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Peak Stress Testing Protocol Framework



Office of Research and Development
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PEAK STRESS TESTING PROTOCOL FRAMEWORK

Peak Wet Weather Flow Stress Testing
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Disclaimer

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Abstract

Treatment of peak flows during wet weather is a common challenge across the country for municipal wastewater utilities with separate sanitary and/or combined sewer systems. Increases in wastewater flow resulting from infiltration and inflow (I/I) during wet weather events can result in operational difficulties for publically-owned treatment works (POTWs) and compromise proper treatment and compliance with discharge permits or receiving water criteria. Thus, a need can exist for POTWs to increase peak wet weather treatment capacity while protecting the functionality of sensitive unit treatment processes.

In order to assess the ability to capture and treat higher peak wet weather flow rates and greater volumes of wet weather flows, POTWs are performing stress testing to demonstrate the capacity of existing unit treatment processes and investigating ways to maximize overall treatment capacity. Communities around the country are embarking on multi-year, capital-improvement programs to upgrade their wastewater facilities for a variety of reasons, including aging infrastructure, regulatory requirements and increasing populations. For these programs, treatment plant stress testing can help by assessing the maximum capacity of existing POTWs that can be achieved through operational changes or cost-effective capital improvements instead of larger capital investments in new treatment facilities. The goal of this stress testing protocol framework report is to build upon knowledge of existing stress testing approaches and procedures discovered during the course of the prior literature review. The main focus is to develop the general equipment, steps, procedures, guidelines, etc. necessary to carry out stress testing for the purpose of peak wet weather flow management. It is not intended to be a handbook, but rather a framework document that outlines the general scheme in a single location.

One objective of this technical report is to recommend the application of the proposed protocol to pilot testing by EPA ORD at POTWs that represent the diverse sizes and unit processes/treatment trains at POTWs across the nation. This information is organized by geographic regions across the United States to take into consideration varying climate, population and water quality concerns.

Another objective is to estimate the approximate level of effort and timeframe/schedule for the completion of the general stress testing protocol and the recommended pilot testing of the protocol. This includes an approximate cost for carrying out the stress testing program for the purpose of wet weather flow management. Various sidestream treatments, solids handling considerations, and energy impacts will not be covered in great detail in this document.

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Acronyms

ADF	Average Daily Flow
ASM1	Activated Sludge Model 1
ASM2	Activated Sludge Model 2
ASM3	Activated Sludge Model 3
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
BOD_5	Biochemical Oxygen Demand Five Day
CEPC	Chemically Enhanced Primary Clarification
CFD	Computational Fluid Dynamics
CRTC	American Society of Civil Engineers Clarifier Research Technical Committee
CSO	Combined Sewer Overflow
DO	Dissolved Oxygen
DSS	Dissolved Suspended Solids
ENR	Enhanced Nitrogen Removal
e^{-KX}	Sludge Specific Settling Parameter and Concentration
ESS	Effluent Suspended Solids
F/M	Food to Mass Ratio
FSS	Final Suspended Solids
g	gram
gpm/sf	gallons per minute per square feet
HPO	High Purity Oxygen
I/I	Infiltration/Inflow
MBR	Membrane Bioreactor
MGD	Million Gallons Per Day
ML	Mixed Liquor
ml	milliliter
MLSS	Mixed Liquor Suspended Solids
POTW	Publically Owned Treatment Works
RAS	Return Activated Sludge
RASSS	Return Activated Sludge Suspended Solids
RPM	Revolution Per Minute
RSSS	Return Sludge Suspended Solids
SBD	Sludge Blanket Depth
sf	square feet
SLR	Solids Loading Rate
SOR	Surface Overflow Rate
SPU	Seattle Public Utilities
SS	Suspended Solids
SSO	Sanitary Sewer Overflow
SSVI	Stirred Sludge Volume Index
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
VFD	Variable Frequency Drive
V_o	Empirical Sludge Settling Parameter

WAS	Waste Activated Sludge
WERF/CRTC	Water Environment Research Foundation/Clarifier Research Technical Committee
WWTP	Wastewater Treatment Plant

Section 1
Introduction, Goal & Objectives, Document Purpose, and Report Organization

1.1 Introduction

Treatment of peak flows during wet weather is a common challenge across the country for municipal wastewater utilities with separate and/or combined sewer systems. Increases in wastewater flow resulting from infiltration and inflow (I/I) during wet weather events can result in operational difficulties for publically-owned treatment works (POTWs) and compromise proper treatment and compliance with discharge permits or receiving water criteria. Thus, a need can exist for POTWs to increase peak wet weather capacity while protecting the functionality of sensitive unit treatment processes.

In order to assess the ability to capture and treat higher peak flow rates and greater volumes of wet weather flows, POTWs are performing stress testing to demonstrate the capacity of existing unit treatment processes and investigating ways to maximize overall treatment capacity (WERF, 1999).

Communities around the country are embarking on multi-year, capital-improvement programs to upgrade their wastewater facilities for a variety of reasons, including aging infrastructure, regulatory requirements and increasing populations. For these programs, treatment plant stress testing can help by assessing the maximum capacity of existing POTWs that can be achieved through operational changes or cost-effective capital improvements instead of larger capital investments in new treatment facilities.

1.2 Goal & Objectives

The goal of this stress testing protocol framework is to build upon existing stress testing approaches and procedures discovered during the course of the prior literature review (Task 1). The main focus is to develop the general equipment, steps, procedures, guidelines, etc. necessary to carry out stress testing for the purpose of peak wet weather flow management. It is not intended to be a handbook, but rather a framework document that outlines the general scheme in a single location.

One objective of this technical plan is to recommend the application of the proposed protocol to pilot testing at POTWs that represent the diverse sizes and unit processes/treatment trains at POTWs across the nation. This information is organized by geographic regions across the United States to take into consideration varying climate, population and water quality concerns. For the purpose of this document the following breakdown of plant sizes will be used, as seen in Table 1.1.

Table 1.1. POTW Size Classification

Classification	*Flow Range of the Facility (MGD)*
Small	1 to 5
Medium	5 to 30
Large	> 30

Another objective is to estimate the approximate level of effort and timeframe/schedule for the completion of the general stress testing protocol and the recommended pilot testing of the protocol. This includes an approximate cost for carrying out the stress testing program for the purpose of wet weather flow management.

Various sidestream treatments, solids handling considerations, and energy impacts will not be covered in great detail in this document.

1.3 Document Purpose and Audience

This is intended to serve as a guidance document and not a regulation for POTWs that are considering stress testing for wet weather flow management. It is intended to covey the general steps that POTWs will need for carrying out a stress testing program and considerations to keep in mind focusing on the main liquid flow stream. Each treatment facility is unique with its own requirements, and deviations from the recommendations in this document will be necessary. This guidance document does not change or substitute for any legal requirement. It is not a rule, is not legally enforceable, and does not confer legal rights or impose legal obligations.

1.4 Report Organization

This report is divided into eight sections: (1) Introduction, Goals and Objectives; (2) Stress Testing Methodologies; (3) Wastewater Characteristics and Nutrient Considerations; (4) Modeling Considerations; (5) Protocol Framework; (6) Applying the Proposed Protocol at POTWs; (7) Stress Testing Program Cost; and (8) Conclusions and Recommendations.

Literature review references are included in Appendix A. The modeling process is included in Appendix B. The limitations of activated sludge modeling are included in Appendix C. Common deficiencies found during stress testing (secondary treatment) are included in Appendix D. Results from the Task 1 Literature Review have been included in Appendix E

Section 2
Stress Testing Methodologies

When embarking on stress testing, the dynamic character of the influent wastewater and plant operation should be considered. All systems have a flow (hydraulic) limitation and a load (solids, etc.) limitation. The POTW will need to determine and conduct the appropriate test. Additionally, both hydraulic flow and the concentration of contaminants change on a diurnal, weekly, seasonal and long-term basis. Effluent quality requirements also vary, most often on a seasonal basis. An understanding of these variations and identification of the critical conditions are necessary for successful stress testing.

Peak Flows

Peak flows are usually triggered by a combination of precipitation, snowmelt and high groundwater table (depending on the propensity of the collection system to infiltration and inflow or if the collection system is combined). The biological process is typically designed to hydraulically pass the peak hour flows, as opposed to effectively treat peak hour flows. However, depending on the geographic area, large incoming peak flows can reduce a secondary system process mixed liquor temperature, which in turn slows the microbial activity and may impact plant performance. Depending on the type of biological process (conventional activated sludge, membrane bioreactors, attached growth, etc.) high flows may also wash out the active biomass within the secondary systems (bioreactors), which will take the equivalent of at least one solids retention time (SRT) to recover may impair effluent quality for a significant period.

Peak Loads

In addition to plant influent peak loads, significant peak loads are attributed to plant recycle streams from sludge processing, which can have a considerable impact on the bioreactor loading, especially in terms of nitrogen and phosphorus. Recycle streams can contribute up to 30 percent of the secondary system's nitrogen load. Since sludge processing is typically not continuous, the POTWs need to evaluate the impact of intermittent recycles on the biological process during the different operating conditions. The POTW should conduct an overall mass balance to understand the magnitude of the various loads returned to the biological process. Based on the peaks and their timing, the bioreactor sizing may need to be increased based on the maximum allowable oxygen uptake rate under peak load conditions, or side stream treatment processes may need to be added to maintain biological process performance.

Design Standards

Guidelines for clarifier design parameters such as these can be found in regulatory and regional standards:

- **TR-16** (Guides for the Design of Wastewater Treatment Works, NEIWPCC, 1998)
- **10-State Standards** (Recommended Standards for Wastewater Facilities, 2004)
- **WEF MOP on Clarifier Design** (Water Environment Federation, Manual of Practice No. FD-8, 2006)

The standards provide for maximum allowable surface overflow rates, solids loading rates, weir loading rates, side water depths, hydraulic residence time, and number of clarifier units. These resources should be consulted prior to development of a testing program when requirements are specific to a particular plant, state or region. Often the conservative nature of these standards allows for additional capacities that can be used for peak wet weather events.

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2.1 Peak Flow (Hydraulic) Stress Testing Considerations

The purpose of stress testing is to evaluate the hydraulic performance characteristics and identify hydraulic bottlenecks. Specifically, it can be used to identify the occurrence of short-circuiting, dead zones, and density/thermal currents. The information generated allows strategies to be developed (e.g., baffling) for improving clarifier hydraulics. This, in turn, will result in enhanced process efficiency.

Capacity of primary clarifiers as an individual unit operation is typically evaluated based on surface overflow rate (SOR) and biochemical oxygen demand (BOD) removal criteria. Primary clarifier performance is dependent on SOR and sludge withdrawal rates. Performance expectations are tied to the process capacity of the subsequent biological systems and primary sludge handling systems.

Secondary clarifier performance is more complex to test because it is dependent upon SOR, mixed liquor suspended solids (MLSS) concentrations and recycle ratios, aeration system performance, and sludge withdrawal rates (Parker et al, 1999). Slug dye tests and the solids distribution/flow pattern tests are carried out during the stress tests in an effort to better assess the hydraulic characteristics of the settling tank. Additionally, sludge settling characteristic play a crucial role and is only as effective as upstream process. Episodes of bulking can be normally attributed to excessive solids carryover from the aeration basins.

A desktop review or hydraulic calculation check (typically computer based) based on the plant hydraulic profile is the first step in determining the existing system limitations and what is practical before embarking on a stress testing program. Typical limitations examined as part of the desktop review include: approach velocities, recycle rates, diurnal peak considerations and freeboard limitations.

Primary (Hydraulic Capacity)

For the primary clarifier tests the following methodology is typically used:

Hydraulic review conducted to identify any hydraulic limitations.

Samples of the clarifier influent and effluent at specified time intervals.

- Each sample is analyzed for total suspended solids (TSS); every third sample is analyzed for BOD_5.Typically these are collected typically every twenty minutes.
- The grab samples are used to determine the settleable solids (SS) in the clarifier influent and effluent. Typically these are collected every hour.
- Consider performing dye testing of the clarifier to see if any short circuiting is occurring.

The sludge blanket level is measured with a sludge judge every hour at five locations along the clarifier cross section to monitor the change in the sludge blanket profile during the test. Monitoring of blanket level prior to stress testing will help to establish baseline conditions and help uncover any anomalies discovered during testing.

The supernatant from the effluent settleable solids sample is used to determine the dispersed solids (DSS) in the clarifier effluent. The DSS concentration represents the minimum TSS concentration achievable with an infinite clarifier.

The data from these tests are used to calculate the removal efficiency achieved as a function of flow. A graph of flow versus TSS removal efficiency should be produced to determine the point of failure.

Secondary (Hydraulic Capacity)

For the secondary clarifier tests the following procedures apply:

Desktop analysis conducted to identify any hydraulic limitations.

Suggested target range of flows to the test clarifier. These targets represent total plant flows.

Samples of the clarifier effluent are collected typically every 20 minutes. Every sample is analyzed for TSS and along with every third sample is filtered to analyze soluble CBOD or measured for BOD_5. The data will enable the POTW to determine clarifier performance as a function of hydraulic loading and allow for calculation of the suspended solids in the effluent for a true measure of clarifier performance.

The sludge blanket level is measured with electronic sludge blanket measuring device or a sludge judge at five locations along the clarifier cross section every hour to determine the changes in blanket level profile during the test. These readings may be taken ahead of the suction arms or rakes to allow for the highest blanket levels for the most accurate readings. The depth of the sludge blanket at the peak hydraulic flow periods can have significant impact, since fluid velocity can re-suspend settled solids causing spikes in effluent TSS.

A grab sample of the clarifier influent (mixed liquor) is collected every hour to determine the mixed liquor TSS concentration, stirred sludge volume index (SSVI), and initial settling velocity (ISV).

The data from these tests are used to calculate the removal efficiency achieved as a function of flow. A graph of flow versus TSS removal efficiency should be produced to determine the point of failure.

2.2 Peak Load (Biological) Stress Testing Considerations (Secondary Process)

Peak load stress tests are carried out to determine the performance of a settling tank (typically for secondary treatment processes) in terms of effluent suspended solids concentration for a variety of operating conditions. Effluent suspended solids concentration is examined against parameters such as: SOR, solids loading rate (SLR), return sludge suspended solids (RSSS) concentration, return activated sludge (RAS) flow rate, sludge settling characteristics, dissolved suspended solids (DSS) concentration, and sludge blanket depth Gernant et al, 2009; Peng et al, 2007).

Before starting a peak load stress test, existing plant operational data should be examined in detail to understand the limitations and operational constraints of the POTW. Laboratory data for a unit process are especially critical for a fair comparison with stress testing results. One essential element of stress testing is that a facility needs to have multiple settling tanks. This allows the plant to operate at normal performance levels while also providing space to conduct the test. If the POTW has only one clarifier, the POTW will need to find a creative way to increase the SLR to the test tank, such as diverting a portion of the effluent to the tank influent to increase SLR (Wahlberg, 2004).

2.2.1 Secondary Clarification

Secondary clarifiers have three functions:

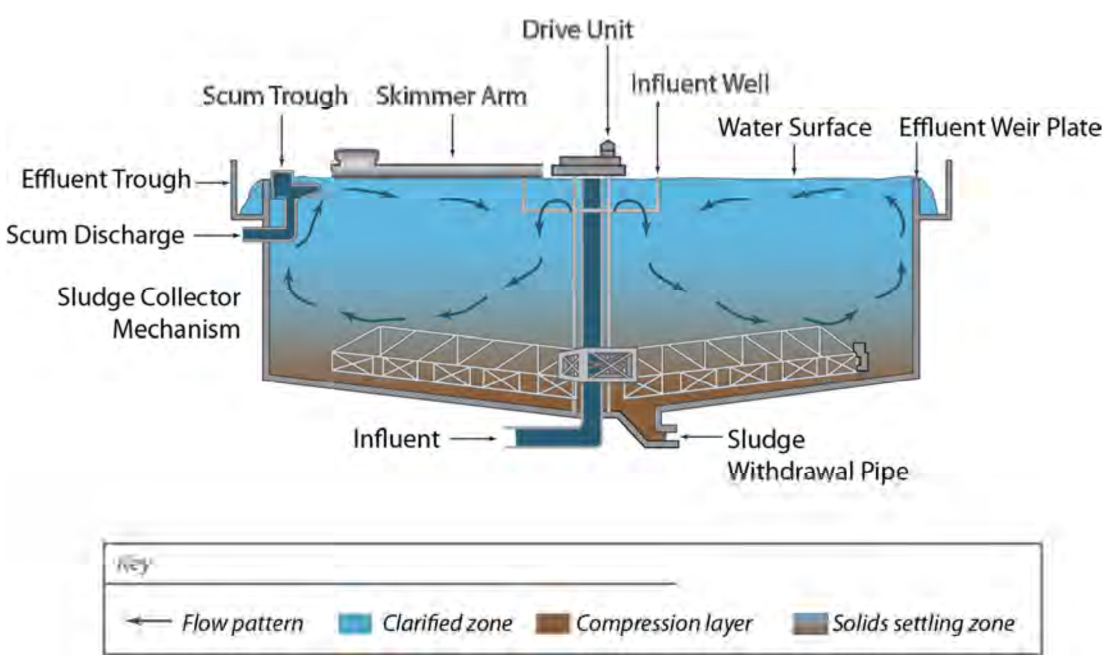
Separate solids from mixed liquor and produce a clear effluent (clarification function).

Concentrate sludge to maintain MLSS in aeration tanks (thickening function).

Transfer thickened sludge to the collection point for pumping to the aeration tanks or to wasting (conveyance function).

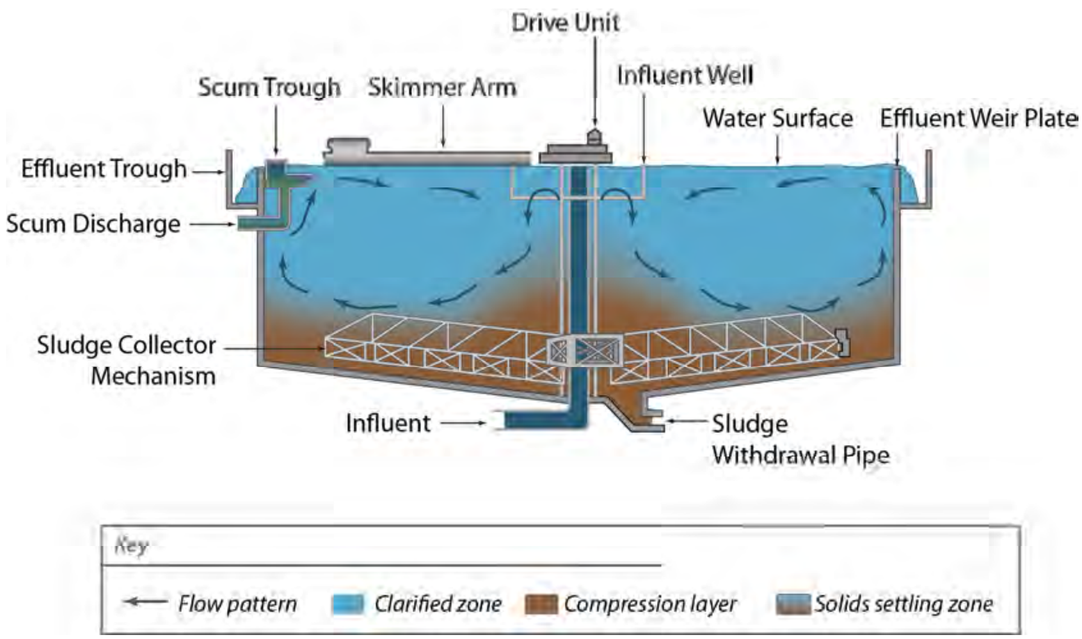
An under loaded clarifier is able to remove the flocculating particles from above the compression layer (clarification function) and is also able to concentrate and remove solids without accumulation of a sludge blanket (thickening function) as seen in Figure 2.1. (Daiger and Roper, 1985; Daiger, 1995)

Figure 2.1. Under loaded Clarifier



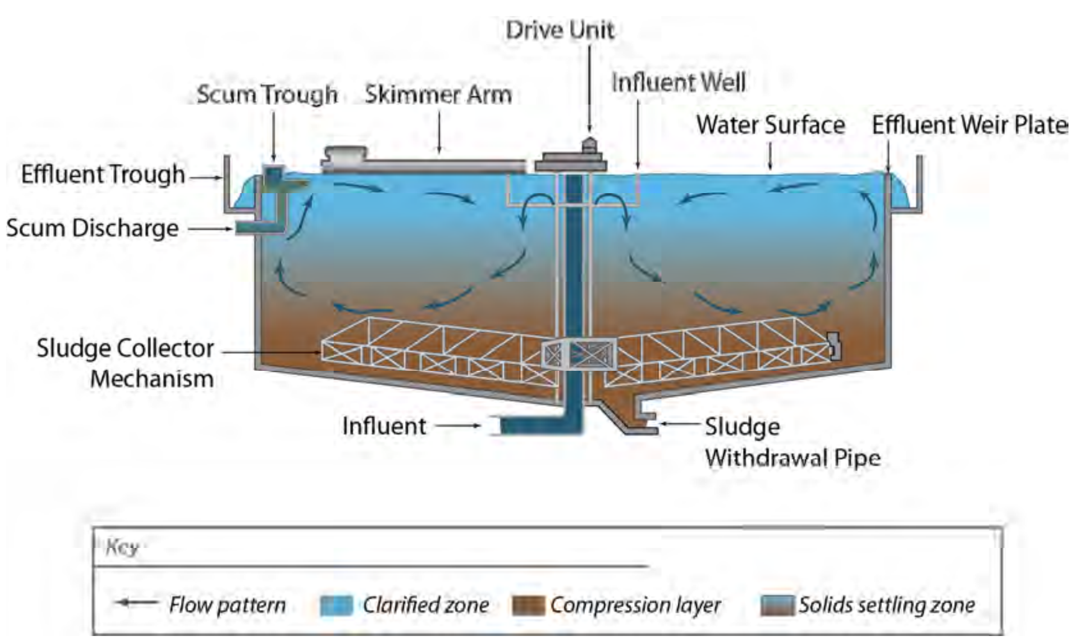
A clarifier that is overloaded with respect to thickening will develop a sludge blanket that propagates upward from the compression layer to the water surface as seen in Figure 2.2.

Figure 2.2. Overloaded Clarifier with Respect to Thickening



A clarifier that is overloaded with respect to thickening and clarification will develop a sludge blanket and will also accumulate solids between the compression layer and the water surface as seen in Figure 2.3.

Figure 2.3 Overloaded Clarifier with Respect to Thickening and Clarification



Failure can occur by being operated at a prolonged overloaded condition, by flocculation problems, by poor tank hydraulics or because of denitrification in a clarifier. (Jenkins et al, 2003)

The SOR is a measurement of the volume of water, in gallons per day, rising up in one square foot of the clarifier surface area. Essentially, this is the upward velocity. As the upward flow rate increases, a point is reached when the water's velocity begins to carry suspended solids upward and solids loss occurs.

The other design standard, SLR, is a measurement of the amount of solids, in pounds per day, applied to one square foot of clarifier surface area. As the pounds of solids per square foot increases, a point is reached when settling rates decrease, resulting in solids loss. Hydraulic failure in the suspended growth treatment process is determined when influent flow rates increase to an intensity or duration that leads to solids loss in the secondary clarification units. Meeting these two design standards is recommended to prevent failure of the secondary clarification units. (Benefield and Randall, 1985)

2.2.2 Polymer Addition to Secondary Clarifiers

Polymer use in a secondary clarification application has been practiced for a long time; however, available data quantifying the benefits of this technique are scarce. Most of the reported applications address sludge settling and foaming problems, such as those caused by filamentous bulking and Nocardia.

Polymer can improve a clarifier's performance in two interrelated but distinct ways. First, polymers effectively increase zone settling velocity and decrease SSVI by creating larger and tighter agglomerates. This increases the critical, allowable solids loading/overflow rate of the clarifier, as predicted by the flux theory. Secondly, polymers facilitate flocculation and capture of the dispersed solids from the supernatant resulting in a lower effluent TSS. This can be beneficial when inadequate flocculation opportunities exist in the secondary clarifiers (e.g. lack of flocculating center well or functionally similar structures).

Before considering polymer as part of a stress testing program for wet weather flow management practices, the POTW should conduct an analysis of the floc present in the secondary clarifier. If the floc present in the secondary clarifier is already considered large and fairly tight, the addition of polymer may have little to no effect on improved clarification.

In addition to TSS removal, the addition of polymer may have some impact on additional phosphorus removal via enhanced settling. This is primarily in the form of inorganic phosphorus by means of chemical precipitation. Commonly Alum, and Ferric have been used with each having alkalinity consumption, chemical sludge production, and pH depression that must be balanced with discharge requirements. Care should be exercised in selecting a polymer that neither inhibits nitrification nor contributes to effluent toxicity.

2.3 Solids Handling Considerations

Stress testing for solids processing systems is a challenging and often difficult task. This usually involves a large number of operational variables to consider. Furthermore, process efficiency is often difficult to obtain in "real time data" and many plants do not usually gather operational data beyond the solids mass entering and leaving the system (Klein, 2008).

Solids processing systems are usually rated in terms of pounds of solids per day in conjunction with hydraulic loading rate. This means that both hydraulic loading and feed solids concentration have to be taken into account. Modifying the solids concentration is more complex than adjusting a pump set point. Making adjustments during a test run is rarely possible; thus, a target feed concentration has to be selected weeks prior to testing. This might require plant staff to modify plant operations to meet the selected target. Historical data analysis and plant staff experience will usually indicate the most practical feed concentrations attainable.

Influent flow increases during peak wet weather events. While the increased flow can result in reduced TSS concentrations due to dilution, a high flow following a prolonged period of dry weather can also result in a first flush event, especially in combined systems. Depending on the region and climate, considerations for the first flush will introduce a noticeable higher solids loading content to the treatment facility from the collection system, following a period of little to no rainfall.

Existing solids handling processes typically have sufficient capacity for single wet weather events. However, back-to-back storm events can exceed the capacity of sludge processing units, such as digesters and storage tanks. Before setting forth on a stress testing program, a thorough evaluation of the existing solids handling train should be conducted with a review of historical performance (Newbigging et al, 2004). Since each POTW and collection system is different, no one general rule will apply. During peak part of a storm to take into account an elevated hydraulic loading rate, additional dewatering trains may be needed or additional storage to act as a buffer to keep up with the influent flow rate.

As with the secondary treatment process, no one solution will work for all POTWs. A review of the solids handling unit processes should be undertaken as part of the overall stress testing approach to understand the current limitations. (Kalinske, 1973)

2.4 Energy Impacts

In recent decades energy costs have skyrocketed for many municipalities. The days of energy costs at 3.5 to 5 cents per kW*hr are practically gone. Municipalities are facing a renewed call to taking into account electrical costs as part of an overall life cycle assessment to provide the best value to their rate payers, when considering capital improvement and plant maintenance projects. Historically wet weather flows have been a small percentage of the flows that POTW must treat, often in the range of 5% though depending on the shape of the collection system and region of the country this number may be higher.

Any projects looking at addressing wet weather flows should be examining the energy impacts, for a holistic approach of process treatment and equipment selection. Items such as process pump stations, aeration blowers, etc. that can see variation numerous variations would be prudent to install energy saving devices, such as variable frequency drives (VFD), to help reduce overall electrical consumption. Since the limit and extent of wet weather flows is often a short time period of high intensity, a cost analysis should be undertaken to determine the relative cost savings for these high but infrequent flow swings.

Section 3
Wastewater Characteristics and Nutrient Considerations

Wastewater comprises a number of different characteristics and nutrients that must be contended with as part of the treatment process. This section is intended to give the reader an overview of characteristics and nutrient considerations and how it relates to modeling and the field portion of a stress testing program. Having a keen understanding of the various nutrient fractions (soluble and insoluble) will allow one to know what portion of the treatment process during stress testing will be the most challenging and have a better opportunity for removal of containments.

3.1 Wastewater Characteristics

Prior to the start of any testing program, a representative sample should be undertaken to understand all the constituents that will be seen during the course of testing. Wastewater characteristics can change over time with population shifts (e.g. leading to longer detention times in the collection systems) or with new industries moving in the area with their associated discharges.

Daily influent plant data will be necessary. Commonly, a composite sampler is used to evaluate the flow over an entire 24 hour sampling period. While one year of data collection is the minimum, three years of data is recommended. Data should be plotted year-to-year to look at trends (e.g. seasonally or yearly). The type of daily influent data needed is a function of the required level of treatment for the facility. The following should be requested at a minimum from facilities providing treatment to the following standards:

Non-nitrifying facilities – Flow, wastewater temperature, BOD, TSS, VSS.

Nitrifying facilities – Flow, wastewater temperature, BOD, TSS, VSS, TKN, ammonia, total phosphorus, alkalinity, and pH.

Biological nutrient removal (BNR) facilities - Flow, wastewater temperature, BOD, TSS, VSS, TKN, ammonia, total phosphorus, orthophosphate, alkalinity, and pH.

Additional data (COD, nitrogen, phosphorus, etc.) will be necessary as part of the baseline conditions for the wastewater characteristics. A summary of these constituents follows:

COD in wastewater influent can be divided into soluble and particulate fractions, as well as biodegradable and inert fractions. An additional distinction can be made between colloidal and truly soluble COD.

Nitrogen in influent wastewater consists of soluble and particulate fractions, as well. Soluble nitrogen is the sum of nitrate/nitrite, ammonia, and soluble organic nitrogen while particulate nitrogen is typically organic. Biodegradable nitrogen is typically thought to comprise nitrate/nitrite, ammonia, and some fraction of both soluble and particulate organic nitrogen.

Phosphorus in influent wastewater can be either soluble or particulate. Soluble forms include orthophosphate ('reactive" phosphorus) and polyphosphates, as well as some metal-phosphate complexes. Particulate forms include organic phosphorus. For a thorough discussion of COD, N, and P characteristics, please refer to WERF (2003).

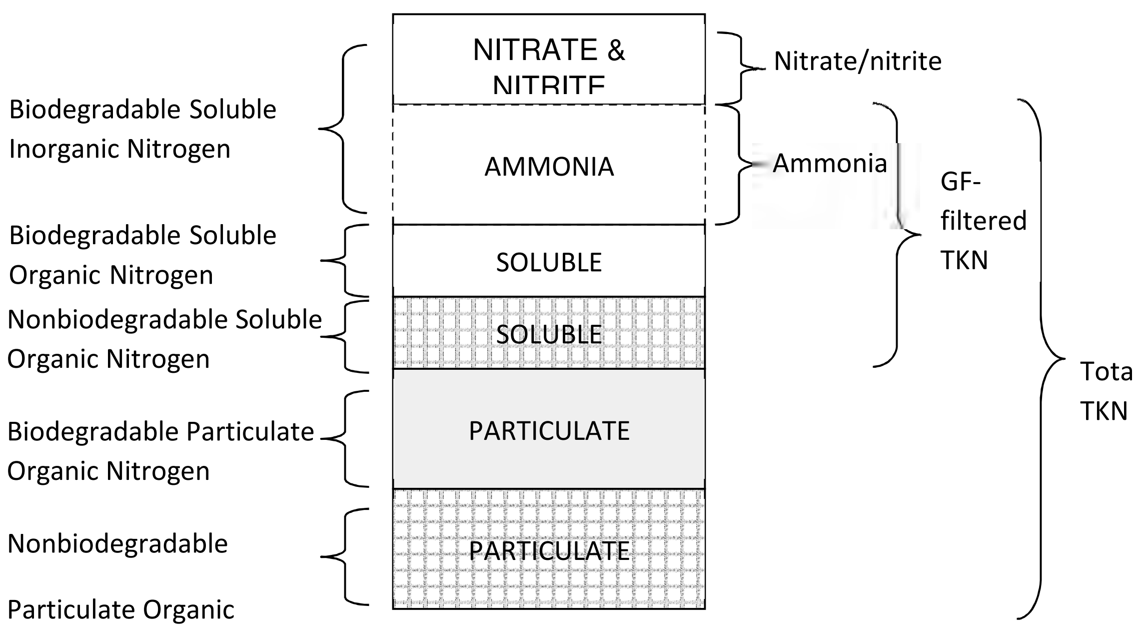
Each part of the treatment process (primary and secondary treatment) is designed to address the specific constituents (particulate and soluble components). The particulate forms are better suited to be handled in the primary treatment process, where as the soluble components are more easily addressed in the secondary and tertiary treatment processes.

3.2 Nutrient Considerations

Nitrogen Fractions

Nitrogen fractions can sometimes be estimated. For example, ammonia can be assumed to be 60 to 70 percent of TKN in plant influent. In the event the facility has primary settling tanks, TKN, TSS and VSS concentrations in the primary influent and effluent can be used to estimate the particulate fraction of TKN. A breakdown of the typical nitrogen components in municipal wastewater can be seen in Figure 3.1.

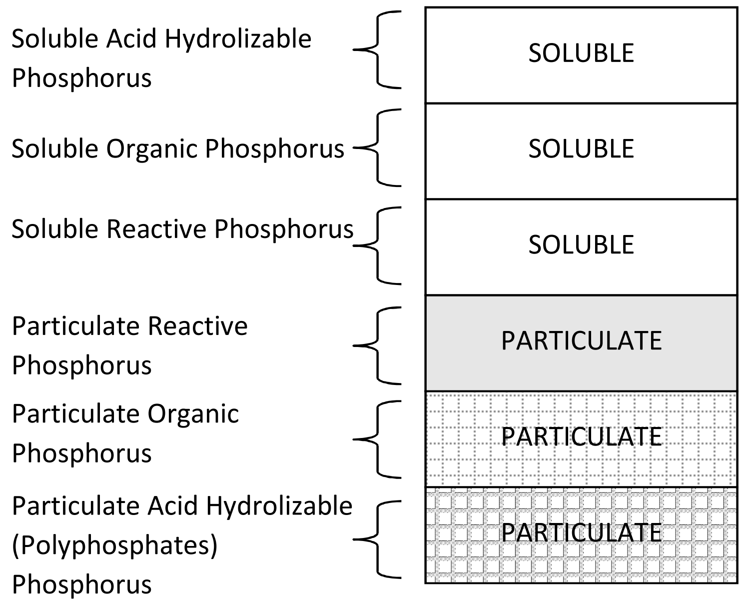
Figure 3.1. Nitrogen Components in Municipal Wastewater



Phosphorus Fractions

Phosphorus is another major nutrient required for biological growth. Wastewater phosphorus is typically divided into orthophosphate, polyphosphate and organic (both soluble and particulate) phosphorus. A breakdown of the typical phosphorus components in municipal wastewater can be seen in Figure 3.2.

Figure 3.2. Phosphorus Components in Municipal Wastewater



3.3 Internal Recycle and Sidestream Considerations

During wet weather events, a reduced effectiveness of the secondary treatment process is expected, simply because of the dilute nature of the influent. Prudence should be used in determining ways to reduce nutrient loads/streams during wet weather events while keeping the treatment facility within discharge limits. Examples of such considerations include:

RAS pumping is used to maintain solids inventory in the bioreactors. Frequently, RAS pumping systems are designed for ultimate conditions and lack appropriate turndown capability for low flow conditions. This situation would generate thin sludge. Depending on the wasting system's capabilities, the thing sludge may impact the system's SRT and process performance. Special consideration should be given to high RAS return flow rates from MBRs, which also carry high dissolved oxygen levels.

Dewatering of anaerobically digested sludge typically recycle 20 to 30 percent of their nitrogen load. During wet weather events the bulk of this nitrogen would be lost to the effluent. Eliminating the bleed through of this nitrogen load during wet weather events by means of sidestream treatment can reduce nitrogen discharges during high flows and allow for reduced operating costs if implemented year round.

Introduction of influent at several locations along the length of bioreactors to minimizes the risk of washout during storm flows. With fine-bubble aeration, distribution across the width of the aeration tanks will need to be considered to avoid short circuiting. Note that this mode of operation (step feeding) would approximate a complete mix reactor system and may favor the growth of filamentous organisms.

In general, a full evaluation of the wet weather mode at a POTW will need to be conducted (including all recycle streams) to identify any potential bottlenecks of nutrient removal. This would be conducted as part of the baseline assessment, prior to the start of any field testing.

Section 4
Modeling Considerations

4.1 Clarification Models

Clarification models are used to describe the behavior of solids, typically in primary or secondary clarifiers. The models available in BioWin and GPS-X include: 1) point or ideal, 2) simple one-dimensional, 3) modified Vesilind, and 4) double exponential. Basic overviews of these models follow:

The point or ideal model is based on a constant percent solids removal in the clarifier.

The simple one-dimensional, modified Vesilind and double exponential models are all one-dimensional models that solve a series of equations describing solids behavior in a number of different clarifier "layers." These models are based on standard solids flux analysis, which assumes that the mass flux of solids in the clarifier is the sum of the gravity settling flux and the flux due to bulk movement.

The modified Vesilind and double exponential models modify the Vesilind approach(interface settling velocity) in that a low settling velocity is estimated for low concentrations instead of having settling velocity approach Vo (empirical sludge settling coefficient) at low solids concentrations. The double-exponential approach has an additional e^{-KX} term (exponential growth function) and the modified Vesilind has a switching function. The simple one-dimensional is equivalent to the double exponential model. The parameters that must be specified for each of these clarifier models are shown in Table 4-1.

Table 4.1. Clarification Parameters

Parameter to Be Specified	*Clarifier Model*		
	Point/		
Area and depth	Yes	Yes	Yes
Underflow rate	Yes	Yes	Yes
Percent solids removal	Yes		
Maximum Vesilind settling velocity		Yes	Yes
Vesilind hindered zone settling		Yes	Yes
Clarification switching function		Yes	
Specific TSS conc. for height calculations		Yes	Yes
Maximum compactability constant		Yes	
Maximum practical settling velocity			Yes
Flocculant zone settling parameter			Yes
Maximum non-settleable TSS			Yes
Non-settleable fraction			Yes

Note: GPS-X allows the user to use the sludge volume index to calculate the maximum Vesilind settling velocity, the hindered zone settling parameter, and the flocculant zone settling parameter.

In addition, any of these clarifier models can be used with or without biological reactions. These biological reactions can be described by any of the activated sludge models described in Section 4.2. Although, the same biological model used to model biological growth and decay in aeration would be used to describe biological reactions in a clarifier.

The general practice is to use a modified Vesilind or double exponential model for dynamic clarification simulations.. This requires that good data on settling characteristics (SSVI data or data from column tests) are available from baseline testing conditions. Using a point or ideal model (with constant percent solids removal) during dynamic simulations will indicate increasing effluent TSS with increasing flows (which is the case when one performs a stress testing program). There a number of correction factors and fine tuning of the modeling necessary to predict clarifier overload (based on field testing data). Without these field data, the point and ideal models are more appropriate for steady-state simulations.

Biological reactions should be modeled only when these are known to have an impact on the wastewater treatment plant process. This can be evaluated by examining data on soluble species (COD or BOD, ammonia, nitrate) before and after the clarifiers. POTW laboratory tests are driven by compliance monitoring of permitted discharges thus not all information might not be readily available. If this is the case, additional time and cost should be factored into the operating budget prior to collecting and analyzing data

Another useful tool in predicting clarifier behavior is the use of computational fluid dynamics (CFD). CFD allows for detailed examination of multiple factors affecting flow within a proposed hydraulic design, specifically:

Creates more accurate scale-ups than with physical models.

Reveals configurations that improve hydraulic distribution and/or reduce head loss.

Identifies turbulent characteristics in the proposed design.

Provides quick assessments of hydraulic fixes in proposed or existing basins.

Details chemical reactions, hydraulic stress, physical barriers, mechanical movements, mass transfer, and other factors affecting flow within an enclosed basin.

Typical outputs from CFD analysis can be seen in Figures 4.1 (particle concentration) and 4.2 (velocity contours).

Figure 4.1. CFD Particle Concentration Example

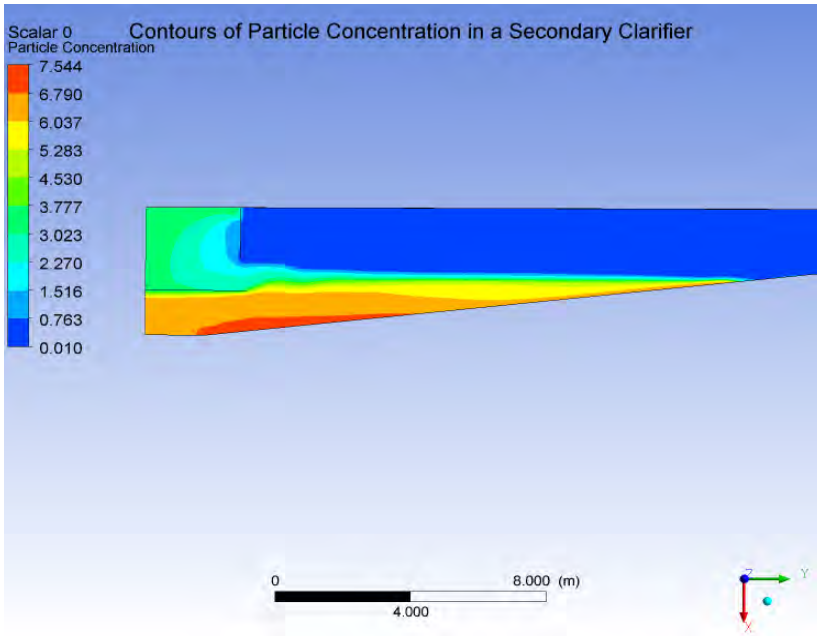
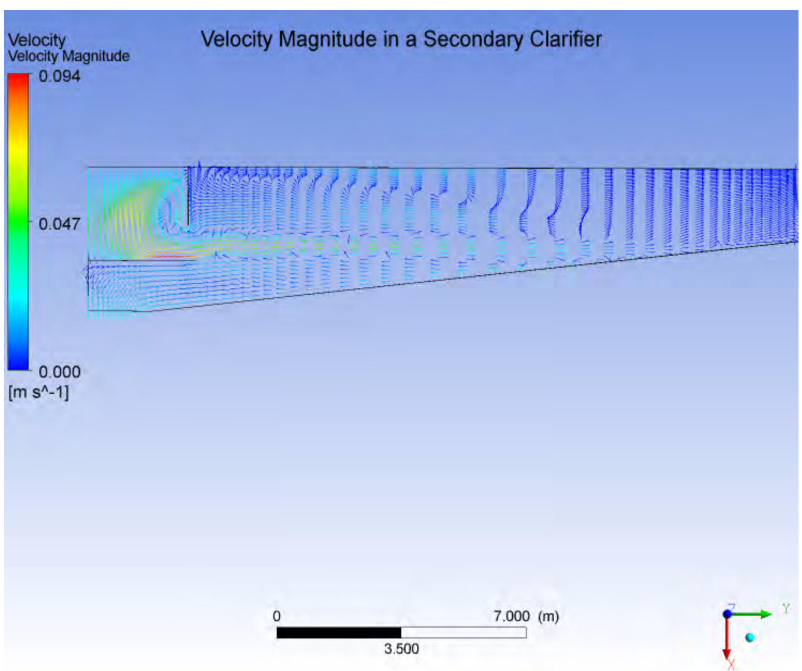


Figure 4.2. CFD Velocity Contour Example



4.2 Activated Sludge Models

Activated sludge models are used to model the microbiological growth and decay processes relevant to biological treatment. These models are collections of process rate equations, which are solved to determine the values of certain state variables. Examples of state variables are: the concentration of autotrophic biomass, the concentration of soluble inert COD, and the concentration of ammonia. When stress testing is examining the impact of nutrimental removal, coordination with activated sludge models will be necessary.

Three models developed by the International Water Association (IWA; formerly IAWPRC then IAWQ) Task Group on Mathematical Modeling for Design and Operation of Biological Wastewater Treatment Processes are commonly used as the basis of software and modeling efforts: Activated Sludge Model No. 1 (ASM1), Activated Sludge Model No. 2d (ASM2d), and Activated Sludge Model No. 3[1]. Additional simulation software is available, BioWin developed by EnviroSim Associates and GPS-X developed by Hydromantis. Both BioWin and GPS-X have their own default biological models: Activated Sludge/Anaerobic Digestion Model (ASDM) for BioWin and Mantis for GPS-X. A comparison of the biological processes included in ASM1, ASM2d, ASM3, ASDM and Mantis is shown in Appendix B. Limitations of each model are presented briefly in Appendix C.

In general, when selecting a biological treatment model, the user should start with the simplest model appropriate to the simulation application. For example, if phosphorus does not need to be included in the simulation, a COD- and N-only model would be sufficient for that application.

For the IWA activated sludge models, the general guidelines hold:

> **ASM1** should be used for COD- and N-removing biological treatment;
>
> **ASM2d** should be used for COD-, N-, and P-removing biological treatment;
>
> **ASM3** should be used for COD- and N- removing biological treatment or to incorporate other add-on processes in a modular fashion, such as the Bio-P module from Reiger et al. (2001).

The BioWin ASDM can be used for COD-, N-, and P-removing biological treatment. An example of this type of modeling can be seen in Figure 4.3. The GPS-X Mantis model is similar to ASM1, except that kinetic parameters are temperature-dependent, aerobic denitrification is included and two additional growth processes (one autotrophic and one heterotrophic) are introduced. Therefore, Mantis can be used for COD- and N-removing biological treatment.

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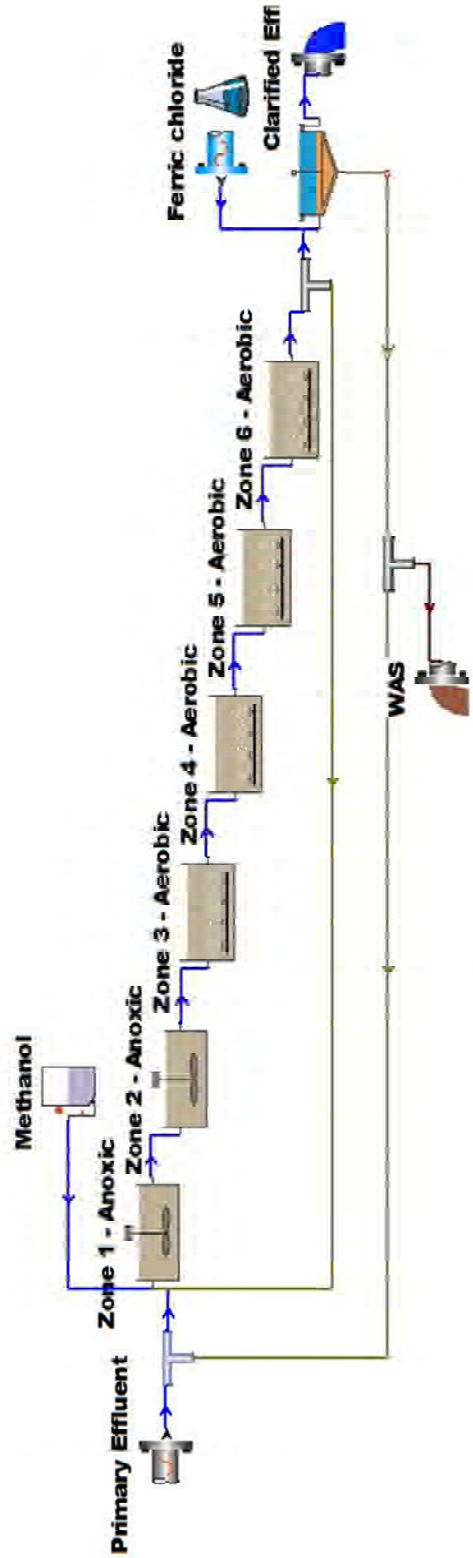
[1] The IWA ASM models are described fully in a report by the IWA Task Group on Mathematical Modeling for Design and Operation of Biological Wastewater Treatment entitled *Activated Sludge Models ASM1, ASM2, ASM2d, and ASM3*, published by IWA Publishing in 2000 as part of their Scientific and Technical Report Series.

Figure 4.3. BioWin Model Example



Section 5
Protocol Framework

Carrying out a stress testing program can be a complicated procedure involving many steps and coordination with multiple departments within a wastewater utility. This section is intended to convey the general steps that a POTW will need to carryout for a stress testing program and considerations to keep in mind. It does not take into account any of the specific details for modifications and temporary piping required for stress testing. Each treatment facility is unique with its own requirements and deviations from this framework will likely be necessary. Stress tests are carried out to determine the performance of a settling tank (both primary and secondary) in terms of ESS concentration for a wide variety of operating conditions especially during peak wet weather flows. Relationships between ESS concentration and SOR, SLR, RSSS concentration, RAS flow rate, sludge settling characteristics, DSS concentration, and sludge blanket depth are examined in great detail. Slug dye tests and solids distribution/flow pattern tests are also performed to assess the hydraulic characteristics of the settling tank.

In 2001, Water Environment Research Foundation/American Society of Civil Engineers Clarifier Research Technical Committee (WERF/CRTC) developed a stress testing protocol (Wahlberg, 2001). This protocol framework is a variation of the WERF/CRTC approach. This modified approach was utilized in a number of the case studies examined as part of the literature review performed previously.

5.1 Protocol Schedule

A typical stress test schedule is summarized in Table 5.1. This schedule is designed to be applied at three different levels of SLR: low, medium, and high. The level of SLR is determined from the solids flux analysis. Each SLR is replicated three times (once for each day). Measurement of flows, SS concentrations, and sludge blanket height are conducted during each test. Four settling tests and SSVI measurements are carried out during each test. Influent DSS, effluent DSS, ESS and FSS concentrations are determined during each test. A slug dye test is carried out (either in the first or second replicate of each test) and a solids distribution/flow pattern test is conducted (either in the second or third replicate of each test).

Table 5.1 . Typical Stress Testing Schedule

Test Day	SLR	Replicate	On line Measurements	Tests to be Conducted During Stress Tests		
1	NA	NA	Conduct flow, suspended solids, and sludge depth with 1 hr intervals	Baseline condition assessment		
2	High	1	Conduct flow, suspended solids, and sludge depth with 1 minute intervals	Conduct 4 settling tests using settling column and 2 SSVI tests during each test	Slug dye test	
3	Low	1			Slug dye test	
4	Low	2				Continuous dye/solids distribution tests
5	High	2				Continuous dye/solids distribution tests
6	Low	3	If sludge blanket measurements are not available on-line, measurements should be done manually every 15-30 minutes	Carry out influent DSS, effluent DSS, ESS and FSS concentrations during each test		
7	Medium	1			Slug dye test	
8	High	3				
9	Medium	2				Continuous dye/solids distribution tests
10	Medium	3				

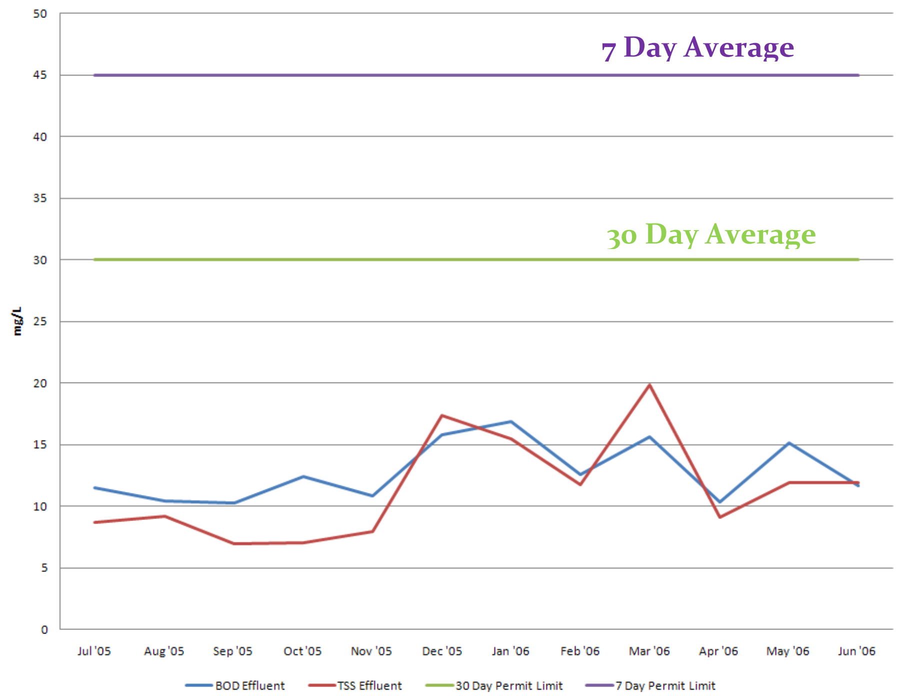
5.2 Framework

The WERF/CRTC protocol focuses on stress testing the secondary treatment process since primary treatment is not typically considered the bottleneck in terms of process constraints. However, the protocol can be applied to primary treatment for stress testing, especially if the facility receives CSO flows.

Considerations Prior to Testing

Prior to the start of testing, a clear failure point should be established early on during the stress testing plan development. At the height of a wet weather event, removal efficiency will be impaired due to the peak flow and loads being seen at the POTW. An acceptable value for failure might be the 7-day average permit value as opposed to the 30-day value.   An example of POTW discharge performance versus treatment requirements can be seen in Figure 5-1.

Figure 5.1 . Example POTW Discharge Performance vs. Treatment Requirements



In many instances the 7-day permit value is taken as the point of failure, since peak wet weather influent flows are experienced for a limited duration of time. Greater treatment performance is typically achievable for the reminding monthly time period providing no operational abnormalities occur. Additionally, consideration for back-to-back storm events should be considered. The clear definition of failure will tie into the regional approach one should use when conducting stress testing. Prior to the start of stress testing, discussions with the regional regulatory body should be undertaken to explain the reason and philosophy of stress testing since it can lead to permit excursions. Often times events leading up to stress testing have been at the request or suggestion of the regional regulatory body to address wet weather flows. This interactive dialogue will ensure all parties are aware of the testing purpose, schedule, and results/potential impacts.

Following the test schedule, as shown in Table 5.1, will result with each stress test taking one day. It will involve determining the SLRs applied during each stress test, with the SLRs derived from the solids flux analysis, based on the results of the mixed liquor settling tests conducted prior to the stress tests.

One consideration would be incorporating the test schedule as it relates to daily diurnal flow periods to allow for higher hydraulic loadings (peaks) than if testing is conducted by just taking clarification units off-line since the peak of the daily influent flow to the facility is being taken into account. Simulation of wet weather flow conditions is key, as described in Section 5.3.

Baseline Conditions and Setup

1. Obtain design data and blueprints of the entire secondary settling tank system, as well as the test settling tank. Identify the sampling locations for influent, effluent and within the test tank. Become

familiar with all the flow control systems for influent, effluent and RAS, as well as flow ranges that can be applied. Review condition of the test tanks versus original manufacturer's design drawings and evaluate the existing condition of the tank equipment (i.e., weir set points and elevations, sludge withdrawal equipment, etc.).

Begin development of CFD, BioWin, or other models discussed in Section 4. The actual data collected during the baseline condition assessment and field testing will be used to calibrate the model and will allow numerous iterations to be performed after field testing has been completed to simulate proposed modifications. Examples of such modifications include: installation of Stamford and peripheral baffles, revisions to the RAS pumping system, and addition of center well EDI baffle arrangement.

2. The tests should be conducted when the plant is operating normally. Conducting the tests during atypical (i.e., upset) conditions may lead to erroneous conclusions regarding plant capacity. Verify if any outstanding maintenance issues or rate limiting steps need to be addressed and corrected prior to commencement of testing.

3. Install various flow measuring devices.

   - Install flow meters in the influent (or effluent), WAS (with totalizing), and RAS lines and capture the output signals electronically. The tester may use a portable flow meter to streamline data collection. Capturing flow measurements on both the influent and effluent is not necessary. If only one flow stream can be measured due to funding constraints, consider concentrating on WAS. Other flow streams can be determined by means of mass balance calculations.

   - Install suspended solids probes into the influent line, effluent launder and RAS line of the test tank and automated sludge blanket monitoring device.

   - Every time sampling is performed manually, it introduces a potential source of error and could possibly skew results. The more automated the sampling process is, the more likely consistent and accurate data collection will be obtained. Measurement of the sludge blanket depth in the test tank manually by means of a sludge judge can introduce error since the sludge blanket layer is being disturbed.

4. Determine a way to adjust the flow rate to the test tank to provide the three different SLRs. The tester may adjust the test tank's influent flow rate by taking other clarifiers out of service gradually, by weir adjustment, or by partial gate closing. The tester should keep the ratio of influent flow to RAS flow constant during each SLR test condition.

   An operator should be present at all times during the tests to collect samples and flow measurements. The operator may also need to increase the RAS rate during the tests to prevent an excessive accumulation of solids in the secondary clarifier.

Field Testing

1. During each stress test, keep the influent flow constant to the test tank for a period of three theoretical hydraulic detention times prior to the start of testing.

   A minimum of three hydraulic retention times should be passed before changing testing conditions. This time period allows the clarification system to return to a steady state value.

2. During each stress test and when the influent flow is constant, collect data from the suspended solids probes, flow and sludge blanket height measuring devices at least at 1-minute intervals. If the sludge blanket height is measured manually, then the measurements should be carried out at 15-30 minute intervals.

3. After a period of time that is equal to three theoretical hydraulic detention times, carry out (at least once) influent DSS, effluent DSS, ESS, and FSS concentration tests.

4. During each stress test, conduct settling tests at four to six different suspended solids concentrations to determine the V_0 and k parameters of the Vesilind equation (zone settling velocity = V_0*exp(-k*X_t)).

5. During each stress test, conduct two SSVI tests, as described in *Standard Methods for Water and Wastewater (APHA, AWWA and WEF, 2005)*. In the SSVI test, mixed liquor is settled in a 1-liter graduated cylinder for 30 minutes, as the contents of the graduated cylinder are stirred at one revolution per minute (rpm).

6. During the first or second replicate of the stress test specified for each SLR and after three theoretical hydraulic detention times have passed, carry out a slug dye test. (If constant flow for three theoretical hydraulic detention times cannot be maintained, a slug dye test can be initiated earlier). Samples should be collected until at least 90% of dye mass is recovered.

7. During the second or third replicate of the stress test specified for each SLR and after three theoretical hydraulic detention times have passed, carry out continuous dye and suspended solids distribution tests (if constant flow for three theoretical hydraulic detention times cannot be maintained, a slug dye test can be initiated earlier). If a manual core sampler such as a sludge judge is used, dye and suspended solids sampling can be done at the same time. If a portable hand-held suspended solids analyzer is used, then the core sampler is employed for taking dye samples only, and the suspended solids concentrations at different depths are determined using the electronic device.

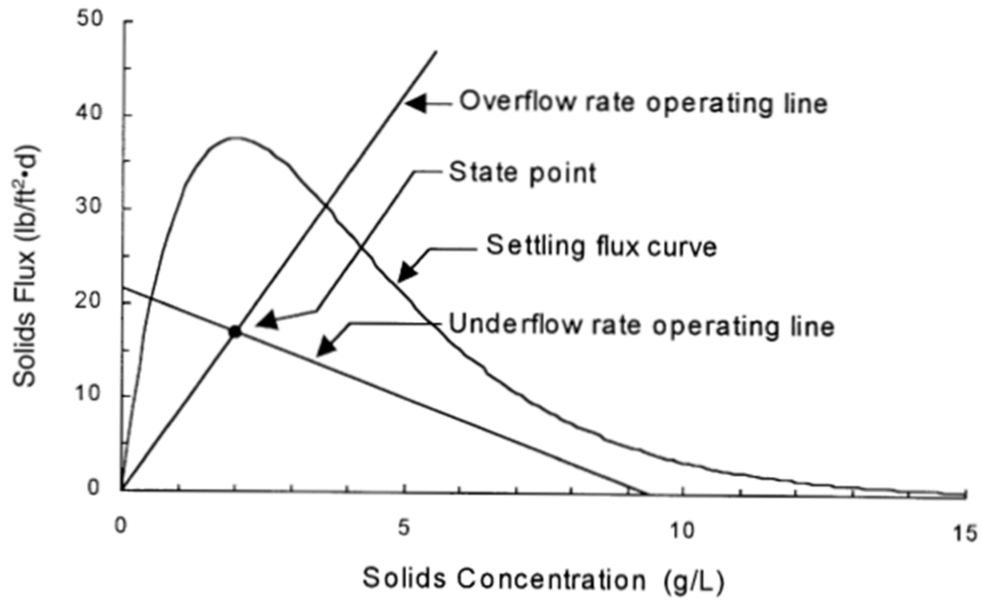
8. Continue the stress test at least for a period equal to one theoretical hydraulic detention time after three theoretical hydraulic detention times have passed, and after completion of the entire slug dye, continuous dye, and solids distribution tests.

9. The tests should only be interrupted if clearly excessive quantities of MLSS are observed going over the secondary clarifier weirs. Interrupting the tests simply because blanket levels are rising or effluent solids appear higher than normal will limit what can be learned from the test procedure. Results should be based on quantified analytical values, rather than simply visual observations.

Data Interpretation

1. Perform solids flux and state point analysis graphs based on field tests for comparison to computer models. This graphical tool allows designers and operators to graphically understand the dynamics of an activated sludge clarifier. An example of a solids flux/state point analysis can be seen in Figure 5-2.

Figure 5.2 . Example State and Flux Point Analysis



An underflow rate operating line exceeding the settling curve will indicate a thickening failure. A perfect balance of underflow rate (RAS pumping) and overflow rate should be accomplished for a highly functional secondary clarifier.

2. Update CFD, BioWin, or other modeling software with field results to determine possible process improvements that could be made to address wet weather flow conditions.

Typical deficiencies found during the course of stress testing and appropriate corrective actions, have been included in Appendix D.

5.3 Wet Weather Considerations

The dilute nature of wet weather flow conditions can present a number of unique challenges for stress testing. Simply taking clarifiers off-line can address the nature of the increased volume of flow for the test clarifiers; however, it does not simulate the true nature of wet weather flow events.

Considerations for Simulating Peak Wet Weather Flow Conditions

Utilizing plant effluent as the make-up source flow is one way to address simulating dilute wet weather influent flows. Although temperature effects from a peak wet weather event will not be simulated, it would give a better indicator of performance for dilute influent than dry weather wastewater.

Peak flow concerns. During a wet weather event several unique influent wastewater characteristics can result that will affect treatment plant performance. These includes: increased TSS loading, additional grit loading from surface runoff, and elevated dissolved oxygen levels. Finding a way to simulate these conditions will allow for a better overall stress testing program for peak wet weather flows.

Consider the season for stress testing. Variability in influent will occur during wet weather events; thus, different operational strategies may be employed at a POTW to manage these flows (i.e., higher salinity from snow and ice removal operations). Performing stress testing under different seasonal conditions will give the POTW a better understanding of the seasonal treatment process performance changes especially if seasonal permit limits exist.

Potential new permit limits. With changing nitrogen and phosphorus control requirements it may be beneficial to conduct stress testing with current and future requirements in mind. May and November have been found to be the most limiting and challenging seasons for meeting nutrient limits. If budgetary constraints only allow for limited testing, consideration of these months will give the best indicator of limiting conditions and can be seasonally adjusted for summer months.

Considerations for Actual Peak Wet Weather Flow Conditions

Testing during actual wet weather flow is something each POTW will need to consider as an alternative to simulating conditions. Testing during actual wet weather flow will give a better indicator of true performance, eliminate artificially creating and managing numerous variables, and the rapid rate of flow changes that operators must manage. If POTW has sufficient staff and resources to carry out such testing, this will give a better indicator of overall wet weather performance.

Section 6:
Applying the Proposed Protocol at POTWs

Treatment processes employed across the US vary significantly along with treatment plant size. Since a number of municipalities are trying to negate capital costs of constructing new treatment trains, a need exists for having a systematic way to conduct stress testing to maximize existing infrastructure to the extent possible. A number of innovations in clarifier design and MLSS strategies have taken place since many of these facilities became operational. A plant scale application of the proposed piloting measures will provide the tools for accomplishing this need and help further refine the proposed protocol by applying it at numerous treatment facilities across the nation.

6.1 Application of Protocol

A number of modified activated sludge processes have been developed over the years to meet specific purposes. These adaptations of the activated sludge process, whether basin configuration, aeration configuration, operating mode, or other proprietary configuration, present a tradeoff for items such as footprint, hydraulic gradient, performance, reliability, flexibility, capital costs, operating costs, etc.

To examine a proper cross-section of POTWs that represents the diverse sizes and unit processes/treatment trains across the nation, we considered the following characteristics:

Size of the facility. Larger treatment facilities tend to be located in metropolitan areas that often have large diameter main interceptors as part of their collection systems. These large interceptors may dampen the effects of wet weather and result in lower peaking factors to the treatment facilities. Smaller to medium size facilities tend to have higher peaking factors as a result of the shorter time of travel in the collection system. Therefore, a larger facility will often have more logistical challenges to simulate peak wet weather flows for stress testing.

Regional location of the facility. Regional characteristics such as rainfall and climate differences, population, and water quality concerns affect drivers for stress testing and permit limitations. It is very difficult to have a "one size fits all" approach for stress testing.

Treatment process. Each treatment process is unique and certain approaches that will work for one process will not necessarily translate into comparable results for another process (e.g., pure oxygen, conventional activated sludge, BNR, etc.).

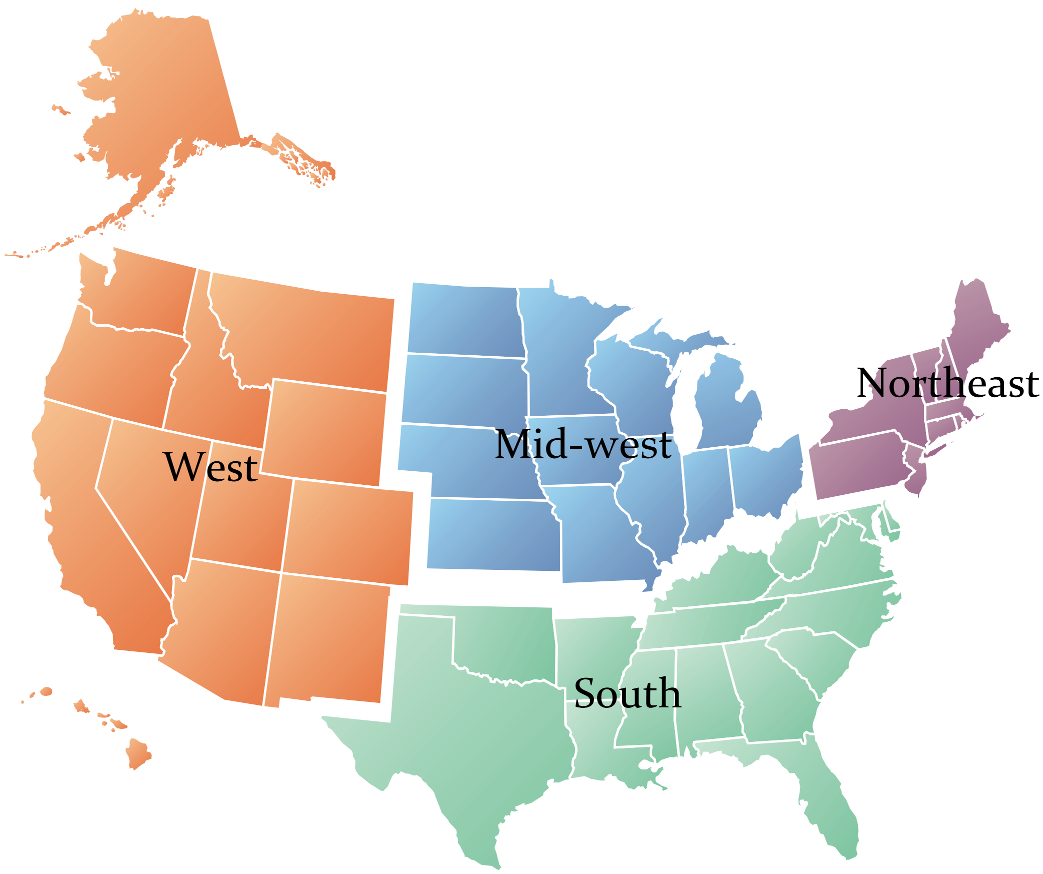
Combined or separate collection systems. Wastewater characteristics can differ between separate and combined sewer systems. In addition, temperature influxes occurring from dilution in a combined system can affect reaction kinetics for both primary and secondary treatment processes. This effect is more pronounced in a combined system than in a separate collection system.

Age of the facility. Older facilities will tend to be located in areas that have more established collection systems and experience a higher degree of I/I impacting the driver for stress testing.

To address the regional location of the facility, different geographic regions were adopted from the delineation of the case studies presented in the literature study, Figure 6.1. The regions were based on the US Census Bureau from the 2010 census.

Recognizing regional differences allows for an easier reference for items such as climate, population and receiving water characteristics, which are all drivers related to wet weather flow management and stress testing at POTWs.

Figure 6.1. Regions of the United States



Recommendations for conducting the plant-scale applications of proposed stress testing protocol are shown in Table 6.1. The matrix represents the different variables previously discussed for the wide ranging unit processes and facility size common for that region.

Table 6.1. POTW Recommendation List

Region	*Flow Range of the Facility (MGD)*	*Process*	*Combine d System*	*Separate Sanitary System*
Northeast	100 to 120	Activated sludge, high pure oxygen setup	X	
South	20 to 30	Conventional Activated sludge		X
Mid-west	40 to 60	Activated sludge, BNR	X	
West	10 to 15	Activated sludge, BNR		X

The matrix shown above represents the different variables previously discussed for the wide ranging unit processes and facility size common for that region. Since peak wet weather flows are experienced by all POTWs, regardless of their location, it is important to look at development of the proposed protocol from a regional perspective. Each region will have different weather patterns and water quality drivers that will influence testing procedure and duration.

Typically speaking, larger more established and extensive combined collection systems are found in the Northeast and the Mid-west with separate collection systems found in the South and the West. The Northeast and Mid-west are predominated by larger treatment facilities for average plant size, partially stemming from the combined collection system influence. The South is considered more rural with regional treatment facilities spread out, with the West having a critical number of smaller treatment facilities in addition to larger facilities in metropolitan areas. All of these regions employ a wide variety of treatment schemes, and certain approaches that will work for one process will not necessarily translate into comparable results for another process. A greater concentration of treatment plants in the Mid-West and the West incorporate some degree of nutrient removal while a number of the treatment plants in the Northeast and the South have some variation of the activated sludge process. The intention of this matrix is not to be a rigid structure, but rather a guideline for selecting facilities that encompass this regional approach with variations in unit process considerations.

Section 7
Stress Testing Cost and Timeframe

Development and conducting stress tests will involve a significant amount of time and expense to achieve the desired results. This section covers the estimated expense and time for conducting stressing operations and emphasis the application of proposed protocol outlined in Section 6.

7.1 Stress Testing Cost

The proposed protocol was used to determine labor, equipment and modeling requirements for developing the cost of carrying out a stress testing protocol demonstration program. This cost focuses on carrying out tests related to the secondary treatment process, which is typically the bottleneck in the treatment process as discovered during the course of the previous literature review (Task 1). For plants that experience a significant amount of CSO flow, this same basic principal can be applied to the primary treatment process.

To reiterate the test protocol previously discussed in Section 5, initial testing is conducted during baseline conditions to generate the data that will be used during field and stress testing. Testing is typically performed over a 10-day period as outlined in Table 5.1, from Section 5.

Baseline Conditions. Settling tests, influent DSS, effluent DSS/FSS/ESS concentrations, and flow and sludge blanket verification tests will be carried out. These tests will be carried out by four persons, will take approximately one day, and are used to establish the baseline conditions. **Care should be taken that this is performed during dry weather flow conditions.**

Field and Stress Testing. The tests to be conducted include: stress tests, flow measurements, sludge blanket measurements, settling tests, DSS/FSS/ESS testing, SSVI, MLSS, RASSS, slug dye test, continuous dye/solids distribution tests, and modeling (CFD and/or BioWin).

These tests will be carried out over a nine day period, typically. For settling tests, three 1.5-meter columns will be used for settling tests. Six different SS concentrations will be used to generate a settling flux curve for stress tests. Up to six people will be needed during a 6-day period of the 9-day test period. Requirements are reduced to approximately four people for the other three days.

Typical Equipment Requirements. Three 3.5”-diameter settling column with 1.5 m height equipped with 1 rpm-stirrer; two, 1- liter graduated cylinders, each, with a 1-rpm stirrer; three SS probes with data loggers; four sludge blanket measuring devices; five sludge judges equipped with discharge ports placed 1 ft apart; one fluorometer; one jar test apparatus; two magnetic flow meter (either portable or fixed), and one Kemmerer sampler.

Stress Testing Costs. Approximate costs associated with carrying out a stress testing program have been included in Table 7-1. These costs will vary with complexity of the system being tested and the level of modeling required.

Table 7.1. Approximate Stress Testing Budget

Labor			*Other Direct Costs (ODC)*	
Position	Hours	Cost[1]	Laboratory	$7,000
Project Management	50	$7,000	Equipment	$20,000
Field Engineers/ Operators	320	$38,400	Modeling Allowance	$12,000
Project Engineer	100	$13,500		
CAD Technician	40	$4,200		
Administration	32	$1,900		
Total	542	$65,000		
			Total Cost	$104,000

Note: 1 – Costs include loaded labor rate to account for all direct and indirect cost associated with personnel.

The costs developed in Table 7-1 represent an approximate cost for carrying out a stress test focusing on the secondary treatment plant process based on previous experience. The costs listed above; do not include time associated with permitting agency discussions nor the temporary piping modifications that might be required for the field portion to simulate wet weather flows for stress testing. These types of discussions and modifications will vary from location to location across the nation. Depending on the existing conditions at a facility, modifications might be an additional $10,000, with time coordinating with permit agencies ranging from $5,000 to $10,000 depending on the level of involvement. Conducting a stress testing program for an entire plant (similar to a rerating study) would involve a great deal more complexity and associated costs.

In addition, the level of modeling development can vary significantly since more complex BNR type processes take more time to build and involve numerous more steps to ensure that acceptable effluent quality is maintained. Depending on the model employed (as described previously in Section 4) and the process being modeled, modeling costs can range from $8,000 to $25,000. The number of simulation runs significantly impacts modeling costs.

POTWs that have adequate resources and staffing can perform a number of activities involved in stress testing and can greatly reduce cost. Since each POTW is different, this is a judgment call each facility will have to determine for development on their internal budget.

7.2 Timeframe

The timeframe for developing an all encompassing protocol will vary based on the particular process train for which the protocol is being utilized. A number of factors ranging from internal recycle and sidestream considerations, to sampling requirements and protocol, to test plans outlining specific roles and responsibilities, to possibly BNR considerations, will need to be examined.

A tentative timeframe for development of protocols in conjunction with actual field testing of the protocol at a POTW has been outlined in Table 7.2.

Table 7.2. Timeframe for Protocol Development and Field Testing

Task	*Component*	*Duration (months)*
1	Review of POTW facility, tabulation of data needs, and baseline condition assessment	2
2	Test Plan Development	1.5
3	Conducting Field Testing and Data Analysis	1
4	Report Findings and Recommendations	2
	Total	6.5

This timeframe may need to be modified for facilities that have seasonal variations in their discharge permits and seasonal variations in their wastewater characteristics as seen in northern climates. In these instances, extending the testing period to multiple seasons may be appropriate. This is an item a POTW will need to evaluate prior and consult historical data trending for their facility.

Section 8
Conclusions and Recommendations

This report has outlined the proposed stress testing protocol to be employed at POTWs across the nation for a wide range of unit processes. This has built upon the previous analysis of case studies from the literature review and past experiences.

Coordination with regulatory agencies is considered key before embarking on such a program.

The implementation of a plant wide stress testing approach requires significant planning, up-front commitment by decision-makers, potential design and flow modifications, and coordination with operations and laboratory staff for the best chance of a successful outcome.

The use of process and hydraulic computer modeling are valuable engineering tools that streamline the evaluation process and reduce demand on plant staff for on-site field stress testing. Modeling also enhances and makes possible quick evaluations of various capital improvement and process optimization methods for increasing flow through wastewater treatment facilities. Even though modeling cannot substitute for practical field testing, one should always view the model results with some skepticism and not blindly accept the values.

Development of a standard stress testing protocol, which can be used by various POTWs serving effectively as a "Go-By," would allow for a quicker comparison of results and techniques employed and aid smaller- to medium-sized municipalities in their commitment to being stewards of the environment. Deviations in the protocol would still be needed to account for the unique nature of each facility since there is not a "one size fits all approach." Many POTWs that have not conducted a stress testing program would find this first-hand information valuable in development of their wet weather program, once collection system alternatives have been exhausted.

Many POTWs share a common driver stemming from increasing water quality concerns for receiving water characteristics. TSS has been the traditional driver, but increasing nitrogen and phosphorus are playing an increasing role even during wet weather events.

Aging infrastructure is another consideration. In some instances, many POTWs are faced with limited build out capacity because of population encroachment at existing treatment facilities. Negating capital cost is a major consideration solely to address peak wet weather flows, especially when examining smaller less funded municipalities.

Through the use of conservative design standards (e.g., Ten States, etc.) there is untapped clarification capacity at a majority of POTWs. POTWs can use this excess capacity to maximize use of their existing infrastructure as part of their weather operational strategy.

Appendix A
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Appendix B

Modeling Processes

Biological Processes Included in Major Activated Sludge Models

Process	ASM1	ASM2d	ASM3	ASDM	Mantis
Non-Phosphate-Accumulating Heterotrophic Biomass Growth and Decay					
Aerobic storage of readily biodegradable substrate			Yes	Yes[3]	
Anoxic storage of readily biodegradable substrate			Yes	Yes[3]	
Aerobic growth of non-phosphate-accumulating heterotrophic biomass	Yes	Yes[1]	Yes	Yes	Yes
Anoxic growth of non-phosphate-accumulating heterotrophic biomass	Yes	Yes[1]	Yes	Yes	Yes
Fermentation (performed under anaerobic conditions by non-phosphate-accumulating heterotrophs)		Yes			
Decay of non-phosphate-accumulating heterotrophic biomass	Yes	Yes	Yes[2]	Yes	Yes
Respiration of organics stored by non-phosphate-accumulating heterotrophs			Yes[2]		
Autotrophic Biomass Growth and Decay					
Aerobic growth of autotrophic biomass (nitrification)	Yes	Yes	Yes	Yes[4]	Yes
Decay of autotrophic biomass	Yes	Yes	Yes[2]	Yes[4]	Yes
Phosphate-Accumulating Heterotrophic Biomass Growth and Decay					
Storage of internal storage material by phosphate-accumulating heterotrophics		Yes		Yes	
Aerobic storage of polyphosphate by phosphate-accumulating heterotrophics		Yes		Yes	
Anoxic storage of polyphosphate by phosphate-accumulating heterotrophics		Yes		Yes	

Process	*ASM1*	*ASM2d*	*ASM3*	*ASDM*	*Mantis*
Aerobic growth of phosphate-accumulating heterotrophics		Yes		Yes	
Anoxic growth of phosphate-accumulating heterotrophics		Yes		Yes	
Decay/lysis of phosphate-accumulating organisms		Yes		Yes	
Lysis of cell internal storage material		Yes		Yes	
Lysis of stored polyphosphate		Yes		Yes	
Anoxic Methylotrophs					
Growth of anoxic methylotrophs				Yes	
Decay of anoxic methylotrophs				Yes	
Hydrolysis					
Aerobic hydrolysis of slowly biodegradable substrate	Yes	Yes	Yes	Yes	Yes
Anoxic hydrolysis of slowly biodegradable substrate	Yes	Yes	Yes	Yes	Yes
Anaerobic hydrolysis of slowly biodegradable substrate		Yes		Yes	
Ammonification of soluble organic nitrogen	Yes			Yes	Yes
Hydrolysis of organic nitrogen	Yes			Yes	Yes
Hydrolysis of organic phosphorus				Yes	
Metal Precipitation					
Precipitation of ferric phosphate		Yes			
Dissolution of ferric phosphate		Yes			
Miscellaneous					
Adsorption or flocculation of colloidal organic material to particulate organic material (occurring spontaneously				Yes	
Assimilative denitrification of nitrate or nitrite to ammonia for synthesis				Yes	

Source: IWA 2000 and BioWin and GPS-X help files.

Notes:

1. Two processes are modeled here with ASM2d: growth on fermentable substrates and growth on fermentation products.
2. Both aerobic and anoxic decay (endogenous respiration) and respiration of organics stored by biomass is modeled.
3. Non-phosphate-accumulating heterotrophs can grow on complex readily-biodegradable organics, acetate, propionate, or methanol under aerobic conditions, but complex readily-biodegradable organics, acetate or propionate under anoxic conditions. Ammonia is used for the nitrogen source.
4. The growth and decay of ammonia-oxidizing and nitrite-oxidizing microorganisms are considered separately.

Appendix C
Limitations of Activated Sludge Models

Model	Limitations
ASM1	Assumes the system operates at constant temperature; Assumes the pH is constant and near neutrality; Does not contain kinetic equations that address nitrogen, phosphorus and alkalinity limitations of heterotrophic growth; Includes biodegradable soluble and particulate organic nitrogen – both of which are difficult to measure; Kinetics of ammonification are fast and don't affect model predictions; Differentiates inert particulate COD based on origin (X_I is from influent, X_P is from biomass decay), even though it is impossible to differentiate these two fractions in reality; Does not directly predict MLSS; Lysis combined with hydrolysis and growth describes the lumped effects of endogenous respiration of storage compounds, death, predation and biomass lysis; it is difficult to evaluate the kinetic parameters for this lumped process; and Does not include processes that occur under anaerobic conditions.
ASM2d	Temperature is expected to be in the range of 10 to 25°C; The wastewater should contain sufficient Mg2+ and K+; pH should be near neutral; and Processes with an overflow of acetate/fermentation products to the aeration tank cannot be modeled.
ASM3	Developed based on experience for wastewater temperatures ranging from of 8 to 23°C; model equations might not be valid outside this range; Developed based on experience for wastewater pH ranging from 6.5 to 7.5; model equations might not be valid outside this range; Does not include any processes that describe biomass behavior under anaerobic conditions; Is not applicable to cases in which nitrite concentrations are elevated; and Not applicable to activated sludge systems with very high loads or very small (< 1 day) solids retention times (SRTs).
ASDM	Model equations are not published in the literature as are the IWA activated sludge models1; Substantially more complex (over 50 state variables and 60 process equations) than the IWA models.

Mantis	All of the ASM1 limitations apply.

Source: Limitations of ASM1, ASM2d and ASM3 are taken from IWA 2000.

Note:

1. Although the BioWin model is based on a general model published by Barker and Dold (1997), the ASDM has evolved substantially since then. The current model process equations are not included in the help files associated with BioWin, nor published in the literature.

Appendix D

Deficiencies Found During Stress Testing (Secondary Treatment)

Performance of a settling tank is measured by the quality of secondary effluent as determined by ESS concentration and by the extent of thickening indicated by RSSS concentration. Before starting the test, the water surface of the settling tank should be free of foam, scum and other floating material that may contribute to high ESS concentrations. Approaches for overcoming the performance, as well as the design problems of settling tanks, are discussed here.

Floating Sludge on the Settling Tank Water Surface

Floating sludge is caused by denitrification, growth of specific organisms, by the presence of poorly degradable surfactants or nutrient limitations. The following discusses how to alleviate floating sludge.

Denitrification

Once it is clear that denitrification is occurring, the problem needs to be corrected before starting the stress tests.

- Lower MCRT, if nitrification is not required or nitrification can be achieved at a lower MCRT. Reduce DO in aeration basin.
- Increase the speed of scraper or hydraulic suction system. Speed should be increased gradually so that flocs at the bottom are not disturbed.
- Increase RAS flow rate.
- Decrease number of on-line clarifiers.
- Increase DO level in the last section of the aeration basin or mixed liquor channel leading to the settling tank.
- Add hydrogen peroxide as an oxygen source in the center well of the settling tank (Richard, 2003).

Filamentous Organisms

- M. parvicella Foam

  Foam due to *M. parvicella* is recognized under the microscope. This organism causes bulking and its presence yields high SVI values (Jenkins et al., 2003). Foam on the settling tank water surface can be eliminated by preventing or reducing the growth of *M. parvicella* in the aeration basin by lowering sludge age, preventing aeration basin zones having low DO levels (such as less than 1 mg/L), avoiding intermittent aeration, or providing plug flow regime in anoxic and aerated zones. Adding polyaluminum chloride has been shown to reduce the growth of this organism (Roels et al., 2002). Eliminating foam trapping systems in the aeration basin also results in reduction of *M. parvicella* growth. Once *M. parvicella* is eliminated from the aeration basin, the remaining foam on the SST water surface can be hosed with water sprayers to the scum collection box.

  Nocardia spp. Foam

  Foam caused by *Nocardia* spp. can be differentiated from other foams through microscopic examination. Even though they are filamentous organisms, they do not influence settleability of activated sludge. High sludge ages, high concentrations of oil and grease in the influent, and higher temperature promotes its growth. Surface trapping also aggravates the foaming problem in aeration basins. Foam can be removed from the water surface of the SST by mechanical means such as scum collectors. Water spraying will help to direct the foam toward the scum collection box. However, true elimination of foam from the settling tanks can be achieved by eliminating it from the aeration basin. This can be accomplished by reducing sludge age, spraying chlorine solution onto the foam on the surface of the aeration basin, physically removing foam from the surface of the aeration basin, adding polymer into the return sludge line or mixed liquor channel to flocculate *Nocardia* spp into activated sludge flocs, or the use of anoxic selectors (Jenkins et al., 2003).

- Type 1863 Foam

  This foam can also be identified easily with microscopic examination. Type 1863 growth is caused by low sludge age (usually less than 3-4 days combined with low aeration basin DO level) and also by high influent oil and grease levels. It can be eliminated by increasing DO concentration and sludge age and by reducing influent oil and grease levels.

- Other Types of Foams

  White to gray foam at the start-up of the activated sludge process, which causes an increase in ESS concentration, is a temporary situation. The gray foam caused by discharge from solids processing systems can be eliminated by eliminating digester overflows and reducing polymer feed to dewatering. Thick pasty or slimy grayish foams due to nutrient deficit conditions can be eliminated by effluent concentrations of 1-2 mg/L for ammonia plus nitrate and for orthophosphate (Richard, 2003).

High Sludge Blankets

High sludge blankets can be caused by a number of factors including higher MLSS concentrations, higher flow rates, lower RAS flow rates, deteriorating sludge settling characteristics, poor design of settling tanks, and poor sludge removal mechanism. The roles of MLSS concentration, influent flow, RAS flow, sludge settling characteristics, and settling tank surface area in causing high sludge blankets can be investigated using the State Point Analysis.

Factors causing high sludge blankets are enumerated as follows:

- Higher MLSS Concentration
  - An increase in MLSS concentration may overload the SST resulting in high sludge blankets. Higher MLSS may be due to an inadequate amount of sludge wasting or excessive solids discharge in the side streams combined with poor solids removal efficiency in the primary settling tanks. There are several options to prevent overloaded conditions.
  - If the state point, where the overflow rate and underflow rate operating lines intersect each other, is below the sludge settling flux curve, increasing RAS flow rate may result in under loaded condition and cause a decrease in sludge blanket depths.
  - Recycle MLSS concentration temporarily in the influent to the settling tank by storing solids in the aeration basin by applying a step-feed configuration and/or reducing aeration rate.
- Higher Flow Rates
  - Higher flow rates cause higher SLRs, and if the solids removal rate is less than the solids application rate, sludge blanket rises.
  - Higher flow rates may be reduced by improving the poor design and/or operation of influent distribution system and diurnal flows.

- If unequal flow distribution is the cause, valves and gate positions can be adjusted to distribute the flow equally.
- Peak flows temporarily cause overloaded condition during which solids are stored in the settling tank, sludge blanket rises, and therefore, the MLSS concentration and SLR decrease. The decrease in MLSS, in turn, may result in an underloaded or a critically loaded condition. Then, the operator does not alter any operational conditions.
- However, if the settling tank is still overloaded despite a decrease in MLSS concentration, the course of action depends on the location of the state point.
- If the state point is below the settling flux curve, the RAS flow rate can be increased to the point that the settling tank becomes critically loaded or underloaded. If the state point is above the settling curve, increasing the RAS flow rate will not remedy the situation. In that case, put a spare settling tank online or expand the plant or provide flow equalization.

- Lower RAS Flow Rate

  Higher sludge blankets may also be due to a low RAS flow rate relative to influent flow rate. The remedial actions to be taken include:

  - Conduct a state point analysis to determine proper RAS flow rate. Applying a constant ratio of influent flow to RAS flow may solve the problem.
  - If one of the RAS pumps is not working properly, then the pump needs to be replaced or repaired.
  - The return sludge line may be clogged and should be cleaned to regain the proper RAS flow rate.

- Poor Sludge Settleability

  Deterioration in settling and compaction characteristics of sludge may be mitigated by preventing overgrowth of filamentous organisms or excessive production of exocellular polymers. Once the identity of filamentous organisms is known, the conditions leading to their growth is determined. By reversing those conditions or adding toxicants, filamentous organisms can be eliminated or reduced in large numbers.

  The sulfides can be reduced by its oxidation to sulfate by aeration or by precipitating with ferric chloride. Other methods of filament control include installing aerobic, anoxic and anaerobic selectors or adding toxicants such as chlorine, hydrogen peroxide and ozone. Polymers and coagulants can be used to improve settleability of activated sludge. If a viscous bulking condition is confirmed, it can be remedied by adding nutrients or by reducing F/M ratio and increasing DO concentration.

- Poor Sludge Removal Mechanism

  High sludge blankets may result from the problems associated with sludge removal mechanisms. These problems and their solutions are summarized below:

  - In settling tanks equipped with suction sludge removal system, the seal between the rotating arm with orifices and the underflow line may be worn out resulting in shortcircuiting of liquid into the RAS line. If this is the case, seals need to be replaced.
  - The orifices on the suction manifold may be plugged, resulting in less sludge removal.
  - Drain the settling tank and clean orifices.
  - In riser type suction sludge removal system, narrow riser tubes may be plugged easily.
  - An inadequately designed scraper system may not effectively divert the sludge to the central hopper.

- The scraper speed may not be optimum. Adjust the scraper speed.
- Sludge collection may not be effective due to broken chains, flights or worn shoes in rectangular settling tanks and uneven squeegees on plows, resulting in plows riding high on one side of the tank and scraping the bottom on the opposite side in circular tanks. To address these problems, take the settling tank out of service and drain it. Replace broken chains, flights, and worn shoes in rectangular tanks, and adjust squeegees in circular tanks.
- Pumps are not running at proper capacity or sludge lines are clogged. Check pump suction line for closed valves. If valves were closed, open them and recheck pump output. All valves are open, backflush sludge lines to remove blockage. If blockage cannot be cleared, remove the settling tank from service, drain it, and remove blockage from the sludge line.

Appendix E

Peak Wet Weather Flow Literature Review

Table of Contents

Acronyms

ADF .... Average Daily Flow -
ALCOSAN .... Allegheny County Sanitary Authority -
ASM2 .... Activated Sludge Model 2 -
BNR .... Biological Nutrient Removal -
BOD .... Biochemical Oxygen Demand -
BOD5 .... Biochemical Oxygen Demand Five Day -
CEPC .... Chemically Enhanced Primary Clarification -
CFD .... Computational Fluid Dynamics -
CRTC .... American Society of Civil Engineers Clarifier Research Technical Committee -
CSO .... Combined Sewer Overflow -
DO .... Dissolved Oxygen -
DSS .... Dissolved Suspended Solids -
ENR .... Enhanced Nitrogen Removal -
ESS .... Effluent Suspended Solids -
F/M .... Food to Mass Ratio -
FSS .... Final Suspended Solids -
g .... gram -
gpm/sf .... gallons per minute per square feet -
HPO .... High Purity Oxygen -
IDEM .... Indiana Department of Environmental Management -
I/I .... Infiltration/Inflow -
MBR .... Membrane Bioreactor -
MC4 .... Minimal Control Principal #4 -
MGD .... Million Gallons Per Day -
ML .... Mixed Liquor -
ml .... milliliter -
MLSS .... Mixed Liquor Suspended Solids -
MMSD .... Milwaukee Metropolitan Sewerage District -
NDWWTP .... North District Wastewater Treatment Plant -
POTW .... Publically Owned Treatment Works -
PPCP .... Pharmaceuticals and Personal Care Products -
PWD .... Philadelphia Water Department -

RAS .... **Return Activated Sludge** -

RPM .... **Revolution Per Minute** -

RSSS .... **Return Sludge Suspended Solids** -

SBD .... **Sludge Blanket Depth** -

sf .... **square feet** -

SLR .... **Solids Loading Rate** -

SOR .... **Surface Overflow Rate** -

SPU .... **Seattle Public Utilities** -

SS .... **Suspended Solids** -

SSO .... **Sanitary Sewer Overflow** -

SSVI .... **Stirred Sludge Volume Index** -

SVI .... **Solids Volatile Index** -

TDS .... **Total Dissolved Solids** -

TKN .... **Total Kjeldahl Nitrogen** -

TMDL .... **Total Maximum Daily Load** -

USEPA .... **United States Environmental Protection Agency** -

WAS .... **Waste Activated Sludge** -

WERF/CRTC .... **Water Environment Research Foundation/Clarifier Research Technical Committee** -

WRC .... **Water Reclamation Center** -

WWTP .... **Wastewater Treatment Plant** -

Section 1: Introduction, Objectives, and Report Organization

1.1 Introduction

Treatment of peak flows during wet weather is a common challenge across the country for municipal wastewater collection systems with separate or combined sewer systems. Increases in wastewater flow resulting from infiltration and inflow (I/I) during wet weather events can result in operational difficulties for publically owned treatment works (POTWs) and compromise proper treatment and compliance with discharge permits or receiving water criteria. Thus, a need can exist for POTWs to increase peak wet weather capacity while protecting the functionality of sensitive unit treatment processes.

In order to access the ability to capture and treat higher peak flow rates and greater volumes of wet weather flow, POTWs are performing stress testing to demonstrate the capacity of existing treatment processing units and investigating ways to maximize treatment capacity (WERF, 1999).

Communities around the country are embarking on multi-year, capital-improvement programs to upgrade their wastewater and stormwater facilities for a variety of reasons, including aging infrastructure, regulatory requirements, and increasing populations. For these programs, treatment plant stress testing can help by assessing the maximum use of existing POTWs through operational changes or cost-effective capital improvements that can potentially reduce larger capital investments in new treatment facilities.

1.2 Objectives

The goal of this literature review is to identify POTW stress testing approaches and procedures implemented around the country. The main focus is on facilities that have conducted stress testing for the purpose of peak wet weather flow management. Published literature for POTWs that performed stress testing for the purpose of plant consolidations was examined in development of the case studies in this report.

One objective of this review was a comprehensive literature search and summary of published examples of stress testing performed at POTWs. This information is organized by geographic regions across the United States to take into consideration varying climate, population, and water quality concerns.

Another objective of the study was to evaluate key elements of a stress testing program for POTW managers to consider when investigating peak wet weather treatment capacities. This includes a review of typical deficiencies that need to be addressed to improve peak wet weather capacity. Lastly, summaries of case studies identified during the course of the literature review are included to provide examples of stress testing programs and conclusions.

1.3 Report Organization

The main report is divided into seven sections: (1) Introduction, Goals, and Objectives; (2) Literature Review Methodology; (3) Overview of Stress Testing Considerations; (4) Stress Testing Strategies and Implementation; (5) Case Studies; (6) Engineering Approaches/Procedures Identified and (7) Evaluation and Conclusions. Literature review references are included in Appendix A.

Section 2: Literature Review Methodology

A literature review was conducted in order to examine the scope of stress testing used in wet weather planning, and to narrow the focus of the review to relevant case studies. This review included planning approaches consistent with traditional wastewater facilities planning as well as innovative testing strategies that have been implemented in the United States.

Sources of information included:

Engineering and scientific journals. This included:

- ASCE Journal of Environmental Engineering
- Journal of Water Science & Technology
- Water Environment Research
- Journal of Water Pollution Control Federation
- Water Environment & Technology

Knovel Interactive Library and Ingentaconnect database. These sources were used for identification of various manuals of practices, and published reference documents.

Various guidance documents. This included information from:

- Water Environment Federation
- Water Environment Research Foundation
- Association of Metropolitan Sewer Agencies
- National Association of Clean Water Agencies

Conference proceedings from various wet weather conferences. These included:

- Water Environment Federation Technical Exhibition Conferences
- Collection System Conferences
- Nutrient Removal Conferences

Internal CDM compilation library. These included past projects and consultation with senior wastewater treatment design experts within CDM.

Review of published literature was generally limited to the past 10 years through the various databases. For the purpose of this report, we focused on information published since 2000. Information from this time period to present is available more commonly in electronic format, thus providing a great amount of information for the literature review.

Section 3: Overview of Stress Testing Considerations

The capacity of a wastewater treatment plant is more than the sum of its parts, yet having a good understanding of the capacity of each part or process unit (including hydraulic), plays a crucial role in plant design and operation. Most unit processes are adaptable to stress testing which is defined as the intentional operation of a unit process to its point of failure. In some cases stress testing is straightforward and simple, e.g., flow is increased through a process until the hydraulic capacity is exceeded (overflows, or back-ups). In other cases the testing process is much more complex, such as when nutrient removal effects are examined (Nailor et al, 2006; Pitt et al, 2007).

3.1 Hydraulic Considerations

Stress testing establishes performance under varying load conditions (Daigger and Buttz, 1998). More often the focus is on primary and secondary capacity (clarification), but preliminary capacity (screening and grit removal) needs to be examined as well. The purpose of this testing is to evaluate the hydraulic performance characteristics and identify hydraulic bottlenecks. Specifically, it can be used to identify occurrence of short-circuiting, dead zones, and density/thermal currents. The information generated allows strategies to be developed (e.g., baffling) for improving clarifier hydraulics. This, in turn, will result in enhanced process efficiency.

Capacity of primary clarifiers as an individual unit operation is typically evaluated based on surface overflow rate (SOR) and biochemical oxygen demand (BOD) removal criteria. Primary clarifier performance is dependent on SOR and sludge withdrawal rates. Performance expectations are tied to the process capacity of the subsequent biological systems and primary sludge handling systems. Secondary clarifier performance is not only dependent on SOR, but also mixed liquor suspended solids (MLSS) concentrations and recycle ratios, aeration system performance, and sludge withdrawal rates, making it a much more complex system to test (Parker et al, 1999). Slug dye tests and the solids distribution/flow pattern tests are carried out during the stress tests in an effort to better assess the hydraulic characteristics of the settling tank.

A desktop review or hydraulic calculation check (typically computer based) based on the plant hydraulic profile is the first step to determine the existing limitations and what is practical before embarking on a stress testing program. Typical limitations examined as part of the desktop review include; approach velocities, recycle rates, diurnal peak considerations, and freeboard limitations.

3.2 Biological Considerations

Stress tests are carried out to determine the performance of a settling tank (typically for secondary treatment processes) in terms of effluent suspended solids concentration for a variety of operating conditions. Effluent suspended solids concentration is examined against parameters such as: SOR, solids loading rate (SLR), return sludge suspended solids (RSSS) concentration, return activated sludge (RAS) flow rate, sludge settling characteristics, dissolved suspended solids (DSS) concentration, and sludge blanket depth (Gernant et al, 2009; Peng et al, 2007).

Before starting a stress test, existing plant operational data must be examined in detail to understand the limitations and operational constraints. Laboratory data for a unit process are especially critical for a fair comparison with stress testing results. One essential element of stress testing is that a facility needs to have multiple settling tanks so as to not impair continued treatment performance of the plant while still having a settling tank available for testing purposes. It is difficult to conduct a stress test with a single clarifier unless creative ways are found to increase the SLR to the test tank, such as diverting a portion of the effluent to the tank influent to increase SLR (Wahlberg, 2004).

3.3 Solids Handling Considerations

Stress testing for solids processing systems is a challenging and often difficult task. This usually involves a large number of operational variables to consider. Furthermore, process efficiency is often difficult to obtain in "real-time data" and many plants do not usually gather operational data beyond the solids mass entering and leaving the system (Klein, 2008).

Solids processing systems are usually rated in terms of pounds of solids per day. This means that both hydraulic loading and feed solids concentration have to be taken into account. Modifying the solids concentration is more complex than adjusting a pump set point. It is rarely possible to make adjustments during a test run, thus a target feed concentration has to be selected weeks prior testing. This might require plant staff to modify plant operations to meet the selected target. Historical data analysis and plant staff experience will usually indicate the most practical feed concentrations attainable.

During the course of this literature review, no examples were found focusing on solids handling stress testing for the purpose of managing peak wet weather flows. Though influent flow increases during peak wet weather events, total suspended solids (TSS) loading to the unit processes is typically reduced because of dilution. First flush considerations will need to be examined however; the first flush and peak wet weather event may not coincide. Depending on the region and climate, considerations for the first flush will introduce a noticeable higher solids loading content to the treatment facility from the collection system, following a period of little to no rainfall.

Existing solids handling processes typically have sufficient capacity for single wet weather events. However, back-to-back storm events can exceed the capacity of sludge processing units, such as digesters and storage tanks. A review of the solids handling unit processes should be undertaken as part of the overall stress testing approach (Newbigging et al, 2004).

Section 4: Stress Testing Strategies and Implementation

The results from the literature search were summarized into four regions of the United States (US) — Northeast, Midwest, South, and West (see Figure 4.1). The delineation of geographic regions was adopted from the US Census Bureau based on the 2010 census. For each region, climate, population, and receiving water considerations were characterized to identify regional issues and drivers for wet weather flow management and stress testing at POTWs (HowStuffWorks, 2011a-e). Regional examples of stress testing programs are included in this section.

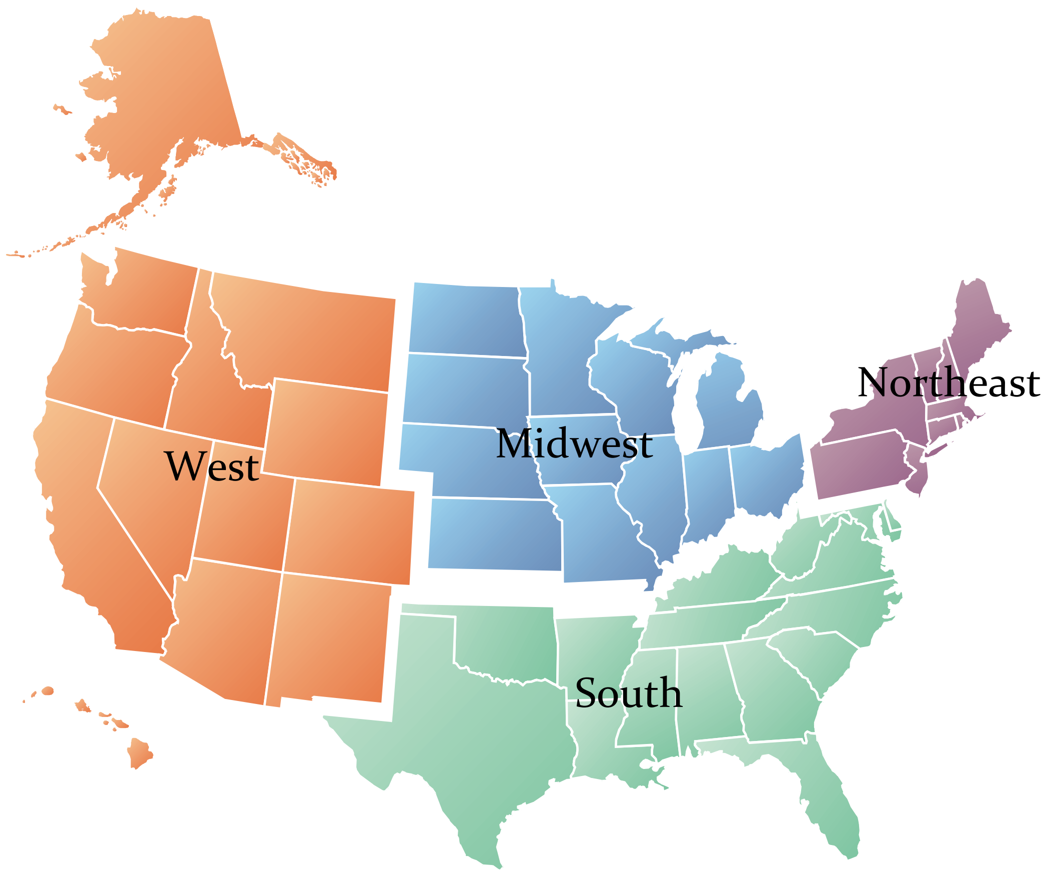


Figure 4.1. Regions of the United States

4.1 Northeast Region

4.1.1 Climate

The Northeast climate is humid continental. Winters are cold with temperatures averaging 0-25^{O}F, and snowfall ranging from 32-100 inches. Summers are warm and humid, with temperatures averaging 65-80^{O}F. "Noreaster" storms in the winter provide steady, but light rain along the coast and spring and summer thunder storms account for the remaining rainfall. Annual rainfall ranges from 32-64 inches.

4.1.2 Population

The Northeast region experienced the lowest population growth rate in the United States between the years 2000 and 2010 with a rate of approximately 3.2 percent (US Census Bureau, 2010). Growth rates were highest in the northern states of Maine (4.2%) and New Hampshire (6.5%) and lowest in Pennsylvania (3.4%), New York (2.1%), and Rhode Island (0.4%).

4.1.3 Receiving Water Considerations

Major water quality drivers in the Northeast include combined sewer overflows (CSOs), Total Maximum Daily Load (TMDL) requirements, nutrient limitations, pharmaceuticals and personal care products (PPCPs) in water supplies, and beach closures after major storm events related to high fecal coliform counts. CSOs are prevalent throughout the Northeast with the majority of cities implementing Long Term Control Plans and many cities under consent decrees to reduce overflows. Approximately 772 cities serving 40 million people in the United States are served by combined sewer systems (US EPA, 2010a). At least 40,000 sanitary sewer overflows (SSO's) are estimated to occur throughout the United States (US EPA, 2010b). SSOs are caused by excessive runoff entering the systems (I&I), excessive sewage flows, blockages, and/or mechanical failures in the system.

SSO and CSO control plan costs in major Northeast cities are estimated to be in the billions of dollars. TMDL compliance is leading to the development of new approaches throughout the East. With sediment being the most common TMDL, flow-based approaches in areas where erosion is a major problem are being developed. After storm events, beach closures along the coast and inland rivers related to high fecal coliform counts are major concerns.

4.1.4 Regional Stress Testing Examples

During the course of the literature review, three published examples of municipalities conducting stress testing in the Northeast were identified and are summarized below.

4.1.4.1 Philadelphia, Pennsylvania

The Philadelphia Water Department (PWD) manages stormwater, drinking water, and wastewater within Philadelphia. The PWD has embarked on a watershed-based methodology using a balanced "land-water-infrastructure" approach to control CSOs. The PWD uses an integrated regional watershed planning approach emphasizing adaptive management to appropriately balance each approach. Each component is balanced to achieve an overall solution to control CSOs. Land is focused on source control, water on ecosystem restoration, and infrastructure on capital improvement projects. The overall goal is to minimize the introduction of runoff into the sewer system.

The PWD has implemented a Capital Improvements Program to construct CSO infrastructure to reduce CSOs. Projects include storage, conveyance, and treatment facilities (Philadelphia Water Department, 2011).

In keeping with their long-term control plan strategy, PWD conducted stress testing at three of its wastewater treatment facilities looking at both primary and secondary treatment processes. These were Southeast, Southwest, and Northeast Water Pollution Control Plants which are of similar design and all underwent secondary treatment plant expansion in the late 1970's. A series of stress tests was performed with varying

SORs for primary treatment, and secondary clarification testing at constant SORs and 15-minute sampling intervals for TSS and BOD_5.

The results showed that a dramatic increase in primary treatment capacity was possible during peak flow conditions. At the Southwest, Southeast, and Northeast treatment facilities, primary capacity was increased from average flow conditions by 115 million gallons per day (MGD), 92 MGD, and 71 MGD, respectively. Secondary treatment capacity was not noticeably increased due to current MLSS strategies and some operational constraints. It was noted that by increasing primary sludge removal pumping rates during peak flows, a reduced organic load would be transmitted downstream to the secondary treatment process. This approach would allow for greater removal at all flow rates (Ferguson et al, 2000).

4.1.4.2 Allegheny County, Pennsylvania

A stress testing program was carried out by Allegheny County Sanitary Authority (ALCOSAN) (Pittsburgh, PA) focusing on primary treatment performance as part of their initiative to reduce CSOs. The main focus of their testing program was to maximize primary treatment capacity through existing process units. A sophisticated approach was undertaken involving the use of a hydraulic model and a year-long test schedule to evaluate various flow conditions. The results showed that the existing primary sedimentation tanks had an additional hydraulic capacity of approximately 60 MGD, resulting in a peak surface over flow rate (SOR) of 3,100 gallons per day per square foot (gpd/sf). All of this equated to an increase in primary treatment over the rated design value of 540 MGD, provided this was accomplished without co-settling of waste activated sludge (WAS). Sampling and laboratory analyses demonstrated similar primary treatment performance in terms of TSS and BOD removals at typical dry weather SORs and peak SORs. Primary effluent TSS and BOD concentrations were essentially the same during dry weather and wet weather conditions. Based on modeling, this method for mitigating CSOs in the collection process aided in capturing of up to 65 percent of the CSOs in the collection system (Mehrotra, 2008).

4.1.4.3 Bergen County Utilities, New Jersey

The Bergen County Utilities provides treatment for several member communities served by older combined collection systems with significant infiltration. At the treatment facility, flows above 160 MGD were not able to be treated in order to protect the established biomass in the secondary treatment process. Restricting wet weather flows to the treatment plant resulted in overflows upstream of the treatment facility. In order to reduce the upstream overflows, a stress testing program was established that focused on the secondary treatment process since there was a deficiency in treatment capacity compared to primary treatment.

The use of polymer addition as part of the secondary clarification process for peak wet weather flow conditions was the focus of the stress testing program. A series of jar and field tests was conducted to determine the optimum dosing rate for the selected SOR for clarifier loading. The results indicated that secondary treatment capacity could be expanded by 48 MGD for excellent (effluent suspended solids (ESS) below 15 mg/L), and 80 MGD for acceptable removal (ESS between 30 to 40 mg/L) for short durations corresponding with a peak wet weather event. This was the only documented occurrence in this literature review of this approach being taken for increased secondary treatment capacity. Other documented cases in this literature review focused on process optimization, such as MLSS concentration, pumping rates, etc. Economic information was not available for predicted chemical and labor cost to determine a preliminary lifecycle cost for this approach (Patoczka, 1998).

4.2 Midwest Region

4.2.1 Climate

Climate in the Midwest is characterized as humid continental in the eastern portion, and semi-arid on the western edge of the region. Winters are cold, with temperatures averaging 0-30^{O}F and snowfall ranging from 10-60 inches. Summers are warm, humid and wet, with average temperatures of 70-85^{O}F. Rainfall is generally heaviest in spring and summer months, averaging between 16-35 inches.

4.2.2 Population –

Population growth in the Midwest is low, with a growth of 3.9 percent between 2000 and 2010 (United States Census Bureau, 2010). Within the region, growth was highest in Missouri (7.0%), and Minnesota (7.8%), while negative growth was experienced in Michigan (-0.6%).

4.2.3 Receiving Water Considerations

Major water quality drivers in the Midwest include CSOs, SSOs, nutrient limitations, and nonpoint source pollution. Nonpoint source pollution attributed to urban and agricultural runoff is increasingly becoming a major water quality driver in the region with impacts downstream and outside of the region in the Gulf of Mexico. Contamination and water quality issues in the Great Lakes have been at the forefront of discussion in this region.

4.2.4 Regional Stress Testing Examples

During the course of the literature review, two published examples of municipalities conducting stress testing in the Midwest region were identified and are summarized below.

4.2.4.1 Indianapolis, Indiana

Indianapolis has two major water issues revolving around water quality in waterways and occasional peak demands exceeding water system capacity of their CSO program. Indianapolis is performing program improvements as part of a consent decree with the United States Environmental Protection Agency (USEPA) and Indiana Department of Environmental Management (IDEM) to reduce raw sewage overflows (CSOs). Efforts to comply with the decree and to reduce peak water demands are highlighted in this section.

Raw Sewage Overflow Long Range Control Plan and Plant Stress Testing

To improve water quality and comply with a USEPA and IDEM consent decree, the City of Indianapolis implemented a CSO long-term program aimed at reducing the occurrences of sewage overflows into waterways. Currently, the White River and its tributaries do not meet Indiana state standards for dissolved oxygen, and bacteria. During the late 1990's, a stress testing program was conducted to evaluate maximizing wet weather flows to the existing treatment facilities, keeping with the minimum control principal #4 (MC4) of the nine minimum control standards (US EPA, 1994). The results demonstrated that maximizing flow to existing treatment facilities was a viable solution, allowing for an additional 10 to 30 MGD of additional capacity at the City's numerous treatment facilities. The evaluation of maximum flow limits also took into consideration other impacts on the facilities including reduced freeboard and additional stress on the concrete structures, limitations of the plant internal piping system due to pipe age, and process equipment coming close to the end of its operational lifespan. To date, no additional stress testing has been carried out, and results from the stress testing program are being evaluated for inclusion into the wet weather operational scheme.

Based on the literature review, implementation of the long term control plan was expected to reduce overflows from 45-80 times per year to two to four times per year. To reduce overflows, the plan contains multiple components, mainly focusing on real-time controls and storage as the primary mitigation means. Major components include construction of a deep tunnel to capture overflows for pump-back and treatment after peak flows subside, new sewers to capture overflows and discharge to the tunnel, and separation of combined sewers (City of Indianapolis, Department of Public Works, 2008, 2011 and 2006).

4.2.5.2 Milwaukee, Wisconsin

Milwaukee, Wisconsin, has undertaken multiple initiatives to address wet weather water quality issues. The City's Office of Environmental Sustainability has developed a green program for the City which includes water quality improvement. Milwaukee Metropolitan Sewerage District (MMSD) has initiated a $1 billion overflow reduction plan to be completed in 2011 to reduce CSO and SSOs to receiving waters. Prior to initiating efforts to reduce CSOs/SSOs, an average of 8 to 9 billion gallons of water in the sewer system was released to Lake

Michigan per year. Additional benefits of the plan include a reduction in non-point source pollutants (MMSD, 2009).

The City's two main treatment facilities are Jones Island and South Shore, with peak treatment capacities of 330 and 450 MGD, respectively. As part of the 2020 Facilities Plan the South Shore facility is to expand biological nutrient removal (BNR) to treat all flows from the existing 300 MGD capacity secondary treatment process. Currently this project is beginning conceptual design, with activated sludge expansion and physical-chemical processes (both ballasted and flocculation only, without bioenhancement) being considered as part of the main process upgrade selection (Fandk and Smith, 2006).

In 2005 the Jones Island facility embarked on a stress testing program to investigate peak flow capabilities resulting from numerous constraints in the secondary treatment process. After thorough investigation, it was determined that poor settleability of the mixed liquor (ML) was the main capacity limiting factor. To address this deficiency, a modification of the aeration system was employed to have a small portion of the aeration system serve as biosolids storage during wet weather events. This process is referred to as tapered aeration and is often used in storm events, sometimes in conjunction with the step-feed approach to lower the peak oxygen demand in the aeration tanks and corresponding food to mass (F/M) ratio. The stress testing and subsequent change in system operation resulted in full reinstatement of the secondary treatment capacity during wet weather events.

The decision to restore performance to the Jones Island wastewater treatment plant (WWTP) was due to its centralized location in the collection system and to protect process performance at the South Shore WWTP. The South Shore WWTP has undergone upgrades in the past decade and features a biosolids program producing Class A reusable biosolids. Any significant disruption to the plant could result in a loss of biomass affecting the quality and market of this product. This market driving consideration is one of the many aspects that must be balanced with operations and funding before a stress testing program is initiated (Marten et al, 2009).

4.3 South Region

4.3.1 Climate

Climate in the South is characterized as humid and sub-tropical. Winters are mild in the south, with little to no snowfall, and average temperatures ranging 50-70^{O}F. Summers are hot and humid, with average temperatures ranging 80-90^{O}F. Annual rainfall averages between 32-64 inches with significant rainfall events occurring both in the summer and winter.

4.3.2 Population

The South region experienced the highest growth rate in the country of approximately 14.3 percent from the year 2000 to 2010 (US Census Bureau, 2010). Growth was highest in Georgia (18.3%), Florida (17.6%), Texas (20.6%), and lowest in Washington, D.C. (5.2%) and West Virginia (2.5%).

4.3.3 Receiving Water Considerations

Water quality is driven in the South by TMDLs, environmental resource permits, and tourism. Major TMDL impairments in the South include nutrients, bacteria, and dissolved oxygen. Environmental resource permits are drivers of water quality in Florida and other states, especially for the aquifer storage and recovery programs (US Census Bureau, 2011). In Florida, environmental resource permits are required for projects involving construction or a significant alteration to storm water or surface water management systems. Water related tourism in the South is a major industry, and providing clean inland and ocean/gulf waters is essential to maintaining that industry. CSOs are not prevalent in the South. In a few sub-regional areas, including Atlanta and Columbus, Georgia, Nashville, Tennessee, and Louisville, Kentucky CSOs are water quality concerns.

4.3.4 Regional Stress Testing Examples -

During the course of the literature review, two published examples of municipalities conducting stress testing in the South region were identified and are summarized below.

4.3.4.1 Atlanta, Georgia

A CSO Consent Decree was issued in 1998 commiting the City of Atlanta to an accelerated program of activities designed to improve water quality in metro Atlanta streams and the Chattahoochee and South Rivers. To this end, the City has expedited ongoing sewer improvements, including an intensive evaluation and rehabilitation of sewer pipe conditions; a grease management program; and a capacity certification program for new development. Additionally, improvements to the main treatment facility have been scheduled relating to increasing capacity for both daily and peak flow conditions (City of Atlanta, Department of Watershed Management, 2011).

The R.M. Clayton Water Reclamation Center (WRC) is an activated sludge plant located in Northwestern Atlanta and is one of the largest wastewater treatment facilities in the Southeastern United States. The WRC serves portions of three counties in addition to most of the City of Atlanta, and provides advanced secondary treatment for approximately 80 MGD of wastewater. The WRC was permitted to discharge 100 MGD of treated wastewater into the Chattahoochee River on a maximum month basis.

The WRC required upgrades and improvements because the plant's service area was increasing in density (i.e., impervious area, and population). Besides flow increases, the plant needed to be expanded because it was unable to pass all flows that it received through the entire treatment process. Primary effluent was blended with secondary effluent when flows reached approximately 110 MGD, and flows in excess of 180 MGD were bypassed with only screening and disinfection. The WRC expansion stress testing program was conducted to rerate the plant for an annual average day flow of 120 MGD from its existing 103 MGD rating. This allowed an increase of 17 MGD of full secondary treatment capacity for all flow conditions, and thereby reducing primary effluent blending during wet weather events (Camp, Dresser, McKee, 2002).

4.3.4.2 Miami, Florida

The Miami-Dade Water and Sewer Department is the regional water and wastewater utility providing service to over thirty muncipalities in southeast Florida. In the late 1980's and early 1990's, enforcement action from the United States EPA and Florida Department of Environmental Protection led to development of two separate Consent Decrees resulting in an estimated $1 billion in improvements. Historically, to address SSOs, theMiami-Dade Water and Sewer Department focused its efforts on plant improvements. Since 1990, an increasing effort has been placed on improving its collection system to reduce large sources of I/I (Maimi-Dade County, Miami-Dade Water and Sewer Department, 2006).

The North District Wastewater Treatment Plant is a 112 MGD treatment facility located in Miami, Florida. In the late 1990's the facility conducted a stress testing program in an effort to maximize secondary treatment capacity, mitigate SSOs in the collection system, and reduce the practice of blending wet weather discharges. Results from the stress testing program revealed that an additional 80.5 MGD in secondary treatment capacity could be realized if process improvements and additional baffling and weir arrangement were optimized (Jimenez 2008).

4.4 West Region

4.4.1 Climate

Climate in the West is the most diverse of all the regions in the United States. It ranges from arid to semi-arid in the southwestern portion, marine and Mediterranean along the coast, and highland in the mountain and northern portions. Winters are typically cool to mild with average temperatures ranging from 30-40^{O}F in the mountain and Pacific Northwest areas, to 50-60^{O}F in the southwest and along the coast. Summers are dry with low humidity, with average temperatures ranging from 50-70^{O}F in the mountain and Pacific Northwest areas, and 85-95^{O}F in the southwest. The majority of precipitation falls along the coast or in areas of increased elevation. Precipitation tends to occur with greater extent during the winter months in the form of rain in coastal areas and snow in the mountain and northern areas. Average annual rainfall ranges from 8-15 inches in the southwest, 16-64 inches along the coast, and as high as 96 inches in the Cascade Mountains. Snowfall can range from 32-64 inches in the mountains.

4.4.2 Population

Between 2000 and 2010, population growth in the West was the second highest of all the other regions, with a growth rate of approximately 13.8 percent (US Census Bureau, 2010). Growth rates were the highest in the desert states of Arizona (24.6%) and Nevada (35.1 %); and lowest in the Rocky Mountain States of Wyoming (14.1 %), and Montana (9.7%).

4.4.3 Receiving Water Considerations

Within the West, water quality is driven by achieving compliance with TMDLs, compliance with discharge requirements, nonpoint source pollution, total dissolved solids (TDS) management, and to a lesser extent CSOs concentrated in the northwest portion of the region. TMDLs have and continue to be adopted in sub-regions of the West for both inland waters and oceans impacting both dry and wet weather discharges. Bacteria and metals are the main TMDLs in the region. Nonpoint source pollution impacts both groundwater and surface waters in the West and requires watershed-based management plans. Compliance with discharge requirements has required innovative solutions to reduce discharge volumes and refinement in treatment processes. High TDS or salinity levels are prevalent in western areas relying on water from the Colorado River and localized groundwater basins. High TDS levels adversely impact groundwater and agriculture, as well as potentially limit the application of recycled water for urban irrigation.

4.4.4 Regional Stress Testing Examples

During the course of the literature review, two published examples of municipalities conducting stress testing in the West region were identified and are summarized below.

4.4.4.1 Seattle, Washington

Management of CSOs began in the 1970s for the greater Seattle area. There are two municipal utilities that have significant involvement in the CSO program; King County (which owns and operates the main interceptors and treatment facilities) and Seattle Public Utilities (SPU), which owns and operates the service lines inside Seattle. Each entity has a significant number of outfalls that discharge CSOs to waterways in Puget Sound and Lake Washington. Each utility can have a significant impact on the other, since the systems are interconnected, and wastewater flow from SPU is conveyed to King County's treatment facilities. SPU's extraneous flow control measures have focused on source reduction and use of green infrastructure to reduce impervious surfaces, while King County has examined wet weather improvements to their treatment facilities.

Due to increased population density in the northeast sewer sub-basin and aging treatment facilities in the greater Seattle area, King County conducted stress testing at the Renton Wastewater Treatment Plant in part to establish the design criteria for the new Brightwater treatment facility currently under construction. Once completed the Brightwater treatment facility will have a capacity to treat 14 MGD average daily flow, and 36 MGD for peak wet weather flow.

Stress testing was carried out at Renton Wastewater Treatment Plant to determine reasonable loadings for the use of chemically enhanced primary clarification (CEPC) for peak wet weather flows. The use of the CEPC process was of critical importance to mitigate and reduce influent TSS to the downstream membrane bioreactor (MBR) process. High TSS and BOD loadings could clog and reduce the lifespan of the MBR equipment. Stress testing showed that a design SOR of 3,600 gpd/sf for average flow conditions could be achieved with a peak loading rate of 5,400 gpd/sf compared to the standard 1,200 gpd/sf employed at the existing King County treatment facilities. The design approach of additional BOD and TSS removal through CEPC resulted in reduced BOD loading on the downstream MBR process, thereby, making the combination of processes economical at the expanded project scale (King County, Combined Sewer Overflow Program, 2011).

4.4.4.2 Corona, California

During the course of this literature review, a small number of published studies were found for facilities in California conducting stress testing for handling peak wet weather flows. The primary driver for one published stress testing program was for plant consolidation to reduce capital expenditures. It is important to note that effluent water quality requirements are among the most stringent in the nation in keeping with the Title 22, Article 7 wastewater reuse strategy (California department of Public Health, 2011).

The City of Corona was facing a capacity shortage and examined numerous options to reduce capital expenditures for plant expansion. The facility features a BNR process with a step-feed mode of operation and total treatment capacity of 15.5 MGD. A stress testing program focusing on primary and secondary treatment was undertaken with careful consideration of the BNR process. A revised version of the International Water Association Activated Sludge Model2 (ASM 2) was used for process simulations (Daiger et al, 1998). The model was necessary due to the various potential changes in the process flow schemes ranging from aeration modifications, MLSS concentrations, and different flow split scenarios though the chemically enhanced primaries. The end result was that an additional 3.5 MGD of capacity was achieved mainly through process optimization, but with some equipment replacement necessary as part of equipment lifespan phasing (Roxburgh et al, 2005).

Section 5: Case Studies

Case Study Criteria

Prior to the start of the literature review, selection criteria were established to ensure a well rounded approach was being utilized to identify key facilities as potential case study candidates. Characteristics used as selection criteria included:

Size of the facility. Larger treatment facilities tend to be located in metropolitan areas that often have large diameter main interceptors as part of their collection systems. These large interceptors dampen the effects of wet weather and result in lower peaking factors to the treatment facilities. Smaller to medium size facilities tend to have higher peaking factors as a result of shorter time of travel in the collection system. Therefore, a wide range of plant sizes were sought to consider these peak flow differences.

Regional location of the facility. To provide a cross-section of treatment facilities across the United States the literature search included a regional perspective. Regional characteristics such as rainfall and climate differences, population, and water quality concerns affect drivers for stress testing. It is very difficult to have a "one size fits all" approach for stress testing.

Treatment process. Each treatment process is unique and certain approaches that will work for one will not necessarily translate into comparable results for another process (i.e., pure oxygen, conventional activated sludge, BNR, etc.). Case studies encompassing different types were considered for easier comparison of treatment facilities across the United States.

Peak wet weather flow handling problem definition. Only treatment facilities that performed stress testing as part of wet weather flow management were considered candidates for case studies. Treatment facilities that had performed stress testing for plant consolidation, although helpful, would not be included for this detailed evaluation.

Loadings (both hydraulically and biologically). The results from the literature search identifying treatment facilities that included both hydraulic and biological aspects of stress testing were considered for case studies.

Combined or separate collection systems. Wastewater characteristics can differ between separate and combined sewer systems. In addition, temperature influxes occurring from dilution in a combined system can affect reaction kinetics for both primary and secondary treatment process. This effect is more pronounced in a combined system than in a separate collection system. Case studies were considered from both types of collection systems.

Age of the facility. Given the aging infrastructure in the United States, a cross-section of older, established, and relatively modern plants was examined.

Level of documentation readily available. Facilities that had performed stress testing where limited information was available were not selected for detailed evaluation.

The evaluation criteria were revisited once the literature review process was complete to ensure a well-rounded selection had been achieved. To aid the reader in the selection of the case study candidates, Table 5.1 outlines the selected case studies with the preceding criteria in mind.

Table 5.1 Case Study Overview

Case Study	*Size of the Facility (ADF)*	*Region*	*Process*	*Stress Testing for Wet Weather Only*	*Combined System*	*Separate Sanitary System*	*Unique Features*
Jones Island WWTP	100	Midwest	Activated sludge, BNR	Yes	Yes		Original plant commissioned in 1925; Nutrient considerations
RM Clayton WRC	120	South	Activated sludge, BNR	Yes	Yes		Restore secondary capacity for increased ADF and peak flow; Simple cost-effective solutions
Mauldin Road WWTP	20	South	Activated sludge, BNR	Yes		Yes	High peaking factor of 8; Extensive modeling for process considerations; Equalization basins
North District WWTP	112	South	Activated sludge, high pure oxygen setup	Yes		Yes	CFD Modeling; Aquifer storage and recovery considerations
City of Corona Plant No. 1 and No. 2	5.5/3	West	Activated sludge, BNR	No		Yes	Rerating for increasing population density; Process Modeling

Case Study #1

Jones Island Wastewater Treatment Plant

Plant Description

The Jones Island Wastewater Treatment Plant (WWTP), which is owned by the Milwaukee Metropolitan Sewerage District (MMSD), is a large advanced secondary treatment plant constructed in phases over approximately 85 years of operation. Liquid treatment processes at the plant include coarse screening, grit removal, primary clarification, activated sludge and disinfection. The plant's design average daily flow capacity is 123 MGD, maximum daily flow capacity is 300 MGD, and peak instantaneous flow capacity is 330 MGD. Jones Island is operated by a private enterprise under contract to MMSD. Due to the cold climate, this plant receives a portion of its wet weather flow from snow melt.

Facility

Jones Island

Location

Milwaukee, Wisconsin (cold weather climate)

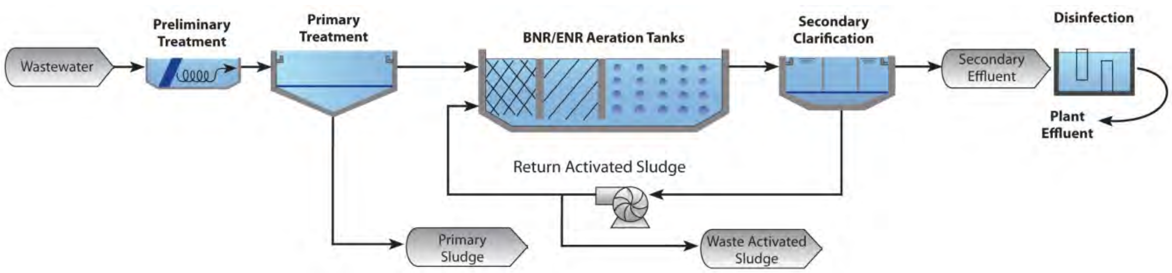
Collection System

Combined

Unique Features

BNR process

Plant commissioned in 1925



Stress Testing Objectives/Goals

A hydraulic and process capacity and operations review of the Jones Island WWTP was completed to determine the available wet weather flow capacity of the facility and to identify methods of improving the limited wet weather treatment capacity and performance due to underperformance above 225 MGD.

Stress Testing Methodology

A desktop analysis was conducted to verify hydraulic capacity and identify specific bottlenecks in the treatment process. Additionally, a computer-based process model was utilized to identify process capacity limitations that might result in treatment deficiencies (Merlo et al, 2007).

Stress Testing Results

The study evaluated both the biological treatment and hydraulic capacity of the activated sludge systems, and determined that secondary clarification was the most significant process bottleneck in terms of peak wet weather capacity. The evaluation found that secondary treatment peak flow capacity varies from approximately 200 to over 330 MGD depending on the mixed liquor concentration and settling characteristics. The MLSS settleability, as measured by stirred sludge volume index (SSVI), was highly variable, noting an historic average of 90 mL/gram (g), with values ranging from 44 to 174 mL/g. To evaluate the effect of sludge settleability on secondary treatment capacity, the study used biological modeling. It was estimated that, with a MLSS concentration of 2,200 mg/L, secondary treatment peak flow capacity would be:

405 MGD at an SSVI of 72 mL/g (very good settling sludge).

295 MGD at an SSVI of 83 mL/g (good settling sludge).

The study noted that the Jones Island WWTP activated sludge systems experienced periods of poor ML settleability, commonly referred to as episodes of bulking (both filamentous and non-filamentous). This condition resulted in poor settling activated sludge that can decrease secondary clarifier capacity, and as a result, the peak flow treatment capacity of the plant.

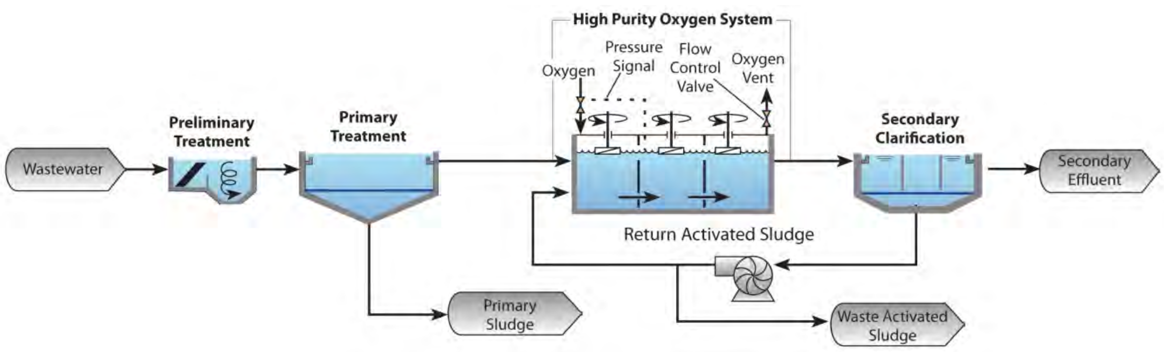
To address secondary treatment plant capacity, a number of corrective actions were implemented while keeping the process in-service. These mainly consisted of low-cost capital improvements to optimize capacity during peak wet weather flow periods. Six of the plant's thirty-two aeration basins were converted to biosolids storage basins, serving as dual purpose units that automatically switch back after a storm event via pumping. Additionally, other changes to the existing secondary clarifiers focusing on the sludge withdrawal and RAS system were undertaken resulting in additional treatment capacity. The recommendations were incorporated into the facility , with the end result restoring lost capacity .

Case Study #2

North District Wastewater Treatment Plant

Plant Description

The North District Wastewater Treatment Plant (NDWWTP) is located in Miami, Florida. The NDWWTP features conventional screening, primary clarification, and an activated sludge system using a high purity oxygen (HPO) process, followed by secondary clarification and disinfection. Treated effluent is discharged to the Atlantic Ocean by means of an ocean outfall or is pumped under pressure to four deep injection wells.



Facility

North District

Location

Miami, Florida

Collection System

Separate

Unique Features

CFD Modeling

Aquifer Storage and Recovery

Stress Testing Objectives/Goals

Two different secondary clarifier sidewall depths (12 feet (ft) and 20.5 ft) were being used as part of the secondary treatment process. The secondary treatment process consisted of eight shallow and six deeper clarifiers. The goal of stress testing was to verify if higher loading rates in the secondary clarification process were possible through enhancements to the shallower clarifiers to address peak hour flows associated with wet weather events in an effort to reduce capital expenditure cost.

Stress Testing Methodology

A series of field tests was conducted to determine secondary clarifier performance under peak flow conditions. Mixed liquor settling and compression characteristics were determined by performing batch settling testing using settling columns following the WERF/CRTC protocol (Walberg, 2004).

Secondary clarifier stress tests were conducted following the WERF/CRTC protocol (Wahlberg, 2004) to measure the response of the test clarifiers to progressively increasing hydraulic and solids loadings. Some secondary clarifiers were removed from service to increase loading to the test unit in service.

A computational fluid dynamics model (CFD) was compiled using the existing plant drawings. The field and laboratory data were collected and used to calibrate the CFD model. Once the CFD model was properly calibrated it was used to establish secondary clarification capacity for the shallow and deep clarifiers. Additionally, the CFD model predicted flow velocity vectors and solids concentration through a two-dimensional perspective of the clarifier, and aided in understanding the sludge blanket depth through the solids concentration profile.

For the purpose of this testing, the 7-day ESS limit of 45mg/L in the plant discharge permit was used as the point of failure.

Stress Testing Results

A series of stress tests were conducted to evaluate performance for peak flow conditions. The shallow clarifiers exceeded 45 mg/L after 8.75 hours (hrs) from the time the stress testing began, while the SOR and SLR reached 940 gpd/sf and 11.6 pounds per day per square foot (lb/d/sf), respectively. In contrast, the deeper clarifiers exceeded 40 mg/L 10.5 hrs into stress testing, with a SOR and SLR of 1,500 gpd/sf and 26.8 lb/d/sf, respectively. As anticipated, the deeper clarifiers demonstrated a greater loading capacity before exceeding the point of failure than the shallow clarifiers. For both clarifiers, the sludge blanket depth (SBD) at the time the units reach 40 mg/L was 10.5 ft for the shallow unit, and 6 ft for the deeper unit.

Once field and laboratory analysis had been completed, this information was used to calibrate the CFD model. Historical data for MLSS concentrations was entered into the CFD and a series of simulations were run with a limit of 45 mg/L ESS concentration as the threshold value. The CFD model was run with increasing flow rates to indicate maximum flow that could be maintained and still maintain regulatory compliance.

With the calibration complete, modifications to the CFD model were made to evaluate making hypothetical improvements to the shallow clarifier to determine if additional capacity could be achieved. These modifications included a larger center well, increased suction withdrawal capabilities, and modification to the effluent launders. The CFD model indicated that if all of the proposed improvements were implemented, peak flow capacity of the shallow clarifier could be increased to 24.5 MGD. This is an additional 8.5 MGD, or a 53 percent increase in capacity in the secondary treatment process for this clarifier size.

Case Study #3

Mauldin Road WastewaterTreatment Plant

Plant Description

The Mauldin Road Wastewater Treatment Plant (WWTP) is one of twelve wastewater treatment plants owned and operated by Western Carolina Regional Sewer Authority in Greenville, South Carolina. The Mauldin Road WWTP routinely treats a dry weather flow of 18 to 20 MGD, but experiences very high wet weather flows of up to 160 MGD during 2-year storm events. This equates to a peaking factor of 8, compared to dry weather conditions.

The primary cause of this high peaking factor is significant I/I from the collection system, in a service area that is almost entirely built out. The plant has a rated dry weather treatment capacity of 29 MGD and had been permitted to discharge a maximum of 70 MGD during wet weather operating conditions under a tiered NPDES permit. The Mauldin Road WWTP has used a combination of flow equalization and blending of primary effluent with tertiary effluent to treat wet weather flows as high as 100 MGD while successfully meeting permit requirements.

Facility

Mauldin Road

Location

Greenville, SC

Collection System

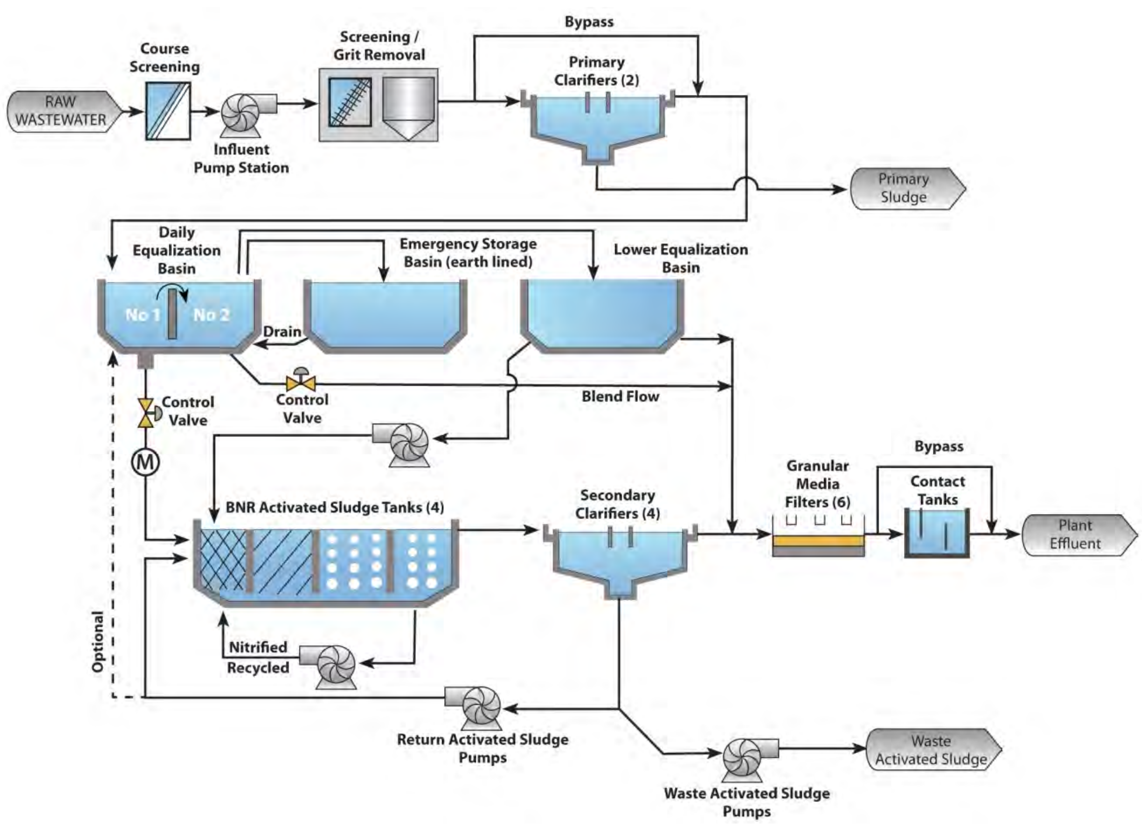
Separate

Unique Features

High peaking factor

Extensive process modeling

Equalization basins



Stress Testing Objectives/Goals

The goal of the stress testing was to verify if higher loading rates in the secondary clarification process were possible through enhancements to the secondary clarifiers to address peak hour flows associated with wet weather events. This would reduce capital cost expenditure for alternative wet weather treatment and reduce the amount of primary and secondary effluent blended during peak wet weather events. This goal is complicated by the fact that this facility has a significant portion of its flow recycled as part of the BNR/enhanced nitrogen removal (ENR) approach (Hildebrand et al, 2004).

Stress Testing Methodology

A series of field tests was conducted to determine secondary clarifier performance under peak flow conditions. Mixed liquor settling and compression characteristics were determined by performing batch settling testing using settling columns equipped with slow speed mixers to minimize wall effects following the WERF/CRTC protocol (Wahlberg, 2004). Mixed liquor flocculation parameters were determined following the protocol described by Wahlberg et al. (1999).

Clarifier stress tests were conducted following the WERF/CRTC protocol (Wahlberg, 2004), to measure the response of the test clarifiers to progressively increasing hydraulic and solids loadings. Some secondary clarifiers were removed from service to increase loading to the test unit in service. Additional flow for simulating wet weather events was available by utilizing an existing 35 MG equalization basin. The equalization basin features a multi-cell design to accommodate both peak flow during storm events and as part of daily diurnal flow management for protection of BNR/ENR bacteria population.

Additional lab testing was performed to gather pertinent data and was incorporated as part of a Biowin™ model. The process model aspect was incorporated since not only could internal plant recycle flow be taken into account, but additional information could be garnered in terms of wastewater strength (TSS and BOD characteristics). This was especially true during the height of the storm event where there are dilution concerns for the nitrifying bacteria and temperature effects.

Stress Testing Results

A series of stress tests was conducted to evaluate performance for peak flow conditions. The existing plant loadings to the secondary clarifiers include an SOR and SLR of 1,000 gpd/sf and 25 lb/d/sf, respectively. Stress testing revealed that a SOR and SLR of 2,000 gpd/sf and 36 lb/d/sf, respectively were possible while keeping the effluent limitation of 15 mg/L TSS. In both instances the MLSS concentration was kept at 3,500 mg/L.

The results from the stress testing were used to calibrate the BioWin™ model. The model was used to predict plant solids inventory in the secondary clarifiers and process performance for nitrogen and phosphorus removal. The model was able to extrapolate that, during winter time peak flow conditions, the existing MLSS concentration would be too low to cope with the increased dissolved oxygen content and lack of nitrifying bacteria present in the dilute influent. The process model determined a minimum of 3,600 mg/L would be necessary to ensure nitrifying conditions. Additional treatment modifications were simulated, including modification of aeration basins for a five stage BNR process and installation of fine bubble diffusers for increased oxygen transfer rates.

The stress testing concluded that flow through the secondary clarifiers could be doubled for peak flow conditions while protecting the acclimated bacteria population for the BNR for nitrogen and phosphorus removal.

Case Study #4

R.M. Clayton Water Reclamation Center

Plant Description

The R.M. Clayton Water Reclamation Center (WRC) is an activated sludge plant located in Northwestern Atlanta and is one of the largest wastewater treatment facilities in the southeastern United States. The WRC serves portions of three counties in addition to most of the City of Atlanta, and provides advanced secondary treatment for approximately 80 MGD of wastewater. The WRC was permitted to discharge 100 MGD of treated wastewater into the Chattahoochee River on a maximum month basis.

Facility

R.M. Clayton WRC

Location

Atlanta, GA

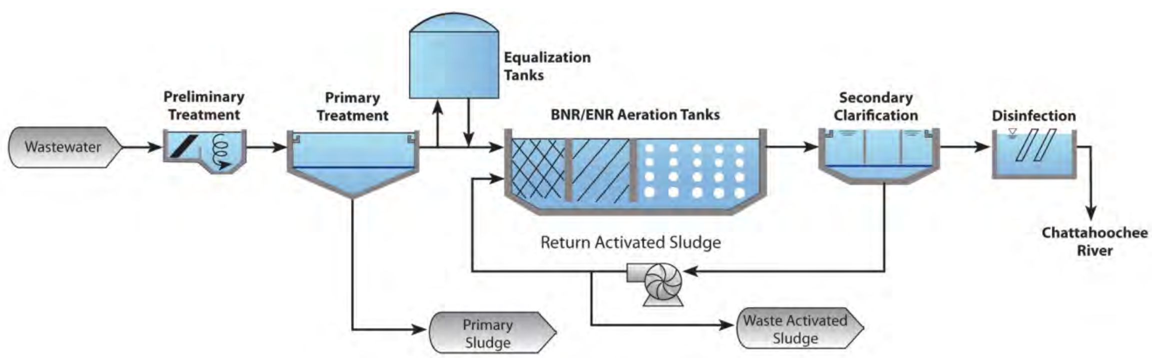
Collection System

Combined

Unique Features

BNR process

Restore process capacity and limit blending during wet weather events



Stress Testing Objectives/Goals

The WRC required upgrades and improvements because the plant's service area was increasing in density (i.e., impervious area, and population). Besides flow increases, the plant needed to be expanded because it was unable to pass all flows that it received through the entire treatment process. Primary effluent was blended with secondary effluent when flows reached approximately 110 MGD, and flows in excess of 180 MGD were bypassed with only screening and disinfection. The WRC expansion stress testing program was to rerate the plant for an annual average day flow of 120 MGD from its current 103 MGD rating. This allowed an increase of 17 MGD of full secondary treatment for all flow conditions, and limited blending during wet weather events.

Stress Testing Methodology

A state point analysis was conducted to determine the limiting solids flux and the corresponding underflow concentration (Levesque et al, 2006). Some site specific settling tests were conducted, in conjunction with a correlation between zone settling velocity and the SVI index developed by Wahlberg and Keinath (1988). To be conservative, higher influent flows and only the circular portion of the settling tank thickening area were considered.

Additionally, testing was conducted to determine sludge blanket depths and SS concentrations within the sludge blanket at two settling tanks.

Stress Testing Results

An evaluation of the estimated oxygen demand from the historical primary effluent BOD_5 and Total Kjeldahl Nitrogen (TKN) concentrations resulted in estimated oxygen demand peaking factors of 1.25 for maximum month, 1.43 for maximum week, and 2.03 for maximum day conditions. For rerating the plant, the aeration system was designed to provide sufficient DO to meet both BOD_5 removal and nitrification requirements at maximum week oxygen demands while maintaining a DO concentration of 2.0 mg/L in the mixed liquor. These oxygen demands are a direct function of the influent BOD_5 and TKN loading parameters and effluent ammonia limit. Revisions to the aeration system consisted of new and refurbished blowers, as well as addition of fine bubble diffusers to achieve the required DO concentration.

The next step was to determine whether or not the seals were leaking in the secondary clarification process. The TowBro® sludge removal system had a rotating "doughnut" at the center to provide connection to the underflow line. The "doughnut" had a 360^{o} rotating seal. This seal was recently replaced at another settling tank and was considered a possible source of leaks in other settling tanks. Clear supernatant from the sludge blanket could be pumped through the leaking seal, creating a "short circuit" resulting in reduced RAS pumping capacity.

In the control tank, the average RAS and blanket SS concentrations were approximately 12,000 mg/L and 14,300 mg/L, respectively. The SS concentration in the RAS was 84 percent of the blanket SS concentration, indicating that short-circuiting was not significant. On the other hand, the average RAS and blanket SS concentrations in the test settling tank were 8,375 mg/L and 28,608 mg/L respectively. The RAS SS concentration in the test tank represented only 29 percent of the blanket SS concentration. This indicated that significant short-circuiting was taking place in the test tank. Furthermore, uniform SS concentration along the bottom of the test tank indicated that the short-circuiting was not occurring along the bottom of the tank, but at the seal at the center column "doughnut" ring. As a result of this study, seals were checked in other settling tanks and a majority was found to be leaking. Replacement of seals led to significant reduction in sludge blanket levels.

The process modifications resulted in an additional 17 MGD available capacity in the secondary treatment train. This in turn reduced the amount of effluent blending necessary during peak wet weather flows.

Case Study #5 – Alternative Case Study

City of Corona Plant No. 1 and No. 2

Facility

City of Corona Plant No.1 and No. 2

Location

Corona, CA

Collection System

Separate

Unique Features

BNR process

Stress testing for plant re-rating study

Plant Description

The City of Corona (City) has three wastewater treatment plants that are currently rated for a total capacity of 15.5 MGD. Plant No.1 features a step-feed activated-sludge process rated at 5.5 MGD. Plant No. 2 utilizes a traditional activated sludge process for a capacity of 6 MGD. Plant No.3 is the newest, featuring a MBR process rated for 1 MGD with a build out capacity of 3 MGD. Waste secondary biosolids from Plant No. 3 are returned to the sewer system leading to Plant's No. 1 and No. 2.

Stress Testing Objectives/Goals

The City has experienced continued population growth since the 1990's and wastewater flows were approaching the rated capacities of the treatment facilities. Seeking alternatives to the large capital costs of new treatment facilities, the City investigated rerating two of the existing plants (plants No.1 and No.2) to provide additional capacity and maximize existing assets. An operational testing program (OTP) was developed to verify if treatment processes could be expanded through a program of short-term and long-term capital improvements, and if operational modifications could be made to the existing facilities. The goal was to provide an additional 3.5 MGD capacity from Plant No. 1 (3.0 MGD) and Plant No. 2 (0.5 MGD). The focus of testing centered on Plant No. 1.

Stress Testing Methodology

Prior to the start of field testing a desktop review focusing on the hydraulic and biological capacity of unit processes was conducted, revealing that primary sedimentation and secondary clarification were the limiting process units. Field tests were conducted with the primary sedimentation and secondary clarifiers. Flow was sent to these unit processes starting at the design rated flow, with all basins online, and increasing the flow by 0.5 MGD on consecutive days until proposed rerated flow was achieved with one basin offline. Influent and effluent sampling was conducted at scheduled intervals during each day of testing, with sludge blanket levels closely monitored. On-line turbidity monitoring was used as an indicator in the secondary clarification process.

The testing process involved three distinct steps. First, sampling along the length of the aeration basins for dissolved oxygen (DO) and oxidation-reduction potential (ORP) for nutrient considerations. Second, optimization of the BNR process using propriety modeling software based on the International Water Association Activated Sludge Model 2 (ASM 2). This modeling examined flow split possibilities, lowering BOD loads to the aeration basin, different DO concentrations, etc. The last step consisted of capacity testing to determine BNR performance at higher influent flows up to the targeted goal.

Stress Testing Results

As a result of the testing, several recommendations were suggested for short-term and long-term implementation, and operations. Recommendations are as follows:

Short-term

> To operate at higher MLSS concentrations consistently, a new gravity belt thickener would provide better reliability. Additionally, a polymer system could be added to the secondary clarifiers to improve solids settling at high flows and loads.

Installation of energy-dissipating baffling in the secondary clarifiers would improve performance.

Long-term

Aeration system capacity could be increased by enabling one of the standby blowers to be brought online during high influent BOD loading conditions.

To enable plug-flow operations of the aeration basins should an aeration basin be taken off-line, an internal recycle system could be installed for each basin. The extent of the recycle could be as high as 300 to 400 percent.

Operational

The RAS flow rate should be reduced as flows increase MLSS to around 3,400 mg/L and when MLSS concentrations are higher.

Stress testing demonstrated that the existing plant capacity could be expanded by approximately 33 percent through a sound testing process that examines all areas of a treatment facility. One of the key lessons learned during this testing program was it is essential to have plant operators integrated into the project team. The plant staff knowledge of existing plant operations can reduce the trial and error process and provide significant insight to a stress testing program

Section 6: Engineering Approaches/ Procedures Identified

Stress tests are carried out to determine the performance of a settling tank in terms of ESS concentration for a wide variety of operating conditions. Relationships between ESS concentration and SOR, SLR, RSSS concentration, RAS flow rate, sludge settling characteristics, DSS concentration, and sludge blanket depth are examined in great detail. Slug dye tests and solids distribution/flow pattern tests are also performed to assess the hydraulic characteristics of the settling tank.

A stress testing protocol was developed by the Water Environment Research Foundation/The American Society of Civil Engineers Clarifier Research Technical Committee (WERF/CRTC) (Wahlberg, 2004). During the course of this literature review, the majority of the published studies use this criteria as part of their stress testing approach or a derivation of this approach.

A typical stress test schedule is summarized in Table 6.1 (Wahlberg, 2004). The schedule is designed to have three different levels of SLR to be applied: low, medium, and high. The level of SLR is determined from the solids flux analysis. Each SLR is replicated three times (once for each day). Measurement of flows, SS concentrations, and sludge blanket height are conducted during each test. Four settling tests and two stirred SVI are carried out during each run. Influent DSS, effluent DSS, ESS and FSS concentrations are determined during each run. A slug dye test is carried out (either in the first or second replicate of each run), and solids distribution/flow pattern test is conducted (either in the second or third replicate of each run).

Table 6-1. Typical Stress Testing Schedule

<table>
<tr><th>Test Day</th><th>SLR</th><th>Replicate</th><th>On line Measurements</th><th colspan="3">Tests to be Conducted During Stress Tests</th></tr>
<tr><td>1</td><td>High</td><td>1</td><td rowspan="4">Conduct flow, suspended solids, and sludge depth with 1 minute intervals</td><td rowspan="4">Conduct 4 settling tests using settling column and 2 stirred SVI tests during each run</td><td>Slug dye test</td><td></td></tr>
<tr><td>2</td><td>Low</td><td>1</td><td>Slug dye test</td><td></td></tr>
<tr><td>3</td><td>Low</td><td>2</td><td></td><td>Continuous dye/solids distribution tests</td></tr>
<tr><td>4</td><td>High</td><td>2</td><td></td><td>Continuous dye/solids distribution tests</td></tr>
<tr><td>5</td><td>Low</td><td>3</td><td rowspan="5">If sludge blanket measurements are not available on-line, measurements should be done manually every 15-30 minutes</td><td rowspan="5">Carry out influent DSS, effluent DSS, ESS and FSS concentrations during each run</td><td></td><td></td></tr>
<tr><td>6</td><td>Medium</td><td>1</td><td>Slug dye test</td><td></td></tr>
<tr><td>7</td><td>High</td><td>3</td><td></td><td></td></tr>
<tr><td>8</td><td>Medium</td><td>2</td><td></td><td>Continuous dye/solids distribution tests</td></tr>
<tr><td>9</td><td>Medium</td><td>3</td><td></td><td></td></tr>
</table>

The WERF/CRTC protocol focuses on stress testing the secondary treatment process, but is amenable for primary stress testing as well although primary treatment is not typically considered the bottleneck in terms of process constraints. For the purpose of this report, a condensed version of the stress testing protocol for secondary treatment is presented for reference (WERF, 2009).

1. Obtain design data and blueprints of the entire secondary settling tank system, as well as the test settling tank. Identify the sampling locations for influent, effluent, and within the test tank. Become familiar with all the flow control systems for influent, effluent, and RAS, as well as flow ranges that can be applied.
2. Install flow measuring devices into the influent line (or effluent line) and RAS line, and capture the output signals electronically. This can be by means of a portable flow meter.
3. Determine a way to change the flow rate to the test tank to provide three different SLRs. Influent flow rate of the test tank can be changed by taking other clarifiers out of service gradually, by weir adjustment, or by partial gate closing. Keep the ratio of influent flow to RAS flow constant during each SLR test condition.
4. Install suspended solids probes into the influent line, effluent launder, and RAS line of the test tank, and capture the signal from the probes electronically.
5. Install an automated sludge blanket monitoring device in the test tank. If this is not possible, measure the sludge blanket depth in the test tank manually.

6. The stress test schedule shown in Table 6-1 should be applied. Each stress test will take a day. Determine the SLRs applied for each stress test. SLRs are determined from the solids flux analysis, based on the results of the mixed liquor settling tests conducted prior to the stress tests.
7. During each stress test, keep the influent flow constant to the test tank for a period of three theoretical hydraulic detention times.
8. During each stress test and when the influent flow is constant, collect data from the suspended solids probes, flow, and sludge blanket height measuring devices at least at one minute intervals. If sludge blanket height is measured manually, then the measurements should be carried out at 15-30 minute intervals.
9. After a period of time that is equal to two theoretical hydraulic detention times, carry out (at least once) influent DSS, effluent DSS, ESS, and FSS concentration tests.
10. During each stress test, conduct settling tests at four to six different suspended solids concentrations to determine the V_0 and k parameters of the Vesilind equation.
11. During each stress test, conduct two stirred sludge volume index (SSVI) tests, as described in *Standard Methods for Water and Wastewater (APHA, AWWA and WEF, 2005)*. In the SSVI test, mixed liquor is settled in a one liter graduated cylinder for 30 minutes, and the content of the graduated cylinder is stirred at one revolution per minute (rpm) during the settling.
12. During the first or second replicate of the stress test specified for a SLR and after three theoretical hydraulic detention times have passed, carry out slug dye test (if constant flow for three theoretical hydraulic detention times cannot be maintained, a slug dye test can be initiated earlier). Samples should be collected until at least 90 percent of dye mass is recovered.
13. During the second or third replicate of the stress test specified for a SLR and after three theoretical hydraulic detention times have passed, carry out continuous dye and SS distribution tests (if constant flow for three theoretical hydraulic detention times cannot be maintained, a slug dye test can be initiated earlier). If a manual core sampler such as a sludge judge is used, dye and SS sampling can be done at the same time. If a portable hand-held SS analyzer is used, then the core sampler is employed for taking dye samples only, and the SS concentrations at different depths are determined using the electronic device.
14. Continue the stress test at least for a period equal to one theoretical hydraulic detention time after three theoretical hydraulic detention times have passed, and after completion of the entire slug dye, continuous dye, and solids distribution tests.

A review of this protocol revealed several key parameters that are critical for treatment of wet weather flows.

Requirement

Existing information on the secondary clarifier system. Having a through understanding of the clarifier dimensions, RAS and influent flow rates, and limitations of the MLSS properties for loading at various SLR is critical.

Steady and constant flow to the test clarifier. Often to accommodate the peak flow rates for wet weather, operational changes are made well in advance to ensure treatment/process train survivability. This is often accomplished by tracking weather/satellite coverage.

Improvement

Increasing flow to the secondary clarification process is often accomplished by taking units off-line. While this does increase flow to the test clarifier, it does not address the dilute nature of the influent associated with wet weather conditions. Utilizing plant effluent as the make-up source flow could be one way to address this issue. Although temperature effects from a peak wet weather event could not be simulated it would give a better indicator of performance for dilute influent.

A minimum of three hydraulic retention times should be passed before changing testing conditions. This time period allows the clarification system to return to a steady state value.

All sampling should be performed by automatic means as much as practically possible. Every time sampling is performed manually, it introduces a potential source of error and could possible skew results.

Same team members perform the same role on each day of stress testing. It is beneficial to have same staff members perform the same function for each of the stress tests. This helps ensure repeatability of results and comparison of different operating conditions.

In theory, other tests can be used to better understand hydraulic conditions inside the settling tanks. One technique is the drogue current test. The drogue or a flow catcher is inserted into the clarifier to observe velocity patterns. One could think of this as a “chip-float test” for a secondary clarifier similar to that which is commonly used in open channel flow measurements.

During the course of the literature review, no examples of municipalities using this technique for a stress testing were identified. This testing procedure is very labor intensive and offers little benefit over the use of the CFD model to predict the velocity vectors.

Prior to the start of a stress testing program, coordination with the authorities having jurisdiction over the discharge permit is recommended. During the course of stress testing there is potential to violate one or more discharge limits while stress testing. Having all stakeholders aware of the procedure and schedule of stress testing and potential reasons for a permit excursion will assist in gaining approval to perform the testing and acceptance of the results.

Section 7: Evaluations and Conclusions

This report has illustrated the state of knowledge and practice of stress testing at POTWs. Through the analysis of real case studies, the report has identified actual plant improvements implemented to manage peak wet weather flows.

The literature review shows stress testing is suited to assist POTWs in maximizing the use of their existing facilities and assets. It is also recognized by regulatory agencies as an acceptable approach for municipalities to meet challenges such as aging infrastructure, population growth and density changes, limited land for plant expansion, increasing regulatory requirements, and revenue limited utilities. The implementation of a plant-wide stress testing approach requires significant planning, up-front commitment by decision-makers, potential design and flow modifications, and coordination with operations and laboratory staff for the best chance of a successful outcome.

The use of process and hydraulic computer modeling are engineering tools that have shown to streamline the evaluation process, and can reduce demand on plant staff for on-site field stress testing. Modeling also enhances and makes possible quick evaluations of various capital improvement and process optimization methods for increasing flow through wastewater treatment facilities.

While most of the published stress testing cases reviewed as part of the literature search used similar techniques, each case had subtle differences that account for site-specific conditions. A stress testing approach that worked for one facility may not work for another facility due to the differences in flow availability, ability to simulate dilute influent corresponding to a wet weather, and considerations of treatment process aspects.

A lesson learned from the different methodologies used by various POTWs undertaking stress testing is that all aspects (hydraulic, biological, and to some degree solids handling) must be examined. Designers often incorporate safety factors into the design of various unit processes to ensure water quality permit compliance through a wide variety of conditions, including but not limiting to peak wet weather flows. These safety factors can vary from design to design. The treatment process is only as effective as its weakest link.

The key objective for stress testing is to identify where treatment process design criteria do not reflect the available capacity under actual operating conditions. Stress testing results can provide a method for POTW operators to document and gain regulatory approval for re-rating treatment plant capacity while maintaining compliance with or justifying modifications to discharge permit requirements.

Appendix A: Peak Wet Weather Flow Literature Review References

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