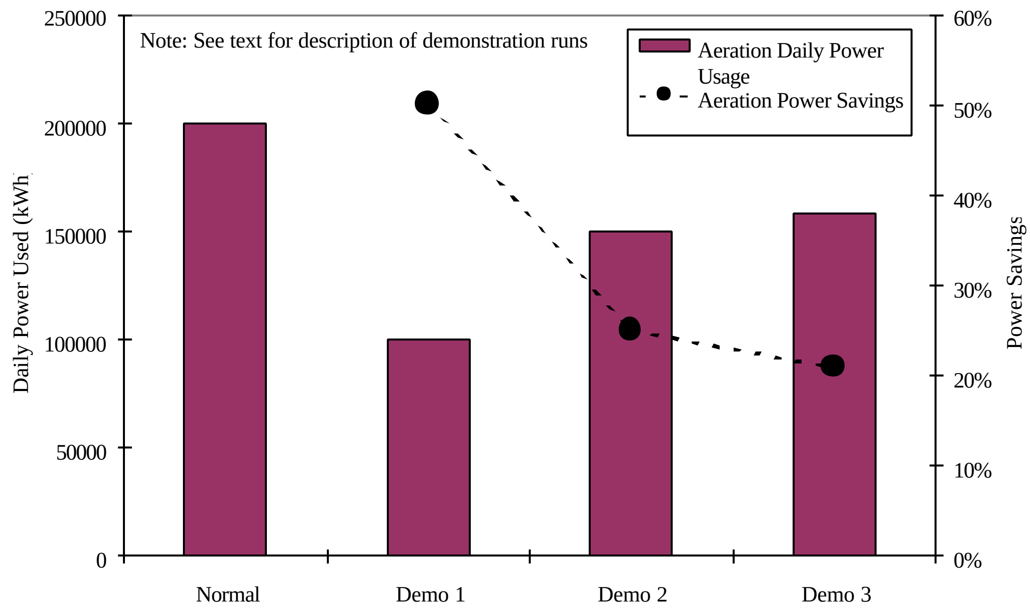

FIGURE 9 – Simulated Energy Savings Associated with On/off Control of Aerators

DISCUSSION

The four case studies presented above indicate the power of utilizing a calibrated mathematical model for optimizing a wastewater treatment plant. The model can be used as a complement to standard wastewater treatment optimization tools. As a tool its usefulness is based on the degree to which the model can characterize the performance of the plant. Therefore, our confidence in the model simulations increases with the degree of calibration conducted. Historical periods defining differing operating conditions, intensive sampling and other optimization techniques assist in matching the performance of the model to the full-scale facility.

If design data is used to define the simulation, we can make predictions of the performance of a facility based on typical kinetic and stoichiometric parameters. These predictions can be useful in defining the operating procedures for a plant and expected concerns and bottlenecks. But this performance will need to be confined once the facility is operational. However, given that the use of modeling is increasing experience gained at other facilities under similar operating conditions, provides confidence in even these initial simulations, prior to a plant's commissioning or prior to changing a plant's operations significantly (i.e. BNR retrofits)

CONCLUSIONS

This paper reviews the part modeling can have in the optimization of a wastewater treatment plant. Many tools are available for providing information on the optimization of a facility, and process modeling is a powerful tool if utilized properly. A well-calibrated model can be used to evaluate process capacities, operational changes and upgrades and process changes. Used in conjunction with other optimization techniques this tool can evaluate any number of “what-if” scenarios. Continual feedback between the model and reality can be used to confirm initial modeling results.

This paper summarizes four case-studies which demonstrates the power of process modeling in plant optimization, including:

- Evaluating plant capacity
- Evaluating cost-effectiveness of plant operations (diffuser cleaning and on/off aeration)
- Changing plant operations (increasing wasting)

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