# Global Warming—Myth or Reality?

## John Crane

### PART 2: THE GREENHOUSE EFFECT

When energy from the sun is reflected from the surface of the earth, the wavelength is increased. While the shorter wavelengths of the incoming energy have no trouble passing through (in order of importance) water vapor, carbon dioxide, methane, ozone, and other gases in the upper atmosphere, the longer wavelength, or infrared, energy has difficulty escaping into space. It is a natural process that makes life as we know it possible; without the greenhouse effect, the earth would be nearly 60°F cooler than it is. It is similar to the process that heats a car sitting in the sun, that makes a cloudy night warmer than a clear night, and that makes a greenhouse work.

At the same time as water vapor and gases in the upper atmosphere tend to warm the planet, clouds in the lower atmosphere tend to reflect sunlight and cool the surface, which is what makes a cloudy day relatively cool.

As early as 1896, the Swedish chemist Svente Arrhenius suggested that burning enough fossil fuels to double atmospheric carbon dioxide concentrations might raise average global temperatures by 10°F. He wasn't that far off from current computer models that predict that doubling the carbon dioxide concentration would increase temperatures by 3 to 8°F.

Industrial nations, of course, generate most of the human-generated greenhouse gases, and the United States accounts for about 22 percent of the annual total.

#### *Carbon Dioxide*

Increased carbon dioxide is a positive feedback mechanism in that as the climate warms, the oceans warm and release more carbon dioxide, which causes the climate to warm still more. Higher temperatures also cause more evaporation, which puts more water vapor into the upper atmosphere, which increases the greenhouse effect. Decreased ice cover decreases the amount of sunlight reflected back into space, again raising temperatures.

A negative feedback also occurs: increased carbon dioxide encourages plant growth, and a warmer climate causes longer growing seasons, all of which causes increased carbon dioxide absorption by plants. Increased evaporation would create more clouds in the lower atmosphere with their resulting cooling.

Since the beginning of the Industrial Revolution in the mid-1800s, the burning of fossil fuels have contributed carbon dioxide. There has been an increase of about 30 percent in the concentration of carbon dioxide in the atmosphere since the mid-1800s, and it is currently increasing at about 0.4 percent per year.

#### *Methane*

After water vapor and carbon dioxide, methane is the most significant greenhouse gas. and since about 1800 human activities have more than doubled the level of atmospheric methane. Like carbon dioxide, methane is generated by the production of fossil fuels, but an even greater source is livestock farming, which contribute 15-20 percent of the methane emissions caused by human activities. Cattle account for around 70% of those emissions. Assuming that worldwide beef and dairy production increases by more than 45 percent by 2025, the United Nations Intergovernmental Panel on Climate Change (IPCC) estimates that over 15 percent of man-induced climate changes over a 100-year time frame will result from methane.

#### *Aerosols*

Some other effects of industrialization decreases the greenhouse effect. Aerosol particles scatter and absorb solar radiation. Sulfur dioxide from fossil fuel burning, yielding sulfate particles after oxidation, is the largest source of human-made aerosols. Another large source is organic and elemental carbon from burning of tropical forests and savannas. Human-made aerosols may currently cancel about 50 percent of the warming effect of human-made greenhouse gases.

### PART 3: EFFECTS OF RISING GLOBAL TEMPERATURES

A rising temperature, even by a few degrees, can have wide-ranging effects on sea levels, agriculture, water resources, and even infectious diseases.

#### *Sea Levels*

If the data are correct, sea levels have risen by about six inches during the past century. There are questions about the reliability of the data because of the distribution of sampling points and the natural rising and subsidence of land.

A warming climate would cause sea levels to rise via two mechanisms: expansion of ocean waters as they become warmer and an increased volume of water as ice melts. The rise in the last century has been almost entirely due to expansion. How much more the oceans would rise due to expansion is complicated. The top layers become warmer first, and warmer water rises. The result is that warming of the upper layers would tend to prevent warming of lower levels. Some mixing occurs among the layers, but that is a slow process, occurring over decades, and is not easily modeled.

The reservoirs of ice that could melt and contribute to rising sea levels are sea ice, mountain glaciers, the Greenland ice sheet, the East Antarctic ice sheet, and the West Antarctic ice sheet. Melting sea ice, including all of that in the Arctic Ocean, would have small effect since it already displaces volume, and the almost insignificant contribution it would have results from the slight differences in salinity between ice and seawater. The total volume of mountain glaciers is not sufficient to make any great contribution.

The three ice sheets sit on land and, unlike sea ice, are not displacing water. However, the Greenland and East Antarctic ice sheets seem to pose little threat. Both are surrounded by mountains, which prevent much "calving" of icebergs. Neither is expected to lose any appreciable mass in anything less than centuries.

The west Antarctic ice sheet is a different matter. Unprotected by mountains and considered unstable by glaciologists, it could collapse or float free in a relatively short time. Should it do so, global sea levels would rise nearly 20 feet, inundating much of Florida and hundreds of low-lying cities from Jakarta to London. There are some indications that the ice sheet may be in the process of breaking free, but that process may have been going on for thousands of years already and could take another thousand years more—or much less; scientists just don't know.

The west Antarctic ice sheet is buttressed by two ice shelves, each about the size of France. The ice shelves float on water, thus having little potential to raise sea levels themselves, but without them the west Antarctic ice sheet could collapse into the ocean within a few decades. Huge pieces of the ice shelves, some larger than Rhode Island, have broken off in recent years.

Without taking into account the west Antarctic ice sheet, and assuming no steps will be taken to reduce greenhouse gas emissions, sea levels are predicted by the IPCC to rise another half foot by 2030 and two feet over current levels by 2100.

With a two-foot rise in sea levels, many populated areas along seashores would become uninhabitable, including entire cities in Asia. Some low-lying areas of the U.S. Gulf and Atlantic shores could see shore lines retreating by as much as two miles. Florida would lose about 300 feet of land at its shores, including about 800 square miles in the southwestern portion of the state (the Everglades) and the Florida Keys. Louisiana would be the hardest hit state with a loss of more than three thousand square miles of its coastal lowlands.

The impact on the tourist and fishing industries, productive tidal wetlands, and mangrove forests would be severe. Saltwater intrusion into groundwater supplies would increase, leading to more potable water shortages. Coastal infrastructures, including sewerage systems and water distribution system, would suffer erosion and saltwater damage. One U.S. study suggested that a three-foot rise in sea-levels would cost the country about $11 billion annually.

#### *Agriculture*

The economic results of an increase in the frequency and strength of storm events, when viewed in terms of Hurricane Camille's impact on the Mississippi coast in 1969, Hurricane Andrew's on southern Florida in 1992, and the Midwest floods of 1996, can be staggering.

Some of the effects on agriculture would be beneficial, including longer growing seasons, most significantly in nations closer to the poles—Canada, Russia, Scandinavia, Japan, southern Chile and Argentina—however, the growth of weeds and pests would also be enhanced. Both warmer weather and higher carbon dioxide concentrations would tend to increase productivity. Some effects, such as changing precipitation patterns, could be beneficial or harmful, depending on the location. Rising sea levels could be expected to inundate some farmland and make coastal groundwater saltier. Trapping of more moisture in warmer air would result in dryer soils and would be especially detrimental to agriculture in countries at mid-latitudes, including the United States. On the other hand, an increased cloud cover would reduce evaporation and tend to increase soil moisture.

### Water Resources

Water resources would be affected by changing precipitation and evaporation patterns. While world-wide precipitation would be expected to increase, it is expected that it would increase in some regions and decrease in others. Higher evaporation rates would tend to cause reduced run-off, and warming would reduce winter snow accumulation. Increased sea levels would cause increased saltwater intrusion and the resulting loss of groundwater supplies. Higher carbon dioxide concentrations would improve the efficiency of photosynthesis in plants, which could cause more rapid evapotranspiration. Taken all together, the effects on water supplies could be severe.

### Infectious Diseases

Warmer temperatures and changes in rainfall create improved conditions for mosquitoes, ticks, rodents, bacteria, and viruses. The IPCC speculates that diseases that have emerged or reemerged in the 1990s may have been influenced by global warming—for example, cholera in Latin America in 1991, pneumonic plague in India in 1994, the hantavirus epidemic in the southwestern U.S. in 1994 (caused by a ten-fold increase in the population of deer mice after six years of drought followed by heavy rains), dengue fever, a mosquito-borne disease that killed 4,000 of 140,000 people infected in Latin America in 1995. IPCC models suggest that by 2100 climate change could increase substantially the proportion of the world's population living in potential malaria transmission zones.

### Predictive Models

Modeling researchers use three-dimensional numerical models that calculate global temperature and precipitation at specified levels of carbon dioxide and other greenhouse gases in the atmosphere. They are based on the models used for weather forecasting and predicting the behavior of hurricanes. They divide the earth's surface into a grid and calculate the flow of atmospheric gases from each cell of the grid into adjacent cells. Solar radiation is then related to changes within each cell and the amount of radiation reaching the earth's surface, as well as the effect of the earth's surface—ocean, ice, vegetation, etc. In the past few years, some atmospheric models have been combined with models that address ocean circulation patterns.

When applied to the past century, the models agree fairly well with the actual measurements of temperatures, which is used as an argument in support of the models.

As for the future, the models predict that without major steps to reduce greenhouse gases, global temperatures would rise by 1.8 to 6.3°F by 2100, with a best guess of about 3.6°F,

The models predict that warming will be greater over land than over oceans and that the greatest warming will be in high northern latitudes in winter. They also predict that nighttime temperatures will increase more than daytime temperatures during warm seasons and that warm season precipitation will come in heavy showers or thunderstorms rather than in longer-lasting rainfalls.

The models also show weather experiencing an increased magnitude of extremes, including cold and heat waves, extreme droughts, and precipitation events, mostly due to a warmer atmosphere being capable of holding more moisture. Some models show a three- to four-fold increase of extreme precipitation events, causing flooding. There would be an increased frequency of tornadoes and hurricanes. Hurricanes would theoretically be stronger as a result of warmer ocean water. However, that is not being seen so far: the number of hurricanes in the North Atlantic have decreased since the 1940s, with the period from 1991 through the present being especially mild.

The models are not examples of exact science. One major uncertainty is the effect on clouds in the lower atmosphere, which reflect sunlight and cause cooling, versus clouds in the upper atmosphere, which act as blankets to cause warming. Another is the effect of increased carbon dioxide on plant growth, which in turn would absorb more carbon dioxide. The limitation of computers is a factor in itself; even the most modern and fastest super computers are daunted by the complexity of the models, as well as the fact that very small changes in temperatures lead to very large consequences. Samuelson (1997) gives the account of one model, when a few assumptions were changed, that reduced its forecast of global warming from 9 to 3.4°F.

A major problem with all the models is that they are based on such a small amount of past time. The past century is hardly a blip in the total history of the earth. Also, the reliability of the temperature data for the past century is questionable.

*The first part of this six-part series was in the October 1997 issue.*

# Optimization of Wastewater Treatment Facilities

## Harold Schmidt, Jr., Gary ReVoir, II, Troy Layton and Terry Wadsworth

During the past decade, utilities have been required to maintain an exhaustive pace with increasingly stringent federal and state regulations. Population growth has caused utilities to expand their facilities. Many utilities have realized that their capital and operational budgets do not increase proportionally with regulatory and development trends and have been forced to stretch limited capital funding resources by optimizing or retrofitting existing treatment processes. This has generated an interest in innovative designs and processes that keep utilities ahead of changing regulatory and capacity requirements without impacting capital budgets.

A large area adjacent to the city of Edgewater requesting service within a time frame that would not permit the city to design and construct necessary improvements. An alternative plan was developed to determine if the WWTP could be optimized to treat increased flows without constructing new facilities.

Edgewater's WWTP has a permitted capacity of 2.25 MGD. The liquid treatment train consists of screening and grit removal; a 5-stage modified Bardenpho facility consisting of fermentation, first anoxic, aeration, second anoxic and reaeration basins for biological nutrient removal; secondary clarifiers for solids removal; filters for additional solids removal; and a chlorination for high level disinfection. Other process components include post aeration and chemical feed systems (alum and chlorine). These process components produce an effluent that is acceptable for disposal to either the city-wide reclaimed water system or to Mosquito Lagoon.

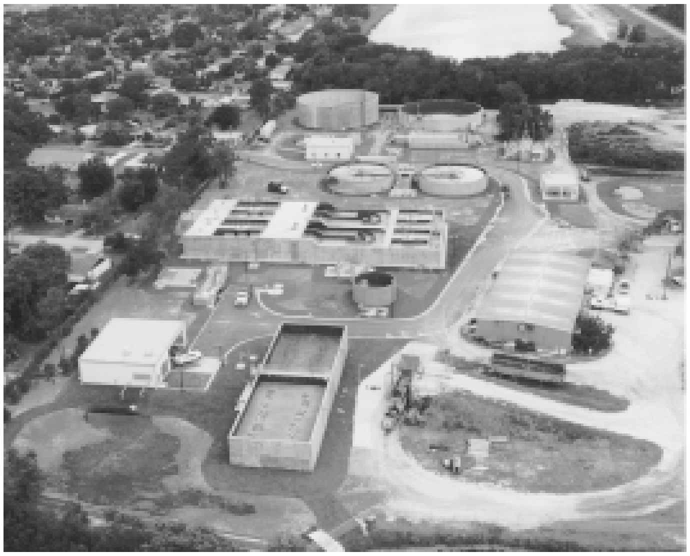
### *Optimization Testing and Modeling*

The methodology used for the overall treatment capacity evaluation of the WWTP consisted of two types of analyses. The first was a desk-top analysis of the treatment process components based on standard practice calculations for unit capacity determination. The second method was a full-scale field analysis, or "stress testing," of the individual process components based on actual varied loading rates to WWTP.

The desk-top analysis was divided into two components: hand calculations to determine capacity for each unit process utilizing standard industry design values, and utilization of an innovative computer model to simulate the treatment process under steady-state conditions.

The computer model used was BIOWIN, version 3.1., which is a modified version of the International Association of Water Pollution Research and Control activated sludge model to include carbon, nitrogen, and phosphorus removal. BIOWIN models unit process performance and biological kinetics on both a steady state and real-time basis, and simulates facility operation to delineate the effects on process variables and overall performance under various loading conditions.

Extensive field data were collected and used to calibrate the model. Inherent to models of this type are a wide variety of variables and constants that must be provided and which can be difficult to obtain. However, unique to BIOWIN is a data base of typical constants that have been developed from the operating data from hundreds of WWTP's. From that data base a set of biological constants were chosen, and the model was calibrated to the actual field data. Once calibrated, the model delineated the effects of different flows and loadings on effluent quality, and identified operational procedures that could be used to accommodate higher loadings. Additionally, the model assessed the facility's capacity based on seasonal variations in temperature and associated biological kinetics.



The ability of the model to predict the facility's performance is due to the wide variety of input data, such as process and bioreactor configuration, basin types and volumes, DO concentrations, and settled solids profile and sludge blanket depth. In addition to specific facility data, the model also considers input for operational and biological data, such as internal recycle, RAS and WAS rates, kinetic and stoichiometric constants, and temperature dependencies for autotrophic, hetertrophic and poly-P organisms.

The stress testing began on June 25, 1996, and ended on October 7, 1996. Daily grab samples of the influent and effluent were collected by the city staff between 7 and 8 a.m. Portions of the individual treatment processes were taken off line during that time to determine the capability of the facility to treat increased wastewater flows under actual field conditions. The first two months of the program were used to make operational adjustments and allow individual unit processes to reach steady state conditions. The parameters of importance in the influent during the stress testing program were in the following ranges:

| | |
|---|---|
| Flow: | 1.33 to 1.85 MGD. |
| CBOD: | 93 to 260 mg/l. |
| TSS: | 88 to 232 mg/l. |
| TKN: | 28 to 42 mg/l. |
| TP: | 3.4 to 8.2 mg/l. |

### *Results and Conclusions*

The premise of the study was that by allowing all of the current flows observed during the testing program to be treated through one process train, the treatment performance that would occur during future flows of 2.66 to 3.7 MGD could be simulated at full-scale. Summarized below are the results of the stress test and desk-top modeling for the various unit treatment processes of concern.

CBOD removal is typically a high-rate process which is not extremely sensitive to low SRT's, HRT's, or temperatures. The model output demonstrated that effluent CBOD levels below 2.0 mg/l can be sustained at flows up to 3.25 MGD, with aerobic SRT's of four days or greater. The only major increase in effluent CBOD occurred at temperatures less than 18°C. Even at temperatures at approximately 20°C, however, effluent CBOD concentrations were consistently below 2.5 mg/l. Based on both the field and model data, the facilities were determined to be suitable for CBOD removal for flows up to 3.0 MGD.

The primary variable which affects biological phosphorus (bio-P) removal is the HRT in the fermentation basins, which allows for certain microorganisms (poly-P bacteria) to "stress" and release phosphorus under anaerobic conditions. The fermentation basins at the city's WWTP theoretically have sufficient volume to accommodate bio-P removal for flows up to 3.0 MGD, based on standard textbook design values. Although sufficient fermentation basin volume appears to be present for bio-P removal, both model and field data suggested that this was not the case. The model results indicated that at higher flows the effluent phosphorous levels decreased at higher temperatures. Due to the higher flows, and subsequent lower HRT values in the second anoxic basin, BIOWIN predicted less phosphorus release in the second anoxic basin. Such a data trend was not evident at low temperatures since apparently there was no nitrification occurring, which causes different net phosphorus uptakes and releases across the entire process. In terms of HRT, this data trend appears contradictory for the fermentation basin, however, this data trend is typical of a process with an oversized second anoxic basin. The HRT for the second anoxic basin is considered to be in the upper range, and accounts for approximately 20 percent of the total basin volume for the system. Typically, oversized second anoxic basins cannot maintain enough nitrates to maintain a true anoxic environment and subsequently become anaerobic, which could then theoretically promote re-release of phosphorus.

The low carbon to phosphorus ratios (C:P) of the influent wastewater also appeared to contribute to high phosphorus levels in the effluent, as noted by the BIOWIN results. Since sufficient carbon was at times unavailable in the wastewater, less phosphorus should be released during fermentation, and will subsequently limit the amount of phosphorus up-take that can occur in the aeration basin. Typical C:P ratios necessary for bio-P removal are on the order of 28:1, and in many cases, the C:P ratio was in the order of 19:1. Although the influent may be at times carbon deficient and the second anoxic basins may be oversized for design flow conditions, both of which may cause effluent phosphorus levels in excess of 1.0 mg/l, the WWTP has the ability to feed alum for chemical phosphorus removal to ensure permit compliance.

The primary variables which affect biological ammonia conversion or nitrification are HRT and SRT. Sufficient aerobic HRT is necessary for proper substrate utilization. Based on the existing aeration basin volume, an HRT of approximately 6 to 7-hours can be obtained between the flows of 2.75 to 3.0 MGD, which is considered to be in the low range for a 5-stage process. SRT is a function of solids inventory and WAS rates. The SRT values used during the field stress test was a 4-day aerobic SRT, and an 8-day total SRT.

Because of the low 4-day aerobic SRT, the model indicated that sufficient nitrification was not achieved at any flow rate for temperatures below 23°C. For flows as low as 2.5 MGD, at 18°C and 20°C the effluent TKN concentration from the model output was 10.0 and 3.0 mg/l, respectively. Additionally, the field data collected did not correlate well with the model results, since the reported effluent TKN data collected ranged from less than 2 mg/l, with high values ranging from 3 to 8 mg/l. Therefore, the field data appears to suggest that at times the facility was possibly overloaded hydraulically and insufficient aerobic HRT was available for complete nitrification. The irregular data trend is typical of grab sampling in a low SRT system. One purpose of establishing a minimum SRT value is to ensure that the microorganisms are in the system long enough to grow and assimilate substrate. If the SRT is too low, then the nitrifiers will be wasted out of the system faster than they can grow, and nitrification essentially ceases. Additionally, since the nitrifier growth rate itself is based on temperature, the rate of nitrification will be substantially increased at higher temperatures.

During the field stress test, operating the system at a low SRT of four days would have little to no safety factor, and thus it is doubtful that the facility was able to reduce peak ammonia loadings to sufficiently low levels. Based on the diurnal data collected, a second peak loading for the facility occurred between the hours of 7 and 9 p.m. with ammonia loadings in excess of 50 mg/l. At an SRT of four days, the facility would not be able to reduce the peak ammonia to desired levels. During the average flow conditions for the stress test, the SRT was on the order of 13 days. Therefore, it is likely that the residual ammonia from the peak loading that occurred in the previous evening, was being grab sampled the following morning. This could explain the high TKN samples observed during the stress test.

The effect of the safety factor and grab sampling on the high effluent TKN values was illustrated by collecting real-time data from the model. Typical peak loadings were inputted into the model and predicted effluent ammonia values were developed for a period of 24 hours. This simulation was run at three different SRT safety factors of 1.00, 1.50, and 2.25. Typical SRT safety factors range between 2.0 to 3.0. The simulation results indicated that as the safety factor and aerobic SRT increases, the peak ammonia loadings in the effluent decrease. This data illustrated the importance of operating at a higher SRT to accommodate peak ammonia loadings to maintain the highest effluent quality possible.

To fully evaluate the effect of different hydraulic loadings and temperatures on nitrification at the city's WWTP, steady-state simulations were performed at various aerobic SRT values. These simulations verified that high aerobic SRT's minimized the effects of increased loadings and lower temperatures, and verified that high SRT systems approach steady-state conditions and theoretically can produce a consistent high quality effluent over a wide range of conditions. These results suggest that the city's WWTP will be able to achieve complete nitrification during the summer and winter temperatures at flows up to 3.25 MGD when utilizing aerobic SRT's on the order of 17 days, and a MLSS of approximately 3,500 mg/l.

The primary variables which affect biological nitrogen removal or denitrification is the capacity of the first and second anoxic basins. The capacity of the first anoxic basin is a function of the influent F/M ratio, nitrate loading from the internal recycle, and the solids inventory of the basin. The capacity of the second anoxic basin is a function of the system SRT, nitrate loading from the aeration basin effluent and solids inventory of the basin. Although sufficient anoxic basin volume is available for denitrification, the model data consistently reported effluent nitrate levels as high as 1.7 mg/l, which did not agree with the field study data which consistently reported nitrates well below 1.0 mg/l.

As discussed earlier, the grab samples were most likely collected during the peak flow events as a result of the low SRT. Since ammonia in many of the samples was high, it could be ascertained that nitrification was incomplete and that nitrate levels were low due to this apparent lack of complete nitrification. Thus, normal operating conditions is not represented. A nitrate balance conducted over the system to evaluate the model indicated that sufficient denitrification was occurring over both the first and second anoxic basins. The model indicates nitrate levels from the second anoxic basin below 1.0 mg/l. Similar to the increase in effluent phosphorus concentration values, the model results indicate that a large HRT in the second anoxic basin causes a change in the overall nitrogen balance of the system. Typically, increases in the HRT's in the second anoxic basin result in a decrease in the rate of denitrification due to the lack of sufficient carbon for the entire volume of microorganisms. Coupled with the low denitrification rate was the possible hydrolysis of organic nitrogen across this bioreactor, which appears to result in an increase in soluble ammonia in the effluent according to the model. Ammonia release, much like the phosphorus release, is a possible occurrence in oversized anoxic basins. This soluble ammonia subsequently enters the reaeration basin where the additional nitrates were being produced. The model data suggests that at higher SRT's complete nitrification occurs, the effluent TKN will be sufficiently low to allow for additional nitrate production without exceeding the desired effluent TN level of 3.0 mg/l.

Sufficient denitrification capacity is available for flows up to 3.0 MGD. Additionally, there is the possibility of ammonia release across the second anoxic basin and subsequent increase in nitrates across the reaeration basin. This situation can only improve as the flows increase and the HRT across the second anoxic basin is reduced. However, during the highest loadings of the model simulations, the nitrate increase was not substantial enough to cause the effluent total nitrogen levels to exceed 3.0 mg/l.

The existing surface mechanical aerators were assessed to determine whether oxygen transfer would be a limiting factor. The data indicated that the existing aerators are sufficient to accommodate flows up to 2.75 MGD without substantially using credits for cell synthesis and denitrification. These credits represent a safety factor equal to approximately 23 HP, and only 2 to 3 HP were used for flows of 2.75 MGD, which left a conservative safety factor 20 HP for aeration.

The clarifiers, filters, and chlorine contact chamber were determined by standard recommended design standards to have capacities of 3.39, 3.47, and 4.99 MGD, respectively. When flows to the single clarifier exceeded 1.8 MGD, however, solids overflow occurred in the field. The effluent filters and chlorine contact chamber did not experience any problems meeting the effluent criteria during the stress testing program. The yard piping was also evaluated, and it was determined that peak flows up to 7.40 MGD, or an average daily flow of 2.96 MGD, could be passed through the WWTP without significantly impacting the hydraulics of the facility.

### *Discussion*

The conclusions of the study were based on collective data obtained from the various process evaluations performed. The standard process calculations prepared for the rerating study provided the results expeczted when utilizing standard practice variables and equations. The BIOWIN model and stress testing results, however, yielded a different set of results.

The major benefit of the stress test was to obtain actual field data of the full scale proposed program. During the study it was difficult to maintain a consistent flow rate to accurately assess the specific capacity of the treatment train in service. However, with the success of one treatment train in service to meet the effluent requirements at the varied flows observed during the program, it allowed us to assess the upper end of the potential treatment capacity of the existing facilities. The stress test also resulted in obtaining actual process variables which were later used in the desk-top calculations. The stress test also allowed us to observe the hydraulic affects of increasing flows through the facility that are often not a factor in process calculations.

The model predicted a decreasing effluent concentration for phosphorus with the premise that the HRT of the anoxic basins would decrease with an increasing flow rate and subsequently reduce the undesirable anaerobic conditions which could cause the rerelease of phosphorus. Typically, rerelease of phosphorus due to anaerobic conditions in anoxic basins is rare. In the case of the first anoxic basin, phosphorus is released in the fermentation basin and designed for subsequent up-take in the aeration basin. Therefore, the concern for rerelease in the first anoxic basin is not warranted. Additionally, most similar facilities utilize alum addition to mask any increase in effluent phosphorus concentrations occurring in the second anoxic basin . Therefore, one should be cautious about overreacting to the model's recommendation to adjust for this situation. An improper adjustment for anaerobic conditions could result in a reduction of anoxic volume and a resulting reduction in the denitrification capacity of the facility. The model also predicted the release of ammonia in the anoxic basins due to hydrolysis. Again this situation is rarely observed at full-scale conditions. Therefore, the need to adjust for this situation may again result in unnecessarily decreasing the anoxic volumes.

It was concluded that the rerated capacity of the city's WWTP should be based on the compilation of results from the three various analyses as opposed to the recommendation based on the result of a sole analysis. The results of the standard process calculations were only as accurate as the safety factor included in the analysis. The results of the BIOWIN model utilized some field verified variables, although the variables were for certain flow rates and grab samples. Therefore, no specific conclusions could be drawn; only a specific theoretical trend could be established for variations to the inputs. The results of the stress test could only be factored based on the consistency of the actual conditions observed during the evaluation period. However, it is much more rewarding to actually observe higher flow rates, and achieve the required effluent standards in the field. The results of this study resulted in the city's WWTP being rerated by FDEP from 2.25 MGD to 2.75 MGD.

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# Nutrient Removal in Small Wastewater Treatment Plants

**Gerald W. Foess, Kenneth Williams. and George Garrett**

Nutrients (nitrogen and phosphorus) are a potential issue of concern whenever wastewater effluent is discharged to a surface or ground water. Excess concentrations are a known cause of eutrophication in surface waters, and excess nitrate concentrations in aquifers used for water supply are a health concern.

DEP has imposed effluent limits for nutrients at some 135 wastewater treatment plants in Florida, including phosphorus limits at 67 plants, nitrogen limits at 33 plants, and limits for both at 35 plants. Half of the limits apply to WWTPs with a capacity of 1 MGD or less, and nearly 20 percent apply to WWTPs with a capacity of 0.1 MGD or less, as shown in Table 1.

### Table 1. Size Distribution of Plants With Nutrient Limits

| *WWTP Capacity (MGD)* | *Number With N or P Limits* |
|---|---|
| <0.1 | 24 |
| 0.1 to 1.0 | 43 |
| 1.1 to 5 | 48 |
| 5.1 to 25 | 16 |
| >25 | 4 |
| **TOTAL** | **135** |

The greatest number of Florida WWTPs with nutrient limits are in the coastal area of the panhandle, the St. Johns River basin, the greater Orlando area, and the Sarasota-Tampa area. There is also a growing concern with nutrients in the Florida Keys causing degradation of canal and nearshore waters. Some 300 small WWTPs (2,000 to 50,000 gallons/day), as well as numerous onsite disposal systems, discharge wastewater into the waters off the Keys and have been implicated.

The situation in the Keys has led DEP to fund a study of the effectiveness of nutrient removal by small WWTPs. The study will review current technologies, levels of achievable treatment, workable flow ranges, ability to retrofit technology to existing plants, and construction and operating costs. This article presents some preliminary information.

## Existing Nutrient Limits in Florida

Existing nutrient limits at plants in Florida vary widely. Nitrogen limits are in the range of 3 to 10 mg/l, with 3 mg/l and 10 mg/l being the most common limits. Phosphorus limits range from 0.1 to 10 mg/l, with 1 mg/l and 10 mg/l being the most common. The reason for the 10 mg/l limit is not known—it is higher than most raw wastewaters. Of the 135 WWTPs with N and/or P limits, there are 49 different combinations of limits.

## Future Nutrient Limits in the Keys

Future DEP treatment requirements in the Keys could be exceptionally stringent. A draft bill introduced into the Florida legislature in September 1997 would eliminate surface water discharges in Monroe County by July 1, 2003, except for limited periods of backup service. It would require advanced waste treatment (limits of 3 and 1 mg/l for N and P, respectively) for discharges to both shallow- and deep-injection wells by the same deadline. Only plants with a design capacity of 50,000 gal/day or less would be granted an exception if the facility demonstrated that it could not reliably achieve AWT limits and provided "best treatment technology available" in lieu of AWT. Table 2 summarizes these requirements.

## Nutrient Removal Process Options

Virtually all the nutrient removal process options available at large WWTPs are also available for small "package" plants of 100,000 gal/day capacity or less. These processes include chemical phosphorus removal and various biological nutrient removal (BNR) processes.

The suspended growth BNR systems all include aerobic, anoxic (absence of free dissolved oxygen), and/or anaerobic (absence of any oxygen) biological reactors, as follows:

- Biological Phosphorus Removal: anaerobic and aerobic reactors
- Biological Nitrogen Removal: anoxic and aerobic reactors
- Biological Nitrogen and Phosphorus Removal: anaerobic, anoxic, and aerobic reactors

### Table 2. DEP Discharge Limits Applicable in the Florida Keys Under Proposed Legislation[a]

| *Effluent Management System* | *Discharge Requirements* |
|---|---|
| Shallow Well Injection, > 0.05 MGD | AWT[b] |
| Shallow Well Injection, < 0.05 MGD | AWT[b] or BAT[c] |
| Deep Well Injection | AWT[b] |
| Surface Water Discharge | No discharge after July 1, 2003[d] |

[a] Draft s. 403.086(9), September 12, 1997.

[b] Advanced Waste Treatment, defined as BOD and TSS = 5 mg/l; N = 3 mg/l; P = 1 mg/l

[c] Best Available Treatment; specific discharge limits undefined.

[d] Except for discharge required by a mechanical integrity test for an injection well or discharge as backup to a reclaimed water reuse system, in which case backup is limited to 20 percent of the permitted reuse capacity.

Examples of flow diagrams for these three types of BNR systems are shown in Figure 1. Alternative process configurations also exist within each of these categories.

BNR processes can be selected to meet a range of effluent limits, as shown in Table 3. The simplest nitrogen removal process, the MLE process, yields an effluent N of about 10 mg/l. The lower limit of effluent N achievable with BNR processes is 2-4 mg/l. In theory, small package plant systems can achieve these performance values; however, the actual performance of small systems remains to be evaluated.

BNR processes can achieve effluent P levels of 1-2 mg/l. Because the biosolids in BNR systems contain up to three or more

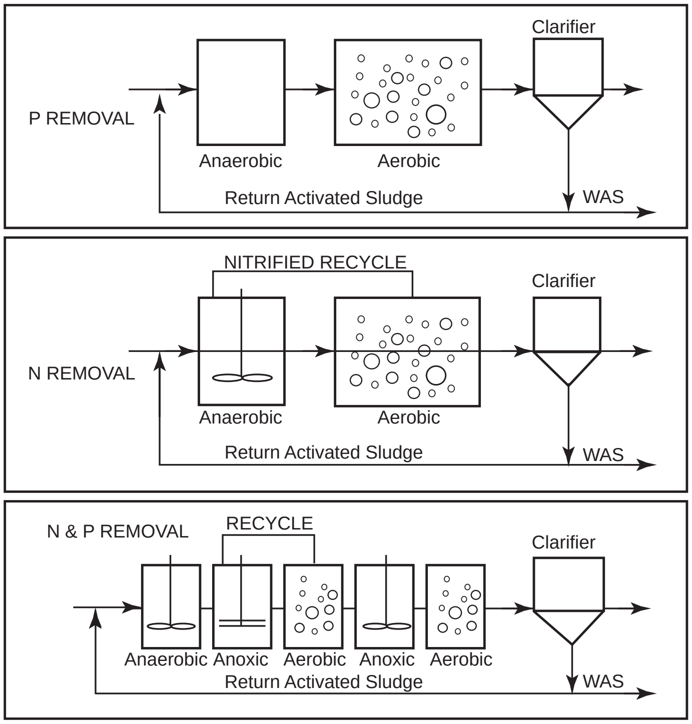

*Figure 1. Example Flow Diagrams for the Three Types of BNR Systems*

## Table 3. Achievable Effluent Limits With BNR Systems

| *Process* | *Effluent N (mg/l)* | *Effluent P (mg/l)* |
|---|---|---|
| Biological P Removal | | |
| Anaerobic/Oxic (A/O) | — | 1-2 |
| Phostrip | — | 1 |
| Biological N Removal | | |
| MLE | 10 | — |
| 4-Stage Bardenpho | 3 | — |
| Denite Filter | 3 | — |
| Biological N & P Removal | | |
| Anaerobic/Anoxic/Oxic ($A^2O$) | 6-10 | 1 |
| 5-Stage Bardenpho | 2-4 | 1-2 |
| Virginia Initiative Process (VIP) | 6-10 | 1 |
| Above with Filtration | Small Improvement | <0.05 |

times the phosphorus content than biosolids from conventional secondary treatment, efficient phosphorus removal is heavily tied to TSS removal (see Figure 2). With the addition of coagulant and filtration, effluent P levels below 0.05 mg/l are achievable.

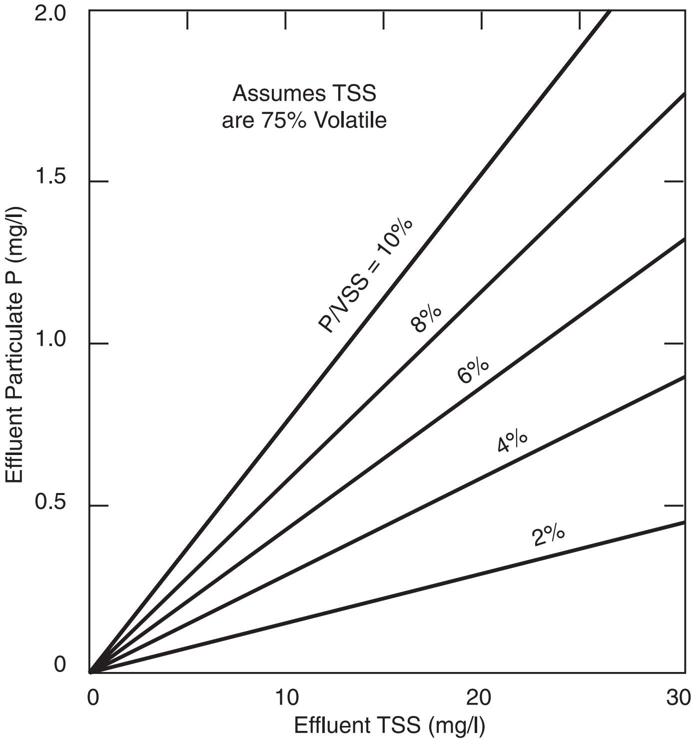

*Figure 2. Efficiency of Phosphorus Removal When TSS is Removed*

## Package Nutrient Removal Plants

Pre-engineered package plants for nutrient removal are available in small sizes, as well as granular media and low pressure membrane (microfiltration) units. Factory built units can be purchased in capacities of as little as 5,000 gal/day or less, whereas field erected packages are rarely furnished below a capacity of 100,000 gal/day. Table 4 lists a few suppliers of package BNR systems and their minimum capacities. In general, sequencing batch reactor (SBR) systems are available in the smallest capacities because a single tank serves several functions and compartmentalization is not required. While some suppliers of field-erected package plants do not compete in size ranges below about 100,000 gal/day for conventional activated sludge systems, they may be interested in providing special order, factory-built BNR systems in this range.

## Table 4. Representative Suppliers of Small Package Systems for Nutrient Removal

| *Supplier* | *Smallest Capacity gal/day)* |
|---|---|
| Davco (conventional configuration) | >100,000 |
| Eimco (oxidation ditch) | >100,000 |
| Aqua Aerobics (SBR) | 10,000 |
| Jet Tech (SBR) | 5,000 |
| Austgen Biojet (ICEAS) | 20,000 |
| Zenon Zeno Gem (membrane process) | 20,000 |
| Tetra (denite filter) | 20,000 |
| Memcor (microfiltration) | 3,000 |

## Cost of Small BNR Package Plants

The cost of small BNR package plants, expressed in terms of dollars/unit of capacity, increases sharply below a capacity of about 200,000 gal/day, as shown in Figure 3. Traditional rules of thumb for estimating capital costs therefore do not apply in the small size ranges. Unit operation and maintenance costs also increase disproportionately as plant size decreases.

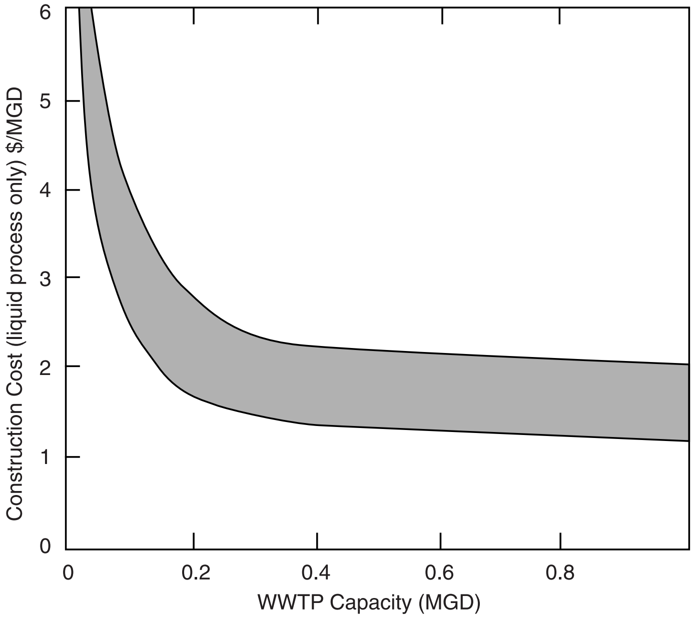

*Figure 3. Costs of Small BNR Package Plants vs. Plant Capacity*

## Retrofitting of Nutrient Removal Processes to Small Package Plants

In general, the simple MLE process and chemical phosphorus removal can be retrofitted in small package plants. Retrofitting with a BNR process by adding a compartment to the existing aeration basin reduces the biological treatment capacity of the plant. Retrofitting multi-stage BNR processes is not considered feasible for small package systems. Additionally, the poor condition of existing package plants often precludes retrofitting.

## Future Work

Future work is intended to develop a comprehensive list of manufacturers of package plants for nutrient removal and enhanced BOD/TSS removal. Detailed information will be compiled for each plant, including the topics described here, as well as operator staffing requirements, monitoring requirements, process control and instrumentation requirements, site requirements, quantity of residuals generated, and list of full-scale facility installations. Selected field visits to operating facilities may also be made to confirm the information collected.

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