Planning for Wastewater Treatment Plants of the Future
Katya Bilyk, P.E.\textsuperscript{1}, Wendell Khundar, PhD\textsuperscript{1}, Paul Pitt, P.E., PhD\textsuperscript{1}, Ronald J. Latimer, P.E.\textsuperscript{1} Scott Hardy, P.E.\textsuperscript{1}

\textsuperscript{1}Hazen and Sawyer, P.C.

ABSTRACT
In recent years, the paradigm in wastewater treatment has shifted from regulatory-driven planning to proactive utility-driven planning aimed at achieving energy neutrality, reducing operating costs, and resource recovery. This paper uses case studies to illustrate the following principles that describe the pro-active utility-driven planning approach: (1) Align biosolids management practices with sustainability goals, (2) research and consider new energy-efficient approaches to wastewater treatment such as deammonification for nitrogen removal, (3) prepare a holistic master plan that considers multiple future scenarios, and (4) consider the unification of process modeling and data from online instrumentation to provide real-time and actionable insights to plant operators.

INTRODUCTION
In recent years, the paradigm in wastewater treatment has shifted from regulatory-driven planning to proactive utility-driven planning aimed at achieving energy neutrality, reducing operating costs, and resource recovery. Although regulations significantly influence infrastructure investment in the water sector, utilities have demonstrated leadership and initiative to seek out long-term solutions that anticipate future challenges, regulations, and opportunities. This approach allows more careful consideration of new technology, opportunities for research prior to decision making deadlines, and ample time for discussion of alternatives. By taking a long-term view, utilities can invest in sustainable approaches with significant paybacks.

This paper will use case studies as examples to illustrate the following principles that describe the pro-active utility-driven planning approach:

1. Align biosolids management practices with sustainability goals.
2. Research and consider new energy-efficient approaches to wastewater treatment such as deammonification for nitrogen removal.
3. Prepare a holistic master plan that considers multiple future scenarios.
4. Consider the unification of process modeling and data from online instrumentation to provide real-time and actionable insights to plant operators.

METHODOLOGY
Case studies are used to explain the concepts presented in the Introduction.

RESULTS AND DISCUSSION
Case studies will be used to explain the concepts presented in the Introduction. This section is organized according to the four principles utilities may find helpful when planning for wastewater treatment plants of the future.

Align Biosolids Management Practices with Sustainability Goals
Biosolids management is an important component of utilities of the future because anaerobic digestion, a common method for stabilizing biosolids, is capable of producing biogas that can be used to offset the need for externally supplied electricity and/or natural gas. In addition, many of the new thermal hydrolysis processes (THP) for biosolids treatment such as Cambi® and Excelys®, greatly reduce the quantity of biosolids produced and enhance biogas production. Although THP adds significant operational complexity, many utilities have been pursuing it because it reduces waste volume via enhanced destruction of volatile suspended solids, and increases biogas production. Energy neutral and energy positive operations have also become a goal for utilities, such as the Strauss Plant in Austria.

Many recent projects have focused on increasing biogas production via a number of pathways. Biogas fosters energy neutrality by providing a fuel source that can be directly coupled to process equipment and/or converted to electricity. Biogas production can be increased through the acceptance of high strength wastes (HSW) like fats, oils,
and greases (FOG) or other specific industrial wastes at plants that have excess anaerobic digester capacity. The treatment of municipal biosolids with HSW is known as codigestion.

When utilities undertake a codigestion program with FOG or other HSW, there are many unknowns including the following (Hardy, 2012):

- How much FOG or HSW can be fed to the digesters?
- Will there be impacts on the digestion of the municipal sludge?
- What will be the actual digester gas production from a particular FOG or HSW?
- Will nutrient loading increase in the plant recycle streams?
- Could hydrogen sulfide and siloxanes levels increase in the digester gas?
- How much will it cost and what is the benefit of co-digesting with a particular HSW and FOG substrate?

These unknowns need to be answered in order to prepare an accurate business case evaluation for selecting a waste feedstock for codigestion. Bench-scale testing using samples of potential waste streams can often be used to answer these questions and help guide the decision process.

In a recent project, the Gwinnett County Department of Water Resources (GCDWR) began developing its FOG and HSW Receiving Program. GCDWR had recently installed a 2.1 Megawatt biogas engine generator at the F. Wayne Hill Water Resource Center (FWHWRC), for which the current digester gas production was about 70% of the full load digester gas demand for the engine. GCDWR desired to increase digester gas production via codigestion to make up the digester gas difference and increase economic benefit created from the engine-generator. However, the FWHWRC had limited digester capacity and wanted to select the waste stream that provided the most gas production per volume feed to the digesters. GCDWR also did not want to produce excess digester gas above the amount for the engine because of adverse air permit implications. GCDWR also evaluated unique high strength industrial waste streams where impacts on the plant’s liquid and solids treatment processes were unknown.

To answer these questions, Georgia Institute of Technology performed bench-scale on the potential sources of FOG and HSW. Subsequently, biological modeling was used to simulate full-scale treatment plant impacts. The results of the study showed that for a digester HRT of 15 to 25 days, which is close to the conditions at the FWHWRC and many other anaerobic digestion facilities, there was a substantial increases in gas production above a sludge-only digester when 20% to 40% of the total volatile solids mass fed to the digester came from FOG (see Figure 1, Hardy, 2012).

![Figure 1: Summary of batch-test experiments simulating anaerobic digestion with different FOG:Municipal Waste Volatile Solids Loading ratios as a function of time.](image-url)
The results of the Georgia Institute of Technology study were used to develop a figure that graphs operating costs and benefits (e.g., revenue) as a function of the gallons per day of FOG received. This information was used to allow GCDWR to identify a breakeven point, determine if that amount of FOG was realistic to accept, and make decisions about pricing.

Research and Consider New Energy-Efficient Approaches to Wastewater Treatment

Significant operational savings can be achieved with next generation nitrogen removal technologies, which include both nitrite shunt (Figure 2) and deammonification (Figure 3). Although it is not yet practical to design for these processes in mainstream treatment, it is a good idea to design new aeration tank or aeration tank modifications with thought given to being able to operate in these modes so that energy and chemical savings can be realized in the future. Thus, the aeration tanks need to be flexible and have an energy efficient design.

Nitrite shunt shortcuts traditional nitrification/denitrification by only converting ammonia to nitrite (as opposed to nitrate). Nitritation/Denitritation is a treatment method that shortcuts the traditional nitrification process by preventing nitrite oxidizing bacteria (NOB) from oxidizing nitrite to nitrate, also known as nitritation. This shortcut theoretically reduces aeration costs by 25% and carbon costs by 40%. In order to shortcut nitrification, the solids retention time (SRT) is controlled to favor ammonia oxidizing bacteria (AOB) and wash out NOB. With this approach the traditional nitrification process is stopped at nitrite.

Nitritation/Deammonification utilizes an autotrophic bacteria (anammox) that converts equal parts ammonia and nitrite directly to nitrogen gas. In this reaction, $$\text{NH}_4^+ + 1.32 \text{NO}_2^- + 0.066 \text{HCO}_3^- + 0.13 \text{H}^+ \rightarrow 1.02 \text{N}_2 + 0.26 \text{NO}_3^- + 0.066 \text{CH}_2\text{O}_{0.15}\text{N}_0.15 + 2.03 \text{H}_2\text{O},$$ ammonia is the electron donor and nitrite the electron acceptor. In doing so, only half of the influent ammonia is converted to nitrite by AOB, and the other half is oxidized by anammox bacteria along with the nitrite generated in the metabolic pathway for deammonification. Therefore, this process theoretically reduces aeration costs by approximately 62.5% and carbon costs by 100% (no supplemental carbon is required).
Anammox bacteria grow approximately eight times more slowly than nitrifying bacteria and are therefore difficult to retain in suspension through conventional treatment approaches that rely on wasting a suspended phase of solids from aeration tanks. Therefore, mainstream application of this approach has not yet been implemented in wastewater treatment. The deammonification reaction has been well studied and implemented in sidestream treatment. Sidestreams that result from dewatering of anaerobically digested solids typically range in temperature from 25 to 35°C. At these temperatures the growth rate of anammox is comparable to AOB and NOB, and hence operating parameters such as dissolved oxygen (DO) concentration can be manipulated to favor growth of anammox and AOB and wash out NOB.

There are at least three utilities internationally that are implementing pilot programs to study mainstream deammonification including Strass, Austria; DC Water, District of Columbia; and the Hampton Roads Sanitation District, Virginia Beach, Virginia. In order to overcome the slow growth rate of anammox at cold temperatures, these pilots have focused on exploiting unique properties of anammox bacteria, their higher weight and size, to retain them in otherwise conventional activated sludge applications. Research approaches have included sieves, cyclone separators (Demon® process), or fixed film addition to the process to provide an additional means of retaining anammox.

**Prepare a Holistic Master Plan**

The City of Durham, North Carolina recently developed a comprehensive and forward thinking Master Plan to achieve a ultimate effluent TN limit of 0.9 mg/L TN and 0.05 mg/L TP. The City owns and operates two 20 million gallon per day (mgd) wastewater treatment facilities, the North and South Durham Water Reclamation Facilities (NDWRF and SDWRF). Both plants receive similar influent and utilize a 5-stage Bardenpho biological nutrient removal process with a 23-hour detention time at design flow. Both facilities produce treated effluent with total phosphorus (TP) concentrations of less than 0.3 mg/L. Without supplemental carbon, the NDWRF produces treated effluent with a total nitrogen (TN) concentration of less than 3 mg/L and the SDWRF produces treated effluent with a TN concentration of less than 8 mg/L. The objectives of the Durham Wastewater Master Plan were to recover nutrients, reduce and reuse energy, and reuse as much clean water as possible.

Both plants discharge into nutrient sensitive watersheds. The low limits that the City has to plan for (TN 0.9 mg/L, TP 0.05 mg/L) are among the most stringent nutrient requirements in the world. The Master Planning effort included specialized workshops and detailed technical memorandums on the following topics:

- Near-term nutrient management strategy
- Long-term nutrient management strategy
- Emerging contaminants
- Energy evaluation
- Long-term biosolids strategy
- Wet weather evaluation
- Sidestream treatment evaluation
- Facilities condition assessment
- Reuse evaluation

The outcome of the Master Plan was a goal and recommendation to use conventional treatment for nutrient removal for as long as is possible. Both sidestream struvite precipitation and nitritation/deammonification processes were recommended as part of the near-term nutrient management strategy as well.

With regard to the long-term nutrient compliance strategy, various technologies and approaches were screened and evaluated with microfiltration (MF) followed by reverse osmosis (RO) being the most viable but also the most expensive and power-consuming technology for the future. Therefore, a reasonable, staged reuse plan was also developed to avoid ever having to install this technology by maintaining the mass-based-concentration equivalent of 2.5 mg/L TN and 0.14 mg/L TP. Several alternative treatment technologies to MF and RO that may become viable and are potentially less expensive than reuse, so the City has a living document that can be referred to in the future.
With regard to the wet weather approach, equalization was recommended to help the plant deal with short duration – high magnitude peak wet weather flows. Both the nutrient management strategies and the wet weather treatment evaluations were conducted with the aid of a calibrated wastewater process model, BioWin™ by Envirosim.

The reuse plan focused on two phases. First, an initial prospective was used to determine the minimum expected size of water reuse system that the City could expect to develop in the early years of reuse program implementation by identifying current non-potable water uses in the service area. In the second phase, referred to as the Assertive Reuse Implementation Plan, a county-wide analysis was undertaken using future land use to determine the maximum practical size that the City could expect to develop a reuse system to within the City service area. It was projected that the City will save $77 million dollars in capital by investing in a reuse program today, and will realize significant additional operational savings since the 20-year net present value of the operating costs of the advanced treatment solution are $230 million. The City’s reuse goal is achievable given that the City has over 45 years to develop the reuse system, and only needs to develop a modest amount of reuse (2 mgd) in the 20-year time frame.

The City also decided to include implementation of a sidestream nitritation/deammonification process in its Master Plan because of the significant cost savings to operating in this mode—it is about 65% less expensive to remove a pound of nitrogen in the sidestream than in the mainstream of the City’s plants. The capital cost for an anammox process is slightly higher, but the operating cost savings result in a very quick and worthwhile payback for the City, mostly due to the fact that no supplemental carbon is required in the deammonification process.

By approaching the Master Plan and nutrient challenges of the City of Durham holistically, the most cost-effective solution and a realistic timetable for implementation were identified.

Real-time Process Control
Online instrumentation (e.g., ammonia probes, nitrate probes, pH probes, DO probes, orthophosphate analyzers) can be integrated with process modeling to provide a framework for real-time process control. Many municipalities have invested in calibrated process models and nutrient analyzers to meet stringent nitrogen and phosphorus effluent standards. The integration of modeling and operations is the next logical step in biological nutrient removal (BNR) operations, and is the subject of an ongoing Water Environment Foundation Plant Operations and Maintenance Committee Task Group.

A calibrated wastewater process model has become the typical tool used to design the activated sludge process at a BNR facility. These simulators are typically dynamic to allow the simulation of varying flows and loads including wet weather. Commonly used and commercially available process simulators in the United States include but are not limited to BioWin™ and GPS-X™.

There are five key functions at BNR facilities that would benefit from the integration of process modeling and instrumentation (Bilyk, 2012). The five key functions include:

1. DO control
2. Nitrification
3. Denitrification
4. Biological phosphorus removal (BPR)
5. Solids separation

This section will present an illustrative example of the process modeling/instrumentation nexus using nitrification as the process to optimize in real-time. The process controls that are related to nitrification performance and reliability include temperature, flow, wasting rate, solids retention time (SRT), DO concentration, airflow distribution, DO control valve positions, DO probes, and any ammonia probe(s) in the BNR basins. Assuming uninhibited growth, a suitable pH, and proper DO control, two key parameters will determine the required SRT to maintain full nitrification—DO and temperature.

The modeling/operations link that would most benefit nitrification in real-time is an ongoing comparison of actual and minimum required SRT for complete nitrification. The comparison can be made several ways depending on the desires of the plant staff and availability of instruments. For example, if TSS probes are available in the mixed liquor and/or on the waste activated sludge (WAS) flow, real-time SRT can be calculated. The corresponding minimum
SRT determined by modeling can be cross-referenced at a programmed interval (operator-adjustable) with the real-time SRT as shown in Table 1 (Bilyk, 2012). If the actual SRT drops below the required SRT, then a warning can be issued through the distributed control system (DCS) or SCADA system. If desired, the wasting pumps can be tied into this algorithm and their operation can be varied to maintain a target SRT. Many medium and large plants compare a target and actual aerobic SRT in daily spreadsheet reports already, but do so independently of the operating system.

Table 1: For a Specific Treatment Plant: Recommended Aerobic SRT as a Function of DO and Temperature for pH values 6.5 – 7

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Dissolved Oxygen Concentration (mg/L)</th>
<th>&lt; 0.5</th>
<th>0.5 - 1.0</th>
<th>1.0 - 2.0</th>
<th>2.0 - 3.0</th>
<th>&gt; 3.0</th>
</tr>
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<tr>
<td>12</td>
<td></td>
<td>34.8</td>
<td>15.5</td>
<td>13.0</td>
<td>11.7</td>
<td>11.2</td>
</tr>
<tr>
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<td></td>
<td>26.5</td>
<td>13.2</td>
<td>11.0</td>
<td>9.9</td>
<td>9.5</td>
</tr>
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<td>4.4</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Some plants do not have online TSS probes, but most measure TSS in the mixed liquor and RAS regularly. In these cases, daily RAS and TSS data from a laboratory test could be extracted from an operations database (i.e., HACHWIMS), and combined with additional information (i.e., number of tanks in service) to estimate the actual SRT. This data will not be in real-time, but it would likely be relevant and enhance the reliability of nitrification because it adds an additional check on nitrification.

CONCLUSION

This paper used case studies to illustrate the several principles that describe the pro-active utility-driven planning approach. The following conclusions came from the case studies:

- Anaerobic digestion is a sustainable biosolids practice around which the plant’s energy balance can be further constructed.
- Aeration tanks ought to be constructed with consideration given to operating them in new more efficient configurations such as nitrite shunt and deammonification when operating parameters for those systems are well understood.
- A holistic master plan is a sound investment to allow utilities to make long-term investments in sustainable infrastructure.
- Real-time process control is an emerging concept that may greatly enhance effluent quality through optimization of nutrient removal.

REFERENCES