WILL NO-ONE RID US OF THESE TURBULENT PRIESTS – MODELLING DOGMA

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ABSTRACT (300 WORDS MAXIMUM)

The prime aim of process modelling is to enable the design and construction of appropriately sized wastewater treatment plants. Modelling is a very useful tool when its outputs are used with recognition of its limitations.

Designers' liability in the USA resulted in aeration equipment, in particular, having safety factors of 200 to 300% resulting in excessive capital costs and often turn down issues. This provided one of the main drivers for the early modelling work – to more accurately predict the average and peak oxygen demand allowing more sensible sizing of plant.

GIGO (Garbage In, Garbage Out) was a common term in the computing industry from the 1960s to the 1990s but it is no longer heard with such frequency. It resulted from the need to combat what appears to be an in-built deferment to authority culturally applied to the computer.

As performance standards have become more stringent the need to consider more chemical and biological processes has delivered more complex models. IT development has provided impressive looking graphical presentation which reinforces the acceptance of model outputs as gospel. I believe that this has resulted in designers providing plant designs which are completely based on modelling outputs with little or no safety factor or flexibility to deal with the real world issues that are still not included in the models. It is my contention that we are seeing more plants that struggle to reliably deliver consistent performance as a result of this new religious acceptance on modelling outputs.

The paper will present selected experiences and opinion on the (sometimes wanting) utilisation of modelling from 34 years in the industry.

KEYWORDS

Modelling, Wastewater treatment

PRESENTER PROFILE

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1 INTRODUCTION

This is an opinion piece based on my experiences in the wastewater treatment industry over the last 34 years. It is not intended to be an attack on modelling or on the designers involved.

Prior to the extensive use of process modelling Wastewater Treatment Plant design was based on Rules of Thumb, curve fitted "acceptable" ranges of design parameters and copying of previous designs. It was understood that these tools had an associated uncertainty and so generous safety factors were applied. Particularly in the USA, fear of litigation resulted in very large safety factors. For example in aeration sizing the USA design would typically include all the safety factors that we would in New Zealand through the calculation process, but once they had the final sizing they would then add a further 100% safety factor. In combination with the typical 25-year design life this resulted in aeration systems which were extremely large and costly. Turn down issues in the earlier years of operation were common.

These "over design" issues were one of the main drivers for the development of modelling for the industry. Modelling has become a very useful tool particularly as performance requirements for our wastewater treatment plants have increased. However, in the past 20 years or so modelling and its predictions have in some cases become close to a religion with the apparent unquestioning acceptance of modelling output as Gospel and a lack of rigor applied to the modelling inputs.

My experience over the last 20 years is that we are seeing plants designed using modelling that are maybe a little too small. They may perform well for most of the year but do not handle the peaks well and are often hard to operate.

This paper will present some brief case studies looking at these issues.

2 DISCUSSION

2.1 GARBAGE IN - GARBAGE OUT

My first introduction to computers was playing on IBM punch card verifiers at my dad's work. Even back then the term GIGO, (Garbage In, Garbage Out) was in common usage. Many people had a tendency to believe the output of these new machines and this term was a punchy way to warn that computer output was only as good as the quality of the input data. The term remained in common usage both inside and outside what is now known as IT up until the mid-90s. Since then GIGO appears to have dropped off in usage while the ever improving graphics of computer output invests it with an appearance of authority it may not at times deserve.

It is my contention that at least in wastewater treatment design and modelling we need to engrave "Garbage In – Garbage Out" on our computer monitor frames.

2.2 Case Study 1 – Modelling must be done

Upgrade of a single SBR based plant to a higher capacity. For various reasons the upgrade was to allow the plant to treat storm flows that had previously been diverted. Discharge criteria were unchanged and the flows and loads to the plant were no higher than historically the case. Introduction of pre-treatment by the two significant industries was expected to reduce organic loads most of the time.

The existing plant had been successfully operating for about 12 years apart from occasional non-compliance events due to industrial spills. For the upgrade the spill issue was addressed by installing a comprehensive in-line monitoring system and diversion pond so that high loads or problematic substances could be stored and metered back to the plant in low load periods or removed if necessary.

The upgrade largely consisted of replicating the existing SBR system with some improvements to address the much larger hydraulic range the SBR system now had to deal with. The process was unchanged, but it was now happening in two SBR vessels rather than one. However, in low load parts of the year (less than 10% of high season design average) the plant would revert to one SBR due to the very large range in organic loading experienced here.

There was 12 years of twice weekly discharge data showing this existing SBR system easily met all discharge criteria. However, this real world data was not enough despite an excellent peer review by a third party. To prove that the upgrade plant would work modelling was required. Little hard data about the influent was available but somehow only modelling could demonstrate that the new plant would work. I agree that if the upgraded plant was a different design concept then modelling should be required.

In this case there was little harm to the Client. The modelling cost a relatively small sum which could have been saved. However, I believe this is a demonstration of the unquestioning acceptance of modelling as a "Good thing" without recognition of its limitations.

2.3 Case Study 2 – Design Basis

Typically, wastewater treatment plant design is performed with little influent data. Flows may be known but frequent sampling of the influent is typically not practiced at most plants because it is usually not a requirement of the Resource Consents. Frequently the Client's engineers or the plant designers are left to establish a basis of design based on a few samples. When dealing with influent peaking it is noticeable that load peaking stops well before flow peaking. The logic behind this is that apart from tourist towns most places have a relatively unchanging population (both human and industry). The flow peaks are due to storm flows and all this rain dilutes the wastewater and so logically the flow peak must be much larger than the load peaks.

After an upgrade a particular plant was not meeting its performance criteria for one specific unit. It was agreed that a comprehensive month long test period of the overall plant would be conducted. During this test period the daily influent loads for BOD_5 and TSS exceeded the design peaks load by 20% for two separate event and by 40% for a third high rainfall event. The design peak loads had been considered to be appropriate.

In this case we found that the terminal sewer was long and of large diameter with typical sewage retention time of 12-16 hours. The influent sampling which had been done showed quite low BOD_5 and TSS, both parameters averaging about 180 - 190 mg/L compared to a more typical 220 - 250 mg/L. What was happening was that during normal flow quite a bit of sedimentation was occurring giving the lower than normal loads. In large rainfall the 12–16 hours of stored full strength sewage is now pushed to the plant at a storm flow rate. Because little to no flow enters the terminal sewer along it length there is no significant dilution of this flow. But the higher flowrates also scour up the settled organics and now increase the sewage TSS and BOD_5 concentrations to well above normal. Once the stored sewage has reached the plant the subsequent sewage concentrations are low due to dilution and so the next day the loads are often much lower than normal. Previous sampling programs had suggested that this might be occurring but these were time proportional composites and it was thought that this might be skewing the results. What had not been anticipated was the rapidity of accumulation of significant settled loads in the terminal sewer over relatively short duration in that these three rainfall events where about a week apart each.

This case study illustrates the need to consider the broader picture when designing wastewater treatment plants. Is the information presented by the client truly representative? What sources of the wastewater or in this case the sewer network might make the influent unusual or more variable than typically seen at such a plant?. In this case no real investigation as to why the wastewater strength was perhaps lower than normal was conducted. There were certainly clues that problems might occur. The plant has been problematic to operate for quite a number of years now.

2.4 Case Study 3 – Ignore the Bits that Don't Suit

Perhaps in common with religion the known uncertainty associated with modelling vs. real life can allow some to ignore the inconvenient bits.

Some years ago a tender for a (detailed) Design/Build of a large wastewater treatment plant contained a concept design report of some 300 pages. Buried in a middle of a discussion of the modelling conducted, stating that the modelling showed the plant would work well, was a single sentence. When modelling was changed from constant flow and load to a diurnal pattern the modelled plant failed. Even worse, in a separate section of the report was the statement that pilot planting of the design worked well while running with constant flows and loads but treatment collapsed when a diurnal pattern of influent was introduced. Neither statement referenced the other, and no further discussion of the issue was raised.

I presume the client and concept design engineers relied on the issue being fixed in the detailed design stage of the contract. It was known to some that the original design/installation of the pilot plant was faulty and so perhaps this failure in the pilot plant was dismissed as an artefact of poor realization. What was ignored was that one of the treatment plant staff had stepped in and modified the pilot plant to a more sensible configuration which why it had worked at constant flow.

In this case it appears that the understanding of the uncertainty of modelling and pilot planting was used to ignore and issue. Presumably it was felt that it could be fixed up at by the successful tenderer.

2.5 Case Study 4 - The Lowest Price Wins the Job

2.5.1 The data is wrong

A Design/Build/Operate tender contained 4.5 years of detailed influent data with 19 parameters plus daily flow for some 300 samples over that period. This is extremely rare in New Zealand and elsewhere and the sampling costs of the order of $100,000 represent a significant investment by the Council in providing good design data with an expectation that this will deliver a good plant. Surely everyone in the industry would agree with the intent and wish it occurred more often. The tender was interactive with a long tender to allow a joint development of a successful plant design.

Partway through the tender process the tenders came back separately. "The influent data is wrong". The basis for these statements was that the influent data did not agree with the defaults in BioWin^{tm}.

A brief background for those not so familiar with BioWin modelling is that only the flow, Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP). The other parameters are calculated within the model using fractionation factors.

Some of these parameters or fractionations are not easily analysed in a laboratory. An Influent Specifier spreadsheet is used with BioWin to determine the various fractionation factors. In this spreadsheet the raw data is entered and then some of the fractionation factors are adjusted by the modeller by more or less trial and error. The spreadsheet then calculates some of the other fractions and the parameters not directly entered into BioWin such as Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), soluble COD (sCOD), filtered and flocculated COD (ffCOD), carbonaceous Biochemical Oxygen Demand ($cBOD_5$), Filtered $cBOD_5$ ($fcBOD_5$). These are compared with the entered raw data and must agree within and acceptable range and preferably be within a smaller "excellent" range. Unfortunately, the fractionations do not have a one for one correspondence with the laboratory parameters. This means that obtaining acceptable; agreement on each parameter can be problematic. For example, adjusting one fractionation factor to bring VSS to within an acceptable range may move calculated $cBOD_5$ outside of its acceptable range. Further making a small change in one fractionation factor may allow a much larger change in another factor while still staying in the acceptable range. This mechanism particularly for wastewaters that do not match the BioWin default values mean that there can be a reasonably large variation in fractionation selected for the same influent data set. In this case five different people did the fractionations for the average of each parameter for all the 4.5 years of data. This produced five different fractionations. Some of the design parameter outputs from these fractionations are shown in Table 1. As can be seen there is quite a degree of variation. This potential for variation in fractionations selected and so variation in the design influent parameters used by the model is quite a weakness in modelling for this project.

Table 1: Design parameter outputs from modelling fractionation selection.

PARAMETER	**TENDER DATA**	**1**	**2**	**3**	**4**	**5**
COD	692	661	661	692	692	692
dCOD	167	157	173	134	218	155
$cBOD_5$	258	284	284	351	313	270
$fcBOD_5$	75	69	96	90	135	70
TSS	335	316	315	347	344	347

The main concerns of the various designers was that the fractionation factor Fup (fraction of COD that is unbiodegradable and particulate)was higher than the BioWin default and the Fbs (fraction of COD that is readily biodegradable and soluble) was much lower than the BioWin default. Low Fbs means there is less carbon available in the wastewater that can be used for denitrification making it more likely that carbon dosing will be required. High Fup means a higher waste sludge production and a requirement to run higher MLSS (Mixed Liquor Suspended Solids) concentration. As well as higher sludge disposal cost it will mean larger aeration and anoxic tanks and clarifier are required. The tenderers all had the attitude that the lowest price will win the tender even with a requirement to guarantee operating costs per cubic metre of influent. As a result the designers wanted to adjust the fractionations closer to the default values as this would allow design of a cheaper plant. The BioWin default for Fbs is 0.16. The average of the fractionation for the real influent data was 0.084. The designers wanted to change it to (variously) between 0.11 – 0.121. For Fup the default value is 0.13 the average from the data is 0.23 and the designers want to change it to around 0.15 and were eventually convinced to use a factor of 0.20.

The prime justification the various tenderers designers gave for their claim that the data and fractionations were wrong and should be changed was that the town had no industry and so the wastewater would just be domestic sewage and so should match the BioWin defaults. Our response as technical advisors to Council was that it is a town dominated by short term and adventure tourism and so would have very high laundry loads and glacial silts in the surrounding waters. As such high Fup and low Fbs would not be surprising. There was a fairly drawn out amount of wrangling around name changes in lab analyses as sometimes happens over such a time scale and a claim of two distinct population of data (which could not be demonstrated). The end result was that the designers chose to adjust the design parameters increasing $cBOD_5$ by 18%, dissolved $cBOD_5$ by 38 – 81% and dissolved COD by 13% - 29%. Under the terms of the tender we could not prevent this but pointed out that the plant performance requirements and guarantees had to apply for the range of data represented by the supplied raw data and for the "modified" influent as well.

It should be noted that the influent analyses for the 75 day test of performance of the plant some three years after the original data set ended showed an identical low $cBOD_5$ concentration when compared to the 4.5 years average of the raw data provided by Council. COD is about 8 % lower than the original data set average. Ammonia nitrogen is 40% higher and TKN is 21% higher than the 4.5 year average of the original data but this may be due to the testing being of relatively short duration during the late summer and early spring when temperatures are higher. The nitrogen loadings are well with in the design loadings for the plant. This suggests that the original long period of sampling data gave a good representation of the range of wastewater parameters for the design of the plant.

2.5.2 Model using average values only

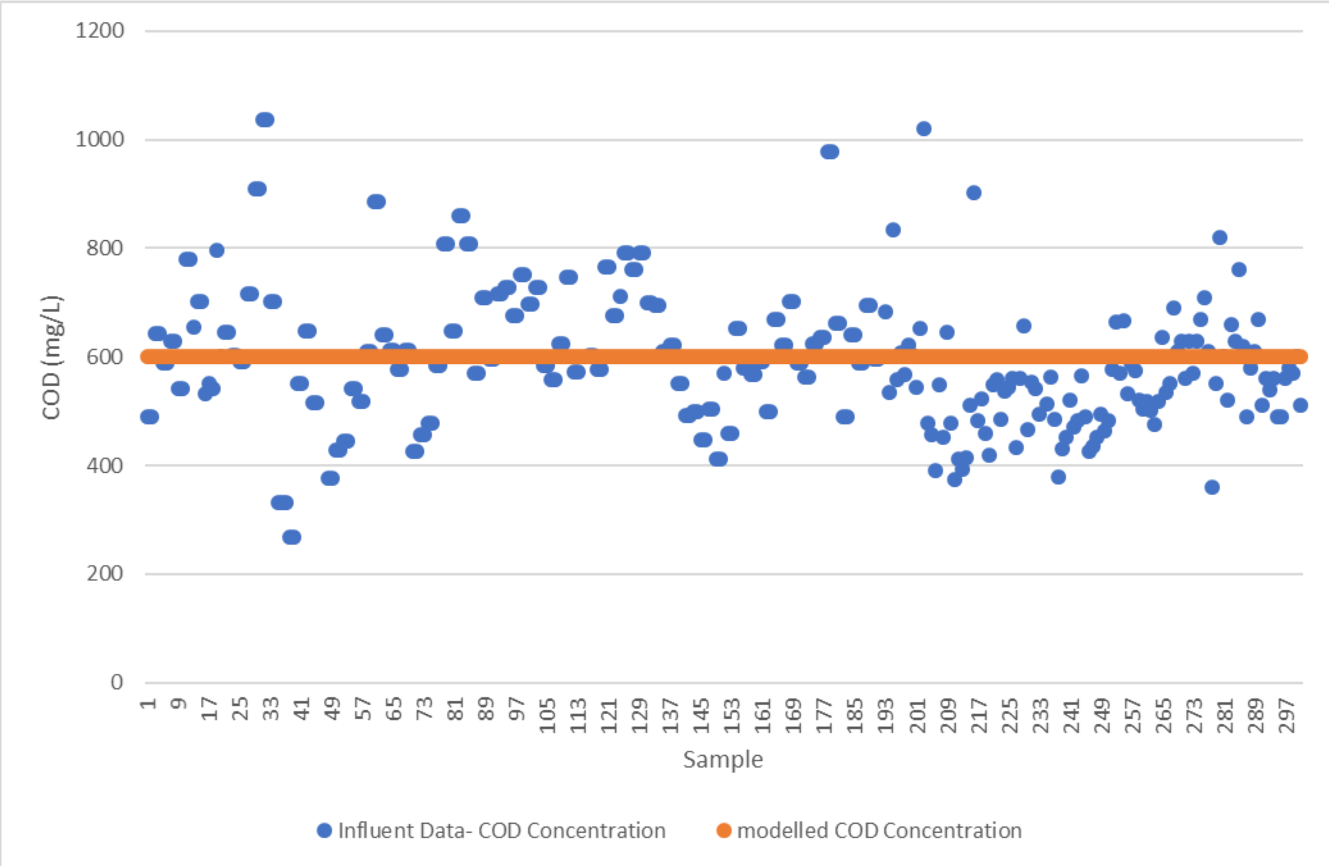
The technical advisors had an overall concern that the designs proposed by the tenderers focused too much on trying to get the lowest tender price and not enough on providing a robust and easy to use plant. Given the variability seen in the influent data collected by Council and the disagreement about its deviation from BioWin default values and the subsequent modification of the data by the tenderers for design purposes the advisers had a concern that the plant was not flexible enough to deal with such issues.

A second issue the technical advisors had with the various designers was that modelling was performed with the long term average parameters only. The designers protested that they had modelled the peaks but investigation showed that a step change from constant average flow and loads to constant average peak flow and loads for a short period and then back to constant average flow and load. This is not representative of the innate variability of the influent flows and loads not the sudden peaks and slow taper of the holiday periods. The difference between the actual influent data COD concentration vs. that modelled is shown in Figure 1.

The use of long term average wastewater concentrations as inputs to the modelling allowed the tenderers to declare that no dosing of alkalinity or Readily Biodegradable COD (RBCOD) would be require by their various plants to allow sufficient denitrification. This was concerning to the technical advisors as the actual data showed that there was significant variation in nitrogen loads from sample to sample and month to month. The alkalinity also showed considerable variation between samples and monthly averages. Unfortunately, the variation was not in step and so a period with high nitrogen load would not necessarily have a high alkalinity and this might limit the effectiveness of nitrogen removal in the real world. Equally the RBCOD as estimated from ffCOD and $fcBOD_5$ was variable and often not in step with the nitrogen load so a risk of RBCOD limitation to denitrification was also evident.

The designers felt that it was too time consuming and so costly to model the day to day variability seen in the influent data.

Figure 1: Real data COD concentration vs modelled COD concentration.



As a compromise the technical advisors produced a synthetic year of monthly averages plus the summer holiday peak period average (giving 13 "months") and required the designers to model this. This synthetic years data was generated by averaging each month of data over the 4.5 year sample period. We then selected one of each month and one of the summer holiday period averages, i.e. one january, one february etc. from the 4.5 years. The selected months had to deliver an annual average equal to the design averages. The same month and year was used for every parameter as much as possible. A few parameters had to be adjusted a little to give the required annual average. Only about six individual parameter points of the 156 points in the synthetic year needed to be adjusted. It was noticeable in doing this the the monthly averages for a particular month, i.e. October, was usually quite variable from year to year. The small requirement for adjustment of parameters to give the required annual average was felt to indicate that the generated sythetic year was, as much as possible, representative of the entire data set.

The tenderers then modelled the sythetic year and had to admit that this showed that both alkalinity dosing and Carbon dosing would be required for part of the year. Eventually the tenders provided estimates of the cost for carbon dosing at $1,000,000 a year but would not provide an estimate of akalinity dosing. The advisors had repeatably reminded the tenders that while the client did not want to pay too much for the plant, they did want to pay the right amount to get a robust and easy to operate plant. This "new" high operational cost was used to require the tenderers to re look at their designs and provide the flexibilty and robust ness the technical advisor had been asking for through out the tender process. For the successful tenderer this meant an increase in tank size by about 15% by volume. This was done by adding a separate walled zone that could be anoxic during high Nitrogen load periods to enhance denitrification without requiring carbon dosing or alkalinity dosing. During high organic load pereiods when RBCOD was more available but the aeration might be struggling this zone, known as the swing zone could be aerated. The secondary clarifier was also increased in size by 15% to allow the use of higher MLSS concentration both to enhance denitrifiction and to allow longer sldueg ages to accumulate sludge prior to the known peak holiday seasons so that there was sufficient biomass available to deal with the reltively rapid rise in load characteristic of these peaks. Various toher minor chnaegs were made to accomdate these major changes. These works added 3.6% to the cost of the plant which the client was happy to pay. They got a much more flexible plant that would be easier on operarotr tiem during the holiday seasons and would in most sitruations avoid yearly dosing costs which were likely to exceed the increase in capital.

2.5.3 Of course the modelling is accurate.

The successful tenders design was based on building a new mechanical activated sludge plant to treat part of the wastewater influent and to treat the rest in the existing ponds. The new resource consent conditions were too tight to be met by the ponds alone but loose enough that a blend of pond effluent and activated sludge effluent would or should comply.

The activated sludge plant was sized by reducing the size of the activate sludge plant and the split of inflow it would take and putting mote flow to the ponds until the sum of the blended effluent of the activated sludge system and the pond system met the first critical discharge parameter. The critical design parameter was Total Nitrogen (TN). The TN out of the activated sludge was produced from BioWin modelling. The estimation of TN output from the ponds was not explained butt appears to have been based on an expectation that the Nitrogen concentration in the pond effluent would improve once the ponds had a lower loading. The average TN from the ponds over a six year period had been 45 mg/l but during this period two of the annual averages had been near to 50 mg/l. The designer estimated that the ponds would produce an annual average TN of 40 mg/l based on the reduced loading. It was pointed out that the new overall pond loading would be well under the old Ministry of works recommended 84 kg BOD_5/Ha.day and that under loaded ponds are often quite fickle in their performance.

The technical advisers pointed out that while the nitrogen load to the pond would reduce, the nitrogen concentration would not. Historically the ponds had been poor at nitrogen removal and had annual average decrease in total nitrogen of about 15% and only 3% for ammonia nitrogen. Little to no nitrogen removal was seen during the colder months. While some volatilization of ammonia might be expected during the warm summers the evaporation of water would appear to effectively reduce that loss. If the discharge criteria had been mass load based the design intent would be easy. However, it was not.

The major concern for the technical advisors was that the designers had taken the annual TN predicted by the modelling and an estimate of pond effluent TN at 40 mg/l compared to the long term average of 39 mg/L. The designers considered this to be conservative, however, over two years monitoring the 95^{th} percentile for TN was 48 mg/l.

The selected flow split then gave a predicted annual average TN concentration of 20°mg/L. The discharge standard was an annual average of 20 mg/L. No safety factor was applied to the design to allow for any inaccuracy in the modelling, in the estimate of pond TN or any other factor that might cause nitrogen removal performance to be a little worse than expected.

In the end the technical advisor team could not prove that the design would definitely fail and the increased tank volumes would certainly help.

During the performance testing period monitoring showed that the average pond effluent TN was 52 mg/L. The design influent split between the activated sludge system and the ponds was 63%:37%. The designers had stated that there was no need to have the ability to send more influent to the activated sludge plant, however, the technical advisors required that this ability be provided.

During the performance test, the average influent split was 69.6% to the activated sludge plant, with just over 30% of the influent flow to the ponds. However, the flow out of the ponds was 23% of the influent ponds. The pond level was not reported so it is not known if this discrepancy is all due to pond evaporation and leakage or if there was some storage of effluent. It is likely that if the full volume had been discharged from the ponds at 52 mg/L TN the plant would have failed the performance test. It should be noted that the test were conducted at a time of year when nitrogen removal could be expected to be at its best in both activated sludge and the ponds.

Here we see the dangers of relying on modelling outputs without critically examining the uncertainty and risks and applying an appropriate safety factors.

3 CONCLUSIONS

Modelling is an extremely useful tool but needs to be treated with both consideration of the inputs and a critical review to the uncertainties of the outputs. It is hoped that most designers/modelers are not falling into the practices illustrated by the Case Studies.

Care is needed to ensure that the impressive graphics and unconscious investment in the model of authority does not cause the designer to take the model outputs on “faith” but instead to exercise a sceptical view of the risk.

NOMENCLATURE

SBR	Sequenced Batch Reactor
BOD_5	Biochemical Oxygen Demand of 5 days duration
TSS	Total Suspended Solids
COD	Chemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
VSS	Volatile Suspended Solids
sCOD	soluble COD
ffCOD	filtered and flocculated COD
$cBOD_5$	carbonaceous Biochemical Oxygen Demand
$fcBOD_5$	Filtered $cBOD_5$

Fup	Fraction of COD that is unbiodegradable and particulate
Fbs	Fraction of COD that is readily biodegradable and soluble
MLSS	Mixed Liquor Suspended Solids
RBCOD	Readily Biodegradable Chemical Oxygen Demand
TN	Total Nitrogen