A Constant SRT Calculated From Liquid Flows Improves BNR Activated Sludge Performance

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ABSTRACT

Control of Solids Retention Time (SRT) in the activated sludge process is critical for ensuring effective wastewater treatment. SRT sets the growth rate of microorganisms in the activated sludge process, thereby selecting the microbial composition of the mixed liquor and its settling and treatment properties.

The industry has developed various methods to control activated sludge. This study evaluated seven (7) methods to calculate SRT and implemented a simple, straightforward hydraulic control of SRT method. The study was conducted at the 34 mgd Seneca WWTP in Eagan, MN, which operates a plug-flow nitrifying activated sludge process with reduced air-flows in initial zones to enhance phosphorus removal.

Hydraulic control of SRT is based on a solids mass balance over the aeration tanks and clarifiers. Specifically, it depends on the influent wastewater forward flow rate into the aeration tanks, the clarifier underflow rate, the waste sludge flow rate and aeration tank volume in service. It eliminates the need for costly TSS sampling at various points in the process, along with its associated measurement variation and time lags. During this study, hydraulic control produced an SRT that agreed with conventional estimation methods, i.e. mass under aeration divided by mass flow rate wasted, when the conventional methods were corrected for solids inventory in the clarifiers.

Hydraulic control of SRT provides a simple, real-time calculation to adjust wasting flow rates of return sludge to maintain a target SRT and a stable microbial population. At the Seneca WWTP, hydraulic control of SRT, combined with gently air-mixed inlet aeration zones, simplified process control, reduced O&M costs, and produced an excellent effluent quality that averaged 4.6 mg/l TSS, 3.6 mg/l BOD, 0.58 mg/ l total phosphorus and 0.14 mg/l ammonia.

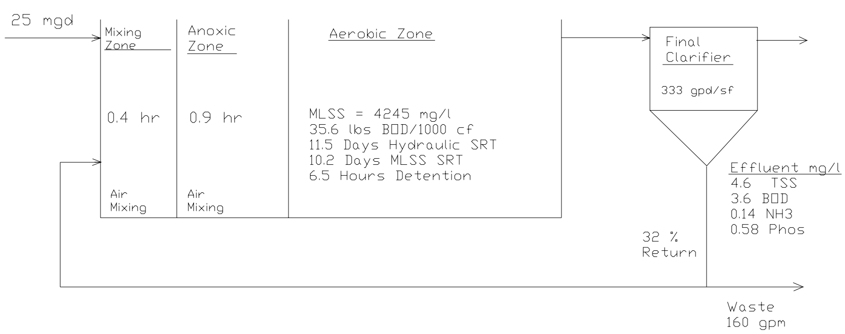
Key Words:

Solids Retention Time, Phosphorous removal, ammonia removal, activated sludge, BNR, SRT

INTRODUCTION

Solids Retention Time (SRT) control in aeration systems is a key parameter for ensuring effective wastewater treatment. This study focuses on the use of hydraulic control of 'Solids Retention Time' to optimize process operations at the 34 mgd Seneca WWTP in Eagan, MN. The Metropolitan Council owns and operates the Seneca WWTP and provides regional wastewater treatment for the Minneapolis – St. Paul area. The Seneca facility operates a plug-flow nitrifying activated sludge process and reduced airflows in initial zones to enhance phosphorus removal (Figure 1). Using liquid flow measurements alone, Seneca successfully implemented a simple, real-time algorithm for hydraulic control of activated sludge SRT, following an initial comparison of alternate SRT calculations.

Figure 1 - Seneca WWTP BNR Process Values
Constant Hydraulic SRT, July - October 2001



Solids Retention Time (SRT) sets the growth rate of microorganisms in an activated sludge process, thereby selecting the microbial composition of the mixed liquor. For consistent wastewater treatment, SRT must be controlled at a level that oxidizes pollutants, e.g. nitrifies, while providing "bugs" that flocculate and settle. When SRT is not controlled or controlled poorly, the mixed liquor contains a composite of microorganisms that are not optimized for the current growth conditions; it is also difficult to determine an SRT response to poor performance. Over the years, the industry has developed various methods to make waste flow adjustments and control activated sludge SRT, including:

1) Direct SRT control using measurements of MLSS inventories and waste sludge solids flow rates (TSS concentrations and flow rates)[1],
2) F:M control[1],
3) Control to a constant MLSS level in the aeration tanks[1],
4) Hydraulic control of SRT[2,4,5].

The first three methods require TSS and BOD estimation by laboratory methods, centrifuge spins or online analyzers. Also, the definition of MLSS inventory may or may not include clarifier inventories or solids not under aeration, e.g. anaerobic zones. The use of the first three methods requires lab analysis of Suspended Solids. This SRT study at Seneca evaluated the seven (7) different variations to calculate SRT.

Other plant changes were made to improve the 'Biological Nutrient Removal' (BNR) process. These changes included improved flow diversion to increase hydraulic detention time in the anaerobic zone and flow restrictions to reduce scum buildup in the anoxic zone.

METHODOLOGY

There are various methods to calculate the Solids Retention Time, depending upon the assumptions made[1]. This section describes seven (7) different SRT calculation methods evaluated.

Method 1- Conventional SRT: The conventional SRT (days) is equal to the mass of MLSS in the aeration tank (lbs.) divided by the mass of solids wasted each day (lbs./day).

SRT_1 = (V * MLSS * 8.34)/ WAS Equation 1

Where:

V = Volume of tanks in service (mg)
MLSS = Mixed Liquor Concentration (mg/l)
WAS = Mass of Solids wasted (lb./day)
= Waste Flow (gpm) * %TS * 24*60*8.34

Method 2 – Modified Conventional SRT_a, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed MLSS concentration:

The SRT is equal to both the mass of MLSS in the aeration tanks, plus the mass of solids in the final clarifiers divided by the mass of solids wasted each day. The mass of solids in the final clarifier is estimated by assuming that the solids concentration in the final clarifier is equal to the MLSS concentration, then is multiplied by the sludge blanket volume and conversion factors.

SRT_a = ((V * MLSS * 8.34) + M_2)/ WAS Equation 2

Where:

M_2 = Estimated mass of solids in the final tanks
= MLSS * (Sludge Depth * Area of Tank) * 7.48 * 8.34 /1,000,000

Method 3 – Modified Conventional SRT_b, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed TSS concentration equal to the average of the MLSS and RAS concentrations

The SRT is equal to the mass of MLSS in the aeration tank plus the mass of final clarifier solids divided by the mass of solids wasted each day. The mass of solids in the final clarifier is estimated by assuming that the solids concentration in the final clarifier is equal to the average of the MLSS and the RAS concentration, then the average concentration is multiplied by the sludge blanket volume and conversion factors.

SRT_b = ((V * MLSS * 8.34) + M_3)/ WAS Equation 3

Where:

M_3 = Estimated mass of solids in the final tanks

=((MLSS + RAS) / 2) * (Sludge Depth * Area of Tank) * 7.48 * 8.34 /1,000,000

RAS = Return Activated Sludge Concentrations (mg/l)
Sludge Depth (feet)
Area of Tank (square feet)

<u>Method 4 – Hydraulically determined SRT:</u>

Hydraulic controlled SRT[2] is based on a simple mass balance around the aeration tanks and final clarifiers. The two equations used to calculate hydraulic controlled SRT are as follow:

Clarifier Input = Clarifier Output
(Q + R –W) * MLSS = R * RAS   Equation 4

Where:

Q = Influent Forward Wastewater Flow
R = Return Rate from the Clarifiers, prior to wasting
W = Waste Rate
MLSS = aeration tank outlet TSS concentration into the clarifiers
RAS = return sludge (waste sludge) TSS concentration out of the clarifiers

Equation 4 is written for the clarifier mass balance, when the waste meter is after the return flow meter, as in the case at the Seneca WWTP.

Assuming a uniform solids concentration along the aeration tank, as is the case with Seneca's plug-flow feed process, and, ignoring minimal solids loss into the plant effluent, SRT can be determined by

SRT = (V * MLSS) / (W * RAS)   Equation 5

Where:

V = Volume of Aeration Tanks in Service

Equations 5 & 6 can be combined to express SRT only in terms of liquid flow rates and tank volume:

Hydraulic Controlled SRT = (V/W) * (RR / (1 + RR – W/Q))   Equation 6

Where:

RR= Recycle Ratio = R/Q

The hydraulic controlled SRT equation can be modified for step feed processes, two-stage processes and other variations of the activated sludge processes. The equation can also be modified to incorporate solids inventories in the final clarifiers, as in the next two SRT variations.

Method 5 - Modified Hydraulically determined SRT1, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed MLSS concentration:

The hydraulically controlled SRT can be modified to incorporate the solids in the final tanks. This modification assumes that;

Solids mass = total blanket depth * unit clarifier area * MLSS concentration

Using mass balance equations, a modified Hydraulic Controlled SRT can be calculated:

Hydraulic Controlled SRT_1 =

$$(V_{at} + V_{clar}) / W * RR/(1+RR-W/Q) \qquad \text{Equation 7}$$

$V_{clar} =$ total blanket depth * unit clarifier area

Method 6 – Modified Hydraulically determined SRT2, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed TSS concentration equal to the average of the MLSS and RAS concentrations. The hydraulically controlled SRT can be modified to incorporate the solids in the final tanks. This modification assumes that;

Solids mass = total blanket depth * clarifier area * (average of the RAS and MLSS concentrations)

Using mass balance equations, a modified Hydraulic Controlled SRT can be calculated:

Hydraulic Controlled SRT_2 =

$$[\ V_{at} + V_{clar} * 0.5 * (1 + (1+RR-W/Q)/RR)\ ] / W * RR/(1+RR-W/Q) \qquad \text{Equation 8}$$

Method 7 - Inverse of the F:M ratio:

This calculation is equal to the inverse of the F:M ratio. The F:M ratio has been used to control municipal activated sludge processes. The F:M inverse ratio is calculated by the dividing the solids inventory in the aeration tank by influent BOD loading to the activated sludge process.

$$SRT_7 = (V_{at} * MLSS * 8.34) / (BOD *Q*8.34) \qquad \text{Equation 9}$$

Where

BOD = BOD primary tank effluent concentration (mg/l)
Q = Influent forward wastewater flow (mgd)

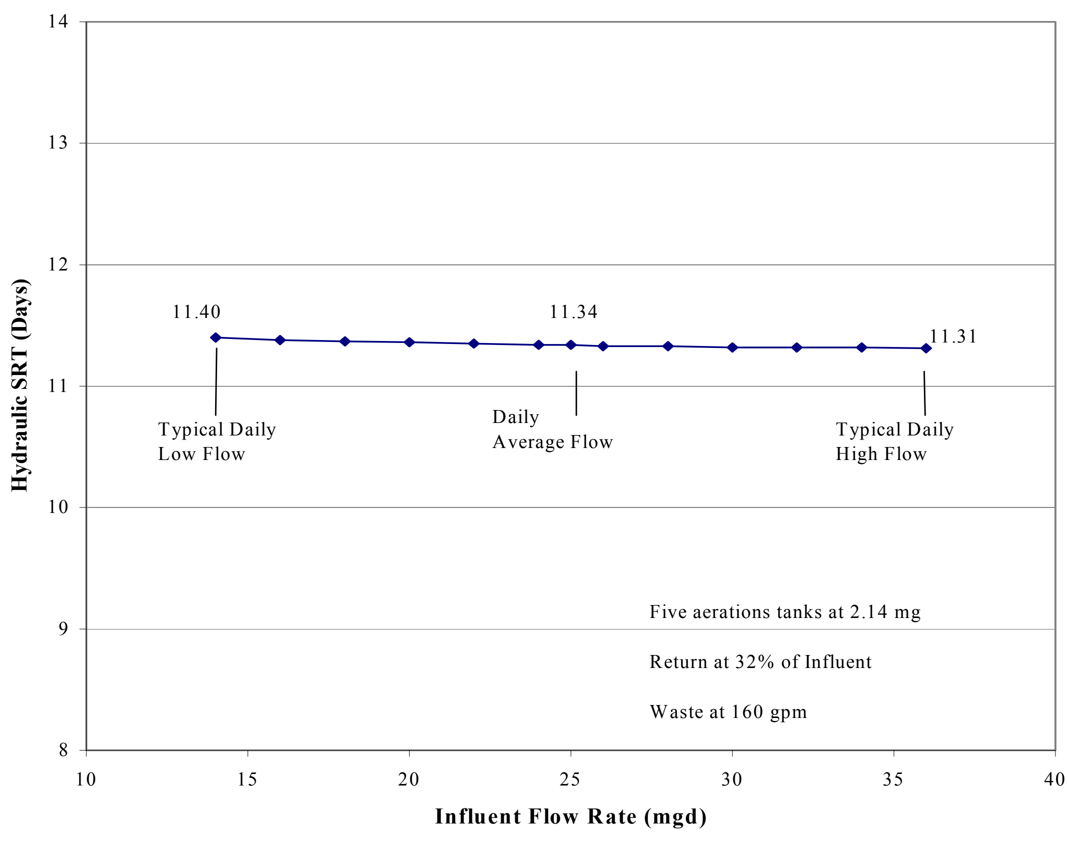
Discussion of Hydraulically Controlled SRT

Hydraulic control of SRT was introduced by Garrett in 1958[4], for direct wasting of mixed liquor solids and did not apply to step feed processes. The method can be extended to return sludge wasting from a plug flow or step feed process[5]. The methodology has been computerized at the Madison, Wisconsin Wastewater Treatment Plant[6]

Hydraulic SRT uses a simple calculation which relates the waste sludge flow rate to the influent wastewater forward flow rate, the clarifier recycle ratio and the volume of aeration tanks in service. A readily apparent advantage of using hydraulic SRT is the elimination or reduced need to conduct lab analysis of MLSS and return sludge total solids and the associated measurement variations and time lags due to sampling and lab analysis.

It is interesting to note that, at longer SRTs, the influent forward wastewater flow has a minimal affect on the SRT determination. The hydraulically determined SRT changes only from 11.40 days to 11.31 days, when the flow increases from Seneca's typical daily low (~14 mgd) to daily high (~36 mgd), assuming other variables (aeration tanks in service, recycle ratio, waste rates) are kept constant (Figure 2). This indicates that a constant hydraulic controlled SRT is easily obtained by keeping the clarifier return ratio and the waste flow rate constant (with a constant number of aeration tanks in service).

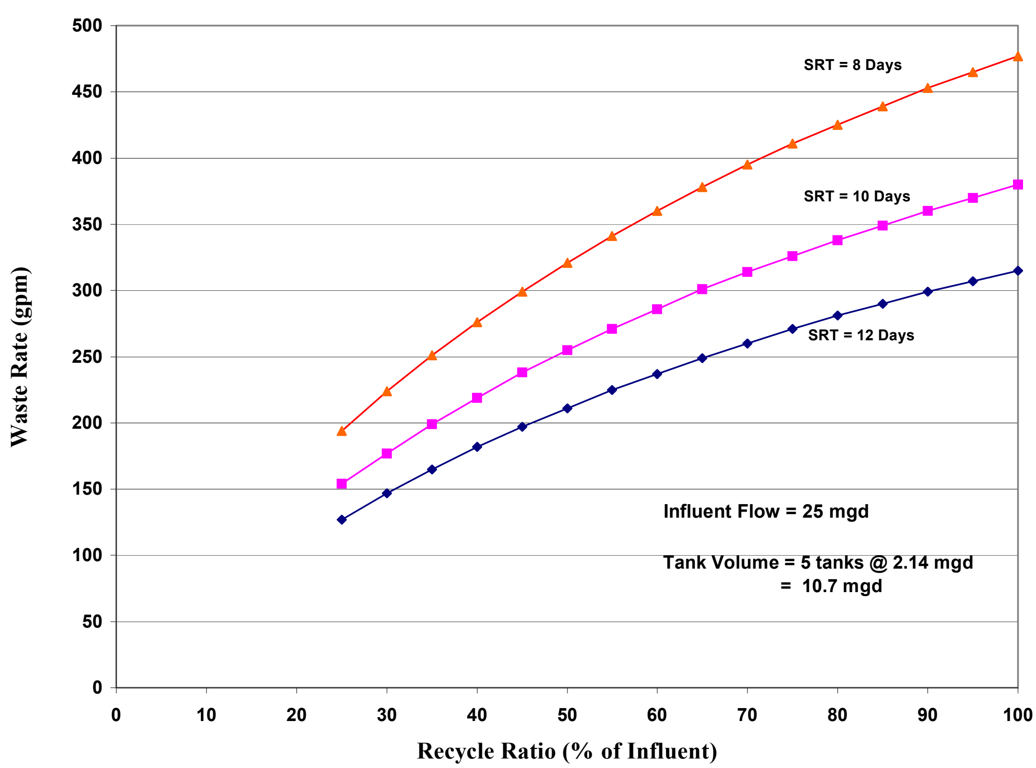
Figure 2 - Hydraulic Controlled SRT- As a Function of Influent Flow Rate, With Constant Waste and Return Rate at Seneca WWTP



The mathematical relationship between the waste rate and recycle rate to maintain a constant SRT for a given number of aeration tanks in service is shown graphically in Figure 3. These equations can be programmed into a computer spreadsheet, providing a real-time target waste sludge flow based on current clarifier recycle ratios, influent flow rates and aeration tanks in service. Figure 3 and its underlying equations provide the operator / engineer a simple way to change the SRT by changing the waste sludge flow or to maintain a constant SRT when there are changes in return sludge recycle ratio. For example, if it is desired to change the current operational target from a 10 day to an 8 day SRT, the waste flow rate would change from 200 gpm to 250 gpm (at a constant 35% recycle ratio). Alternatively, the recycle ratio may be changed in response to pending clarification or thickening failures; this necessitates changes in waste sludge flow rate to maintain a constant SRT. Using Figure 3, a waste flow rate change from 200 to 150 gpm would maintain a 10 day SRT if the recycle ratio is lowered from 35% to 26% as a potential response to a pending clarification failure. On the other hand, a waste flow rate change from 200 to 255 gpm would maintain a 10 day SRT if the recycle ratio is raised from 35% to 50% as a potential response to a pending thickening failure. Estimates of such waste sludge flow rate changes are simply not as straightforward using more conventional control methods (conventional SRT measurements based on TSS, constant MLSS, constant F:M).

The conventional means to measure and control SRT (mass of aeration solids divided by the daily mass wasted) is typically more complicated, with measurement lags in obtaining TSS results, substantial sampling and measurement variations in those results. Thus, there is no straightforward way to adjust return and waste flow rates to obtain a desired SRT.

Figure 3 - Changes in Return Rate and Waste Rate Required to Maintain a Constant Hydraulic SRT



RESULTS

One of the goals of this study is the evaluation of the various methods to calculate SRT. The best SRT calculation method and corresponding optimum SRT for Seneca WWTP needed to be determined. The Seneca WWTP BNR system was operated by trying to maintain a constant mixed liquor solids concentration up to March 2001. However, because the instability of the nitrification process in the winter of 2001, the switch to a constant conventional SRT control was made. In early July, the BNR control was switched to the use of hydraulic control of SRT, as shown in Figure 4.

The average and standard deviations for each of the different methods to calculate SRT, from July through October 2001 are shown in Table 1. During this time, hydraulic controlled SRT was kept constant by keeping the recycle ratios and waste flow rates essentially constant (See Figures 4 & 5).

Table 1 – Statistics for Various SRT Calculations from July through October 2001 (n=122)

	Average	**Std. Deviation**
Conventional SRT	10.2	0.72
Modified Conventional SRTa, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed MLSS concentration	11.3	1.36
Modified Conventional SRTb, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed TSS concentration equal to the average of the MLSS and RAS concentrations.	12.7	1.22
Hydraulically determined SRT	11.5	0.07
Hydraulically determined SRT1, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed MLSS concentration	12.4	0.45
Hydraulically determined SRT2, including the mass of final clarifier solids estimated from clarifier sludge depth measurements at an assumed TSS concentration equal to the average of the MLSS and RAS concentrations.	13.9	1.12
SRT determined by calculating the inverse of the F/M ratio	9.6	2.52

Hydraulic controlled SRT were 1.3 days higher than the conventional SRT, based on solids measurements. As shown in Table 1, the estimation of SRT by simple hydraulic determination agreed with the modified conventional SRTa estimate, the latter including solids inventories in the clarifiers (estimated by sludge depth levels at the MLSS concentration).

Figure 5 shows the daily conventional and hydraulic SRT calculations for 2001. The scatter of the conventional SRT compared to the hydraulic SRT, after July when hydraulic SRT was kept constant, is readily apparent. In this instance, the scatter of the conventional SRT is due to natural variations in sampling and analytical measurements. In practice, more significant variations in conventional SRT levels are introduced by over-adjustments based highly variable, time-delayed measurements.

Figure 4 - Seneca Daily Waste and Return Ratio 2001

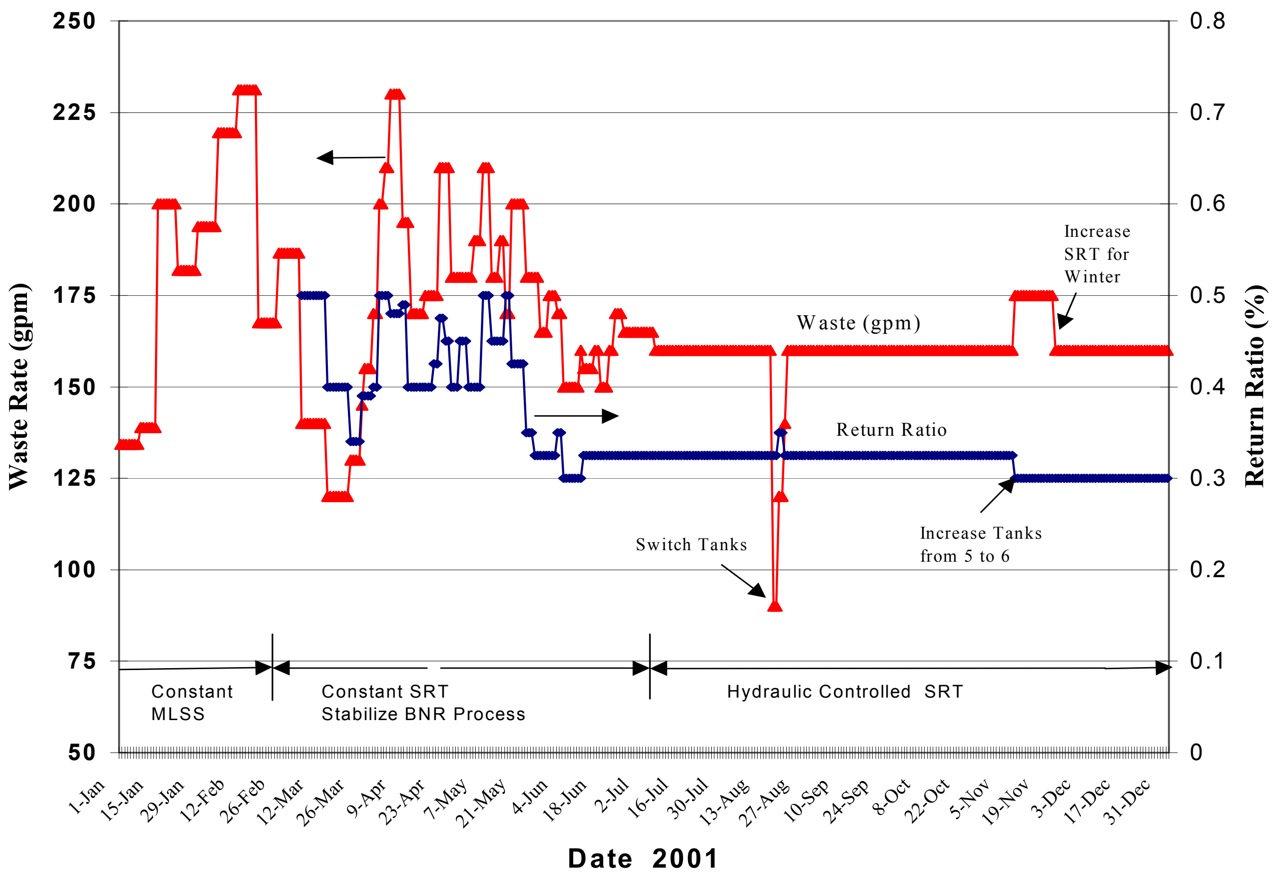


Figure 5 - Daily Convential SRT vs. Hydraulic Controlled SRTs

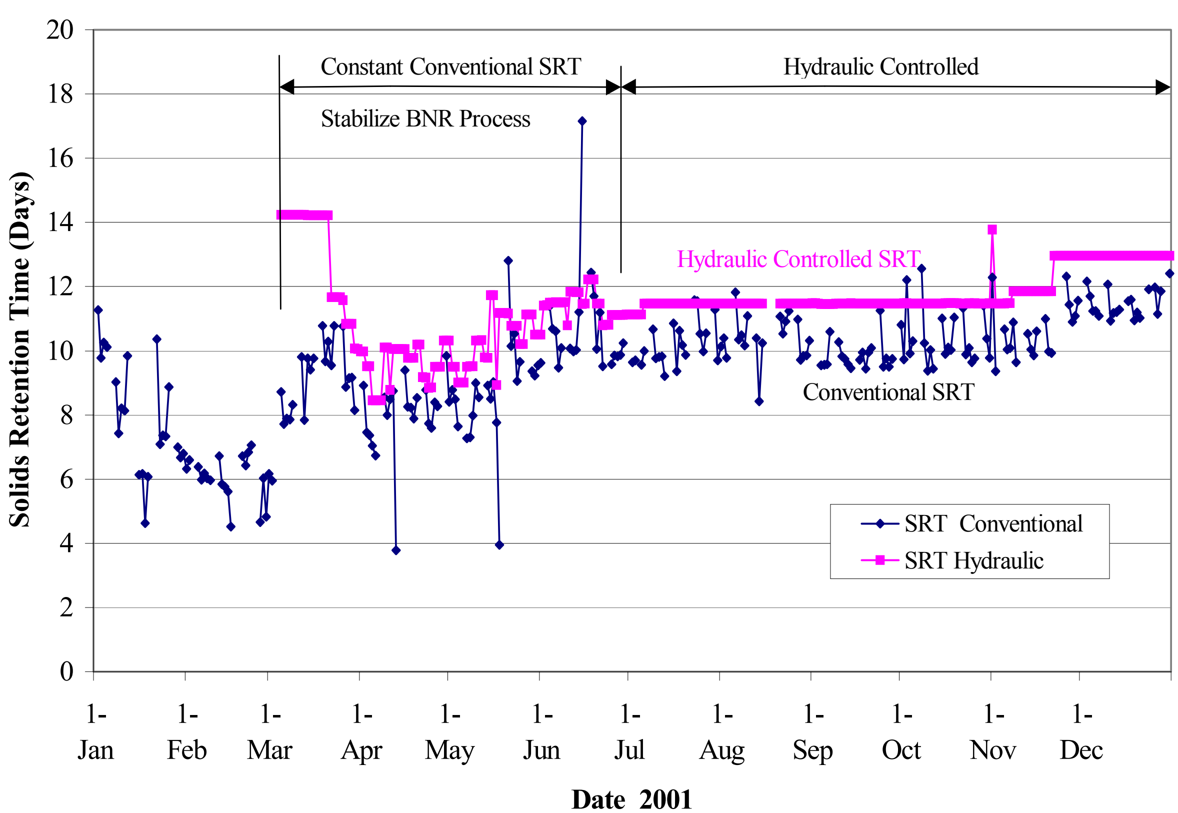


Figure 6 - Hydraulic Controlled SRT (using clarifier blankets @ave of MLSS & RAS) vs. Conventional SRT (with clarifier blankets @ ave of MLSS & RAS)

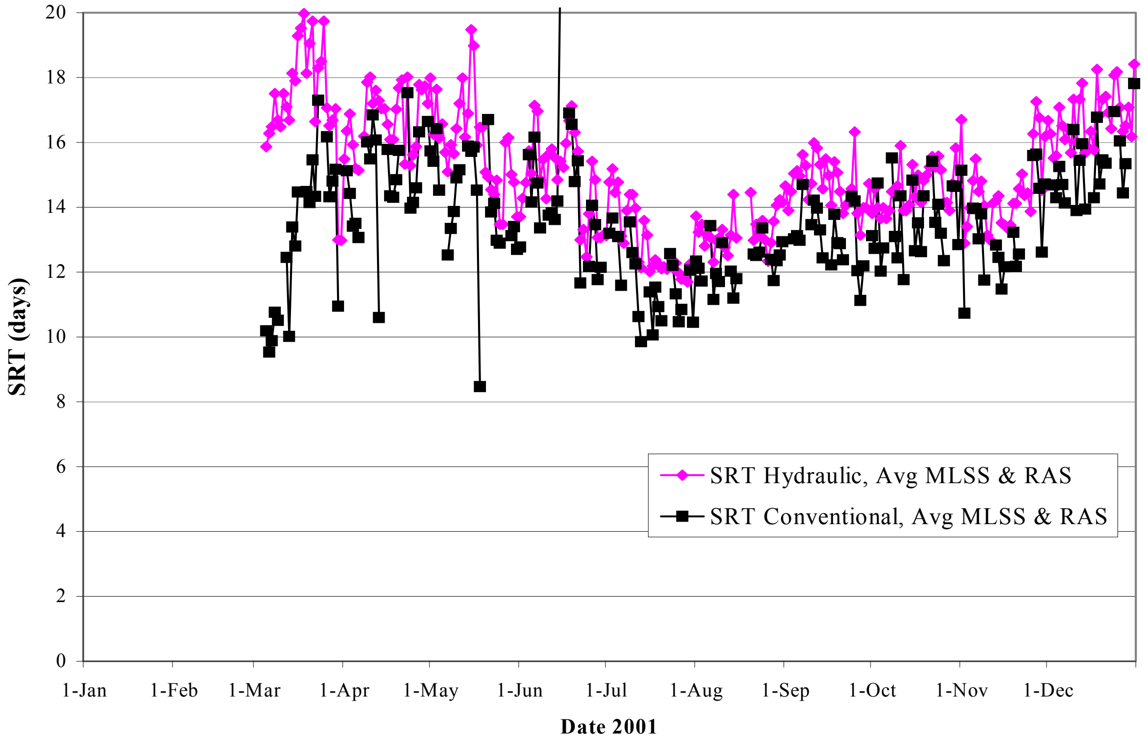


Figure 7 - Hydraulically controlled SRT (clarifier blankets @ MLSS) vs. Conventional SRT (clarifier blanket @ MLSS)

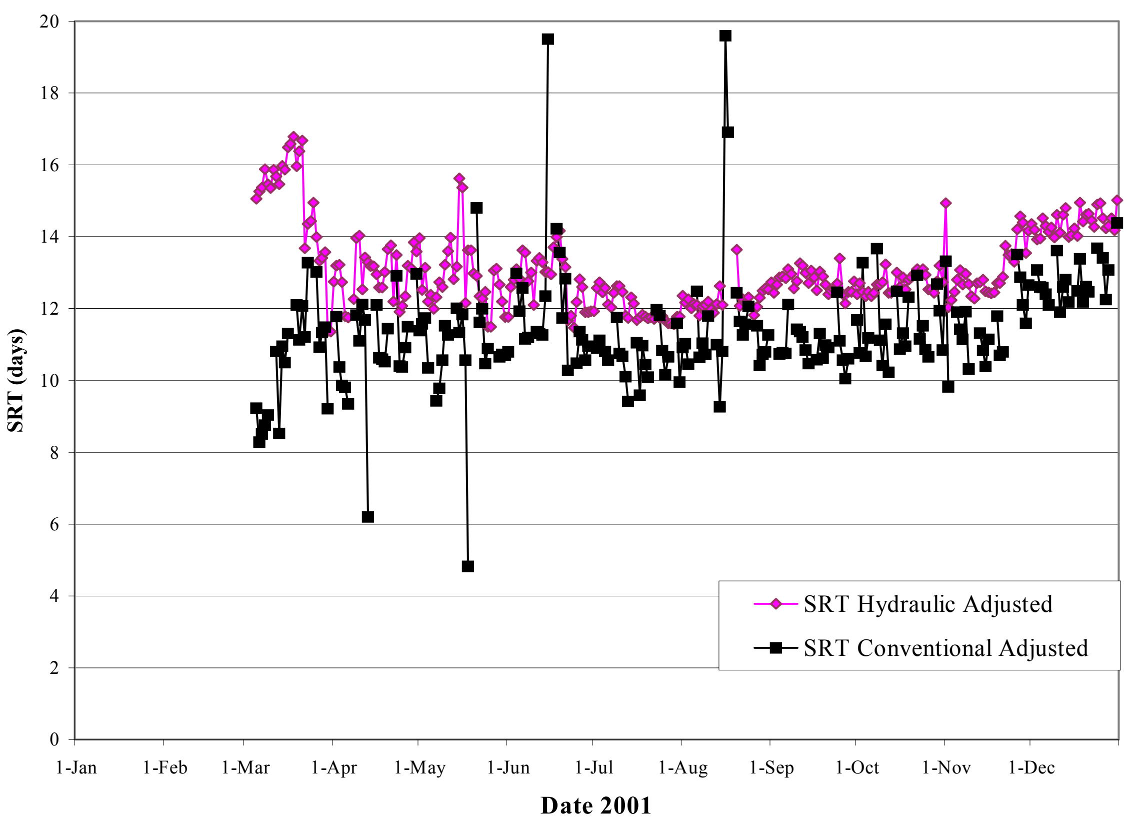
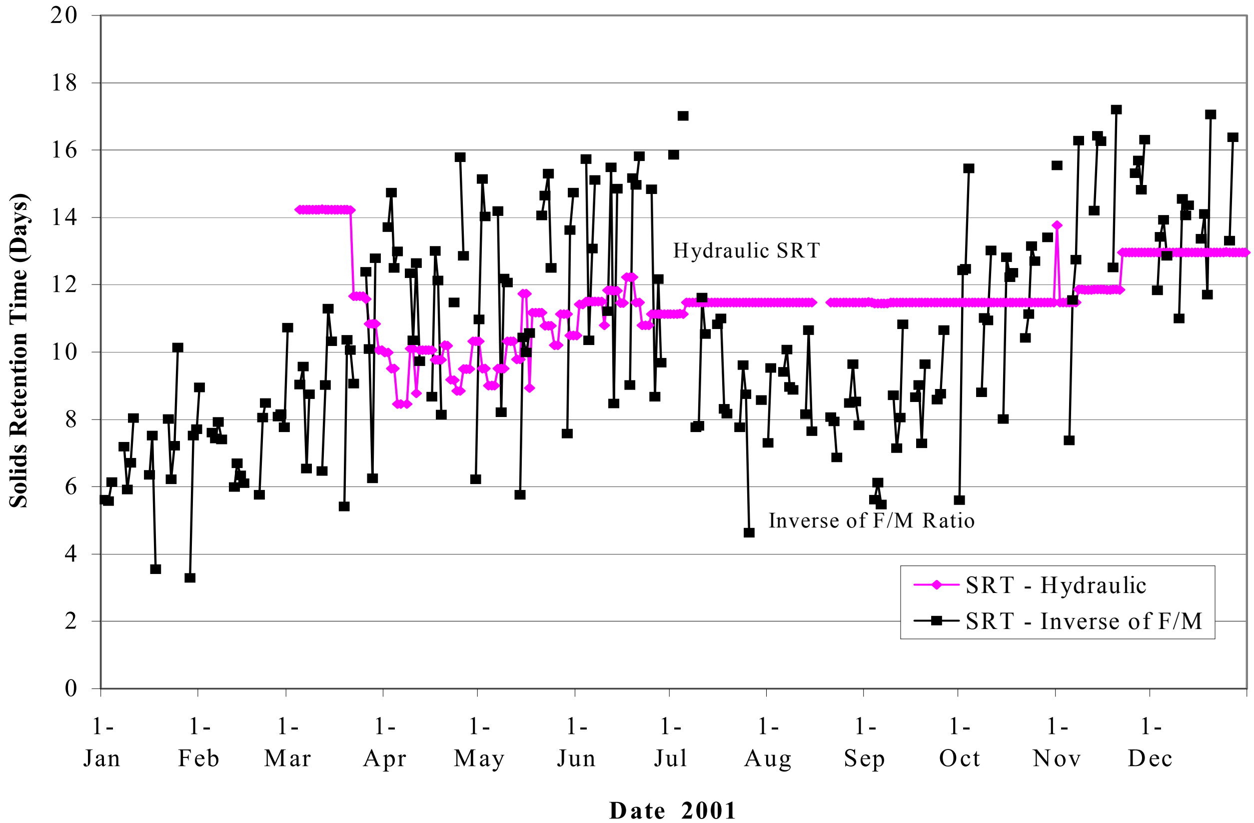


Figure 8 - Daily Hydraulic Controlled SRT vs. Invervse of F/M SRT



Of interest in Figure 5 is in late November, when the hydraulic controlled SRT was increased by 1 day, in order to prepare the activated sludge for slightly longer SRT for the winter months. From July through late November, the conventional SRT was about 1.3 days lower than the hydraulic controlled SRT. However, when the return and waste were changed in late November to increase the hydraulic SRT by 1 day, the conventional SRT also increased by a corresponding amount. This indicates that the changes made by using hydraulic controlled SRT method can successfully be used to change the conventional SRT.

A graphical comparison of modified hydraulic controlled SRT and modified conventional SRT is shown in Figure 6, when the solids estimate is based on the sludge depth, area of the clarifiers and assuming the sludge blanket concentration is equal to the MLSS concentration. The respective SRT averages are 11.3 and 12.4 days. The standard deviations are 1.36 and 1.12 days. There is reasonable agreement between the two methods of calculating the modified SRTs.

A graphical comparison of modified hydraulic controlled SRT and modified conventional SRT is shown in Figure 7, when the solids estimate is based on the sludge depth, area of the clarifiers and assuming the sludge blanket concentration is equal to the average of MLSS and RAS concentration. The respective SRT averages are 12.7 and 13.9 days. The standard deviations are 1.22 and 1.12 days. There is reasonable agreement between the two methods of calculating the modified SRTs.

The added complexity of including sludge blanket level measurements to modify either the conventional or the hydraulic controlled SRT may or may not be worthwhile. One goal of operating a WWTP should be to keep the sludge blanket level in the final clarifiers low at all times. Adding estimates of the solids mass in the final clarifiers, then also increases the chance of adding variability to the basic SRT measurement and the chance of making a wrong decision, in changing the waste and return rates.

A final estimate of SRT can be made by calculating the inverse of the F/M ratio and is shown in Figure 8 and is compared to the hydraulic controlled SRT. This method has the greatest scatter (standard deviation of 2.52) of any of the methods. This is because of the having the sampling and random lab standard errors of both influent BOD and MLSS samples. Obviously, this method is the least desirable to use for process control, because of the significant daily variation of the F:M ratio.

Full Scale Testing of Hydraulic Control of SRT

In the winter of 2001, the Seneca WWTP return and waste rates were adjusted to maintain a constant MLSS target concentration of about 3,500 mg/l. However in the spring of 2001, the BNR aeration process was very unstable with high effluent ammonia concentrations (10 to 13 mg/l, Figure11), high chlorine demand, high SVIs and generally mediocre effluent quality. The mode of operation was changed to maintain a constant SRT, by adjusting the return and waste rates, according to accepted practice, of not more that a 10% change/day[7]. By July 2001, the BNR process was reasonably stabilized, after various problems where solved.

The use of hydraulic control of SRT started in early July. Each day, the conventional and hydraulic SRT's were compared; along with a review all aeration process data and effluent quality data, to ensure that the aeration process would not get out of control. Essentially, the return and waste rates were kept constant from early July (Figure 4). The return and waste rates were changed only three times after early July: 1) increasing the number of tanks from five to six, 2) increase the SRT for winter months and 3) when switching tanks which caused a major shift in MLSS from the north to south side aeration tanks.

The improvement in the stability of the nitrification process, as indicated by the effluent ammonia (Figure 9) is obvious. After July, the effluent ammonia was almost straight lined at an average of 0.15 mg/l.

The stability of the phosphorous removal process also improved, as indicated by the effluent phosphorous (Figure 10). After mid-July through December, the effluent phosphorous was about 0.52 mg/l and was more stable. It appears that gentle air mixing of the anaerobic zone, when combined with good process control can produce effluent with less than 1.0 mg/l of phosphorous. This approach offers substantial reductions in O&M and capital costs for phosphorus removal.

The stability of the CBOD removal process also improved, as indicated by the effluent CBOD (Figure 11). After mid-July through December, the effluent CBOD was about 3.6 mg/l and more stable.

The stability of the Total Solids effluent also improved, as indicated by the effluent TSS (Figure 12). After mid-July through December, the effluent TSS was about 4.6 mg/l and more stable. A completely stable BNR process was achieved for 6 months, considering the consistently low values of effluent ammonia, phosphorous, CBOD and total solids.

Figure 9 - Seneca WWTP, Effluent Ammonia 2001

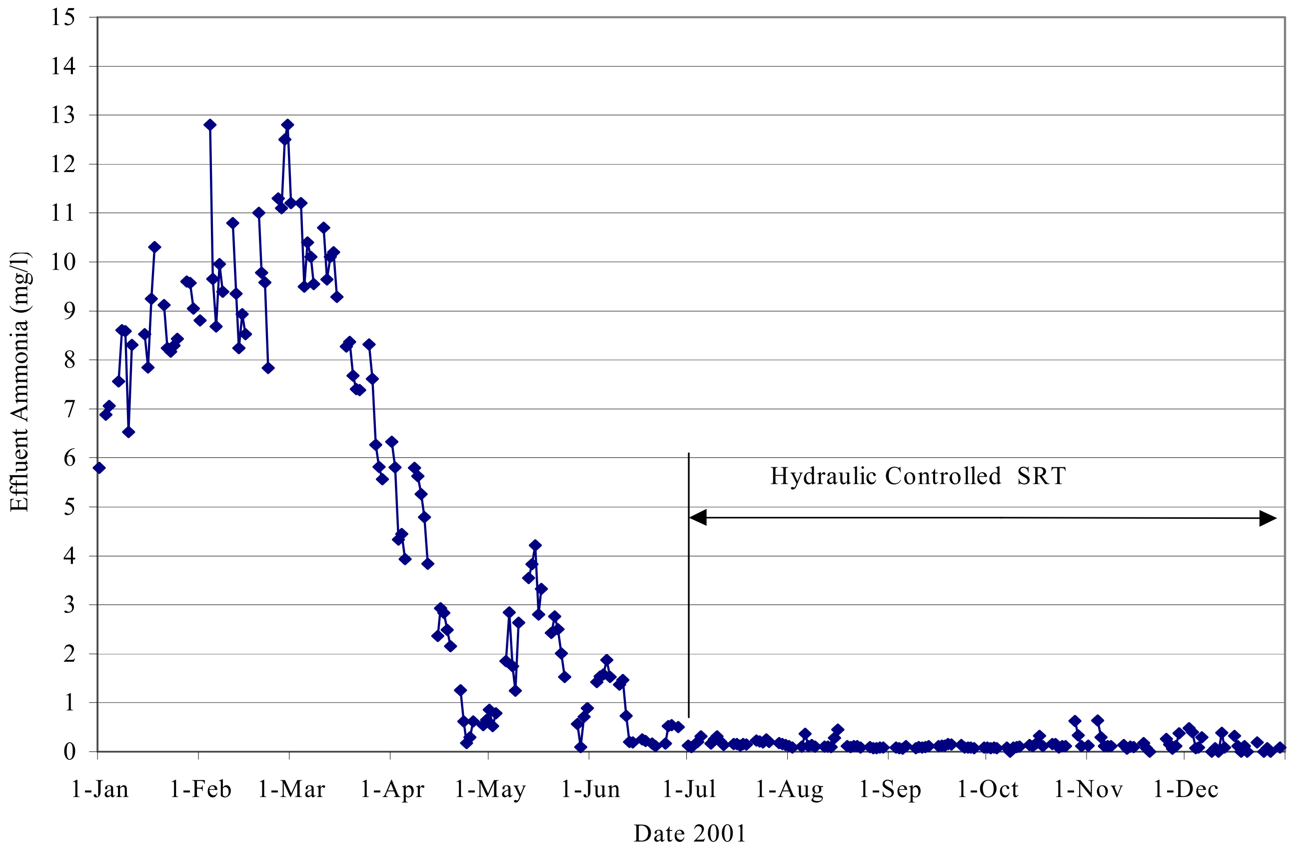


Figure 10 - Effluent Phosphorous

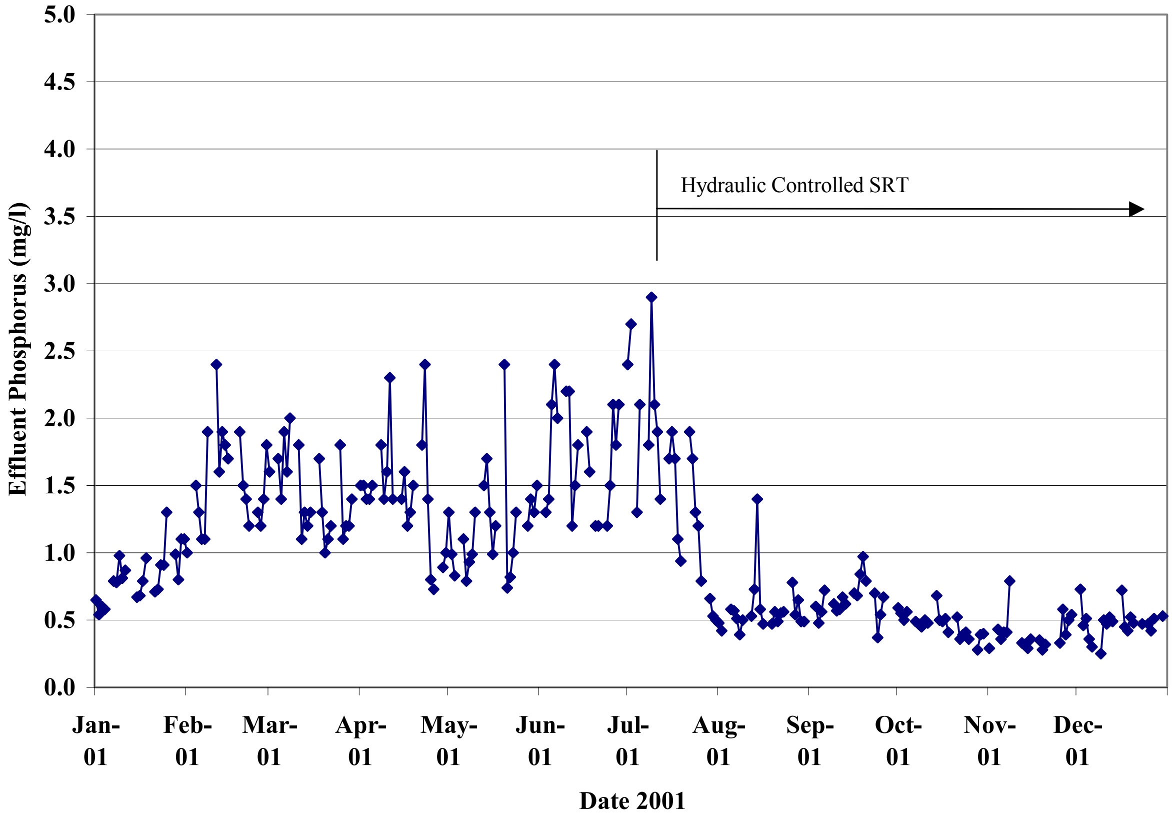


Figure 11 - Seneca WWTP - Effluent CBOD 2001

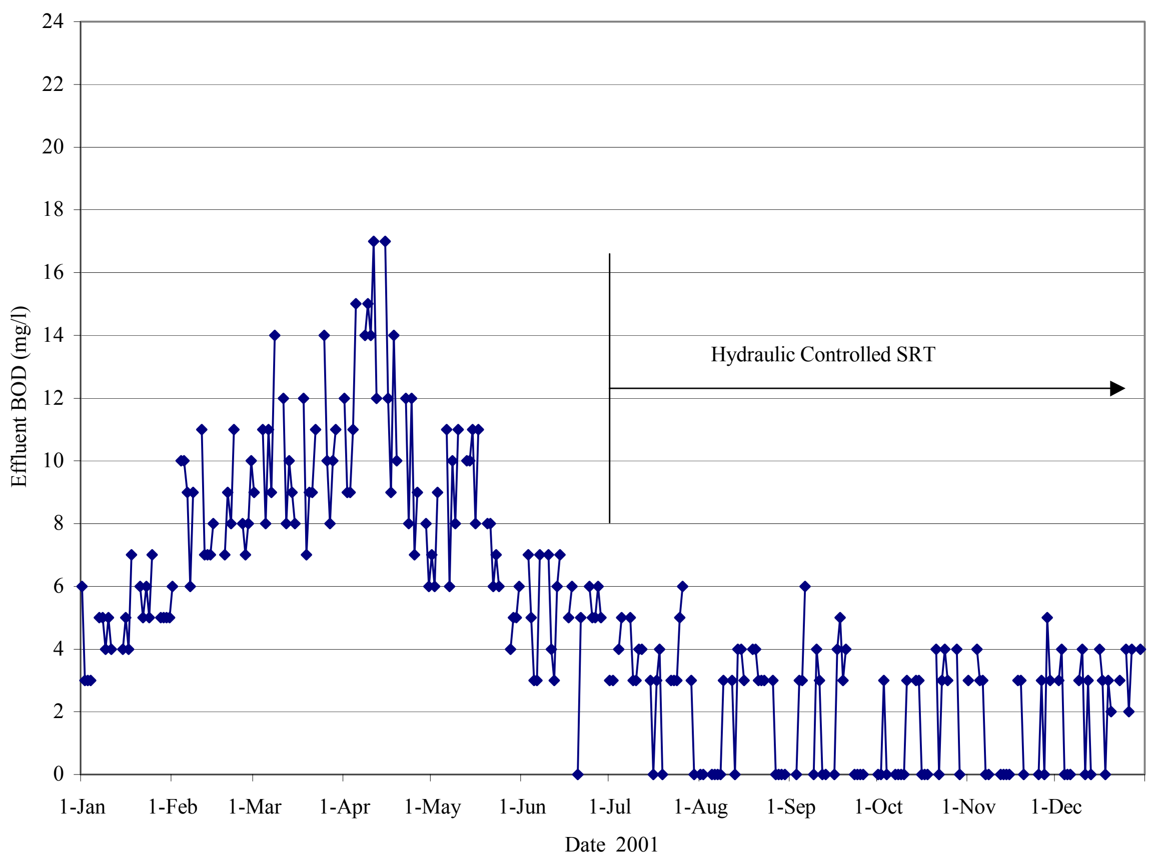
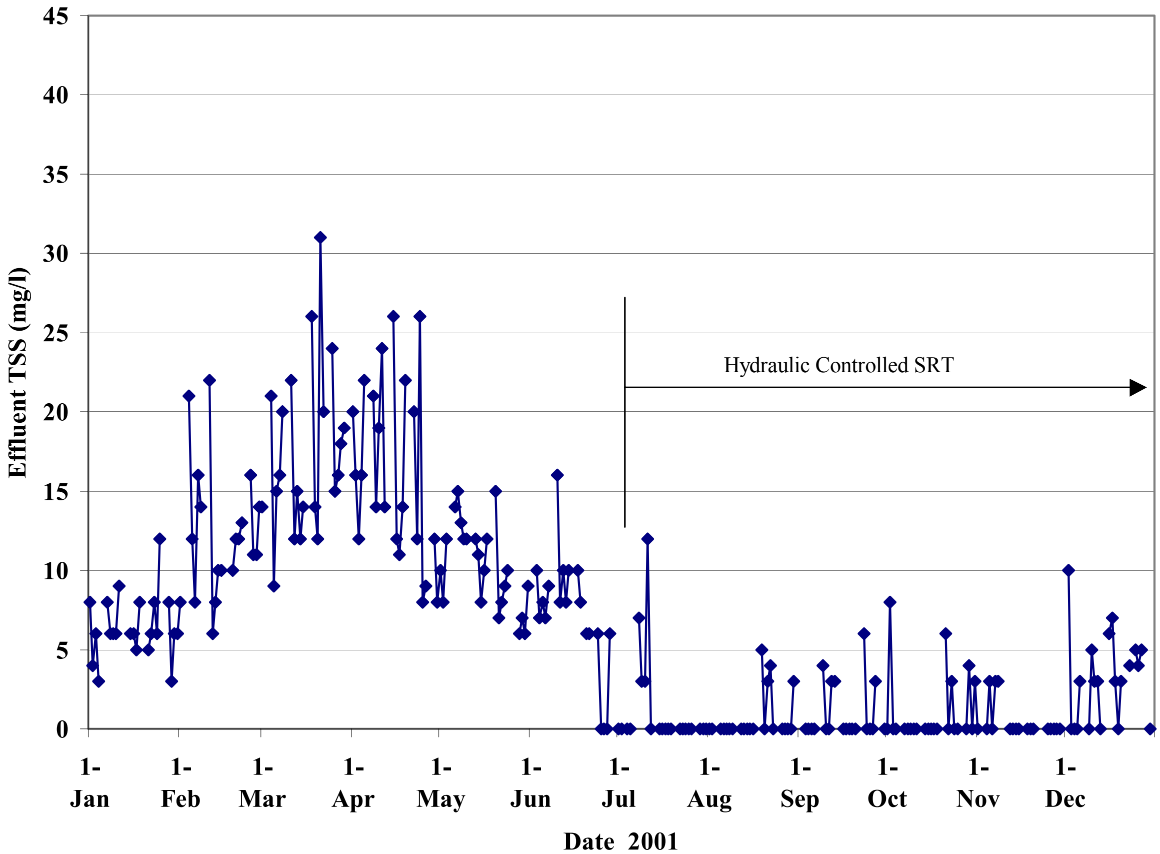


Figure 12 - Effluent Total Solids

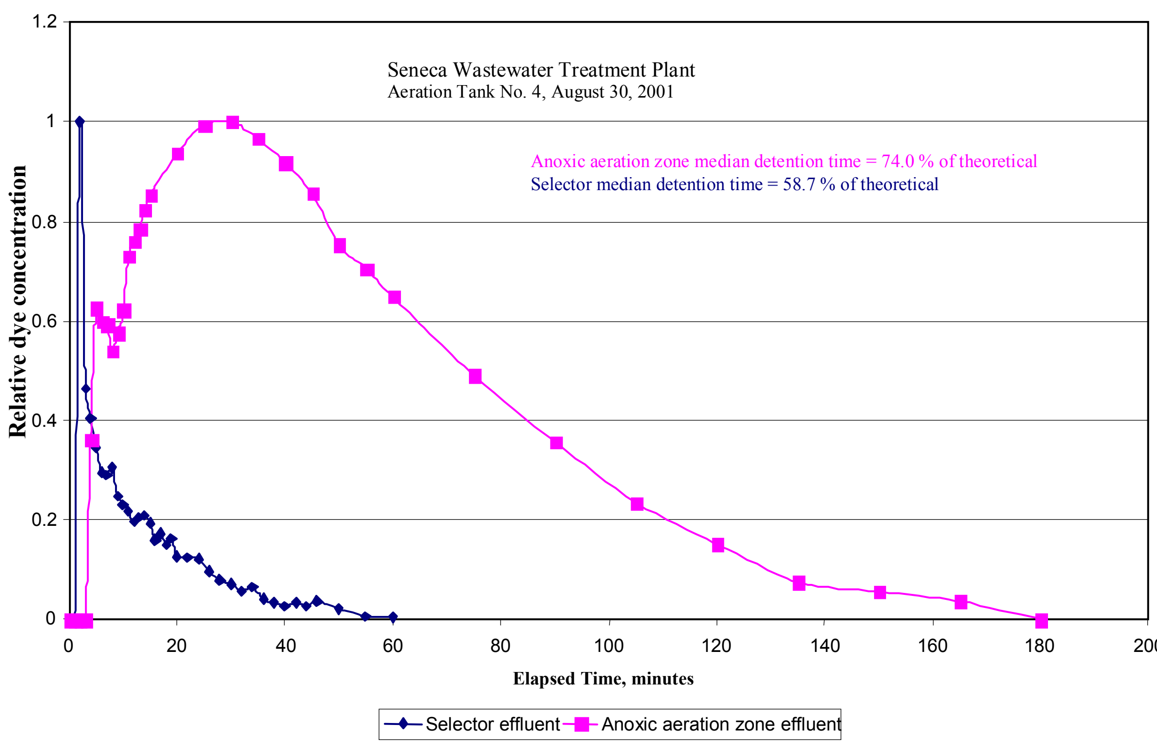


Hydraulic Modifications to Reduce Scum Accumulation and Reduce Short-circuiting

The Seneca WWTP has undertaken efforts to reduce the scum layer that accumulates in the head end of the aeration basins, especially in the selector and anoxic aeration zones. Structural and operational changes were made to reduce flow short-circuiting in these locations. The structural changes included the addition of various flow baffles and the conversion from fine bubble to coarse bubble diffusers in the mixing zones. The flow restrictions forced scum spillover, and redirect flows across the width of the aeration tank for improved hydraulic retention time. The coarse bubble diffusers lessen scum flotation by creating more surface turbulence for dispersing the scum layer. Coarse bubbles also transfered less oxygen per unit of air, enhancing phosphorus release in the air-mixed zones. The changes were made by sequentially making minor modifications to an aeration tank and then evaluating the effectiveness of each modification on reducing the scum layer and increasing hydraulic detention time. The effectiveness of a modification on reducing the scum layer was visually apparent. Since modifications made to reduce scum layers could have a detrimental effect on the overall hydraulic characteristics of the tank, dye studies were conducted to quantify any changes on hydraulic detention time resulting from the modifications.

To conduct the dye tests, a slug dose of the fluorescent dye, Rhodamine WT, was added immediately upstream of the aeration basin being evaluated. Grab samples were collected at the effluent of the anoxic aeration zone. For some of the tests, it was also possible to collect an additional set of samples at the effluent of the selector. Typical dye dispersion curves for the selector effluent and anoxic aeration zone of an aeration basin are shown in Figure 13.

Fig. 13 - Dye Dispersion



Modifications to the selector zones eliminated the scum buildup problem. The various mixing and baffling arrangements evaluated resulted in detention times ranging from 59% to 85% of the theoretical detention time. Results of flow baffling and diffuser changes in the gently air-mixed inlet aeration zones showed progressive improvement. The initial flow baffle configuration induced liquid jets and caused flow short-circuiting; the wall roll diffuser arrangement dampened plug-flow hydraulic characteristics. The final baffling and diffuser design (full-floor coverage coarse bubble) showed minimal short-circuiting and good plug-flow characteristics. The hydraulic detention time increased from a minimum of 66% to 83% of theoretical, all done by making minor changes in the baffles and diffuser layout. Phosphorous samples taken at the exit of the gently air-mixed verified active phosphorous release upwards of 60 mg/l P-PO4.

CONCLUSIONS

1) During six (6) months of constant hydraulic control of SRT, the Seneca WWTP achieved a very stable BNR process operation. Hydraulic control of SRT at a constant level, combined with gently air-mixed inlet anaerobic zones, simplified process control, reduced O&M costs, produced good clarification and excellent effluent quality. Plant effluent averaged 4.6 mg/l TSS, 3.6 mg/l BOD, 0.58 mg/l total phosphorus and 0.14 mg/l ammonia.

2) The use of hydraulic control of SRT provides an operator or engineer a simple, cheap, real-time means to calculate the waste and return flow rates (given the influent flow and aeration tank volume) in order to achieve a desired SRT. It requires a simple spreadsheet or overlay graphs for calculation of return and waste sludge flow rates to achieve a target SRT. Adjustments in the waste and/or return flow rates to achieve a target SRT are not as straight forward or real-time using conventional SRT, constant MLSS or F:M ratio control.

3) Hydraulic control of SRT can improve the measurement and control process. More accurate and reliable liquid flow meters (Q, R and W) replace noisy TSS measurements involving sampling and analytical errors. It may be necessary to assess the reliability of the liquid flow meters if they are suspect. Furthermore, hydraulic SRT control can be done real-time, eliminating time lags associated with TSS measurements used in conventional control systems.

4) It is possible to include clarifier solids inventories in the hydraulically determined SRT. In this study, conventional and hydraulically determined SRT estimates showed agreement when both included clarifier inventories estimated from clarifier blanket depths at a TSS concentration equal to the average of the MLTSS and the RAS TSS levels. The added complexity of including sludge blanket level measurements to hydraulically determined SRT may or may not be worthwhile, depending on the process. The unmodified hydraulic controlled SRT is about 1.3 days longer, than the unmodified conventional SRT.

5) Hydraulic control of SRT simplifies process operation. Operators are provided a target waste sludge flow on a daily basis. This target flow rate is insensitive to changes in influent flow rates and essentially remains constant, unless there are process changes in the clarifier recycle ratio or the number of aeration tanks in service.

6) Hydraulic control of SRT reduces O&M costs. There is no need to sample extensively for TSS in the aeration basins and return sludge streams, and no corresponding need for laboratory analyses, data compilation and manual process adjustment.

7) Mass balance equations for hydraulic control of SRT can be modified for step feed processes, two-stage nitrification systems and other variations of the activated sludge process.

8) Gentle air agitation can be successfully used in inlet aeration zones for phosphorous removal, thus eliminating the need for mechanical mixers in the anoxic zones. Various patterns and diffusers types are being evaluated for the anoxic zone. To date, there has been no significant difference in phosphorous release between four different tanks.

9) Hydraulic detention times in anaerobic zones can be increased by the use of deflector baffles.

10) Scum buildup in selector zones can be significantly reduced by appropriate modifications to the tank flow patterns, which allow scum to overflow.

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