RANDAL W. SAMSTAG
STATE OF WASHINGTON
22407
REGISTERED
PROFESSIONAL ENGINEER

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION

SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES

PROJECT REPORT

FINAL
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The undersigned has approved this document for and on behalf of Carollo Engineers, P.C.
Partner

1218 THIRD AVENUE • SUITE 1600 • SEATTLE, WASHINGTON 98101-3032 • (206) 684-6532 • FAX (206) 903-0419

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION

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PROJECT REPORT

TABLE OF CONTENTS

Page

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION AND SUMMARY

This work was initiated by project staff at King County as part of preparations for a potential flood emergency in the Green River Basin, which is tributary to King County's South Treatment Plant (STP). The Corps of Engineers has notified the public that during the rainy winter season of 2009/2010 that there is a significant probability (variously reported as one in three to one in four) that to avoid failure of abutments to the Howard Hanson Dam, the Corps may find it necessary to release sufficient water from the dam to cause the downstream Green River to overflow its banks. Since the Green River basin lies within the tributary area for the STP, there is concern among King County staff that sewers will be flooded causing potentially large flows to the STP. The Effluent Transfer System (ETS), which delivers wastewater effluent from the STP to Puget Sound, is limited by the capacity of the Effluent Pump Station to a flow of approximately 325 million gallons per day (mgd). During peak flows the STP has the capability to discharge excess flow directly to the Green River Outfall (the Green River merges with Springbrook Creek, formerly part of the Black River, to become the Duwamish River immediately downstream of the STP outfall). It is anticipated by King County staff that the flow control gates from the STP to the Green River Outfall will be closed to minimize the impact of plant discharge on upstream flooding as well as to minimize potential for river water to flood the STP via the outfall.

The objective of the current project is to evaluate potential strategies to maximize flow capacity through the secondary system at the STP during a flood event without putting the secondary process at risk of failure after the flood event. It is estimated that the hydraulic flow capacity of the secondary system in plug flow mode is approximately 160 mgd and in contact reaeration mode is up to approximately 250 mgd. The STP has the capability for bypass of effluent from the primary sedimentation tanks around the secondary system. The current work is limited to evaluation of process effects. Hydraulic effects have been estimated based on information received from King County staff. As flooding could impact the domestic water supply, efforts will be made to maintain production of reclaimed water for internal nonpotable use. In addition, King County currently has a contractual commitment to deliver reclaimed water to external users as early as February of each year. It is important to King County that it provide reliable reclaimed water service.

The report incorporates the following elements:

- Lessons learned as a result of interviews with wastewater treatment plants that have experienced similar flood emergencies.
- Calibration of steady state and dynamic models of the STP to existing plant data.

- Development of alternative operational strategies for control of the plant during a flood emergency.
- Presentation of modeling results for the alternative process management strategies.

Conclusions of the study include the following:

- Recommendations for preparation to be able to add alkalinity and chemical treatment to maintain adequate settleability during storm flows.
- Modes of operation with 160 mgd to the first pass of the aeration tanks and up to 60 mgd to the second pass of the aeration tanks were investigated. It was concluded that these partial plug flow modes of operation of the secondary system should be limited to approximately 220 mgd under conditions of settleability less than 200 milligrams per liter (mL/g) sludge volume index (SVI).
- Contact reaeration modes of operation with primary effluent feed to the second or third passes of the aeration tanks should provide the STP with capacity to accommodate a peak flow of 220 mgd with SVI excursions as high as 300 mL/g.
- The strategies outlined in the report to maintain secondary treatment during a potential storm event should minimize impact on distribution of reclaimed water during and following the storm event. Elevated suspended solids levels during a storm event may make reclaimed water filtration difficult during the storm event, but solids levels should return to normal soon after the flooding event.

2.0 LESSONS LEARNED FROM OTHER PLANTS

Prior to embarking upon evaluation of alternatives, Carollo staff interviewed representatives of operations staff for two wastewater treatment plants (WWTP) who have recently experienced similar flooding events: the R. M. Clayton WWTP in Atlanta, Georgia and the Aberdeen WWTP in Aberdeen, Washington. Summaries of interviews are presented in Appendix A. Key outcomes from the interviews are summarized below. Neither of these facilities have Class A reclaimed water facilities; however, their experience with a major flooding event provides insight into possible impacts on overall plant operations, including reclaimed water faculties, with specific evidence on the performance of the secondary process.

2.1 RM Clayton WWTP

- Physical flooding was experienced at the R. M. Clayton WWTP. Flood waters from the Chattahoochee River entered the plant site through a storm culvert during late September 2009.
- Underground equipment tunnels were flooded and major plant electrical and control equipment was damaged by water. The WWTP was bypassed for several days.

- Dilute wastewater was not the problem; the problem was flooding of the treatment units causing bypass of the entire plant.

- Max week permit levels were exceeded.

- The plant came back on line and was in stable operation in one to two days. First primary treatment was established, then secondary treatment.

2.2 Aberdeen, WA

- Aberdeen had two major peak flow incidents:
  - October 20-21 2003 - 2 days of peak flow of 20-21 mgd (average dry weather flow - 2-3 mgd).
  - December 2007 - 60 hours of peak flow of 15-18 mgd; this second incident had high flows, but also a power failure.

- Influent concentrations during the 10/20/2003 flow:
  - Biochemical oxygen demand (5-day) (BOD_5) 35 milligrams per liter (mg/L), Total suspended solids (TSS) 71 mg/L, Ammonia nitrogen (NH_3-N) 2 mg/L, Alkalinity 40 mg/L as calcium carbonate ($CaCO_3$).

- Effluent quality during 10/20/2003 flow:
  - BOD_5 52 mg/L, TSS 68 mg/L, but 7-day running average less than 15 mg/L TSS.

- Dilution during storm flows caused alkalinity to drop significantly. Operations staff added significant amounts of caustic to an influent manhole and sodium carbonate to the activated sludge system.

- Peak flows brought a surge of grit and screenings. There was a 7 to 10 fold increase in screenings during the recent storm flow. Grit and screenings during the storm flow filled up one dumpster in a day that would normally take a week.

- The plant was back to normal in a day after both incidents.

- The plant management strategy for peak flows is SVI and alkalinity control; reduce the SVI in anticipation of storm flows by maintaining a solids residence time (SRT) of 5 days and using chlorination of the return activated sludge (RAS), if necessary.

3.0 MODEL CALIBRATION

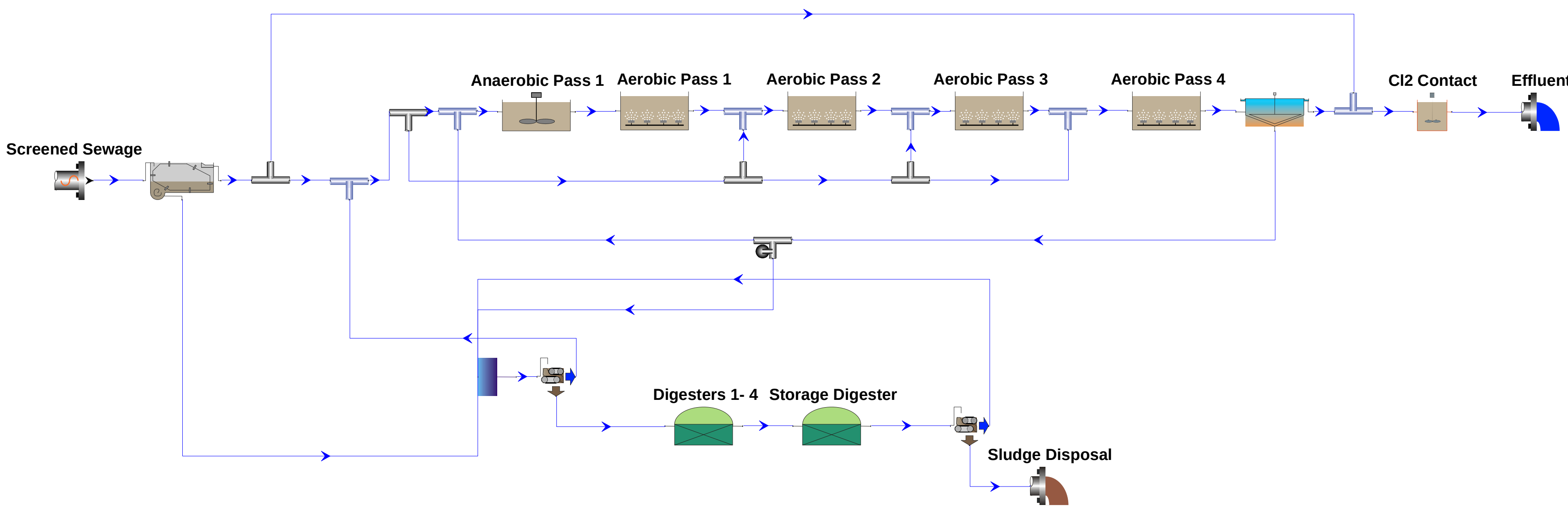
As part of the work Carollo prepared two models: a steady state model using Biotran, a proprietary Carollo spreadsheet model, and BioWin, a commercial process analysis software from Envirosim. The Biotran program was used to calculate apparent influent wastewater characteristics. The BioWin model was run in both steady state and dynamic modes. The model includes primary treatment, activated sludge reactors, secondary sedimentation tanks, solids thickening, digestion, and dewatering unit process and return flows. Figure 1 presents a schematic of the model developed in BioWin.

4.0 PLANT DATA ANALYSIS

In preparation for the model analysis, operating data from 2005 through 2009 were reviewed. Figure 2 presents a time series graph of influent flow at the STP for the period. The plant experienced four periods with flows as high as 200 mgd, with the maximum daily peak of approximately 250 mgd occurring during December of 2007. A full year of data for 2007 was taken as representative of the period and was used for calibration of the Biotran model. The average and maximum month flows for 2007 were 76.5 mgd and approximately 120 mgd, respectively. Influent BOD_5 loadings in 2007 averaged approximately 165,000 pounds per day (ppd) with a maximum month average of approximately 195,000 ppd. The maximum month TSS load has historically been approximately the same as the maximum month BOD_5 load. Daily influent loadings for the entire period are shown in Figure 3. An important parameter for storm flow modeling is the performance of the primary sedimentation tanks under the conditions of high overflow rate that would be found during peak flow periods. Figure 4 presents primary TSS removal data at the STP from 2005 to 2009 as a function of overflow rate in gallons per day per square foot (gpd/sf).

At 325 mgd the overflow rate on the primary sedimentation tanks would be approximately 5,300 gpd/sf with one of the twelve primary tanks out of service and 4,700 gpd/sf with all twelve in service. The highest overflow rates experienced in the current record were approximately 4,200 gpd/sf. The mean removal rate at this overflow rate was in the neighborhood of 48 percent compared to an average removal rate of over 60 percent for normal flow periods. The removal rate for TSS at 5,300 gpd/sf was assumed to be 25 percent at very high flow rates during flood conditions. High overflow rates sometimes occur in the summer as a result of tanks being out of service. During this period influent concentrations are relatively high and TSS removal rates are closer to 40-45 percent, rather than 25 percent. A combination of the high overflow rate together with very high flow rate results in TSS removal rates of approximately 25 percent. Based on the data presented in Figure 4, this assumed removal rate is conservative. This represents a relatively high rate of removal compared to typically reported performance. The graph shows a comparison with the results from a survey of WWTPs conducted by the Water Pollution Control Federation (WPCF) in 1989. Almost all of the STP data show a higher removal rate than the mean data found in the WPCF survey.

For the steady-state storm flow modeling Carollo based its estimates of wastewater quality on maximum month loading values for the calendar year 2007, diluted by the expected maximum sustained flow of 325 mgd. Maximum month flows and concentrations for 2007 compared to the predicted diluted values during a sustained 325 mgd peak flow are shown in Table 1.



PROCESS SCHEMATIC FOR STP BIOWIN MODEL

FIGURE 1

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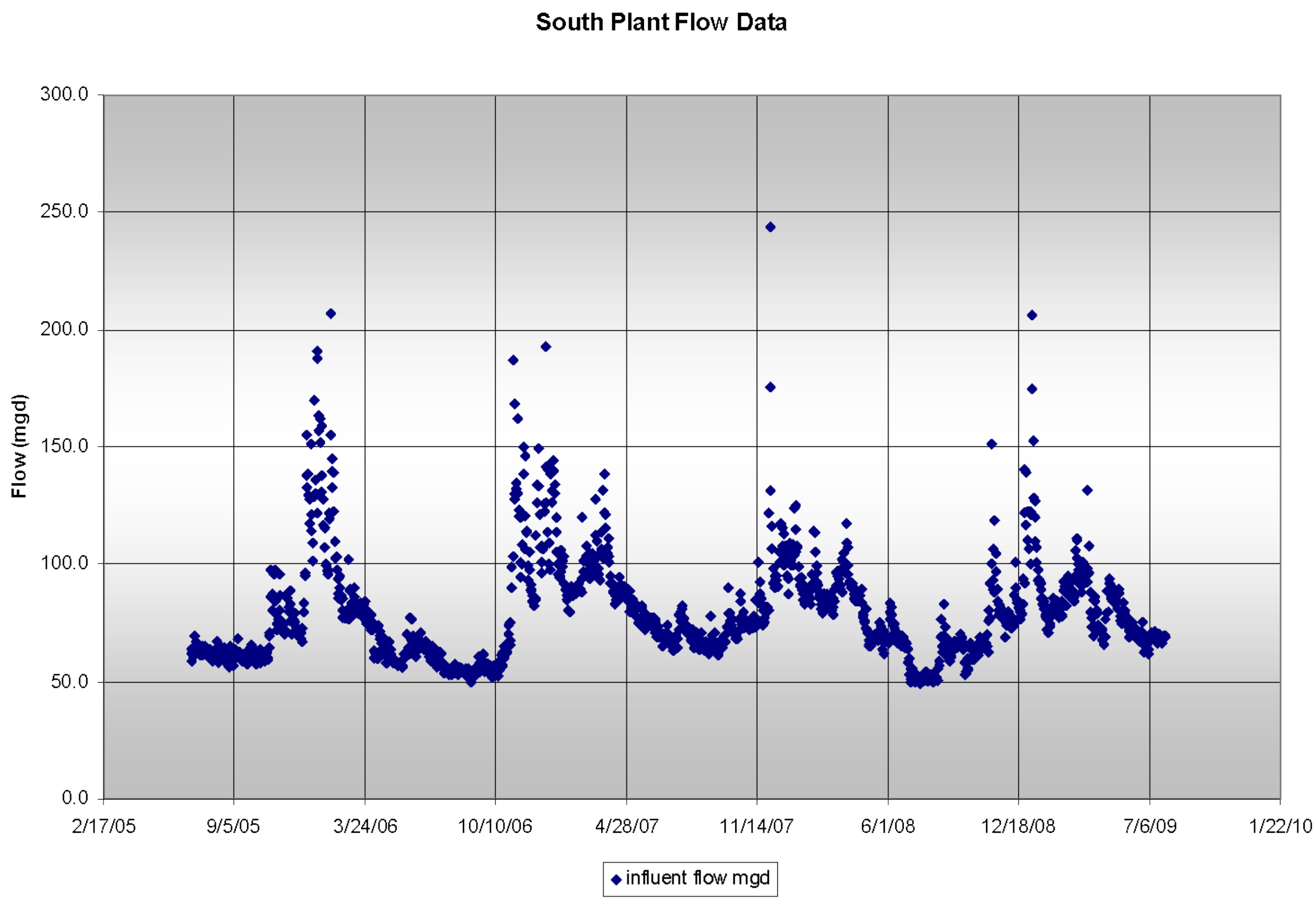

RAW SEWAGE FLOW FOR THE PERIOD FROM 2005 TO 2009

FIGURE 2

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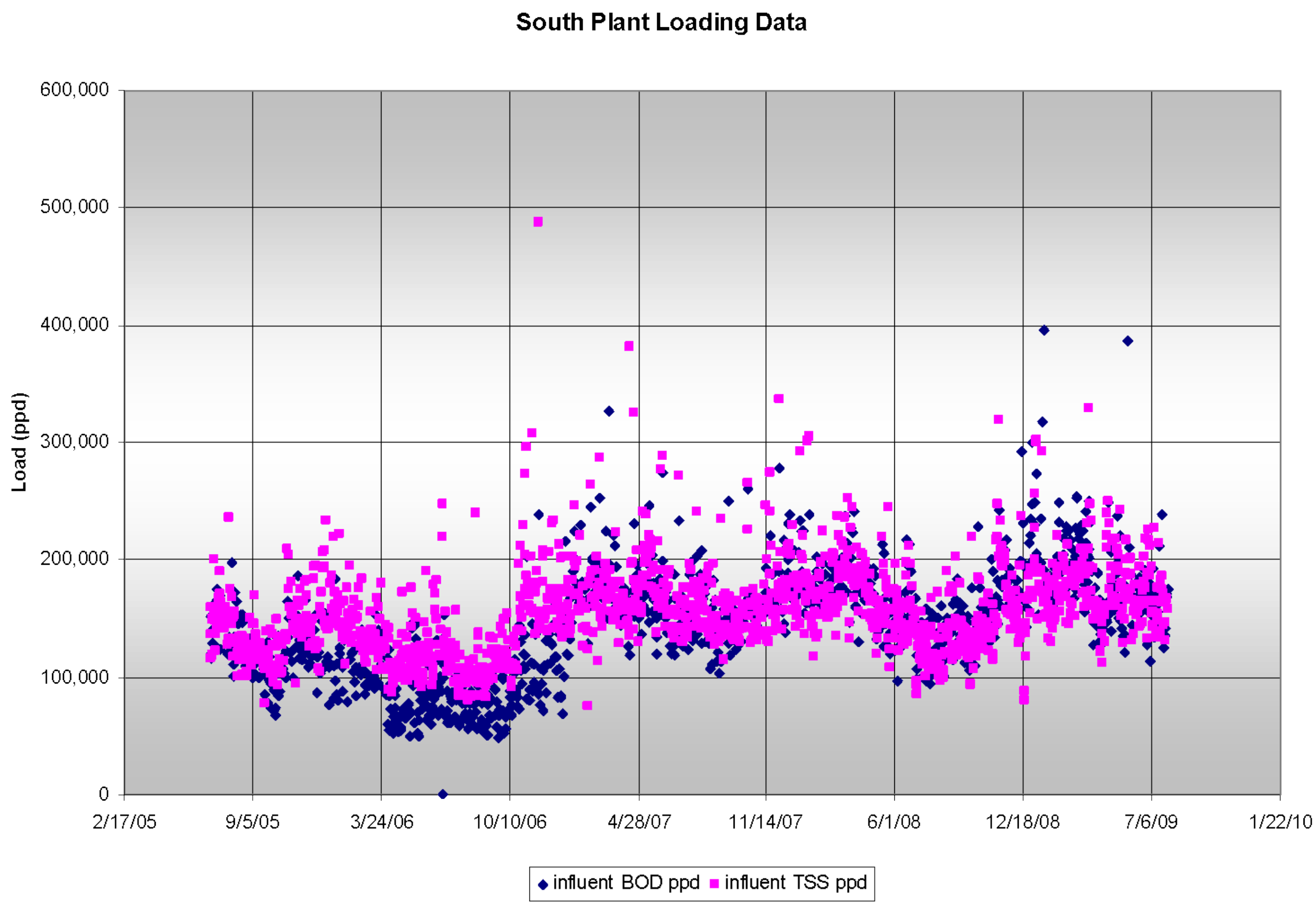

RAW SEWAGE LOADING DATA FOR THE PERIOD FROM 2005 TO 2009

FIGURE 3

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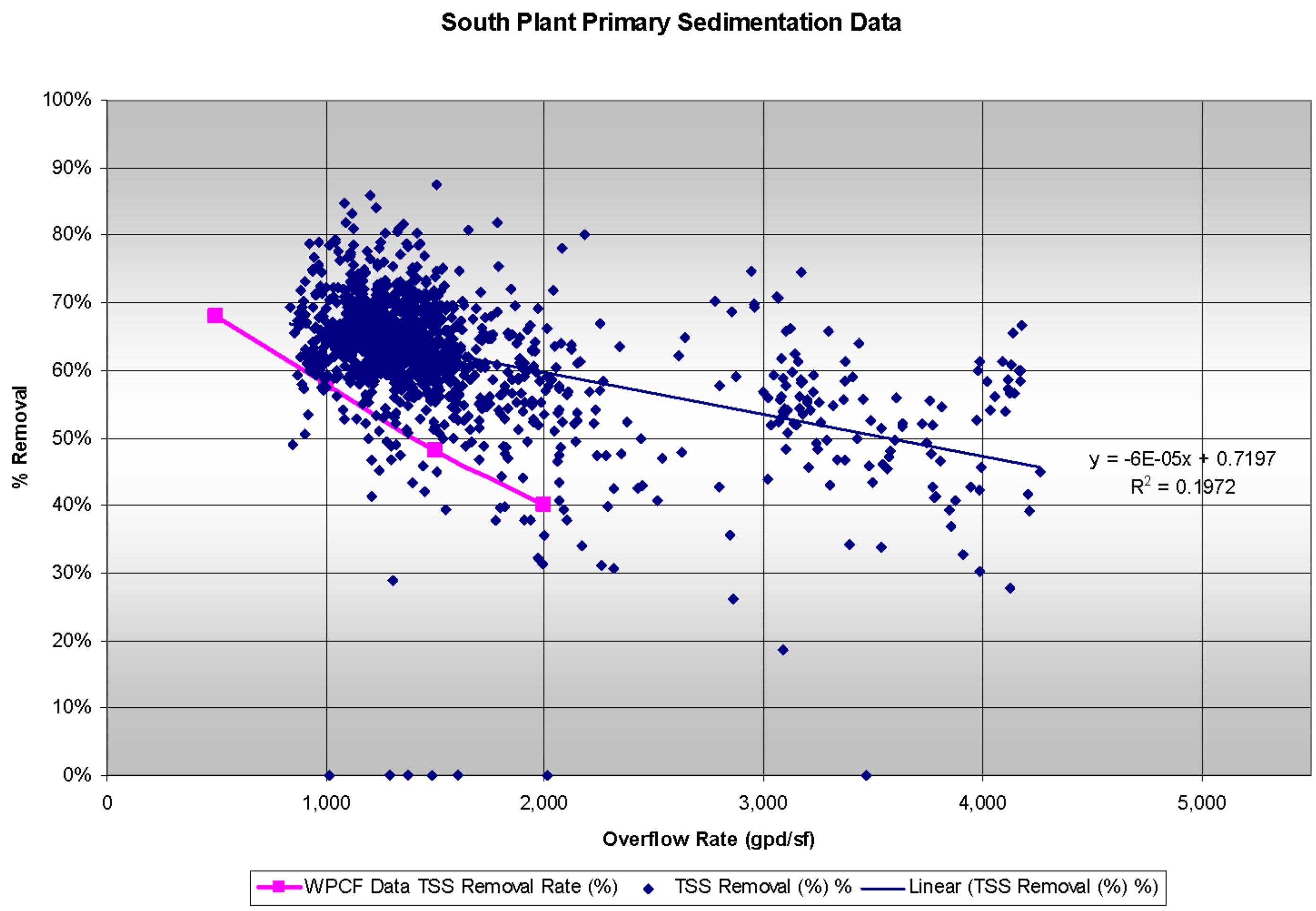

PRIMARY SEDIMENTATION TSS REMOVAL DATA

FIGURE 4

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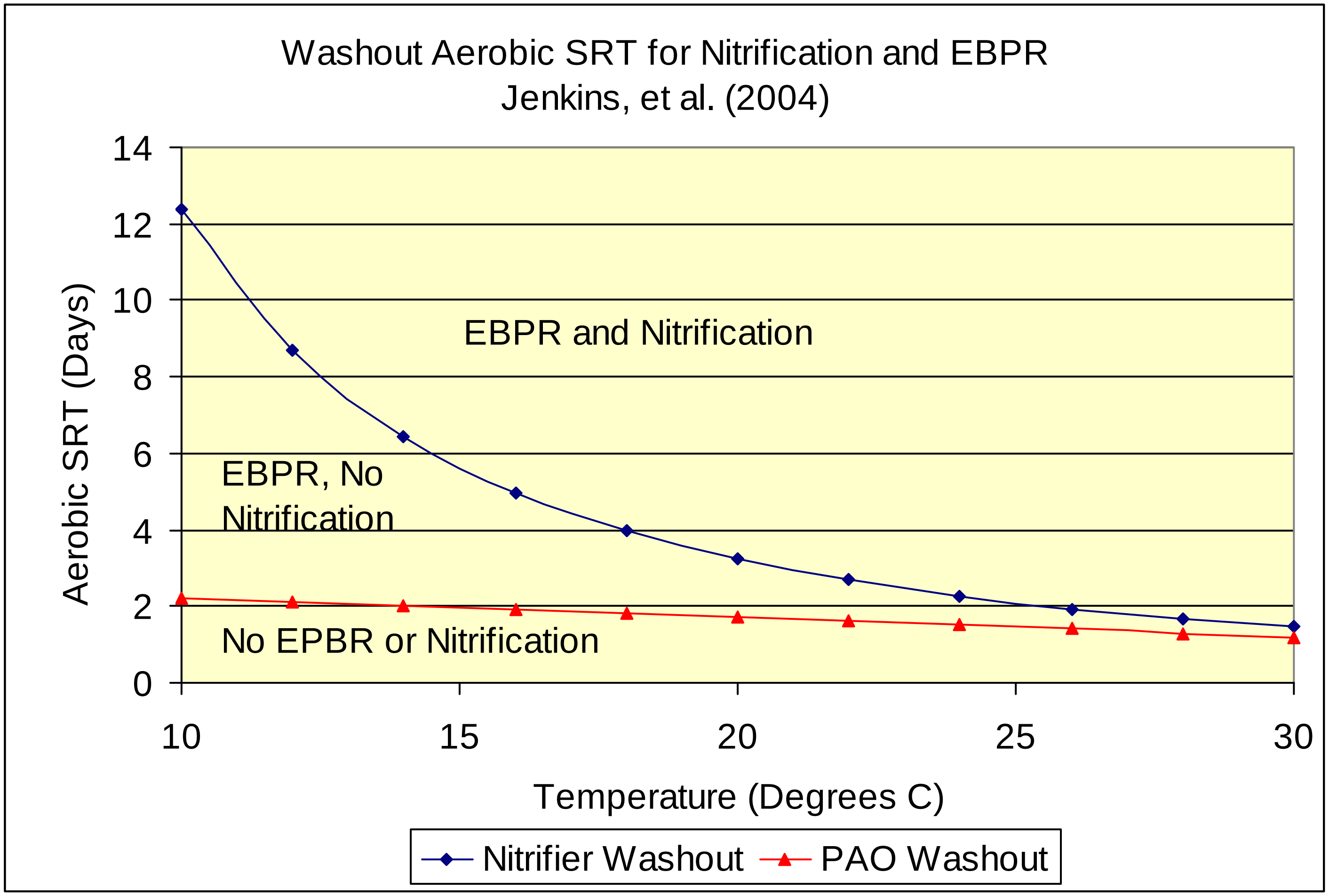
Table 1	Influent Characteristics for Predicted Storm Flow South Plant Emergency Peak Flow Management Alternatives King County Department of Natural Resources and Parks Wastewater Treatment Division	
Description	**Max Month 2007 Value**	**Predicted Storm Flow Value**
Flow, mgd	124	325
Biochemical Oxygen Demand (BOD_5), mg/L	230.0	61.9
Total Suspended Solids (TSS), mg/L	189.7	76.8
Volatile Suspended Solids (VSS), mg/L	168.8	68.3
Ammonia Nitrogen (NH4-N), mg/L	17.6	7.8
Organic Nitrogen (Org-N), mg/L	10.9	4.4
Total Phosphorus (Total P), mg/L	10.1	2.6
Alkalinity (as $CaCO_3$), mg/L	183.0	47.8

Three key parameters are especially important for successful activated sludge operation: sludge settleability, temperature, and SRT. SVI gives an indication of sludge settling rates, which are important for solids capture in the secondary sedimentation tanks. Temperature affects biological growth and sludge settling. In general, for higher temperatures, growth rates and oxygen consumption in the activated sludge process increase. Settling rates may also increase as a result of lower fluid viscosity. At lower temperatures biological growth slows. A key group of organisms for successful operation of the STP is the phosphorus accumulating organisms (PAO). It is thought that maintenance of these organisms in the activated sludge system is crucial for maintenance of good sludge settleability. These organisms are sensitive to temperature as is illustrated in Figure 5. This graph shows the washout SRT for two different organism groups: nitrifiers and PAO. At the minimum temperature of approximately 12 degrees Celsius (C), PAO organisms are washed out of the system when the aerobic SRT is less that approximately 2.1 days. This corresponds to a total aeration basin SRT of approximately 2.4 days. Operating data from the STP for these parameters are illustrated in Table 2. Figure 6 shows temperature data. The minimum daily influent temperature for the period was 10 degrees C. The 1.9th percentile value, corresponding approximately to the minimum week temperature, was 11.4 degrees C and the 8.3rd percentile value, corresponding approximately to the minimum monthly value was 11.8 degrees C. A value 11.4 degrees C was used for initial modeling, but the impact of potentially even lower temperatures was considered in a sensitivity evaluation.



WASHOUT AEROBIC SRT VALUES FOR NITRIFIER AND PAO ORGANISMS

FIGURE 5

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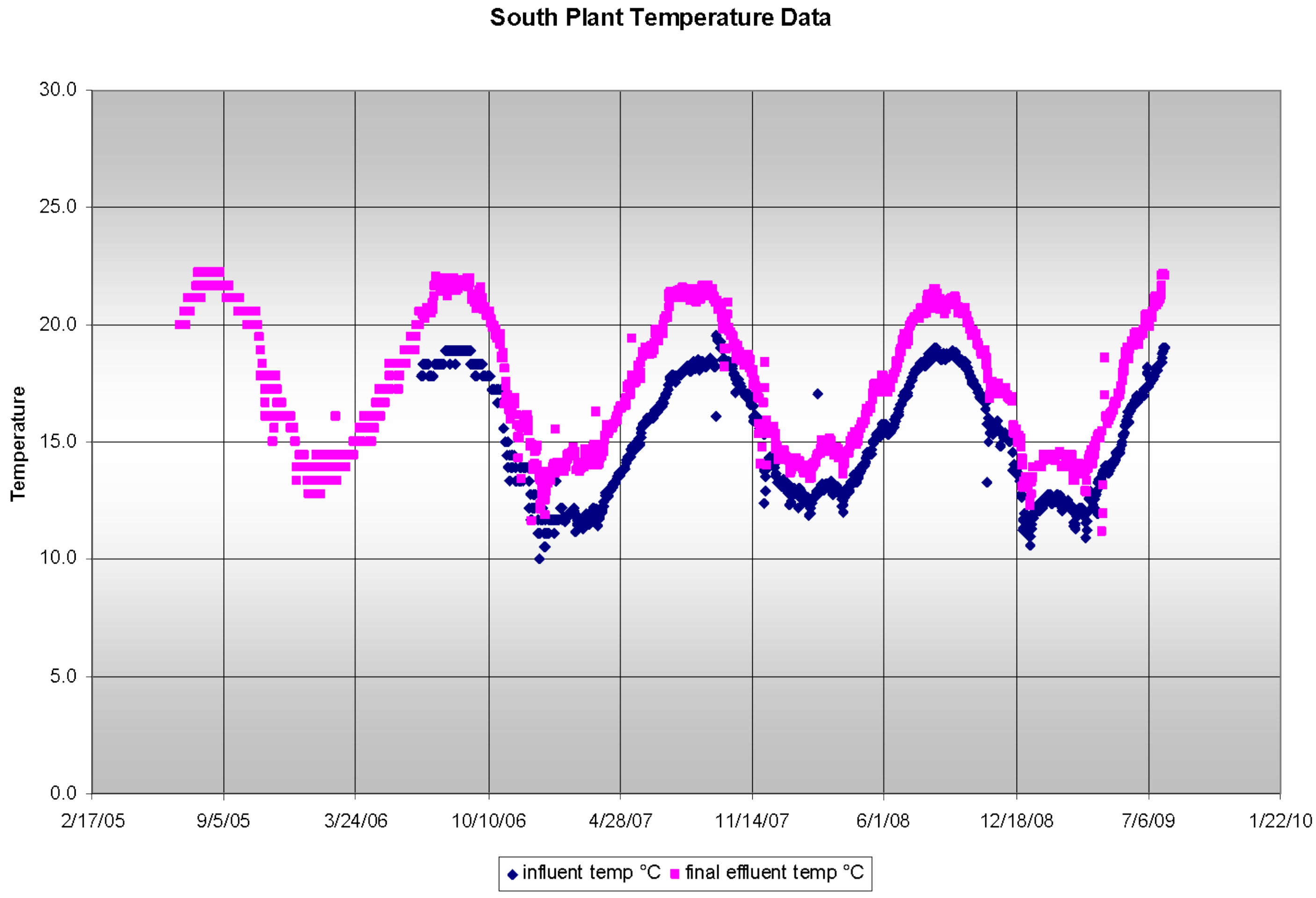

TEMPERATURE DATA FOR THE PERIOD FROM 2005 TO 2009

FIGURE 6

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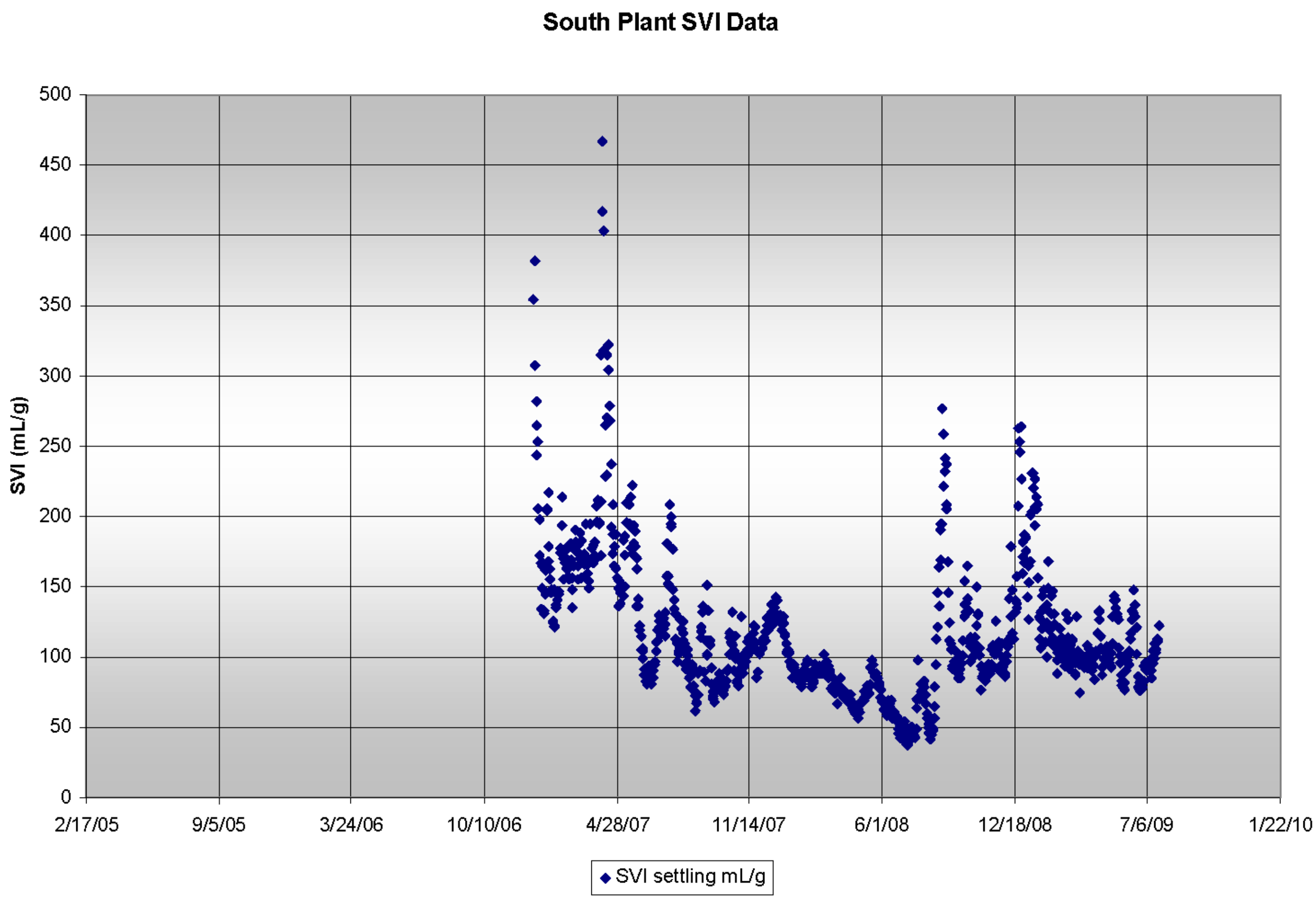
Table 2	Operating Data Statistics for the Period from 2005 through 2009 South Plant Emergency Peak Flow Management Alternatives King County Department of Natural Resources and Parks Wastewater Treatment Division				
Parameter	**SVI (mL/g)**	**Influent Temp (Deg C)**	**Effluent Temp (Deg C)**	**Total SRT (Days)**	**Aerobic SRT (Days)**
Average	117.4	15.2	17.5	3.6	3.1
Min	37.8	10.0	11.2	2.1	1.9
Max	467.5	19.5	22.2	5.8	5.1
1.9th Percentile	45.8	11.4	13.3	2.6	2.2
8.3rd Percentile	58.3	11.8	13.9	2.7	2.4
91.7th Percentile	192.7	18.5	21.4	4.2	3.7
98.1st Percentile	208.7	18.9	21.9	4.4	3.8

SVI values have mostly been below 150 mL/g with several excursions as high as 250 mL/g in the last two years. Figure 7 shows a time-series plot of SVI data since 2007. Solids settling capacity can be calculated based on settling tests or estimated from statistically derived formula. The Capacity and Re-rating Evaluation (Brown and Caldwell, 2004) included settling velocity data for two test periods. These data are compared in Figure 8 to data calculated using the Daigger and Pitman equations (see Daigger, 1995 and Pittman, 1985) and using the default settling parameters from BioWin. The graph shows the calculated solids flux capacity in pounds of solids per square foot of clarifier cross-section per day (ppd/sf). The solids flux rate based on the Daigger equation for an SVI of 150 mL/g is conservative based on recent data and lies between the two values measured in 2003. For the initial modeling the BioWin default values were used, but impact of settleability on performance will be considered in a sensitivity evaluation.

Figure 9 presents data for aeration basin SRT. The SRT has varied from a minimum of 2.1 days to a maximum of 5.8 days over the period. The 1.9th percentile value, corresponding approximately to the minimum week SRT, was 2.6 days and the 8.3rd percentile value, corresponding approximately to the minimum monthly value, was 2.7 days. A 3.5-day total SRT was used for initial modeling, but the impact of different values for SRT will be considered as a sensitivity issue.

4.1 Model Calibration

Data received from the County for the year 2007 was used to match primary organics removal, the amount of solids produced in waste activated sludge (WAS), and the recorded SRT for the average mixed liquor suspended solids for the period. Two primary parameters were used to produce the calibration: the apparent filterable BOD_5 fraction (fbf = 0.415) and the non-biodegradable volatile suspended solids (fvu = 0.15). These values were used to produce wastewater characteristic ratios for the raw wastewater.



SVI DATA FOR THE PERIOD FROM 2007 TO 2009

FIGURE 7

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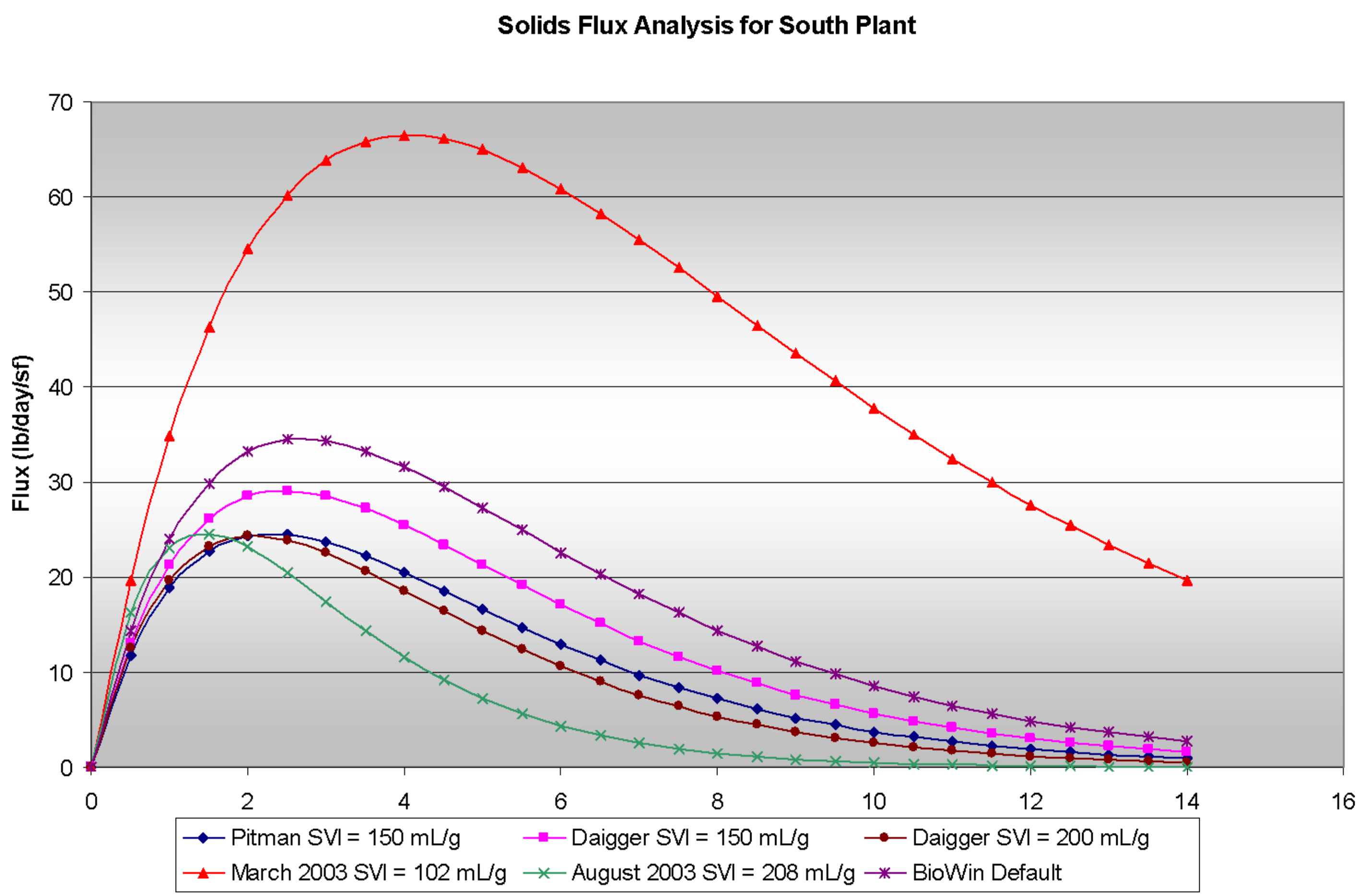

SETTLEABILITY DATA FROM 2003 TESTS COMPARED TO STANDARD SVI-BASED FORMULAS

FIGURE 8

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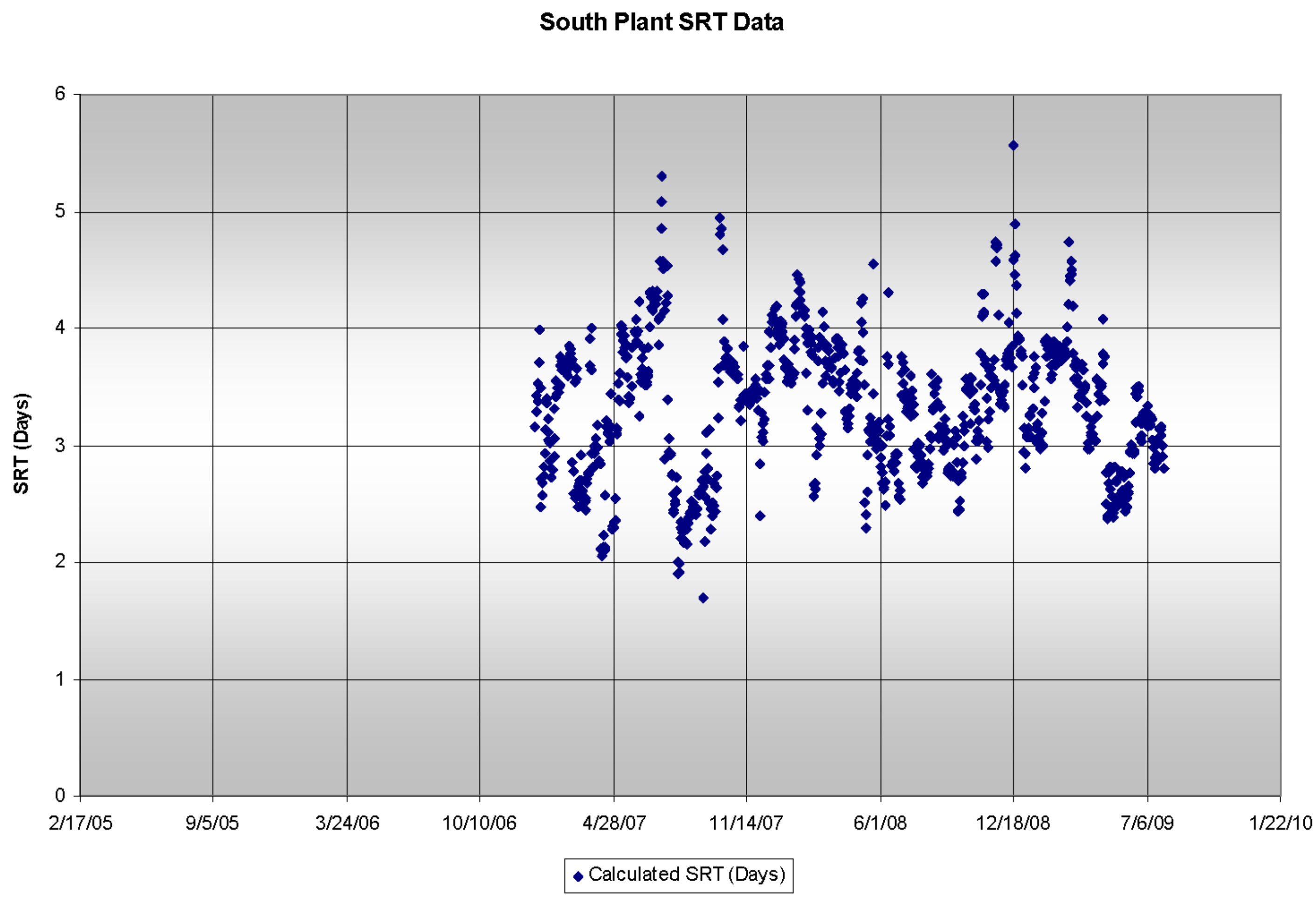

SRT DATA FOR THE PERIOD FROM 2005 TO 2009

FIGURE 9

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These characteristic ratios were in turn used as input to a BioWin model of the entire STP. Table 3 presents a comparison of characteristic ratios based on three different approaches:

1. The default values from BioWin for raw sewage.

2. The values from Biotran calibrated to 2007 STP data.

3. Values assumed in the 2000 Brown and Caldwell Evaluation.

The characteristics based on the Biotran calibration were used for initial modeling, but the impact of different characteristics will be considered as a sensitivity issue.

Table 3 Comparison of Wastewater Characteristic Ratios
South Plant Emergency Peak Flow Management Alternatives
King County Department of Natural Resources and Parks Wastewater Treatment Division

Parameter	BioWin Default	Biotran Calibration	BC Calibration
Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]	0.16	0.19	0.16
Fac - Acetate [gCOD/g of readily biodegradable COD]	0.15	0.15	0.3
Fxsp - Non-colloidal slowly biodegradable [gCOD/g of s. degr. COD]	0.75	0.82	0.7
Fus - Unbiodegradable soluble [gCOD/g of total COD]	0.05	0.06	0.14
Fup - Unbiodegradable particulate [gCOD/g of total COD]	0.13	0.14	0.08
Fna - Ammonia [gNH3-N/gTKN]	0.66	0.62	0.75
Fnox - Particulate organic nitrogen [gN/g Organic N]	0.5	0.58	0.69
Fnus - Soluble unbiodegradable TKN [gN/gTKN]	0.02	0.02	0.02
FupN - N: COD ratio for unbiodegradable part. COD [gN/gCOD]	0.035	0.020	0.035
Fpo4 - Phosphate [gPO4-P/gTP]	0.5	0.40	0.5
FupP - P: COD ratio for influent unbiodegradable part. COD [gP/gCOD]	0.011	0.011	0.011
FZbh - Non-poly-P heterotrophs [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbm - Anoxic methanol utilizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZaob - Ammonia oxidizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZnob - Nitrite oxidizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZamob - Anaerobic ammonia oxidizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbp - PAOs [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbpa - Propionic acetogens [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbam - Acetoclastic methanogens [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbhm - H2-utilizing methanogens [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04

5.0 ALTERNATIVES DEVELOPMENT

A series of alternative operating strategies were developed to compare plug flow to step feed operation of the STP aeration tanks. A basic criterion for each strategy was that the maximum hydraulic flow capacity of an individual aeration tank inlet gate is 5 mgd. There are eight inlet gates into each pass of each tank, resulting in a maximum flow of 40 mgd per pass per tank. With four tanks on-line, the maximum flow to a single pass is limited to 160 mgd. The second general assumption was that primary effluent bypass is limited to the hydraulic capacity of the bypass system, which was assumed to be 150 mgd. So during a peak flow period with 325 mgd continuously pumped through the STP, the minimum flow that would be required to pass through the secondary system would be 175 mgd. When initial modeling indicated that a configuration could function well at 175 mgd in plug flow mode with a small amount of feed to the second aeration tank pass, subsequent modeling was conducted with a higher secondary flow of 220 mgd.

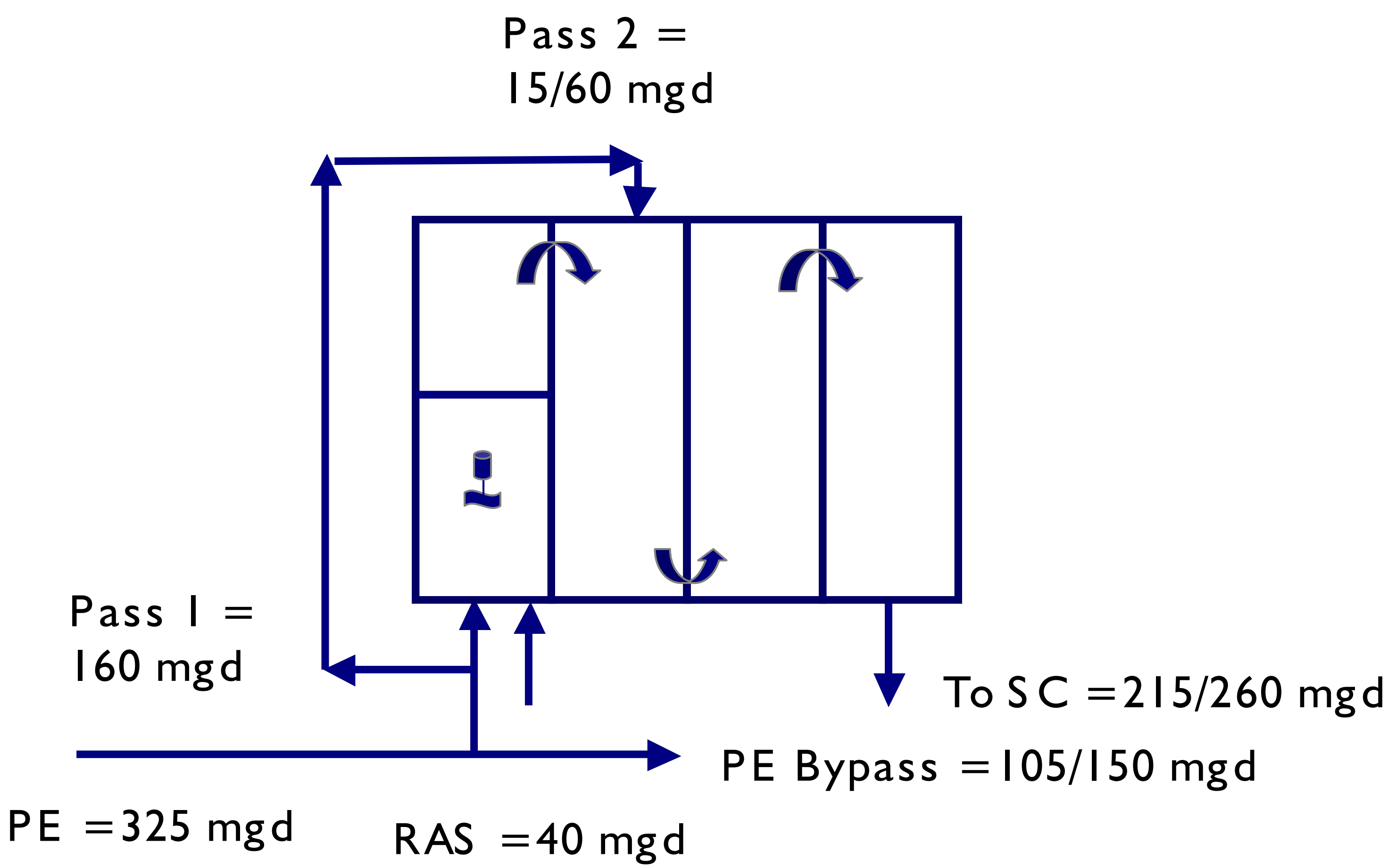
The five operating alternatives considered included:

1. Partial plug flow - 160 mgd to pass one and 15 mgd to pass two.
2. Partial plug flow - 160 mgd to pass one and 60 mgd to pass two.
3. 75% contact reaeration - 60 mgd to pass one and 160 mgd to pass two.
4. 50% contact reaeration - 60 mgd to pass two and 160 mgd to pass three.
5. 25% contact reaeration - 60 mgd to pass three and 160 mgd to pass four.

These five operating scenarios are shown schematically in Figures 10 through 13. These figures do not include solids handling return flows, which were assumed to operate continuously, bringing an additional flow stream of approximately 3 mgd directly to the secondary system. RAS flows were set at a constant flow of approximately 40 mgd. Process data for operating facilities are summarized in Table 4.

Table 4 Operating Facility Data
South Plant Emergency Peak Flow Management Alternatives
King County Department of Natural Resources and Parks Wastewater Treatment Division

Description	Value
Primary Sedimentation	
Area, sf	61,336
Primary Sedimentation TSS Removal, %	
Pre and Post Storm Flow (2,022 gpd/sf)	60
Storm Flow Period (5,300 gpd/sf)	25
Aeration Basin	
Volume, mgal	
Anaerobic Pass 1	2.42
Aerobic Pass 1	2.42
Aerobic Pass 2	4.85
Aerobic Pass 3	4.85
Aerobic Pass 4	4.85
Total	19.38
Secondary Sedimentation	
Tank Area, sf	180,642
DAF Thickener	
Solids Capture, %	85
Digestion System	
Primary Digester Volume, mgal	10.22
Storage Volume, mgal	2.56
Total, mgal	12.78
Dewatering	
Solids Capture, %	95



SCENARIOS 1/2 - PARTIAL PLUG FLOW

FIGURE 10

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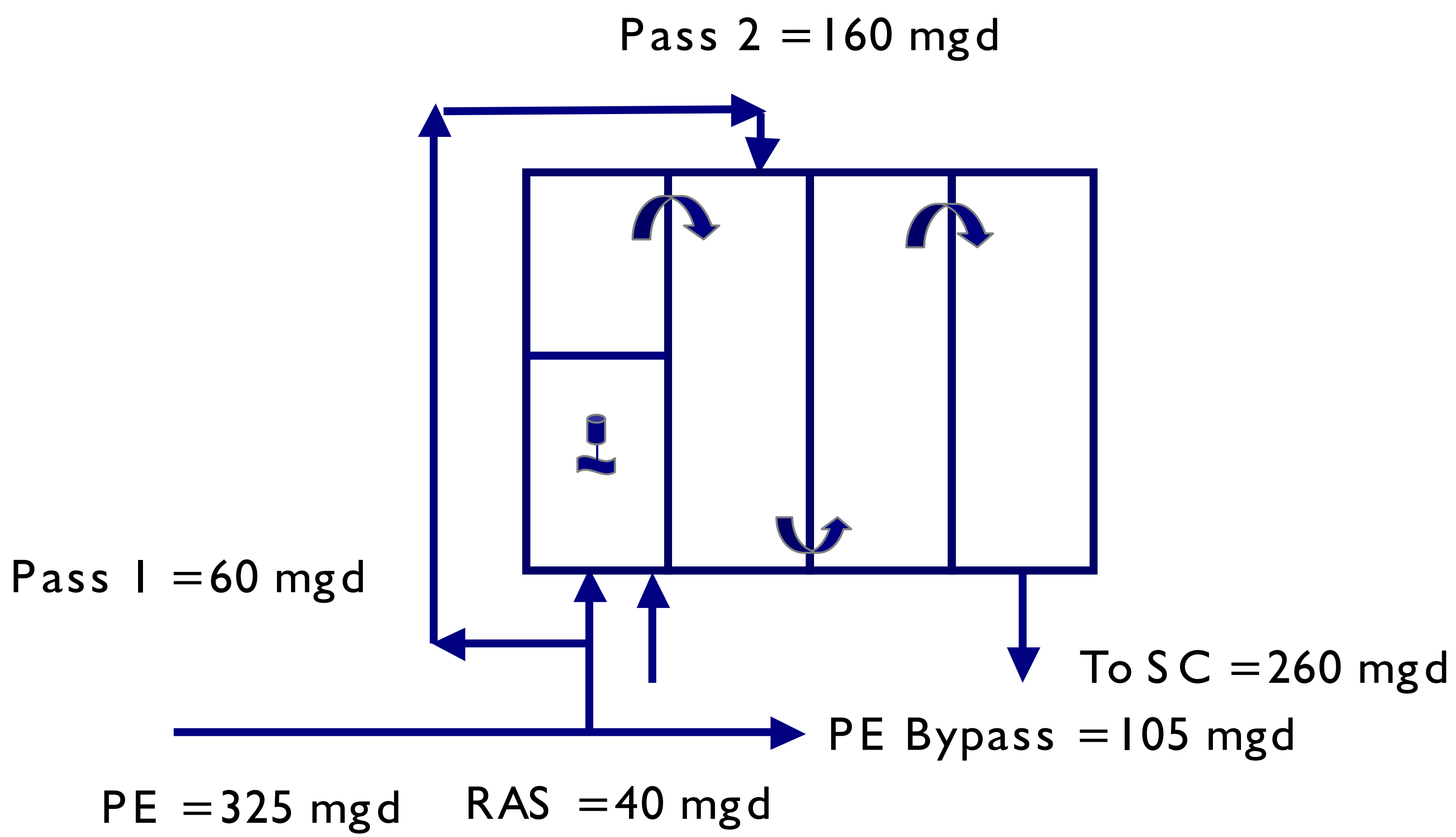

SCENARIO 3 - 75% CONTACT REAERATION

FIGURE 11

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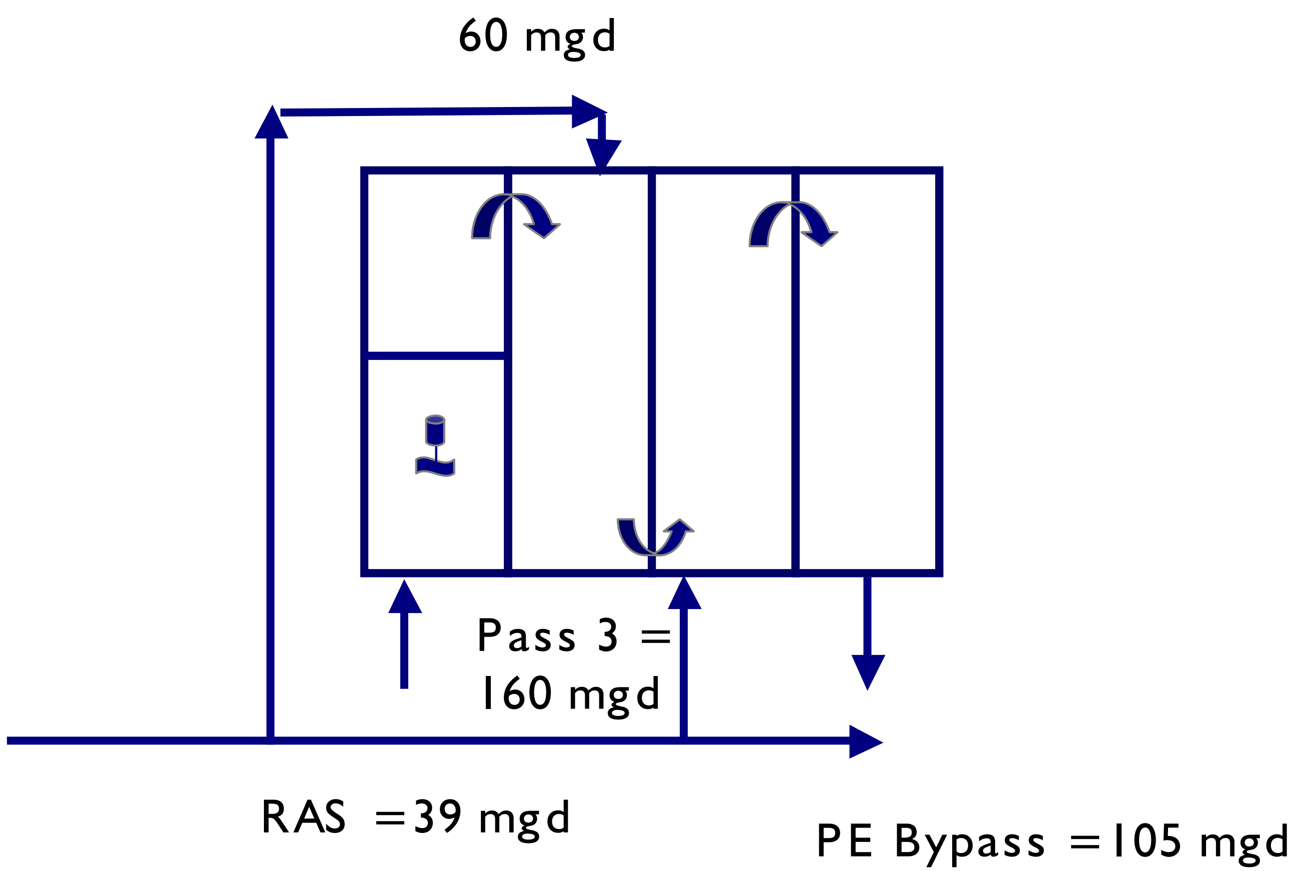

SCENARIO 4 - 50% CONTACT REAERATION

FIGURE 12

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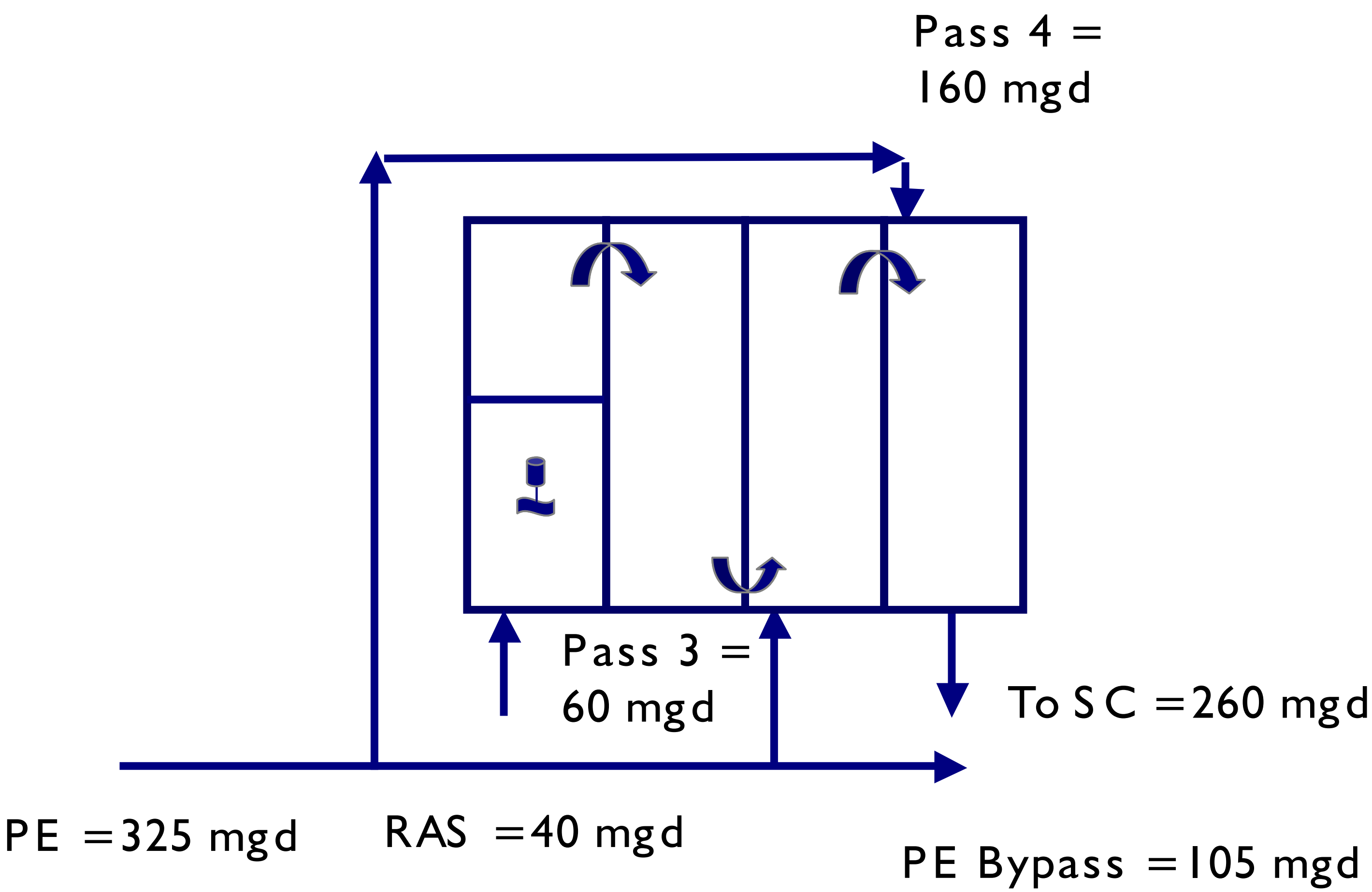

SCENARIO 5 - 25% CONTACT REAERATION

FIGURE 13

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6.0 MODELING RESULTS

Results from the BioWin model are presented for both steady-state and dynamic runs. The results for all five alternatives are presented for the steady-state model at a sustained peak flow of 325 mgd. The dynamic model was run assuming maximum month flows and loads prior to and immediately following a seven day peaking event at 325 mgd. Results from the two partial plug flow scenarios (Scenario 1 and 2) and the 25 percent contact reaeration scenario (Scenario 5) are presented for the dynamic model. Since the steady state and dynamic model results are dependent on several assumptions, a sensitivity analysis was performed on key assumptions. The results of this analysis are presented after the model results.

6.1 Steady State Results

Table 5 summarizes the steady state results of the five operating scenarios under steady peak flow. In the first scenario the activated sludge system is configured in a plug flow mode with a total of approximately 175 mgd (without return flows) to the aeration tanks and with 150 mgd bypass of the secondary system at peak flow. In the remaining four scenarios approximately 105 mgd bypasses secondary treatment and approximately 220 mgd is directed to the aeration tanks. Results were generated from the calibrated BioWin model run in a steady state mode with a constant sewage flow of 325 mgd. The simulation was run with a constant RAS rate of approximately 40 mgd, resulting in a return ratio of approximately 18 percent.

All simulations were conducted with a total SRT of 3.5 days, resulting in an aerobic SRT of approximately 3 days. The SRT calculation included solids wasting from both the secondary effluent and WAS flows. For the first partial plug flow case, a total waste sludge mass rate of approximately 84,000 ppd was split evenly between WAS and clarifier effluent. For the higher flow plug flow case, approximately 80,000 ppd of the total waste of 100,000 ppd is from the secondary clarifier effluent. Step feed results in a reduction of the last pass mixed liquor suspended solids (MLSS) concentration and consequently in a reduction of the solids loading onto the secondary sedimentation tanks.

The table indicates a predicted solids flux safety factor (SF) based on calculations in Biotran. This is the maximum capacity of the tank for solids handling divided by the actual loading rate. The calculations indicate that under each scenario there is a positive SF, indicating that the secondary clarifier tanks have the theoretical capacity to operate without thickening failure. This conclusion does not include hydraulic effects caused by turbulent flow in the tanks, however, which have the effect of retarding sludge particle settling. As a result, a SF over solids flux failure greater than 1.0 must always be maintained. A typical SF for design would be in the range of 1.15 to 1.25. It is seen that the SF is higher than this range for all of the scenarios with exception of the partial plug flow alternative at 220 mgd, where the theoretical SF is 1.22.

Table 5 **Steady State Results of Storm Flow Modeling**
South Plant Emergency Peak Flow Management Alternatives
King County Department of Natural Resources and Parks Wastewater Treatment Division

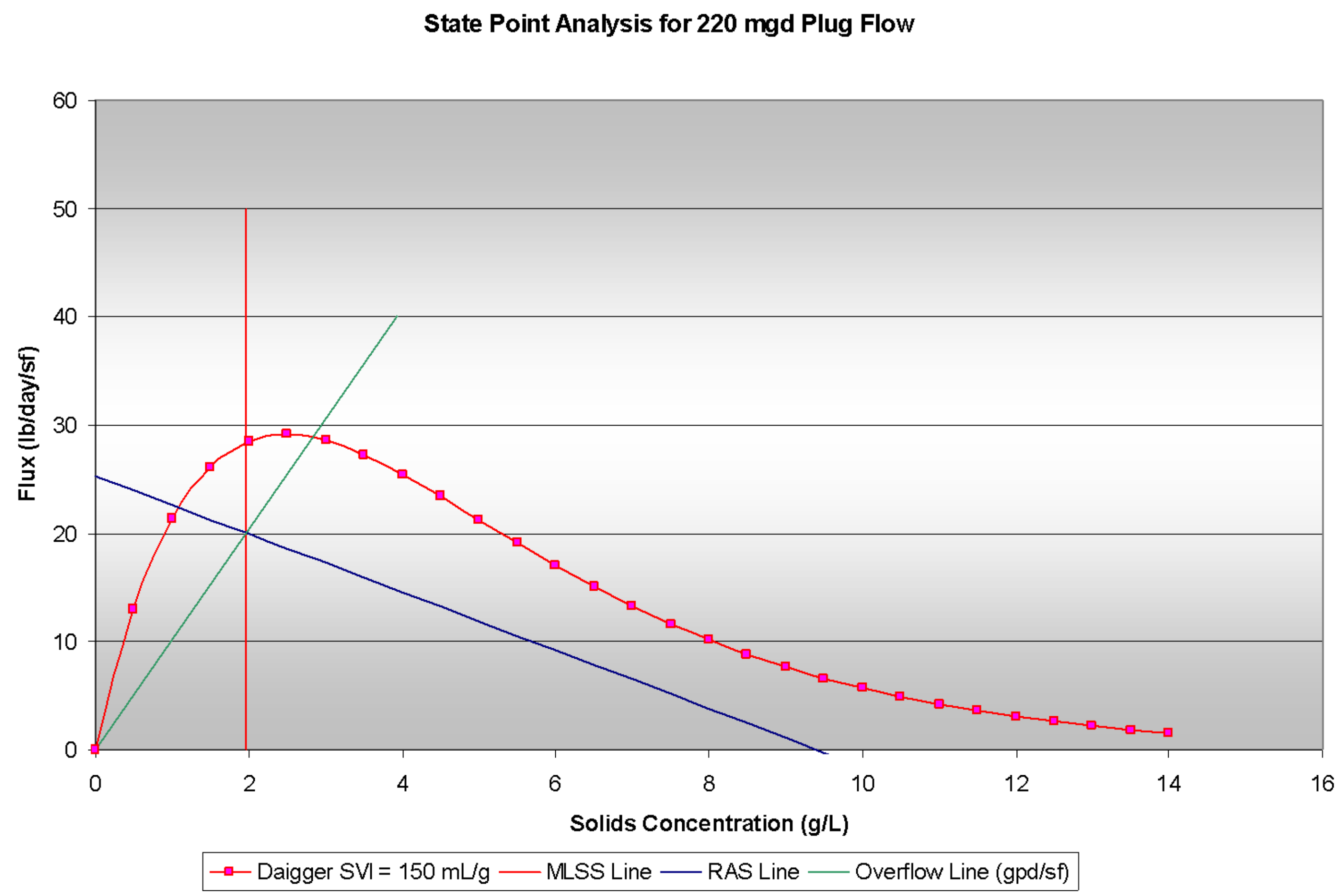
Description	Partial Plug Flow	Partial Plug Flow	75% CR	50% CR	25% CR
Sewage Flow (mgd)	325	325	325	325	325
Secondary Flow (mgd)	176	221	221	221	221
RAS Flow (mgd)	40	40	40	40	40
Primary Bypass Flow (mgd)	149	104	104	104	104
Secondary Aerobic SRT (days)	3.05	3.04	3.04	3.05	3.04
Last Pass MLSS (mg/L)	1,773	1,975	1,430	843	547
Aeration Rate (scfm)	23,863	29,478	28,657	27,380	25,630
PAO Population (%)	12.4%	13.3%	13.8%	14.1%	11.2%
Secondary Clarifier Overflow Rate (gpd/sf)	992	1,225	1,225	1,225	1,225
Secondary Clarifier Solids Loading Rate (ppd/sf)	18	24	17	10	7
Secondary Clarifier SF	1.68	1.22	1.55	2.01	2.30
Predicted Storm Flow Primary Effluent Quality (mg/L)					
Carbonaceous BOD_5	54	54	54	54	54
TSS	43	43	43	43	43
Predicted Storm Flow Secondary Effluent Quality (mg/L)					
Carbonaceous BOD_5	12	19	17	15	19
TSS	27	43	38	30	26
Predicted Storm Flow Plant Effluent Quality (mg/L)					
BOD_5	31	30	29	27	30
TSS	35	43	40	34	32

Another way to consider the impact of operating conditions on sedimentation tank performance is to construct a state point diagram. Figure 14 presents a state point diagram for the plug flow condition with a 220 mgd secondary flow under the conditions defined for Scenario 2. The state point diagram shows the allowable solids loading in ppd/sf as a function of initial solids loading concentration in grams per liter (g/L). The red line with square data points shows this. The state point diagram is constructed by drawing an overflow line from the graph origin (in green in the graph) whose slope represents the overflow rate on the sedimentation tank (gpd/sf). Then a MLSS line (red) is constructed by drawing a vertical line at the MLSS concentration. Finally the RAS line (blue) is drawn from the intersection of the overflow and MLSS lines to the RAS concentration on the horizontal axis. The intersection (or state) point represents the operating point for the sedimentation tank. As long as the operating point is inside the solids flux curve and the RAS line remains below the falling limb of the solids flux line, the sedimentation tank is in a safe operating mode (neglecting turbulence.) The chart indicates that under partial plug flow mode at 220 mgd the sedimentation tanks are operating under stressed conditions, but theoretically in a safe range. Figure 15 presents the same diagram for Scenario 5, the case of 25 percent of the aeration tank in contact. This diagram shows that the state point is much lower relative to the solids flux line, indicating a much safer operating condition.

6.2 Dynamic Model Results

In addition to the steady state modeling, Carollo performed dynamic modeling of the flood scenario. In the dynamic modeling it was assumed that prior to the beginning of flood flows the plant was operating at 124 mgd with concentrations representing the 2007 maximum month condition. After three days of operation at a steady rate of 124 mgd it was assumed that a seven-day flood period was started during which the plant was operated at a constant flow of 325 mgd. For the first day of the flood, it was assumed that the BOD_5 load peak factor increased to 1.5 (based on average annual loads, or increased to 16 percent above the maximum month loads) to account for initial washout of solids from the sewer, which had been stationary under lower flows. For the second through seventh day of the flood, the BOD_5 load was assumed to be equal to the maximum month load. For the first day of the flood the TSS load peak factor was assumed to increase to 1.8 (based on average annual loads, or 41 percent above the maximum month loads) to account for initial solids washout. For the second and third day, the TSS load peak factor was assumed to decrease to 1.3 (based on average annual loads, or 2 percent above maximum month TSS loads) and for the fourth through seventh day of the flood, the TSS load was assumed to be equal to the maximum month load. Following the high flow period, it was assumed that flows returned to the maximum month flow of 124 mgd for another three days.

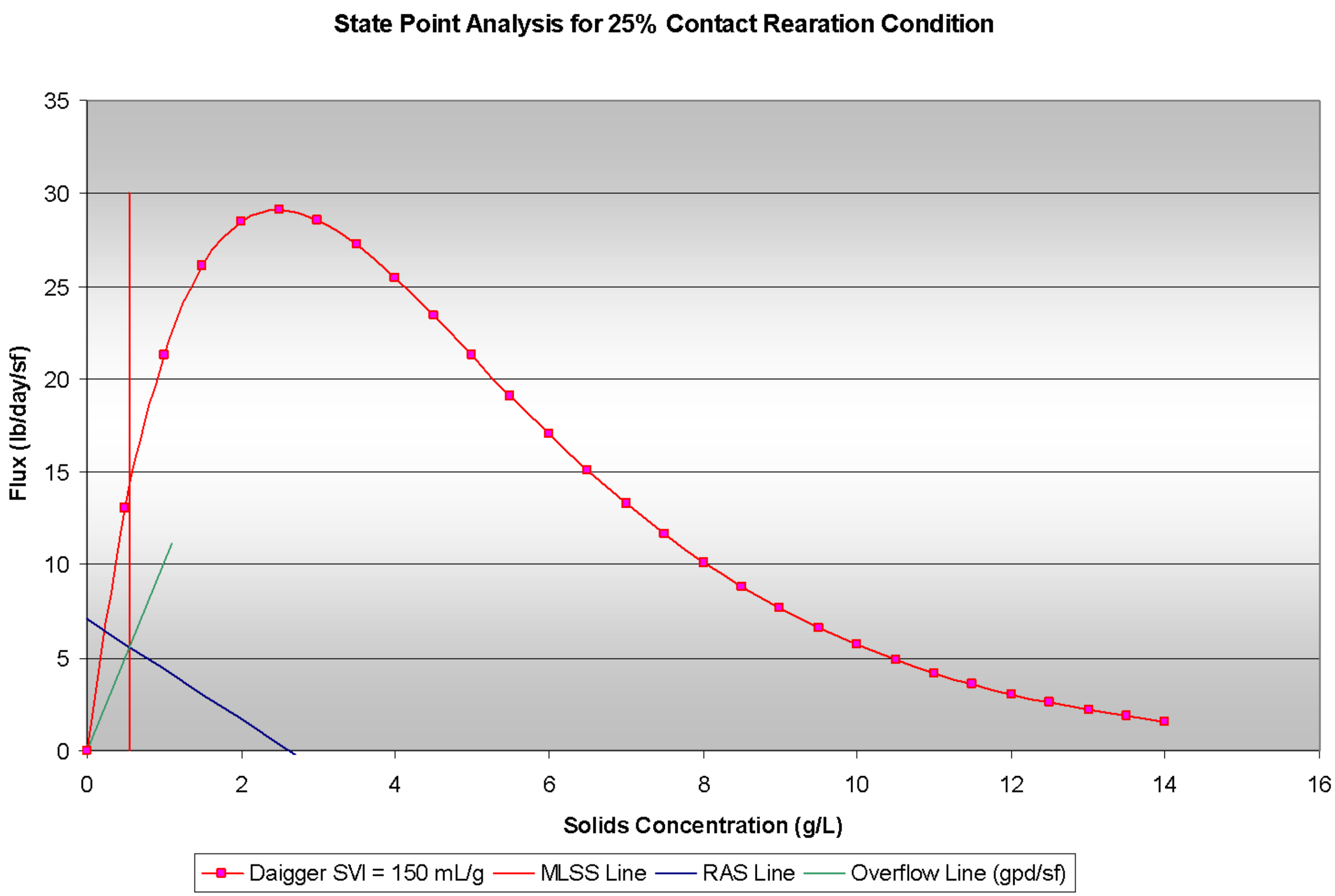
Figure 16 presents a chart of predicted dynamic effluent TSS and BOD_5 concentrations in the secondary and final effluent during the 13-day simulation period for Scenario 1 (the partial plug flow condition with an assumed peak sustained primary effluent flow to the aeration basins of 175 mgd and 150 mgd of primary effluent bypass).



STATE POINT GRAPH FOR 220 MGD PLUG FLOW CONDITION

FIGURE 14

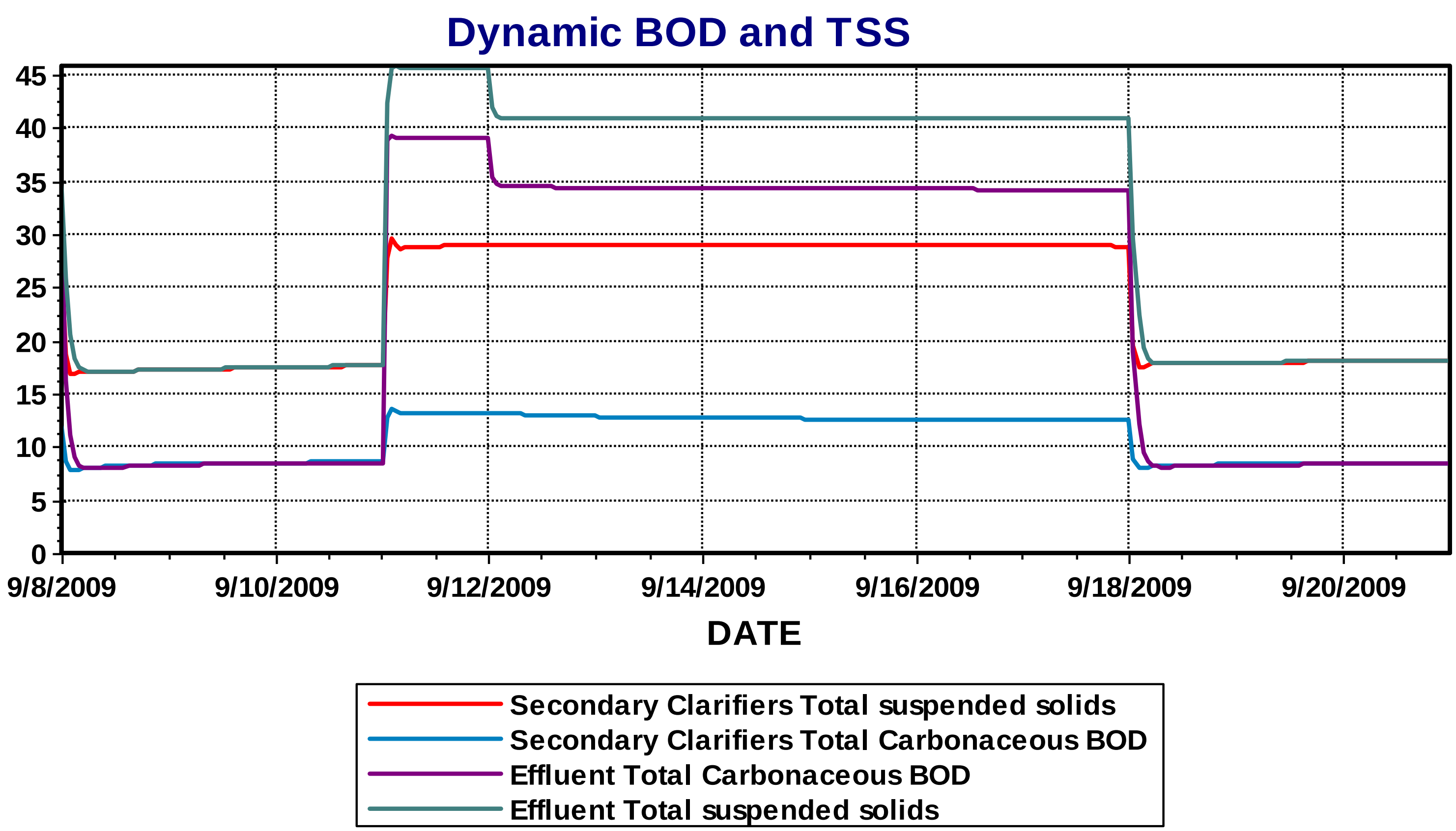
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES



STATE POINT GRAPH FOR 25% CONTACT REAERATION FLOW CONDITION

FIGURE 15

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES



PREDICTED DYNAMIC EFFLUENT QUALITY FOR THE 175 MGD PARTIAL PLUG FLOW CONDITION (SCENARIO 1)

FIGURE 16

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES

The dynamic simulation predicts that the final effluent TSS and BOD_5 concentrations reach approximately 45 mg/L and 40 mg/L, respectively, immediately after the beginning of the flood flows, but that the levels decrease to approximately 40 mg/L and 35 mg/L after about one day of steady operation at 325 mgd. The secondary effluent TSS and BOD_5 concentrations are approximately 30 mg/L and 13 mg/L, respectively. The dynamic results are slightly higher than the predicted concentrations based on steady state operation.

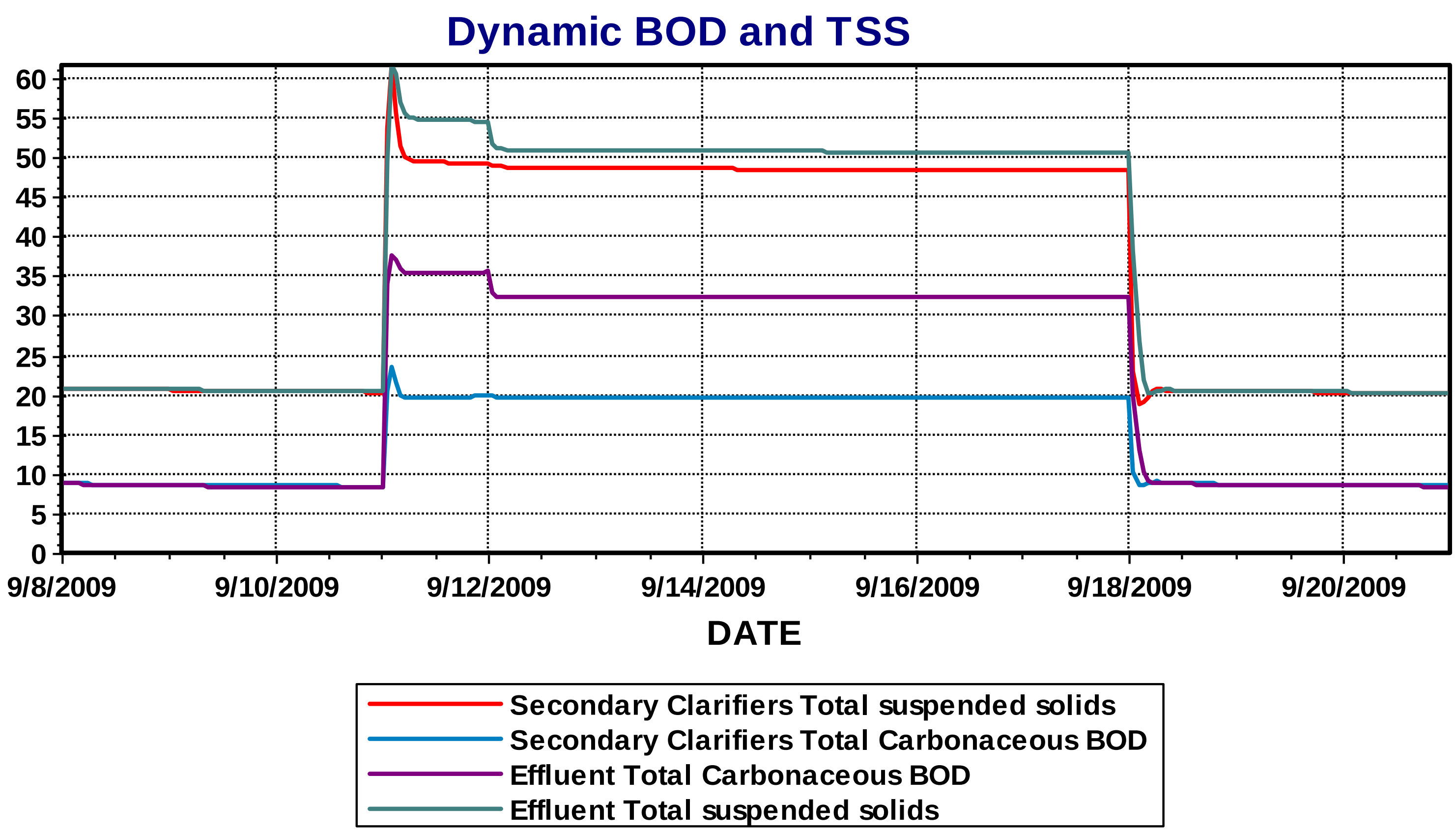
Figure 17 presents the dynamic model results for Scenario 2: the partial plug flow configuration with bypass of only 104 mgd around the aeration tanks. With this scenario, the final effluent and secondary effluent TSS concentrations both reach approximately 60 mg/L immediately after the beginning of the flood flows. The TSS concentrations decrease to approximately 50 mg/L after about one day of steady operation at 325 mgd. The final effluent BOD_5 concentration is approximately 30 mg/L and the secondary effluent BOD_5 concentration is approximately 20 mg/L. The dynamic model results predict higher effluent concentrations than the steady state model. With the higher flow to the aeration basins, the effluent TSS from the secondary clarifiers and the associated particulate BOD_5 in the secondary effluent are significantly higher. For both the partial plug flow scenarios, the final effluent BOD_5 is approximately the same, in the range of 30 to 32 mg/L. For the second scenario, the secondary effluent BOD_5 concentration increases as a result of the higher secondary sedimentation flow. However, blending that higher secondary effluent BOD_5 concentration with a lower flow of primary effluent produces approximately the same final effluent BOD_5 concentration as with Scenario 1. The final effluent TSS concentration is noticeably higher for Scenario 2 due to the increased secondary clarifier TSS concentration.

Figure 18 presents the comparable dynamic effluent concentrations for Scenario 5, the case with 25 percent of the aeration tank in contact. In this scenario the final effluent TSS concentration is less than in the partial plug flow scenarios, approximately 38 mg/L, after an initial increase to slightly over 40 mg/L. The final effluent BOD_5 concentration is approximately the same as for Scenario 2 at approximately 30 mg/L. Results for the other scenarios were intermediate between the results shown for these alternatives and have not been included in this Project Report.

6.3 Sensitivity Analysis

This section presents a sensitivity analysis on several key parameters:

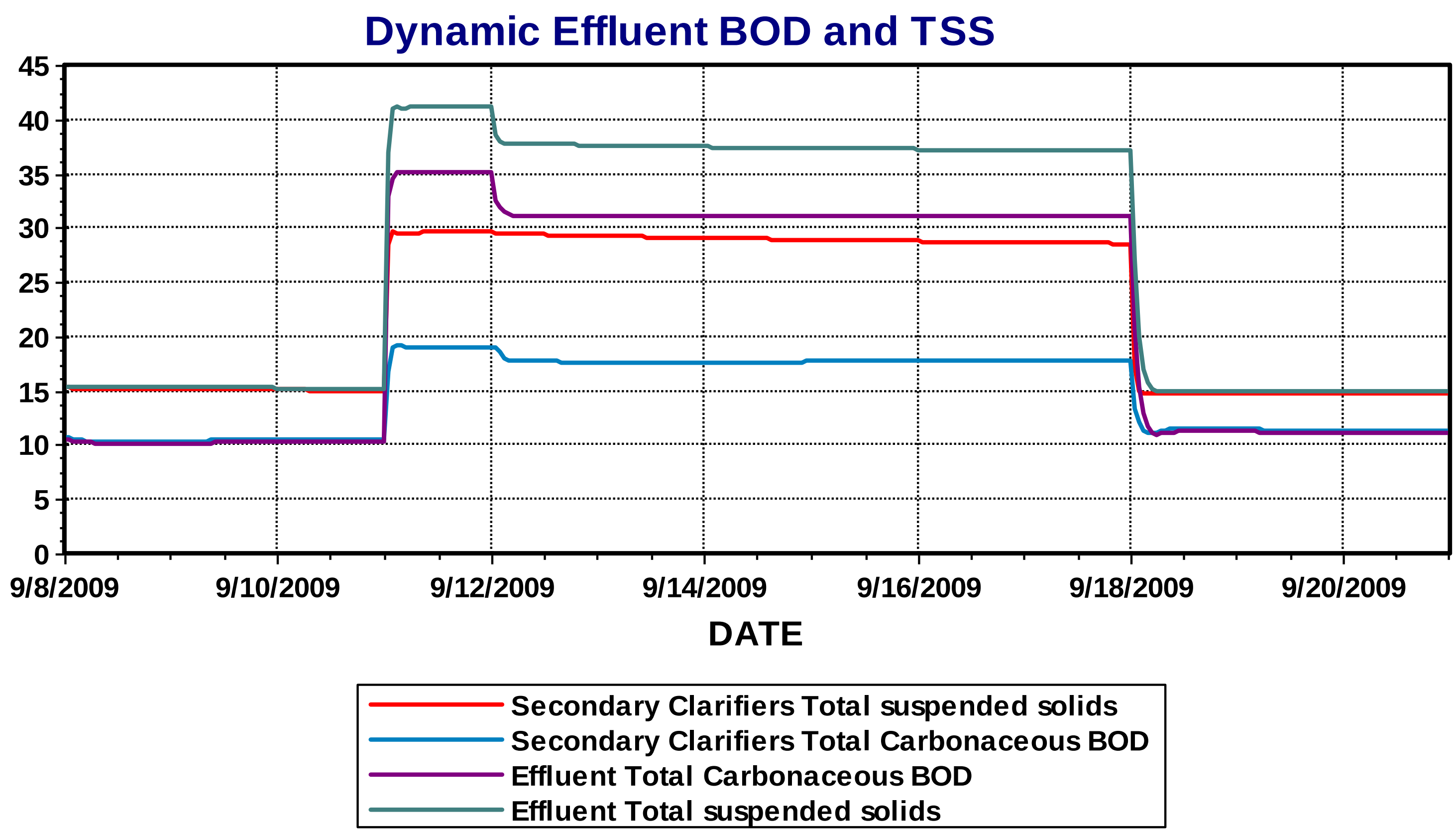
- Wastewater Characteristics
- Temperature
- Influent dissolved oxygen (DO) concentration



PREDICTED DYNAMIC EFFLUENT QUALITY FOR THE 220 MGD PLUG FLOW SCENARIO

FIGURE 17

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES



PREDICTED DYNAMIC EFFLUENT QUALITY FOR THE 25% CR FLOW SCENARIO

FIGURE 18

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WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES

- Operating SRT
- Settleability

6.3.1 Wastewater Characteristics

Table 6 presents a comparison of the steady state results for simulation of Scenario 1 (partial plug flow with a secondary flow of 175 mgd) using the three different sets of wastewater characteristic ratios discussed in the Model Calibration section above. There are two parameters where the different ratios produce significantly different results. The default BioWin ratios produce a 10 percent PAO percentage ratio, while the other two wastewater characteristics produce approximately 12.5 percent. The default BioWin and Biotran ratios produce a predicted primary effluent TSS concentration of approximately 44 mg/L, while the Brown and Caldwell ratios produce a predicted primary effluent TSS concentration of 35 mg/L. This difference produces a lower final effluent TSS concentration. Considering that the Biotran calibration ratios relied on more recent data from the STP and also seem to produce the most conservative result, these wastewater characteristics were chosen for use in model comparisons.

Table 6 Comparison of Plug Flow to Low Temperature and High DO Simulations
South Plant Emergency Peak Flow Management Alternatives
King County Department of Natural Resources and Parks Wastewater Treatment Division

Description	Plug Flow BioWin Ratios	Plug Flow Biotran Ratios	Plug Flow BC Ratios
Sewage Flow (mgd)	325	325	325
Secondary Flow (mgd)	176	176	176
RAS Flow (mgd)	40	40	40
Primary Bypass Flow (mgd)	149	149	149
Secondary Aerobic SRT (days)	3.05	3.05	3.05
Last Pass MLSS (mg/L)	1,742	1,773	1,634
Aeration Rate (scfm)	24,593	23,863	23,427
PAO Population (%)	9.9%	12.4%	12.5%
Secondary Clarifier Overflow Rate (gpd/sf)	976	992	976
Secondary Clarifier Solids Loading Rate(ppd/sf)	17	18	16
Secondary Clarifier SF	1.36	1.68	1.42
Predicted Primary Effluent Quality (mg/L)			
Carbonaceous BOD_5	55	54	55
TSS	42	43	35
Predicted Secondary Effluent Quality (mg/L)			
Carbonaceous BOD_5	12	12	13
TSS	27	27	27
Predicted Plant Effluent Quality (mg/L)			
Carbonaceous BOD_5	32	31	32
TSS	34	35	31

6.3.2 Temperature and DO

In previous modeling the influent temperature was assumed to be 11.4 degrees C, approximately the lowest weekly influent temperature experienced during the last several years of record. The influent DO concentration had been assumed to be zero. The exact nature of the influent wastewater during a flood condition is not known. This would be an unprecedented event and it is possible that temperatures could be even lower than the plant has experienced on the lowest days to date. It is also possible that the flood water during cold temperatures could have a high DO. To investigate the potential impact of an even lower temperature, a steady state simulation was undertaken with an influent temperature of 8 degrees C (approximately 46 degrees Fahrenheit). To investigate the impact of high influent DO, the influent DO concentration was assumed to be 5 mg/L, rather than zero. Results of steady state BioWin simulations for these two conditions, compared to Scenario 2, plug flow with 220 mgd flow to the aeration tanks, are presented in Table 6. Other operating parameters for the simulations, such as the assumed 3.5-day total aeration tank SRT and sludge settleability remained the same as for Scenario 2.

The results presented in Table 7 show that low temperature does not seem to have a significant impact. The predicted MLSS concentration is slightly higher, the aeration requirement slightly lower, and the PAO percentage is slightly lower, when the model was run assuming a lower wastewater temperature. The simulations indicate that this would not have an effect on effluent quality, unless the lower temperature reduced sludge settling rates because of higher viscosity. However, a high assumed influent DO concentration has potentially more significant impacts. With this scenario, the MLSS concentration is depressed compared to Scenario 2, but the PAO percentage in the system is significantly reduced, from 13.3 percent to 6.7 percent. If flood flows were seen to have a significantly higher than zero DO, the operations staff should consider operating in a contact reaeration mode, to help alleviate any capacity loss due to poor settleability from a potential loss of the PAO population.

6.3.3 SRT

The key operating parameter for an activated sludge process is SRT because it controls the kind of organisms that can be maintained in the system, determines the MLSS concentration which, in turn, determines the flow capacity of secondary sedimentation, and controls the oxygen consumption of the process. For all of the simulations considered above a total aeration tank SRT of 3.5 days was assumed. This was calculated by dividing the total inventory of solids in the aeration tanks by the sum of the waste solids rates from the sedimentation tank effluent and the WAS. In this sensitivity analysis, performance in operating Scenario 2 was compared to operation at lower and higher SRT setpoints, 2.5 days and 4.5 days, respectively.

Table 7	**Comparison of Plug Flow to Low Temperature and High DO Simulations South Plant Emergency Peak Flow Management Alternatives King County Department of Natural Resources and Parks Wastewater Treatment Division**		
Description	**Plug Flow**	**Plug Flow Low Temp**	**Plug Flow High DO**
Sewage Flow (mgd)	325	325	325
Secondary Flow (mgd)	221	221	221
RAS Flow (mgd)	40	40	40
Primary Bypass Flow (mgd)	104	104	104
Secondary Aerobic SRT (days)	3.04	3.04	3.04
Last Pass MLSS (mg/L)	1,975	2,002	1,836
Aeration Rate (scfm)	29,478	27,512	27,874
PAO Population (%)	13.3%	12.8%	6.7%
Secondary Clarifier Overflow Rate (gpd/sf)	1,225	1,225	1,225
Secondary Clarifier Solids Loading Rate(ppd/sf)	24	24	22
Secondary Clarifier SF	1.22	1.21	1.30
Predicted Primary Effluent Quality (mg/L)			
Carbonaceous BOD_5	54	54	54
TSS	43	43	43
Predicted Secondary Effluent Quality (mg/L)			
Carbonaceous BOD_5	19	19	19
TSS	43	43	41
Predicted Plant Effluent Quality (mg/L)			
BOD_5	30	30	30
TSS	43	44	42

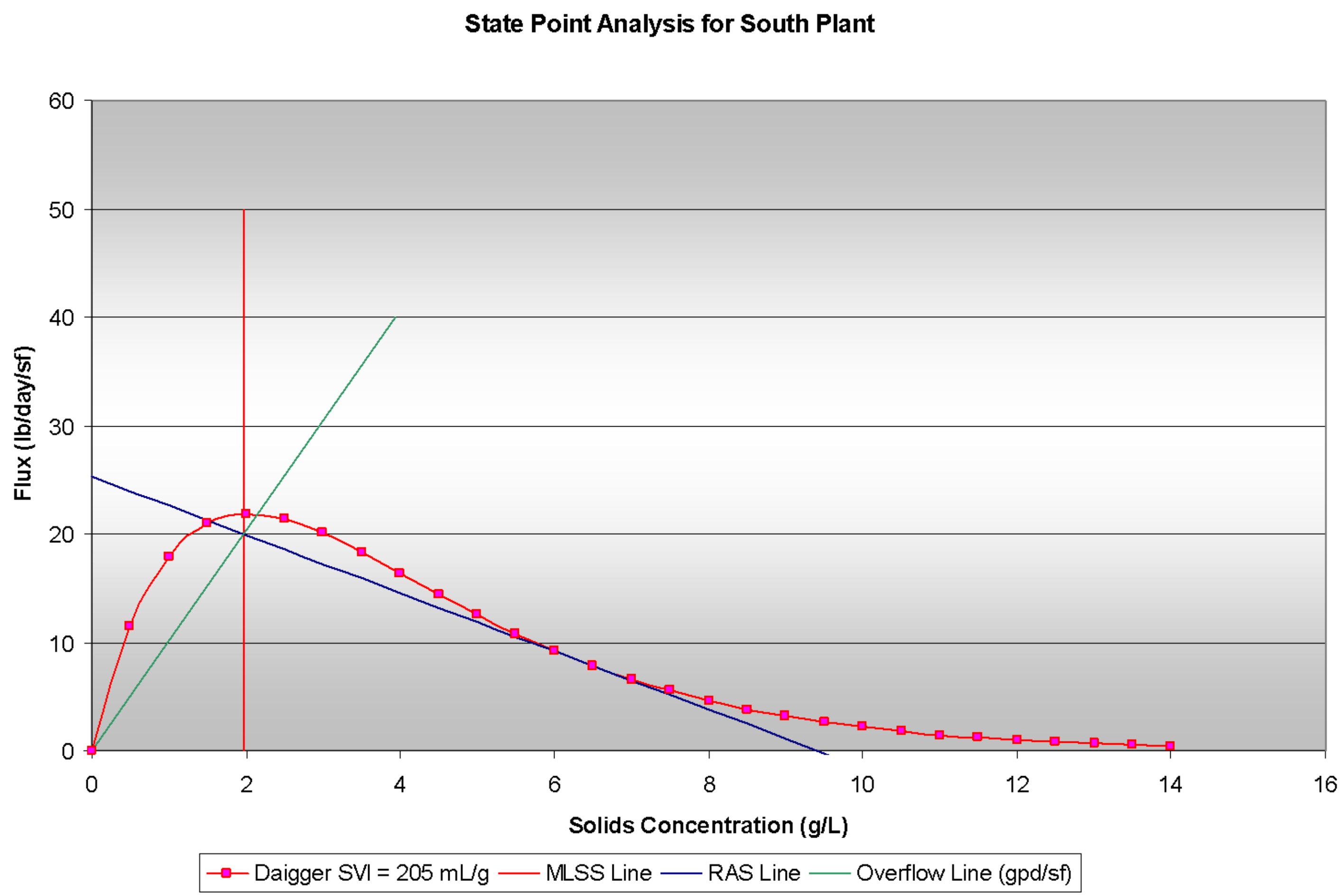
Results from this analysis are shown in Table 8. It is seen that dropping the SRT to 2.5 days has one significant effect: the predicted PAO population drops approximately in half. Settleability constants for the different simulations shown in the table were assumed to be the same. However, it may be expected that the lower PAO population predicted for the lower SRT operation would result in poorer settleability. The simulation for the 4.5-day SRT condition resulted in clarifier failure. It may be assumed that 4.5 days SRT would not be a stable operating point during a storm flow. It should be noted, however, that the higher SRT caused a dramatic increase in PAO population. It could well be in practice that the higher PAO population would cause better settleability conditions than had been assumed in the sensitivity analysis and could conceivably be a stable operating point for that reason.

Table 8	Comparison of Lower and Higher SRT in Plug Flow Mode South Plant Emergency Peak Flow Management Alternatives King County Department of Natural Resources and Parks Wastewater Treatment Division		
Description	**Plug Flow 3.5 Day SRT**	**Plug Flow 2.5 Day SRT**	**Plug Flow 4.5 Day SRT**
Sewage Flow (mgd)	325	325	325
Secondary Flow (mgd)	221	221	221
RAS Flow (mgd)	40	40	40
Primary Bypass Flow (mgd)	104	104	104
Secondary Aerobic SRT (days)	3.04	2.18	3.20
Last Pass MLSS (mg/L)	1,975	1,438	>2,331
Aeration Rate (scfm)	29,478	28,265	37,370
PAO Population (%)	13.3%	7.2%	22.1%
Secondary Clarifier Overflow Rate (gpd/sf)	1,225	1,225	1,225
Secondary Clarifier Solids Loading Rate(ppd/sf)	24	17	28
Secondary Clarifier SF	1.22	1.55	<1.05
Predicted Primary Effluent Quality (mg/L)			
Carbonaceous BOD_5	54	54	54
TSS	43	43	43
Predicted Secondary Effluent Quality (mg/L)			
Carbonaceous BOD_5	19	18	27
TSS	43	37	59
Predicted Plant Effluent Quality (mg/L)			
BOD_5	30	29	35
TSS	43	39	54

6.3.4 Settleability

Another key parameter that dramatically affects the capacity of activated sludge operation is sludge settleability. The higher the sludge settling rate, the more capacity an activated sludge sedimentation tank will have to remove solids and protect plant effluent quality. In the forgoing steady-state modeling safety factors for activated sludge sedimentation were calculated based on the Daigger equation for SVI of 150 mL/g. Dynamic simulations were done using the default BioWin settling parameters that are somewhat less conservative than the Daigger equation at 150 mL/g SVI. In this section we will compare the impacts of variation from these values on potential secondary sedimentation capacity and effluent quality.

Figure 19 presents the state point diagram for the conditions Scenario 2, but with SVI of 205 mL/g, instead of the 150 mL/g assumed in Figure 14. For this figure the Daigger relationship between SVI and sludge settling velocity was assumed. The diagram indicates incipient failure under these conditions. Considering that the state point condition neglects hydraulic factors in sedimentation, this would surely be the limit of successful operation during flood conditions.



PREDICTED STATE POINT FOR PLUG FLOW AT 220 MGD AT THICKENING FAILURE

FIGURE 19

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES

carollo

Figure 20 shows the impact of poorer settleability when operating in a contact reaeration configuration. The figure shows the impact of SVI of 300 mL/g on the state point diagram for the condition of 25 percent contact reaeration, Scenario 5. The state point indicates that there is ample capacity under these conditions.

7.0 CONCLUSIONS

Based on the work conducted for this assignment the following conclusions have been reached:

1. Based on experience at other plants, key operating considerations for storm flow operation should include planning for alkalinity addition and maintenance of adequate activated sludge settleability. Recovery of effective process operation after the flooding events was relatively rapid (within three days) at each location.

2. Five different scenarios were developed for storm flow operation at the STP: two plug flow scenarios and three contact reaeration scenarios. Based on steady state modeling of a 325 mgd flood flow condition, all five of the operating scenarios should produce effluent under the 45/45 mg/L NPDES permit limit for maximum week BOD_5/TSS.

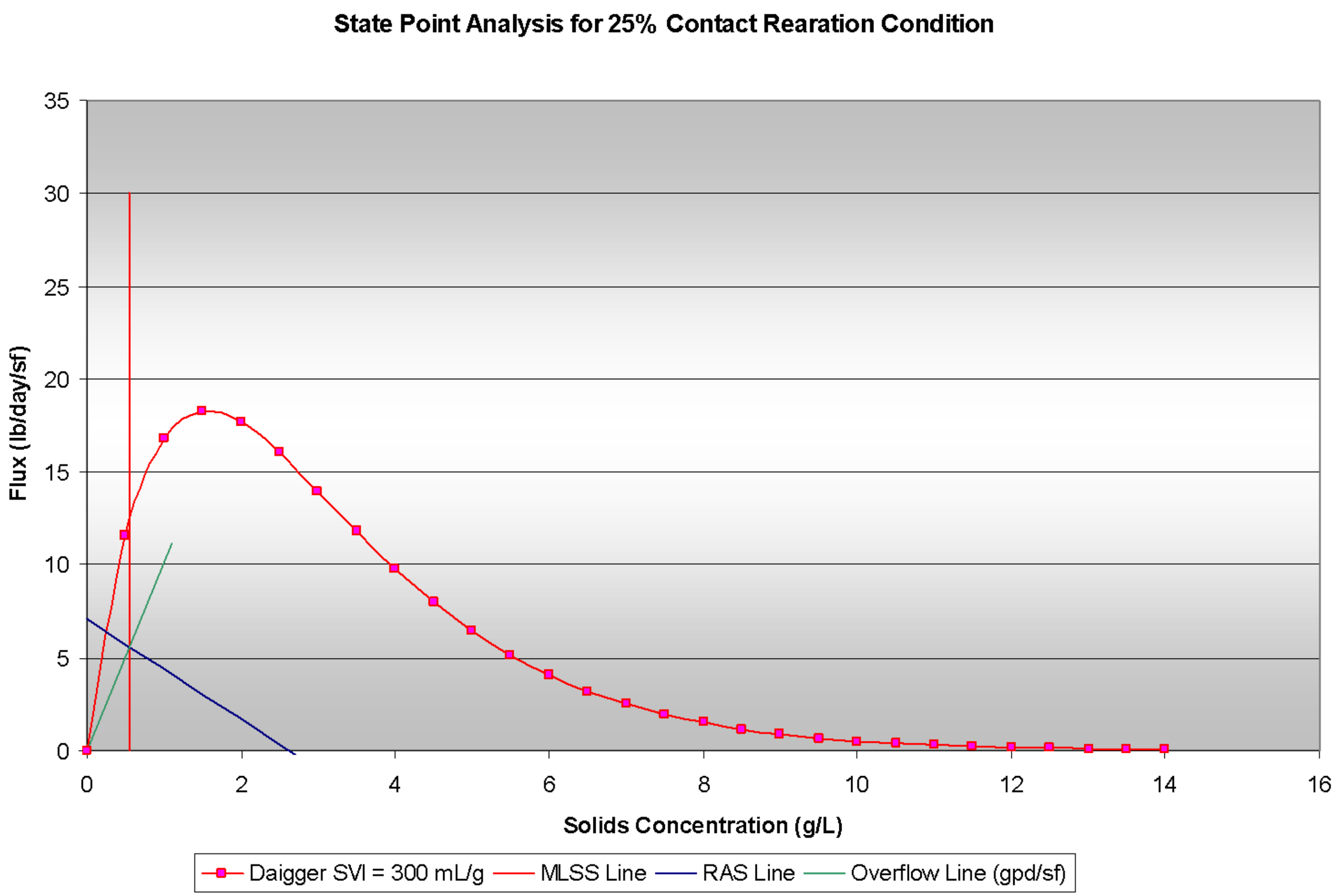
3. Based on steady state modeling, a 50 percent contact reaeration contact reaeration scenario produces the lowest predicted BOD_5 and the 25 percent contact reaeration scenario (Scenario 5) produces the lowest predicted TSS, but all scenarios produced effluent quality within the range of 27-31 mg/L BOD_5 and 32-40 mg/L TSS.

4. Dynamic model results predicted higher effluent values for BOD_5 and TSS. Simulations of Scenario 1 (175 mgd plug flow) and Scenario 5 (25 percent contact reaeration) produced dynamic effluent values under the permit level of 45/45-mg/L. Simulations of the same conditions for Scenario 2 (220 mgd plug flow) did not.

5. A sensitivity analysis based on simulation of the 220 mgd plug flow scenario (Scenario 2) indicated the following:

    a. Wastewater characteristic ratios based on Biotran calibration to recent STP data were used for the modeling. Using either the default BioWin values for these ratios or the ratios recommended in an earlier Brown and Caldwell evaluation produced similar results, although the Biotran calibration is more conservative, in that it predicts a slightly higher final effluent TSS.

    b. If temperatures were as low as 8 degrees C, there would be little impact on effluent quality.



PREDICTED STATE POINT FOR 25% CR AT 220 MGD AT SVI = 300 ML/G

FIGURE 20

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WASTEWATER TREATMENT DIVISION
SOUTH PLANT EMERGENCY PEAK FLOW MANAGEMENT ALTERNATIVES

c. A high DO of 5 mg/L could cause a significant reduction in PAO organism populations and threaten sludge settleability and plant capacity. If high DO were detected in storm flows, contact reaeration operation should be considered to ameliorate potential detrimental effects on settleability.

d. Reducing the SRT to 2.5 days based on the total aeration volume could reduce the PAO population to a level similar to having an influent DO of 5 mg/L.

e. Operation at a SRT of 4.5 days may be feasible, depending on the sludge settleability improvement that may be expected with this higher SRT, but the modeling indicates this to be approximately the maximum SRT that could be operated in partial plug flow mode during storm flows.

f. In partial plug flow mode, the limit of activated sludge operation at 220 mgd in the peak flow mode occurs at about 200 mL/g SVI.

g. In contact reaeration mode, the STP should have adequate sedimentation capacity at 220 mgd secondary flow to handle SVI excursions as high as 300 mL/g.

6. Maintenance of secondary treatment capacity through one of these strategies may result in elevated suspended solids levels that may make reclaim water filtration challenging. However, reclaimed water production should be able to resume shortly after a flooding event.

8.0 REFERENCES

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Appendix A

PLANT INTERVIEWS

Engineers...Working Wonders With Water™

Interoffice Memorandum

To: File

Copies To: cc

From: Randal Samstag

Date: October 19, 2009 **WO#:** 7683F00

Subject: Experience of WWTP with Flood-induced Peak Flow Management at the Aberdeen WWTP

Questionnaire for interview of treatment plant operators who have experienced severe flood events at their wastewater treatment plant:

1. Contact Name: Kyle Scott, Wastewater Manager

2. Contact Phone Number: (360) 537-3285

3. WWTP Name: Aberdeen WWTP

4. WWTP Location: Aberdeen, WA

5. What was the peak flow compared to the dry weather average flow and how long did the peak flow last? October 20-21 2003 - 2 days; 20-21 mgd, average dry weather flow - 2-3 mgd, December 2007 - 60 hours of peak flow; 15-18 mgd.

6. What were the influent concentrations for BOD, TSS, TKN, and alkalinity? 10/20/2003: Influent BOD 35 mg/L, TSS 71 mg/L, NH4-N 2 mg/L, Alkalinity -40 mg/L; Effluent BOD 52 mg/L, TSS 68 mg/L, but 7-day running average less than 15 mg/L TSS.

7. Was there a violation of the NPDES permit requirements for maximum week or maximum day effluent quality? No

8. Did dilution from flood waters cause and specific problems like:
   a. Low alkalinity and pH? Yes. Ops staff added significant amounts of caustic to an influent manhole and sodium carbonate to the activated sludge system.
   b. Clarifier overflow? PC OFR > 3000 gpd/sf
   c. Deflocculation of MLSS? MLSS low - 790 mg/L, but SVI was OK - 179 mL/g

9. Was there a surge of grit and other debris into the plant headworks as a result of the flood conditions? Yes. There was a 7-10 fold increase in screenings. They filled up one dumpster in a day that would normally take a week.

10. How long did it take the plant to recover normal operations after the flood conditions? Plant back to normal in a day.

11. What was the recovery strategy? Get the SVI down in anticipation of storm flows by maintaining MCRT of 5 days and using chlorination of the RAS, if necessary.

12. Was there a problem with power outage as well as peak flow? Yes. This was a serious problem in the 2007 storm.

13. Were there any impacts on biosolids? No significant increase or other impacts.
    a. Who is the contact for biosolids?
        1) Name: Same
        2) Phone Number: Same

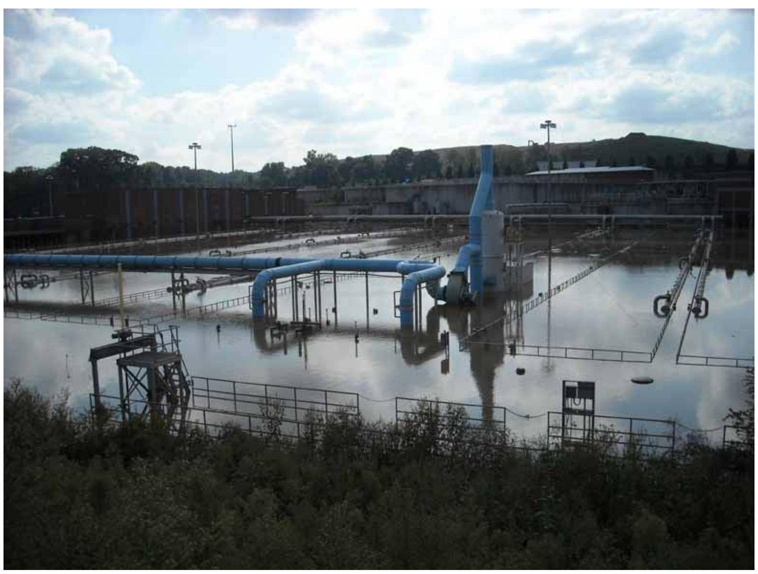
Engineers...Working Wonders With Water™

Interoffice Memorandum

To:	File
Copies To:	cc
From:	Randal Samstag
Date:	October 19, 2009 **WO#:** 7683F00
Subject:	Experience of WWTP with Flood-induced Peak Flow Management at the Aberdeen WWTP

Questionnaire for interview of treatment plant operators who have experienced severe flood events at their wastewater treatment plant:

1. Contact Name: George Barnes, Bureau of Engineering Services, Deputy Commissioner
2. Contact Phone Number: 404-330-6708
3. WWTP Name: RM Clayton WWTP
4. WWTP Location: Atlanta, GA
5. What was the peak flow compared to the dry weather average flow and how long did the peak flow last? The RM Clayton WWTP was severely impacted in recent flooding during late September 2009. Water from the adjacent Chattahoochee River entered the WWTP and flooded major portions of the plant. There was 6-8 foot of water over the aeration basins. Underground equipment tunnels were flooded and major plant electrical and control equipment damaged by water. The WWTP was bypassed for several days. The problem was not peak flows, but flooding of process units. The following photo shows the aeration tanks under water.



6. What were the influent concentrations for BOD, TSS, TKN, and alkalinity? Dilute wastewater was not the problem; the problem was flooding of the treatment units causing bypass of the entire plant.

7. Was there a violation of the NPDES permit requirements for maximum week or maximum day effluent quality? Yes. Max week permit levels were exceeded.

8. Did dilution from flood waters cause and specific problems like:
   a. Low alkalinity and pH? No.
   b. Clarifier overflow? PC OFR > No
   c. Deflocculation of MLSS? No

9. Was there a surge of grit and other debris into the plant headworks as a result of the flood conditions? There was a lot of debris from the river after the flood waters receded.

10. How long did it take the plant to recover normal operations after the flood conditions? The plant came back on line and was in stable operation in one to two days.

11. What was the recovery strategy? First primary treatment was established, then secondary treatment.

12. Was there a problem with power outage as well as peak flow? Yes. There were internal power outages caused by flooding of electrical control equipment.

13. Were there any impacts on biosolids? No significant increase or other impacts.
    a. Who is the contact for biosolids?
       1) Name: Rob Busch, Plant Manager
       2) Phone Number: 404-350-4901