West Point Treatment Plant Peak Flow and Wasteload Projections

2010–2060

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King County

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Contents

1. Introduction 1
Background 1
Conveyance System Modeling 1
Flow Projections 4
2. Wastewater Flow Projections 5
Current (2004–2017) Flows 5
Flow Transfers 5
Recycle Streams 5
Flow Simulation 6
Flow Projections 8
Projected Flows Through 2060 12
3. Wasteload Forecasts 13
Current (2007–2017) Influent Loadings 13
Influent Loading Data Validation 14
Influent Loading Peaking Factors 15
Load Adjustments 15
Day of Week Variation 19
Flow Variation 20
Peak Loading Rates 22
Peaking Factors 25
Projected Loading Rates Through 2060 26
Projected Influent Concentrations Through 2060 27
4. References 28
APPENDIX A Future Population Projection A1

Tables

Table 1. Projected Growth in the West Point Service Area 9
Table 2. Relative Growth of Base Flow and Sewered Area 9
Table 3. Components of Projected Flows by Decade 11
Table 4. Projected Flows for West Point, 2010–2060 12
Table 5. Peaking Factors for 20-year Peak Loading Rates 25
Table 6. Projected Flow and Loads for West Point, 2010–2060 26

Table 7. Projected Influent Concentrations for West Point, 2010−2060 27
Table A1. Total Population Based on ACS Data Clipped to Service Area................................ A3
Table A2. Projected Sewered Population and Employment by Decade A3

Figures

Figure 1. Wastewater Flow Projection Process 3
Figure 2. Difference between Original West Point Model Daily Flow and Observed West Point Daily Flows by Flow (mgd) for 2004–2015 7
Figure 3. Comparison of Adjusted Hydraulic Model (Model Less 15 mgd) Daily Flow to West Point Daily Effluent Flow for the Period from October 1, 2012, to October 1, 2014........ 8
Figure 4. Monthly Average BOD, TSS Loads for West Point (WP)... 14
Figure 5. Observed West Point Influent Loading Rates 16
Figure 6. Observed West Point Influent Loading Rates with Questionable Values Removed 17
Figure 7. West Point Influent Loading Rates Adjusted for Flow Transfers 18
Figure 8. West Point Influent Loading Rates after Removal of Linear Trend in Time 18
Figure 9. Ratio of Influent to Primary Effluent and Sludge Loading Rates................................. 19
Figure 10. Average Weekday Variation in BOD and TSS Loading Rate 20
Figure 11. Regression of West Point Daily BOD Loading Residual after Subtraction of Temporal Trend to Average Daily Flow for January 2004 to February 2017, June 2017 to December 2017 21
Figure 12. Regression of West Point Daily TSS Loading Residual after Subtraction of Temporal Trend to Average Daily Flow for January 2004 to February 2017, June 2017 to December 2017 22
Figure 13. Cumulative Probability Plots of Daily, Weekly, and Monthly BOD and TSS Loads. Twenty-year Recurrence Value Denoted by Red Marker. 23
Figure A1. Total Population Projections for Each Service Area from Estimates Made in 2003, 2013, and 2018 .... A4

1. INTRODUCTION

This report documents the methodology and results of peak flow and wasteload projections for King County's West Point Treatment Plant (West Point). The projections supplement those described in *Treatment Plant Flow and Wasteload Projections 2010−2060* (King County Department of Natural Resources and Parks [DNRP], 2014a) to develop estimates of the peak monthly, weekly, and daily flows and loads.

This analysis uses a calibrated collection system model (MIKE URBAN) along with flow and wasteload data measured at West Point from January 2004 through December 2017. Corrections are made to reflect the flow transfers from the Brightwater Treatment Plant (Brightwater) service area.

The collection system model, calibrated to observed flows at many locations in the West Point service area, is used to estimate the infiltration and inflow (I/I) corresponding to the peak conditions of maximum month, maximum week, and peak day. These flows are combined with the base wastewater flow and forecast assumptions used in (King County DNRP, 2014a) to estimate peak flows from 2010 through 2060.

A statistical analysis was applied to the observed 2004 to 2017 loading rates at West Point to develop peaking factors relating maximum month, maximum week, and peak day loads to the annual average load. These peaking factors were combined with the projected annual loading rates in (King County DNRP, 2014a) to estimate loading rates from 2010 through 2060.

Background

As part of the Regional Wastewater Services Plan (RWSP) 2007−2013 comprehensive review, projections of average wet weather flow (AWWF), annual total suspended solids (TSS), and biochemical oxygen demand (BOD) loadings to King County's three regional wastewater treatment plants were developed for use as summary parameters to evaluate available capacity through 2060 (King County, 2014a). At the time of the RWSP comprehensive review, projections of future peak flows for the treatment plants were being developed.

In general, the King County Wastewater Treatment Division (WTD) updates its treatment plant flow and loading projections every 10 years using population and employment forecasts provided by the Puget Sound Regional Council (PSRC) that reflect the most recent U.S. Census data. WTD also evaluates and updates other key planning assumptions, such as water use, water conservation, and the service area growth rate.

Conveyance System Modeling

West Point serves both combined areas, where wastewater and stormwater are conveyed in the same pipe system, and separated areas, where separate stormwater systems exist. Plant inflow consists of two components: base wastewater flow (sewage) and rain-induced flow, either from directly connected basins in combined system areas or from I/I in separated areas. Base flow is primarily a function of how many households and businesses are connected to the sewer system. I/I is primarily a function of the extent of sewered area served by the wastewater collection system and of the response of the system to rainfall and groundwater conditions.[1] The

[1] Base flow is wastewater (not including I/I) that originates from homes, businesses, and industries. Infiltration is groundwater that seeps into sewers through holes, breaks, joint failures, defective

flow response to rainfall from combined basins is typically much greater than I/I from the separated basins.

This report addresses peak flows characterizing the maximum month, maximum week, and peak day. The year 2010 was established as the existing, or baseline, condition for estimating the current 20-year peak flow conditions. To estimate these flows, the following tasks were completed:

- A North Interceptor model was developed by WTD and Seattle Public Utilities, and calibrated to flow and levels monitored during the period from 2007 to 2015. Subsequently, the North Interceptor Model was updated with the proposed Lake Washington Ship Canal Water Quality Project facility to allow for simulation of the proposed tunnel. This model is referred to as the "Integrated Tunnel Model." MIKE URBAN is the modeling software being used.
- Once good calibrations were achieved (i.e., model results closely approximated metered data), hydrologic and hydraulic simulations were done using the 38-year rainfall record from 1978 through 2015. Flows from the Interbay Pump Station were simulated with the UNSTDY model, run 2016c.
- The 38-year hydrograph was processed to obtain the peak day, peak week, and peak month flows expected to occur on average once every 20 years. To forecast wastewater treatment plant flow, these flows were separated into a base flow and an I/I component.
- The base flow and I/I components of each peak flow were then projected through 2060 using the expected flow increases obtained from King County's wastewater flow projection process, as depicted in Figure 1. Each component was then scaled by the ratio of the future expected flow to the 2010 flow.

connections, and other openings; inflow is stormwater that rapidly flows into sewers via roof and foundation drains, catch basins, downspouts, maintenance hole covers, and other sources.

Base Wastewater Flow

Puget Sound Regional Council (PSRC)

- Forecast population/employment by model basins
- Forecast population and employment through 2040

King County Wastewater Treatment Division (WTD)

1. **Define Who Is Sewered**
   - Overlay local agency sewer maps
   - Define sewered area
   - Identify current sewered population
2. **Project Population/Employment/ Sewered Areas**
   - Project extension of PSRC data
   - Assume potentially sewerable areas are 100% sewered by 2060
3. **Determine Future Commercial, Industrial, and Residential Per Capita Flow Factors**
   - Review water consumption and industrial discharge data
   - Estimate effects of future water conservation
4. **Project Base Wastewater Flow**
   Apply flow factors to population and employment projections

Infiltration and Inflow (I/I) Flows

King County Wastewater Treatment Division (WTD)

1. **Collect Current I/I Data**
   - Measure flows by tributary basin
   - Calibrate hydrologic and hydraulic models to flow data
   - Use calibrated models to estimate peak I/I rates
   - Use flows at treatment plants to estimate current average I/I
   - Use recent developments to estimate new sewered area I/I
2. **Project Future I/I**
   - Add new sewered area
   - Assume new area I/I is same as estimated from recent developments
   - Assume no change in average wet weather I/I per unit area for treatment plant service areas
   - Assume peak I/I increases 7% per decade because of deterioration in collection/conveyance system through 2060

Total Wastewater Flow (sum of base and I/I flows)

Figure 1. Wastewater Flow Projection Process

Flow Projections

The RWSP 2007−2013 comprehensive review updated King County's planning assumptions used in projecting future flows in the collection system and at treatment facilities. Explanations of the updated assumptions related to treatment plant flow projections are as follows:

- **Population.** For the RWSP 2007−2013 comprehensive review, WTD used the 2013 PSRC population forecasts aggregated to WTD model basins. These forecasts extend to 2040. WTD linearly extrapolated the 2040 estimates to the year 2060.[2] The projections described here update the PSRC 2020 population estimate by extrapolating the 2016 population by the average growth rate from 2012 to 2016. Beyond 2020, the original PSRC growth rate was used. Employment estimates were also increased in 2020 by the same ratio as the extrapolated ACS population to the original PSRC estimate. As for population, the original PSRC estimates were used for growth in employment beyond 2020.
- **Water Conservation.** A water conservation planning assumption was developed based on wintertime water use conservation projections obtained from several water purveyors. The assumption is that water conservation will reduce the 2010 flow factors (per capita and per-employee water use) by 5 percent in each of the next two decades, for a total 10 percent reduction by 2030. No additional reduction is assumed after 2030.
- **Sewered Area.** It is now forecast that 100 percent of the unsewered potentially sewerable area will be sewered by 2060, rather than the earlier assumption of 2050.
- **I/I Degradation.** To assess how to project the average wet weather (AWW) I/I, available service area and flow data from West Point between 1985 and 2012 were reviewed. The yearly AWW I/I was then normalized by the ratio of wet season rainfall to average rainfall. Normalization by rainfall reduced the year-to-year variation, yet no discernable trend was apparent on a per-acre basis. Based on this analysis, the 2010 average dry weather (ADW) I/I and AWW I/I (in gallons per acre per day [gpad]) were used for all future years.
- **Peak I/I Degradation.** Peak I/I estimates were compared for basins with good data and good calibrations in the 2001 to 2002 and 2009 to 2011 periods. The variability in the results was considered too great to have a high confidence in the average difference in peak I/I, but was generally consistent with the previous planning assumption for the peak I/I degradation rate of 7 percent per decade. Therefore, WTD assumes a peak I/I degradation rate of 7 percent per decade for the planning horizon (50 years) to forecast future wastewater flows.
- **New Construction I/I.** WTD used 2009–2011 Decennial Flow Monitoring Project data to assess peak I/I from newly sewered areas. Based on this analysis, newly sewered areas are conservatively assumed to have a peak I/I of 2,000 gpad, with a 7 percent degradation per decade increase.

[2] More detail on the population forecast can be found in *Updated Planning Assumptions for Wastewater Flow Forecasting* (King County DNRP, 2014b).

2. WASTEWATER FLOW PROJECTIONS

This section describes the methodology and results of estimating current (2017) flows and projecting future flows at West Point.

Current (2004–2017) Flows

The collection system model for separated basins was calibrated to match the observed flow throughout the separated portion of the collection system from 2009 to 2011. Combined basins were calibrated for the 2010 to 2015 period.

West Point flows were taken from the calculated effluent flow (pi tag: \\wphistpi\WP707FI09AH011). These flows were then modified to account for flow diversions, as discussed below.

Flow Transfers

The planning basis for West Point flows was that all flows generated in the service area would be conveyed to the treatment plant. Before Brightwater became fully operational in 2012, flows from the Swamp Creek and North Creek areas of the Brightwater service area were conveyed to West Point at certain times of the year. The current West Point model assumes no transfers from the Brightwater service area.

West Point flows were adjusted, as follows, to remove the contribution from the Brightwater service area: Before December 13, 2012, West Point flows were reduced by the estimated flow from the SWAMP029 basin. Before September 8, 2011, if North Creek Pump Station was not pumping, West Point flows were reduced by an additional amount reflecting estimated flow from the NCREK001 and BOTHW087 basins. The daily average flow from portable flow meters is used when available, generally from September 2009 through May 2011. Outside of this period, the monthly average flow is used.

During construction of Brightwater, King County had an agreement to send additional flows from the Lake Ballinger Pump Station (Lake Ballinger PS) to Edmonds Wastewater Treatment Plant (Edmonds WWTP). This agreement ended January 1, 2013. Flows before this date were increased by the difference between the Richmond Beach Pump Station flows to Edmonds WWTP and the Lake Ballinger PS flows to Lake Ballinger–McAleer Trunk.

West Point flows were increased to reflect future combined sewer overflow (CSO) storage facilities. Recorded overflows were assumed to be stored up to the projected CSO storage volume and returned to West Point on the following calendar day.

Recycle Streams

West Point produces reclaimed water, which is predominately used within the plant and then returned to the plant. No correction was made for reclaimed water that is not returned to the plant.

Flow Simulation

The simulated flow from the West Point service area (North Interceptor Model + UNSTDY run 2016c) was averaged to a daily value and compared to the observed flow, adjusted for flow diversions and recycle streams. The West Point hydraulic model was observed to overpredict the observed flows, although this overprediction was within the expected range of portable meter accuracy. Portable flow meters were the primary data source for the hydraulic model calibration; the effluent flow meter at West Point is expected to be more accurate.

The West Point model includes the projected facilities to control all CSOs to a one-event-per-year standard. Return flows from storage facilities are included in the model.

Figure 2 presents the bias in daily flows of the original West Point model flow. On average, the model is approximately 20 million gallons per day (mgd) higher than the observed flows. Because future CSO facilities are included in the model, but not the measured flows, the model would be expected to have slightly greater flows when storage facilities are being returned to the conveyance system. To match the minimum month flow rates, all model flows were adjusted down by a constant 15 mgd.

Figure 3 presents the adjusted model flows together with the West Point measured flows for the period from October 1, 2012, to October 1, 2014.

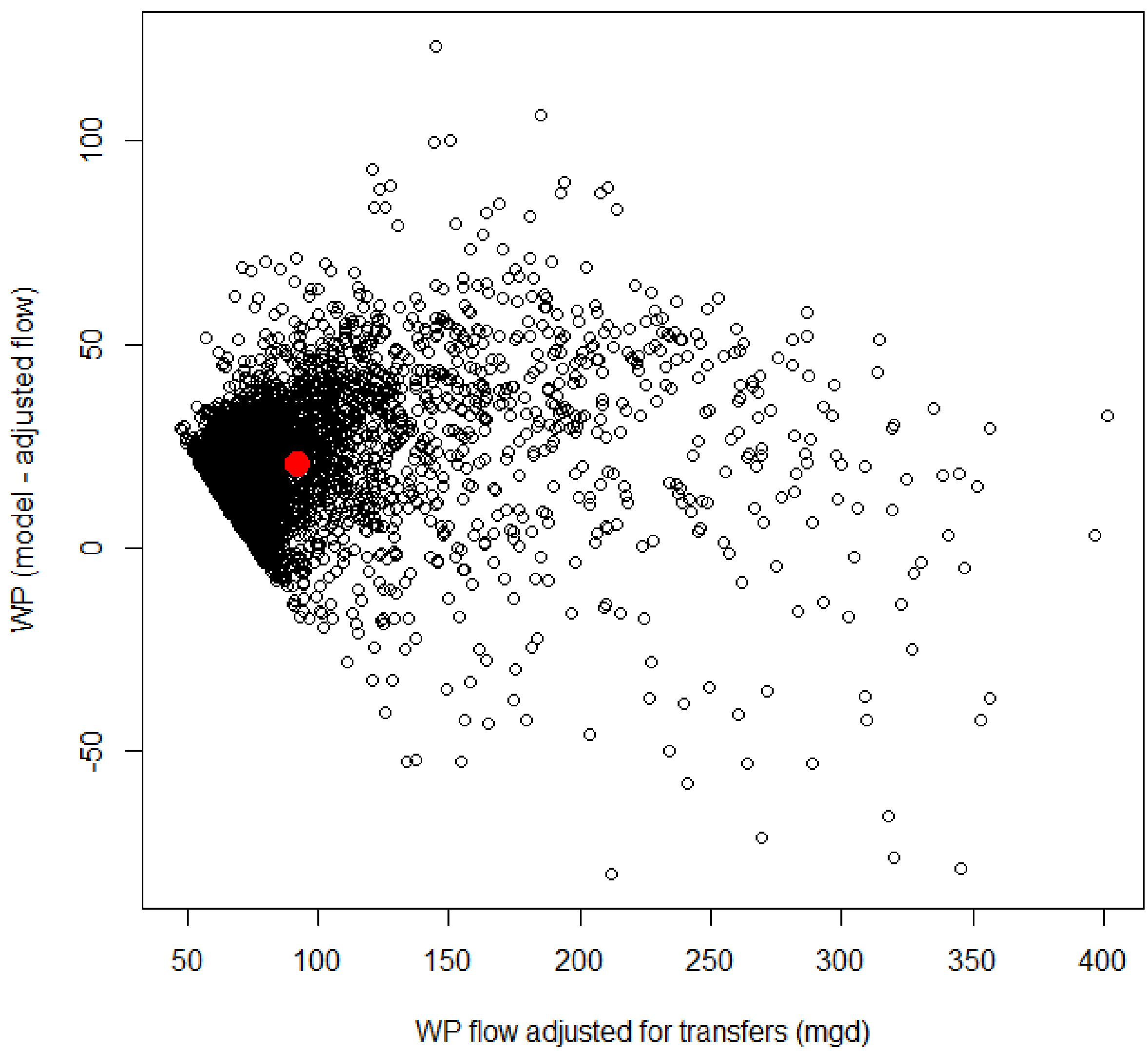


Figure 2. Difference between Original West Point Model Daily Flow and Observed West Point Daily Flows by Flow (mgd) for 2004–2015

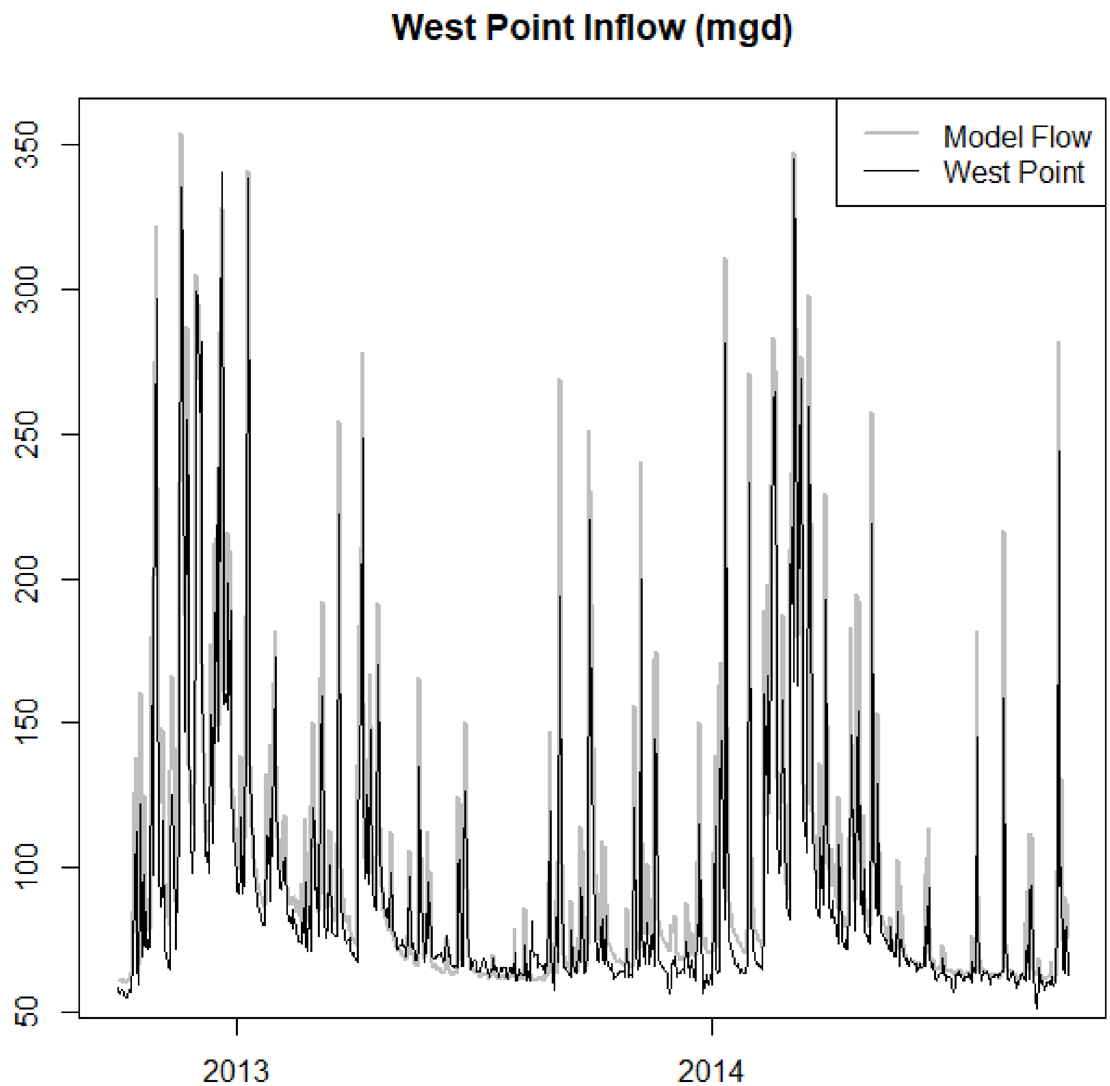


Figure 3. Comparison of Adjusted Hydraulic Model (Model Less 15 mgd) Daily Flow to West Point Daily Effluent Flow for the Period from October 1, 2012, to October 1, 2014

Flow Projections

The RWSP 2014 comprehensive review updated planning assumptions (King County DNRP, 2014b) and developed flow and load forecasts for each of King County's three regional treatment plants. Since that time, population within Seattle has increased at a faster-than-anticipated rate. To adjust for this, population data for 2010 through 2016 were obtained for the West Point service area and used to determine the relative increase in population. The current rate of population growth was extrapolated to 2020. Beyond 2020, population was projected by applying the relative rate of population growth projected by PSRC and used in the planning assumptions (King County DNRP, 2014b). Commercial and industrial employment was assumed to grow at the same rate as residential population for 2010 to 2020. The higher-than-anticipated population growth results in an approximate 10 percent increase to future base wastewater flow projections. Table 1 summarizes expected population and employment, sewered area, and base wastewater flow for the West Point service area.

Table 1. Projected Growth in the West Point Service Area

	West Point Service Area Projections					
	2010*	**2020**	**2030**	**2040**	**2050**	**2060**
Residential Population	642,725	782,992	826,669	883,049	955,619	1,028,474
Commercial Employment	493,502	672,740	750,392	840,846	941,748	1,051,058
Industrial Employment	33,618	41,729	39,947	43,568	44,875	46,182
Sewered Area (acres)	62,154	62,634	63,114	63,593	64,073	64,553
Base Wastewater Flow (mgd)	47	56	57	62	68	74

* King County DNRP, 2014a

Table 2 summarizes the projected growth in sewered area and base flow relative to 2010 for the West Point service area.

Table 2. Relative Growth of Base Flow and Sewered Area

	West Point Service Area Projections					
	2010*	**2020**	**2030**	**2040**	**2050**	**2060**
Sewered Area Relative to 2010	1	1.01	1.02	1.02	1.03	1.04
Base Wastewater Flow Relative to 2010	1	1.20	1.22	1.33	1.46	1.59

* King County DNRP, 2014a

Two 38-year flow time series were generated from the hydraulic model using the 1978 through 2015 rainfall record. One time series was for current (2010) conditions (model run 53) and the second included projected 2060 flows at Matthews Park Pump Station (Matthews Park PS) (model run 59). Both time series include current and future CSO control projects. These time series and base flow estimates from projected population and employment were used as the basis for flow projections. The following steps were used to develop flow projections:

1. The current conditions model output for West Point was separated into two components: the base wastewater flow and the I/I component.
    a. The weekly diurnal pattern was extracted from a low-flow period with no rainfall in the hydrograph. For the West Point model, this was the week of 1993-09-19 through 1993-09-25.
    b. The base I/I flow was determined as the difference between the average of the diurnal pattern and the population- and employment-based wastewater flow.
    c. The base wastewater flow, calculated as the diurnal pattern less the base I/I flow, was replicated for the 38-year period.
    d. The I/I component was calculated as the total model flow less the base wastewater for the entire 38-year time series.
2. The base I/I flow was estimated, using steps a and b above, for the existing (2010) and future condition (2060). The existing and future conditions models differ by the Matthews Park PS inflow time series used in the model runs. The base I/I flow at West Point increased by 2.08 mgd under future conditions (2010 to 2060).
3. The future conditions model output was separated into the base wastewater flow and the I/I component. The procedure of step 1 above was used with the exception of base I/I flow, which was estimated as the base I/I flow of the current conditions model plus the additional base I/I flow at Matthews Park PS (2.08 mgd).
4. The two resulting 38-year hydrographs of I/I flow were analyzed to determine flows representing the following: ADW (May 1 to October 31), AWW (November 1 to April 30), the average December, the maximum calendar year, maximum calendar month, maximum seven-day period (week), and maximum calendar day. All maximum/peak flows were taken as corresponding to a 20-year recurrence interval.
5. I/I flows at intermediate times were estimated by linearly interpolating between the 2010 and 2060 time series.
6. Total flow was estimated by adding the population/employment-derived base flow (Table 1) to the I/I flows. The peak hour flow rate was assumed to remain at 440 mgd, with excess flows controlled by CSO facilities or overflows. Additional detail on the development of base flow estimates can be found in *Updated Planning Assumptions for Wastewater Flow Forecasting* (King County DNRP, 2014b).
7. To develop hydrographs for intermediate periods, the base wastewater time series was scaled to future times according to the projected ratio in base flows between the future time and 2010 (Table 2).

Table 3 presents the base sewage flow, peak I/I, and peak flow estimates tabulated by decade. The RWSP update (King County DNRP, 2014a) developed projections for average dry weather flow and AWWF with rain days and the day following rain excluded. Table 4 presents these projections along with the flow components estimated from the procedure above.

Table 3. Components of Projected Flows by Decade

	2010			2020			2030		
	Base (mgd)	I/I (mgd)	**Total (mgd)**	Base (mgd)	I/I (mgd)	**Total (mgd)**	Base (mgd)	I/I (mgd)	**Total (mgd)**
Maximum Calendar Month (20-yr Recurrence)	47	141	188	56	143	199	57	144	202
Maximum Week (20-yr Recurrence)	47	216	263	56	218	274	57	220	277
Maximum Day (20-yr Recurrence)	47	358	405	56	357	414	57	357	414
Maximum Hour (20-yr Recurrence)			440*			440*			440*
	2040			**2050**			**2060**		
	Base (mgd)	I/I (mgd)	**Total (mgd)**	Base (mgd)	I/I (mgd)	**Total (mgd)**	Base (mgd)	I/I (mgd)	**Total (mgd)**
Maximum Calendar Month (20-yr Recurrence)	62	146	208	68	148	216	74	150	224
Maximum Week (20-yr Recurrence)	62	221	283	68	223	291	74	224	298
Maximum Day (20-yr Recurrence)	62	357	419	68	357	425	74	356	431
Maximum Hour (20-yr Recurrence)			440*			440*			440*

* Limited by plant capacity

Projected Flows Through 2060

Table 4 summarizes the projected flow forecasts for the West Point service area.

Table 4. Projected Flows for West Point, 2010–2060

Flow Condition	Flow (mgd)					
	2010	2020	2030	2040	2050	2060
Average annual, no rain days	70	82	83	88	94	100
ADW, no rain days	65	76	77	82	88	95
AWW, no rain days	75	87	88	94	100	106
Average annual, all days	95	105	107	113	120	127
ADW, all days	74	84	85	91	97	104
AWW, all days	116	127	129	135	142	149
Maximum month	188	199	202	208	216	224
Maximum week	263	274	277	284	291	298
Peak day	405	414	415	419	425	431
Peak hour	440*	440*	440*	440*	440*	440*

* Limited by plant capacity

3. WASTELOAD FORECASTS

Annual average loading rates of TSS and BOD were previously developed for the period from 2010 to 2060 (King County DNRP, 2014a). These projections applied loading factors to population and employment projections. Daily TSS and BOD measured at the plants were used as a basis for estimating current and future solids loadings.[3]

This analysis extends the previous work by using observed loading rates at West Point between 2007 and 2017 to develop peaking factors to relate loading rates for average December, maximum month, maximum week, and maximum day to the annual average loading rate. Future peak loads are projected using the previous estimates for annual average loads and assuming the peaking factors remain constant over time.

Current (2007–2017) Influent Loadings

A daily composite sample is collected at West Point to measure the influent BOD and TSS concentrations. The measurements from 2007 through 2017 were multiplied by the observed flow to calculate the daily influent load. These loads were then adjusted, as shown below, to obtain an estimated daily load for the current West Point service area (adjusted as described in the Flow Transfers section of this report).

Flows from the Brightwater service area were assumed to have dry weather (May 1 to October 31) concentrations of 325 mg/l BOD and 257 mg/l TSS, and wet weather (November 1 to April 30) concentrations of 287 mg/l BOD and 232 mg/l TSS. Flow adjustments from the Richmond Beach/Lake Ballinger flow transfer were assumed to have the same influent BOD and TSS concentrations as observed at West Point on that day.

Flows returned from CSO storage facilities were assumed to be returned on the day following the filling event and contain 125 mg/l BOD and 125 mg/l TSS. Future CSO treatment facilities were assumed to return solids on the day following an overflow. CSO treatment facilities were assumed to capture 80 percent of the influent TSS and BOD; influent BOD and TSS were assumed to average 125 mg/l.

Figure 4 presents the corresponding monthly average BOD and TSS loads, along with the projected loading rates from the 2014 analysis (dashed lines). The projected loading rates using current population estimates are also shown as dotted lines.

[3] WTD measures BOD_5, which is the amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter.

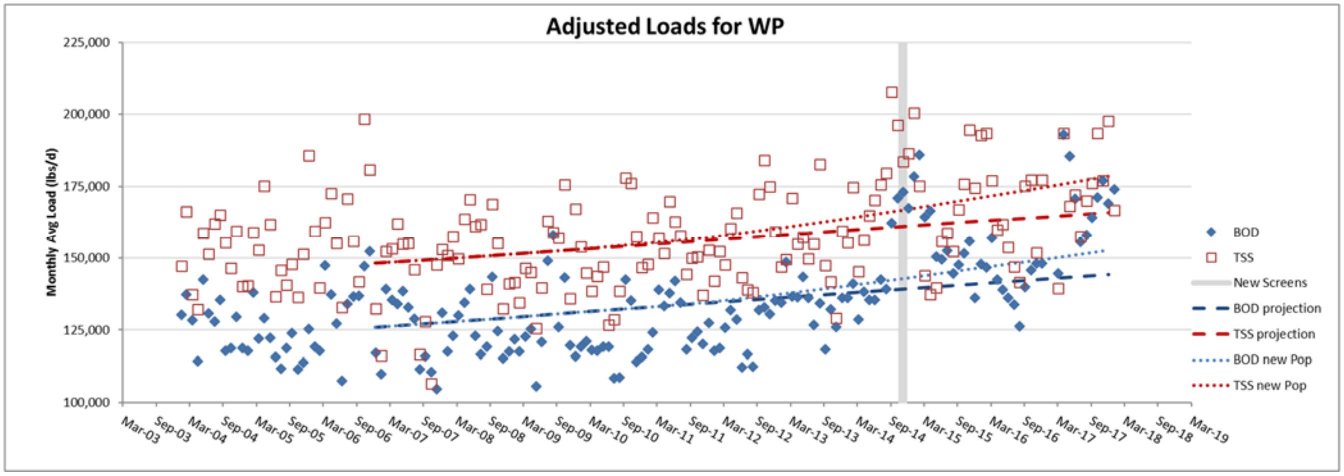


Figure 4. Monthly Average BOD, TSS Loads for West Point (WP)

Influent Loading Data Validation

The West Point recycle stream enters at the side of the channel upstream of the influent sampler; therefore, recycle flows are not thought to contribute significantly to the influent sample taken from the middle of the channel. However, when the backup influent sampler is used (RS2), more of these flows are part of the sample, and sample values are historically higher than when using the primary sampler. For this analysis, influent data on days sampled with the backup influent sampler, or days in which the influent wet well was noted as being pumped down, are excluded. The period from February 9, 2017, to June 15, 2017, was excluded from the analysis because of the West Point upset and recovery.

A daily mass balance was created around the primary process to identify uncharacteristic influent BOD or TSS concentrations. The influent load was compared to the sum of the primary effluent load plus the primary sludge. For TSS loads, the primary effluent TSS and the primary sludge total solids are measured. For BOD loads, the primary effluent BOD is measured, and BOD in the primary sludge was assumed to be proportional to the primary sludge volatile suspended solids (VSS). An average BOD/VSS ratio for primary sludge was estimated as (where PS = primary sludge and PE = primary effluent):

$$\frac{PS\ BOD}{PS\ VSS} = \frac{Inf\ BOD - PE\ BOD}{Inf\ VSS - PE\ VSS}$$

The average primary sludge BOD/VSS ratio was 0.6, tending to be slightly lower on days with high flows (0.55 for flows above 100 mgd). A ratio of 0.6 was used.

The ratio of influent TSS or BOD to the sum of primary effluent plus Primary Sludge TSS or BOD was calculated. The long-term average of this ratio is 0.92 (TSS) and 0.98 (BOD), using a primary sludge BOD/VSS ratio of 0.6. Presumably, the values slightly below unity reflect the addition of internal plant recycle streams.

Examination of the data suggested that the primary sedimentation basins were emptied of solids prior to a large storm, and solids were continuing to be removed the day following the storm (e.g., November 2, 2006). A mass balance was created around the primaries using the influent loads, primary effluent loads, and primary sludge. When the average influent load exceeded 150 percent of the primary effluent and sludge, and the total load from the day prior, that day, and the following day both exceeded 130 percent of the primary effluent plus primary sludge, the day was flagged as questionable data and excluded from the calculations.

Influent Loading Peaking Factors

A peaking factor is the ratio of a peak load to an average loading rate. To develop peaking factors, the observed loading rates at West Point between 2007 and 2017 were used to estimate the peak loading rates. Peak or maximum loads were assumed to correspond to the loading rate that would be anticipated to occur once every 20 years, consistent with the King County design standard for capacity in the separated wastewater system. To estimate these peak loads from existing data, the following approach was used:

- Data were adjusted to reflect flow transfers and a linear trend with time was removed to adjust the loadings to 2010 conditions.
- The resulting sequence of daily loading rates was then averaged to monthly and weekly loading rates using calendar months and seven-day running means, respectively.
- Probability plots of the cumulative distribution of loads were constructed and the cumulative distribution was extrapolated based on the tail of the distribution curve. The loading rate that corresponded to a once in 20-year recurrence interval was then determined from the cumulative distribution of the daily, weekly, and monthly loading rates corresponding to the probability that had a once in 20-year occurrence: daily loading once in 20 x 365.25 days and monthly loading once in 20 x 12 months. The weekly loads are a seven-day rolling mean, creating a value for each day, and the 20-year recurrence is once in 20 x 365.25 days.

Load Adjustments

The first steps in determining peaking factors were to remove data identified as unrepresentative, adjust the data for flow transfers, and remove the long-term growth trend. These steps are illustrated with time series of monthly loadings. The following data were excluded from the analysis: loads from February 2017 through June 2017 because of West Point flooding and recovery, day samples collected with RS2 because of a known high bias, and days noted for wet well pumpdown. Figure 5 presents the observed monthly West Point influent loads.

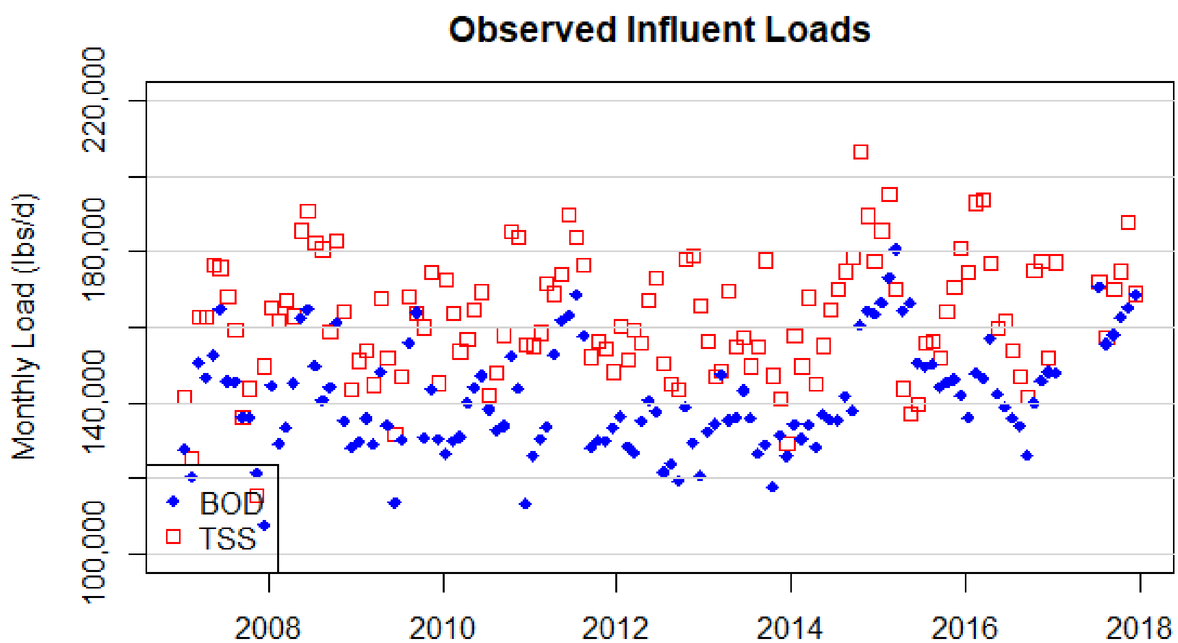


Figure 5. Observed West Point Influent Loading Rates

Removing the additional days identified as questionable data from the primary clarifier mass balance, Figure 6 presents monthly West Point influent loads. Comparison to loads without these additional days removed (Figure 5 and Figure 6) shows a slight reduction in monthly loadings, as expected.

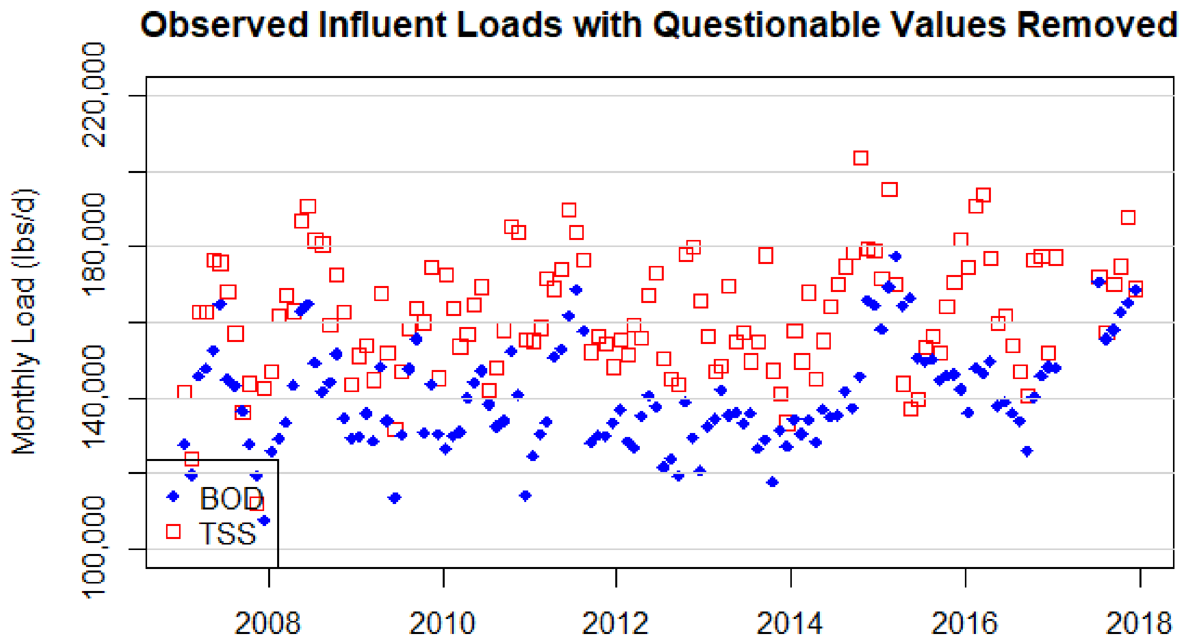


Figure 6. Observed West Point Influent Loading Rates with Questionable Values Removed

Next, loadings were adjusted to account for flow transfers. This is primarily a reduction of loads prior to 2013 for flows that are now treated at Brightwater. Loads were also increased to reflect future CSO storage or treatment facilities. An increasing trend over time is apparent. Figure 7 presents the resulting loads and the best linear fit to the data. The linear regression of the data against time is given by:

- BOD^5 = 125,090 + 9.741*(days after 2010-01-01) (lb/day)
- TSS = 149,660 + 7.924*(days after 2010-01-01) (lb/day)

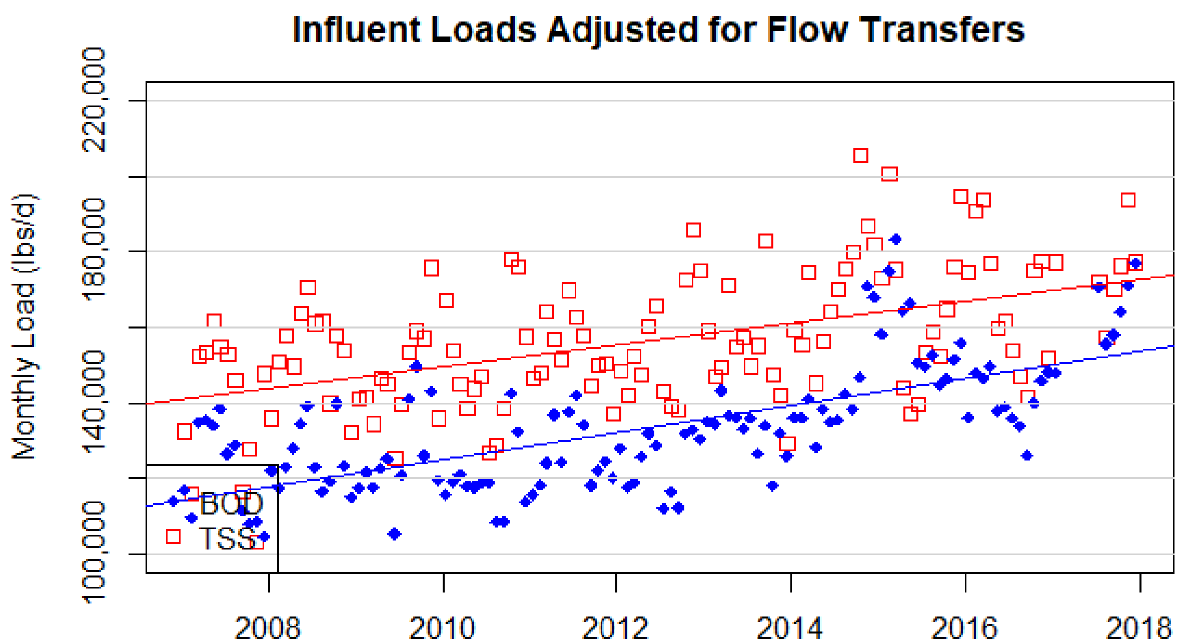


Figure 7. West Point Influent Loading Rates Adjusted for Flow Transfers

The loading data are adjusted to a 2010 baseline by removing this trend with time from the data, as shown in Figure 8. These data, adjusted to the 2010, baseline are used to evaluate the peaking factors.

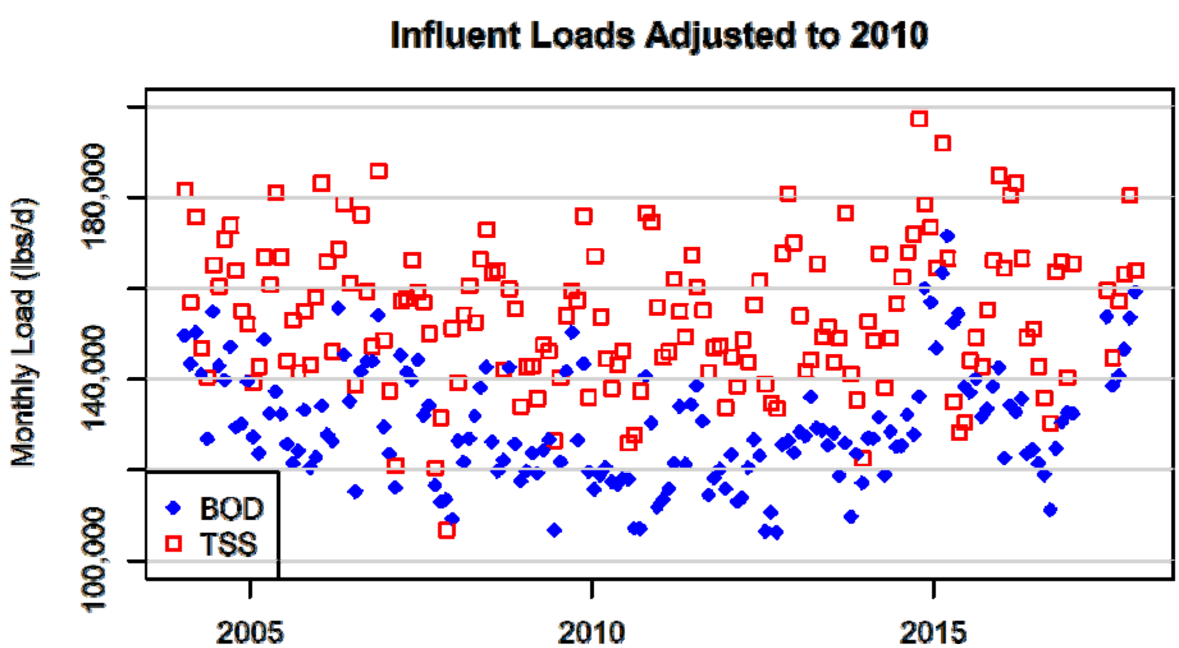


Figure 8. West Point Influent Loading Rates after Removal of Linear Trend in Time

Loads near the end of 2014 to the beginning of 2015 tend to be among the highest loadings. Figure 9 shows the ratio of influent loads to primary effluent plus sludge loadings averaged by month after the identified questionable data has been removed. Conceptually, this ratio should not exceed one, and would drop below one if additional (in-plant) loads were added to the primaries. Additionally, this loading ratio tends to be high during this period, suggesting the influent loads may be biased high. Yet, the loading ratio appeared normal in December 2014 (103 percent of effluent) and May 2015 (98 percent of effluent). Given the assumptions in this mass balance, the ratio may be high because the load estimates for the primary effluent or primary sludge are low. Thus, no additional data were removed.

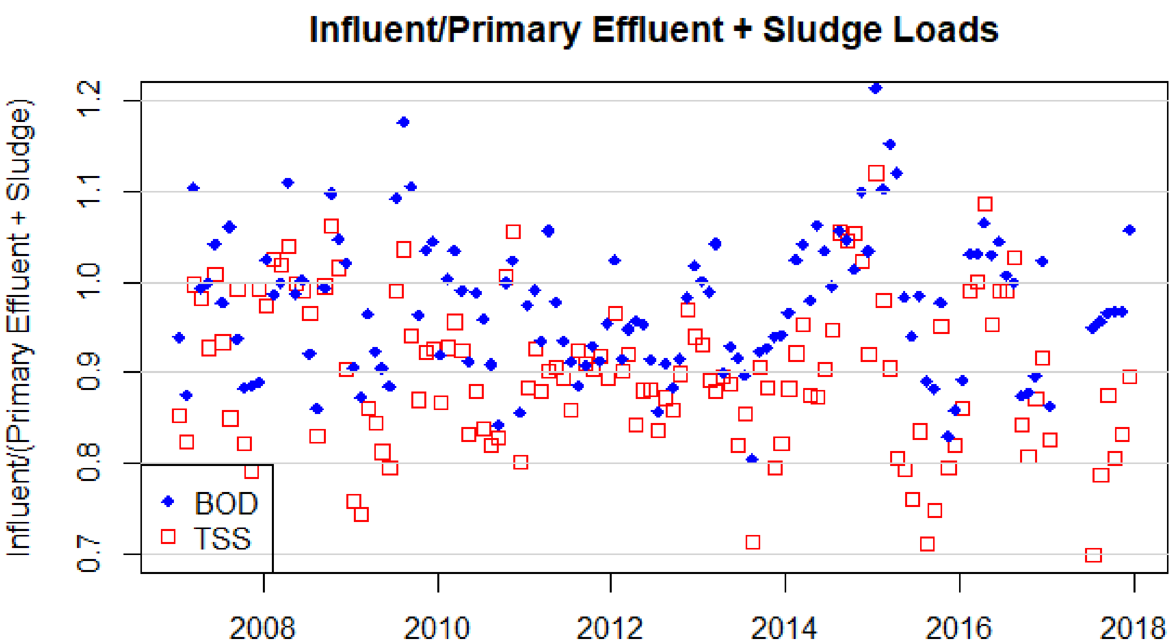
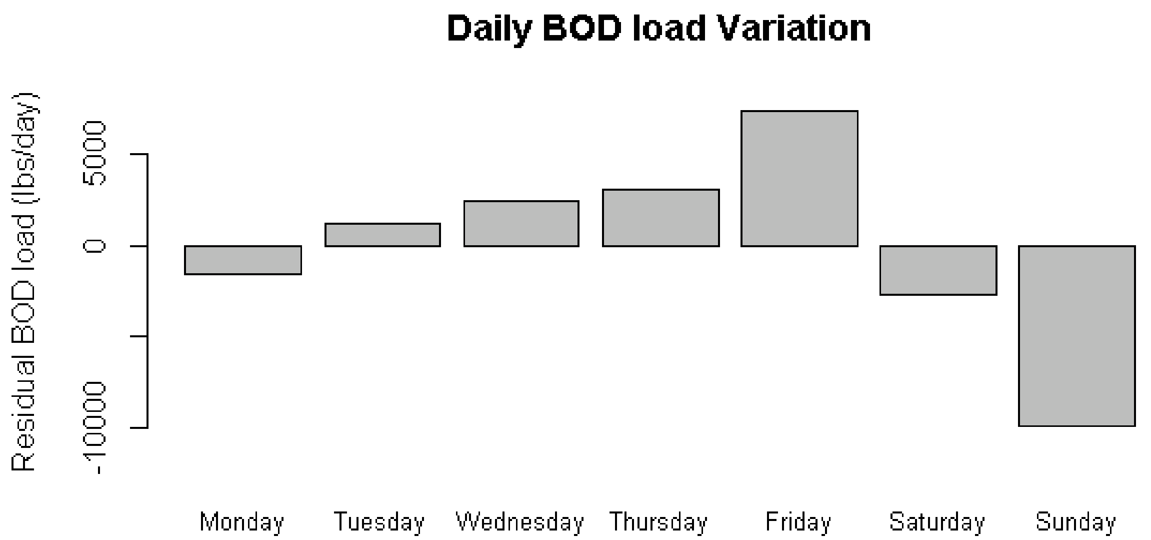


Figure 9. Ratio of Influent to Primary Effluent and Sludge Loading Rates

Day of Week Variation

Although not used in this analysis, loading rates were analyzed for a dependence on the day of the week. Lower loading rates occurred on Saturday and Sunday (Figure 10). Inspection of the monthly average loading rates did not indicate a consistent seasonal pattern.



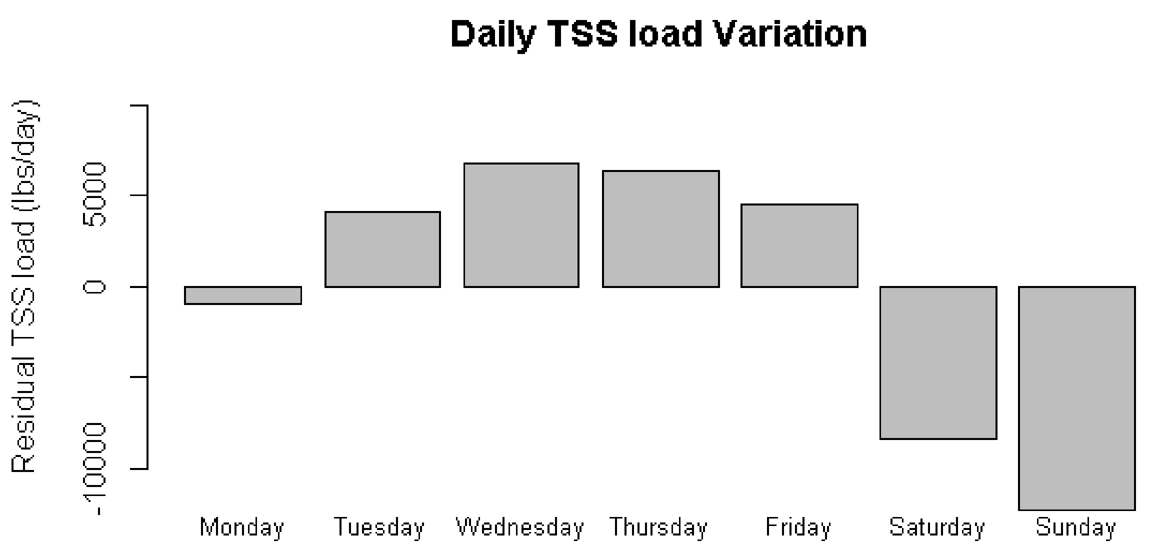


Figure 10. Average Weekday Variation in BOD and TSS Loading Rate

Flow Variation

Influent loads tend to increase with the daily flow (Figure 11, Figure 12). Because peak loading rates were estimated from the measured inflow rate, this dependence is included in the analysis and was not separated from the loading data.

Relative to the mean 2010 BOD and TSS loads of 125,000 lb/day and 150,000 lb/day, respectively, the data suggest higher TSS loads can be expected during periods of higher inflow rates.

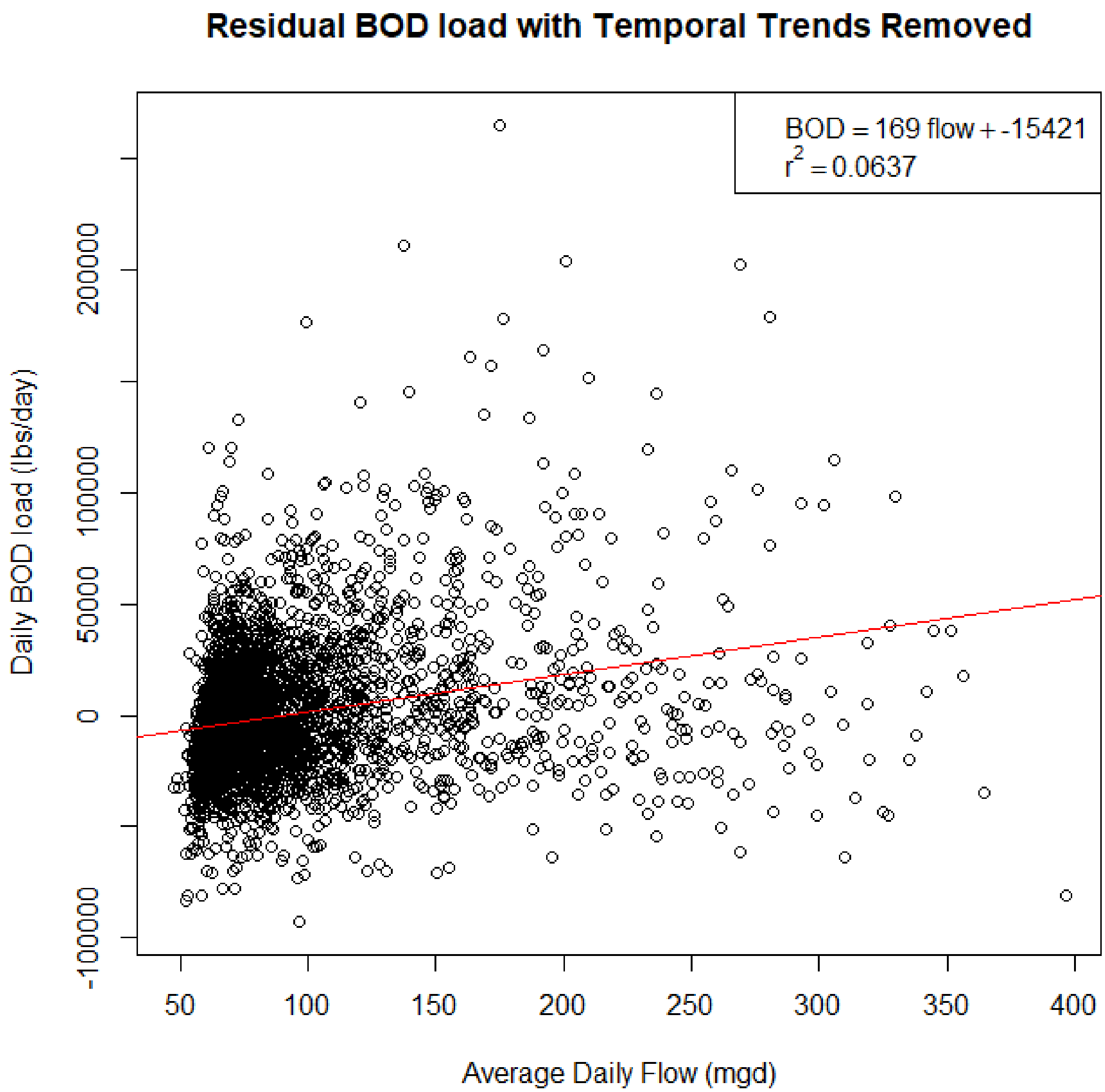


Figure 11. Regression of West Point Daily BOD Loading Residual after Subtraction of Temporal Trend to Average Daily Flow for January 2004 to February 2017, June 2017 to December 2017

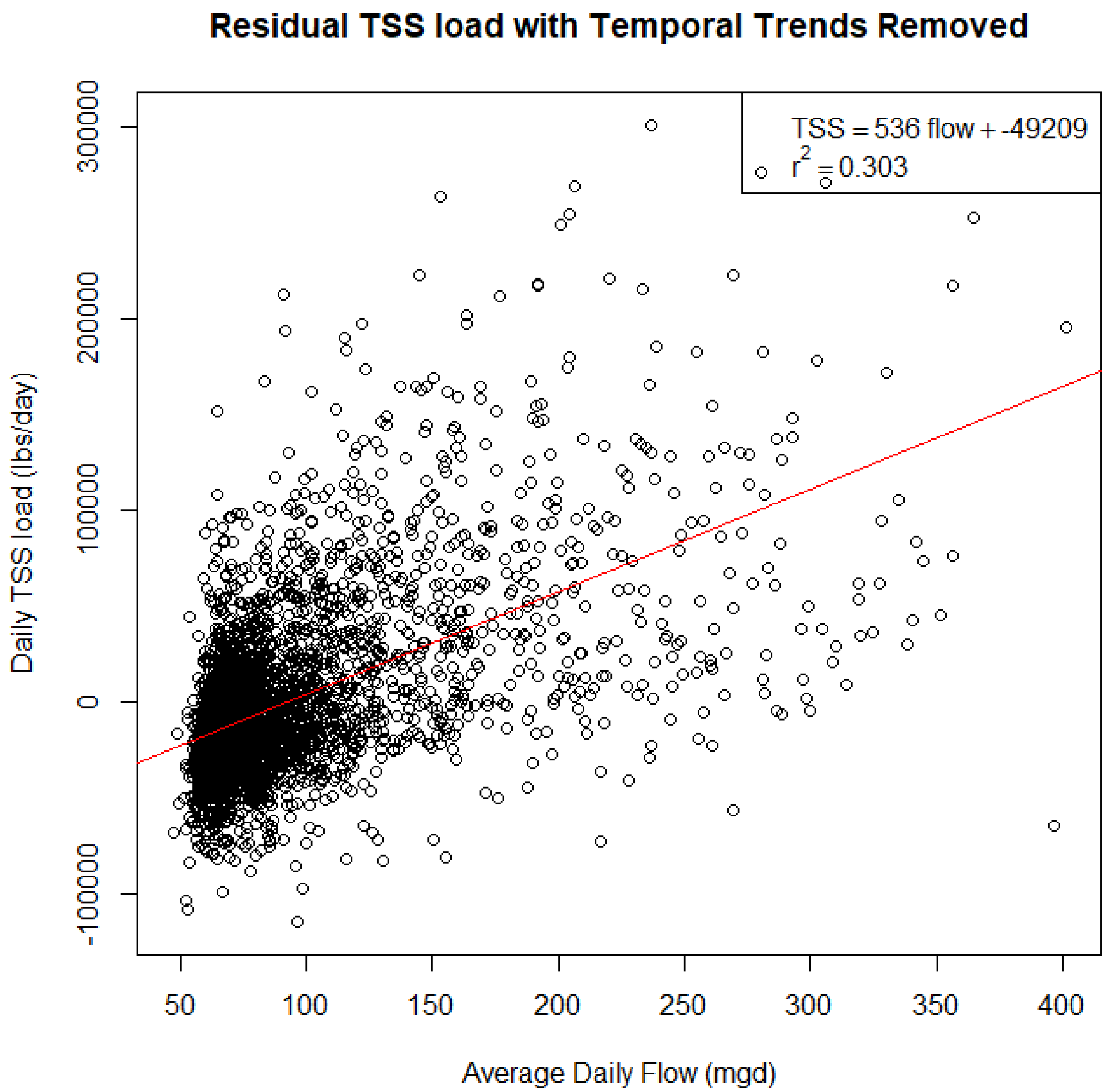


Figure 12. Regression of West Point Daily TSS Loading Residual after Subtraction of Temporal Trend to Average Daily Flow for January 2004 to February 2017, June 2017 to December 2017

Peak Loading Rates

The distribution of the daily residual loading rates followed a skewed (non-normal) distribution. The sequence of daily loading rates was averaged to monthly and weekly loading rates using calendar months and seven-day running means, respectively.

In Figure 13, all of the data (adjusted to 2010) are plotted as cumulative distribution curves for daily, weekly, and monthly loading rates.

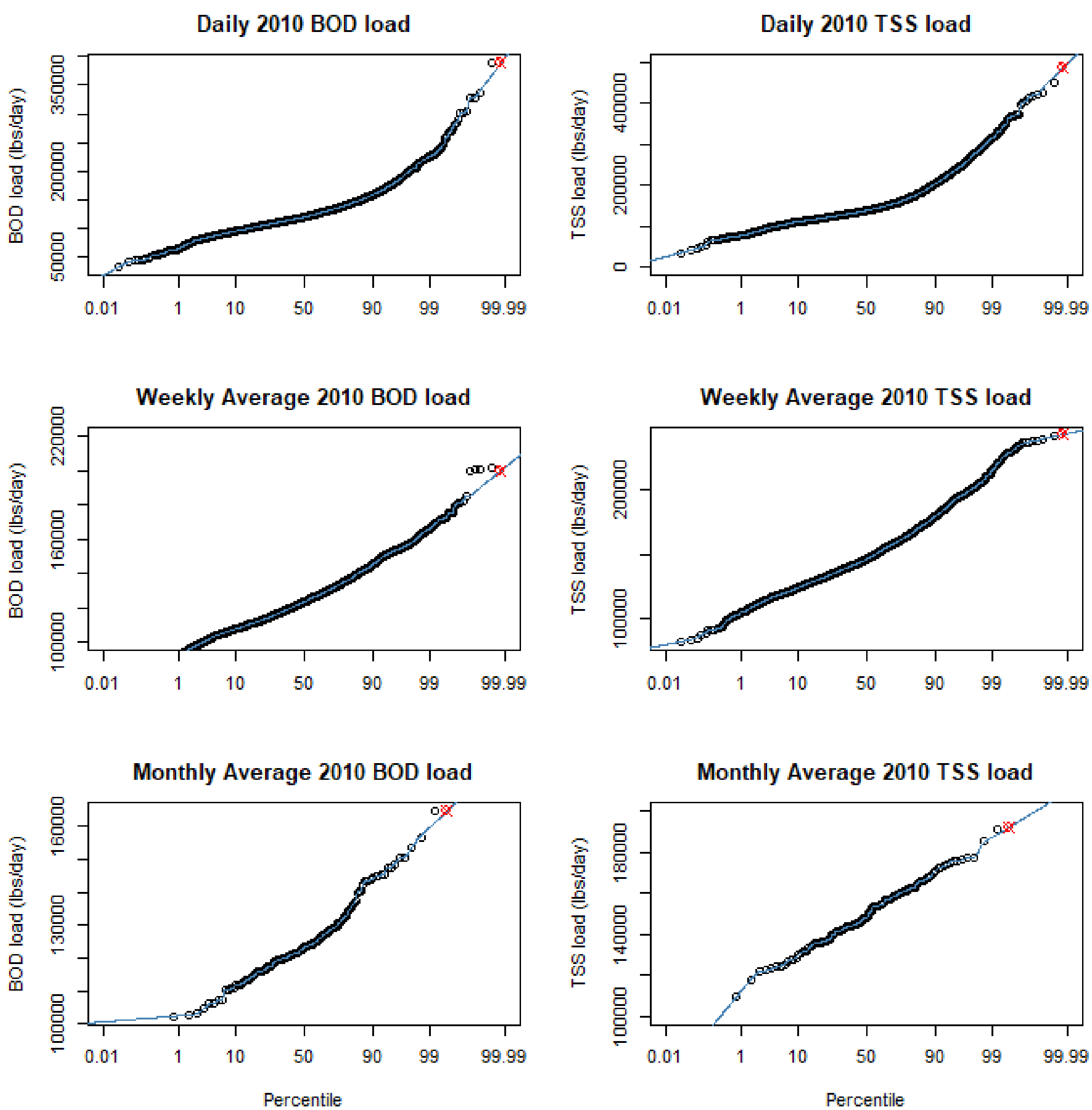


Figure 13. Cumulative Probability Plots of Daily, Weekly, and Monthly BOD and TSS Loads. Twenty-year Recurrence Value Denoted by Red Marker.

The greatest daily BOD load, adjusted to 2010, occurred on March 14, 2015, with an influent BOD concentration of 280 mg/l at an average flow rate of 175 mgd. The resulting influent load of 409,000 lb/day was 31 percent higher than the sum of the primary effluent (213,000 lb/day) and the estimated primary sludge (60 percent of VSS load at 163,000 lb/day). The total influent load during the three-day period from the day before to the following day was 19 percent higher than the sum of the primary effluent plus primary sludge. These data suggest the influent load may be high, but is likely within the uncertainty in measurements and estimating the amount of BOD removed in the primary sludge. The adjustment to the 2010 load decreases the 2015 load.

The day with the greatest daily TSS load was March 9, 2011, with an average daily flow of 244 mgd and an influent TSS of 230 mg/l. The observed load at West Point was 468,000 lb/day, which is reduced by flows that now flow to Brightwater to a total projected load of 455,000 lb/day.

The highest monthly BOD load was March 2015 at 183,000 lb/day, or 165,000 lb/day relative to 2010. Adjusted to a common 2010 base, four of the top six monthly loads were from the late 2014 and early 2015 period: March 2015, February 2015, November 2014, and December 2014. The other two were September 2009 (151,000 lb/day adjusted to 2010) and December 2017 (149,000 lb/day adjusted to 2010). While early 2015 coincides with the period during which the mass balance indicated a higher influent load than output from the primary clarifiers, the March 2015 load is about 10 percent higher than other years.

The highest monthly TSS loading was observed in October 2014 and February 2015. The ratio of influent solids to primary effluent plus solids did not appear abnormally high during these two months (1.05 in October and 0.98 in February). Additionally, the October 2014 load of 191,000 lb/day (adjusted to 2010) is less than 10 percent above loading rates in 2009 and 2012.

Peaking Factors

The corresponding peaking factor was calculated by dividing the peak load by the average annual 2010 loading rate. Table 5 summarizes the calculated peaking factors (pf) as peak load = mean * pf.

No attempt was made to estimate how peaking factors might change as flows change over time; the peaking factors were applied to all future projected average loads to estimate future peak loads. The peaking factors may change throughout the treatment process; at the time of the West Point secondary upgrade, higher peaking factors were expected for primary effluent than for influent (CH2M Hill, 1989).

Table 5. Peaking Factors for 20-year Peak Loading Rates

Influent BOD			
	West Point Current Analysis 2007–2017	**South Treatment Plant 2007–2017**	**West Point Design***
Peak Month/Average Annual	1.32	1.19	1.20
Peak Week/Average Annual	1.60	1.41	1.50
Peak Day/Average Annual	3.12	1.84	2.1
Peak Day/Peak Month	2.37	1.54	1.75
Influent TSS			
	West Point Current Analysis 2007–2017	**South Treatment Plant 2007–2017**	**West Point Design***
Peak Month/Average Annual	1.28	1.25	1.20
Peak Week/Average Annual	1.62	1.57	1.50
Peak Day/Average Annual	3.25	2.05	3.0
Peak Day/Peak Month	2.53	1.64	2.5

* Addendum to the March 1989 West Point Facilities Plan, prepared by CH2M Hill, October 1990

Projected Loading Rates Through 2060

Average annual BOD and TSS load projections were based on the projected population and employment and the average per capita loading factors determined in *Treatment Plant Flow and Wasteload Projections 2010–2060* (King County DNRP, 2014a). As discussed in the flow projections, the current rate of population growth was extrapolated to 2020 to account for the faster-than-anticipated rate of population growth within the Seattle area. Beyond 2020, population was projected by applying the relative rate of population growth projected by PSRC and used in the planning assumptions (King County DNRP, 2014b). Commercial and industrial employment was assumed to grow at the same rate as residential population for 2010 to 2020. The higher-than-anticipated population growth results in an approximate 10 percent increase to future TSS and BOD loading projections.

The annual loading projections developed for the RWSP 2014 comprehensive review (King County DNRP, 2014a) were updated with revised population projections (see Appendix A, Future Population Projection) using the same assumptions and per capita loading factors as in the original loading projections. The peaking factors estimated for current loadings were applied to these revised loading projections to estimate future peak loading rates, as shown in Table 6.

Table 6. Projected Flow and Loads for West Point, 2010–2060

Flow Condition	Influent BOD Load (lb/day)						Influent TSS Load (lb/day)					
	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
Average Annual	131,000	162,600	172,900	186,400	201,700	217,400	153,000	186,500	198,000	211,200	227,100	243,300
ADW	131,000	162,600	172,900	186,400	201,700	217,400	153,000	169,200	179,600	191,600	206,000	220,700
AWW	131,000	162,600	172,900	186,400	201,700	217,400	153,000	169,200	179,600	191,600	206,000	220,700
Maximum Month	172,900	214,600	228,200	246,100	266,300	287,000	195,800	238,700	253,400	270,300	290,700	311,500
Maximum Week	209,500	260,200	276,600	298,300	322,800	347,800	247,800	302,100	320,700	342,200	367,900	394,200
Peak Day	408,600	507,300	539,300	581,700	629,400	678,300	497,200	606,200	643,400	686,400	738,000	790,800

Projected Influent Concentrations Through 2060

The projected flow and influent loads are combined to provide estimated influent concentration, given in Table 7.

Table 7. Projected Influent Concentrations for West Point, 2010–2060

Load Condition	Flow Condition	Influent BOD (mg/l)					
		2010	**2020**	**2030**	**2040**	**2050**	**2060**
Average Annual	Average Annual	165.4	185.1	193.6	197.8	202.1	205.8
Maximum Month	ADW	281.6	307.5	321.1	324.9	328.3	331.1
Maximum Month	Maximum Month	110.5	129.4	135.7	141.6	147.8	153.7
		Influent TSS (mg/l)					
		2010	**2020**	**2030**	**2040**	**2050**	**2060**
Average Annual	Average Annual	193.2	212.4	221.6	224.1	227.5	230.4
Maximum Month	ADW	319.0	342.0	356.6	356.9	358.3	359.3
Maximum Month	AWW	125.2	143.9	150.7	155.6	161.4	166.8

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King County Department of Natural Resources and Parks. 2014a. *Treatment Plant Flow and Wasteload Projections 2010–2060*. Available at: http://your.kingcounty.gov/dnrp/library/wastewater/wtd/construction/Planning/RWSP/CompReview/13/1411_TPFlowAndWasteloadProjections_2010-2060.pdf (Accessed March 3, 2016).

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APPENDIX A FUTURE POPULATION PROJECTION

This appendix provides background information on Puget Sound Regional Council (PSRC) and American Community Survey (ACS) data that the King County Wastewater Treatment Division (WTD) is using to project population growth and wastewater flow in its service area. It also provides information on how data sources were adapted for use in the 2018 projections and summarizes the projections themselves.

Background

WTD typically relies on forecasts from PSRC to project flows in model basins. Model basins are delineations of subareas in the WTD service area used to quantify flow contributed by local sewer systems to various portions of the regional conveyance system.

Projections were last made using the PSRC 2013 Land Use Forecast as input for population and employment numbers (King County, 2014). This forecast was developed using data from the 2000 and 2010 U.S. Census. Since 2010, the Puget Sound region has experienced significant growth, outpacing the PSRC 2013 projections for the 2010 to 2020 period. Updated projections from PSRC are not expected to be available until 2019, leading to this interim update using ACS data.

For its 2014 flow projections, WTD used the PSRC 2013 Land Use Forecast as a source for population and employment numbers. The 2013 Land Use Forecast was developed using PSRC's UrbanSim model. The model was designed primarily for transportation planning and modeling. It provides greater detail than previous models, can fit forecasts to different geographies, and forecasts growth for each year out to 2040 for residential populations and several employment categories.

The 2013 WTD model basin forecasts were developed by aggregating the UrbanSim parcel-level data up to the WTD model basins (see King County, 2014). WTD extrapolated the 2013 Land Use Forecast growth rates to develop projections through 2060, matching WTD's 50-year planning horizon.

In addition to the decadal census, the U.S. Census Bureau conducts an ACS every year to provide up-to-date information, randomly sampling about 3.5 million households in every state, the District of Columbia, and Puerto Rico. These data are available at the census tract level approximately two years after collection. Currently, data through 2016 are available.

WTD analyzed ACS data to estimate the annual population growth rate for 2012 to 2016 for each wastewater service area or flow transfer area. The growth rate was extrapolated to the 2010 to 2020 decade and compared to the PSRC estimate. The additional growth rate was defined as the difference between these two rates. This additional growth rate was applied to the PSRC residential population, commercial employment, and industrial employment projections to develop a revised estimate for population and employment in 2020.

PSRC has released a draft regional macroeconomic forecast through 2050, describing the long-range "big picture" forecast of jobs, population, and households at the regional scale. The forecast reflects an upward adjustment from the previous series, with similar long-term growth.

In WTD projections beyond 2020, growth in both population and employment was assumed to continue at the same rate as projected in the PSRC 2013 Land Use Forecast.

Methodology

WTD used the following steps to adapt ACS information for wastewater flow projection:

1. ACS population data were added to a geographic information system file of census tracts covering the WTD service area (ACS_Pop2010).
2. The area of each census tract that is within each of the following service areas was calculated:
    - Brightwater Treatment Plant (Brightwater) service area
    - South Treatment Plant (South Plant) service area, excluding Sammamish Plateau basins
    - West Point Treatment Plant (West Point) service area

   Additionally, the area of each census track within the following flow transfer regions was calculated:
    - Richmond Beach
    - Edmonds Transfer
    - Sammamish Plateau basins
3. The population in each of the above service or flow transfer areas was calculated by multiplying the total population in each census tract by the area ratio of the census tract in the service area to the total census tract area. All census tracts were summed to calculate the population in each service area for each year from 2010 to 2016.
4. For each service area, the yearly population growth was determined as the ratio of the ACS population to the ACS population in the previous year. The current annual growth rate was taken as an average of the ratios from the previous four years (2012 to 2016).
5. The 2016 ACS population was extrapolated to 2020 (ACS_Pop2020) by increasing the population by the current annual growth rate (Table A1).
6. The additional growth rate of each service area was calculated as the ratio of projected growth rates from 2010 to 2020 [(ACS_Pop2020 – ACS_Pop2010) / (ACS_Pop2010)] / [(Pop2020 – Pop2010)/Pop2010].
7. Updated sewered population and employment estimates for 2020 to 2060 were calculated as the 2014 WTD estimate multiplied by the additional growth rate.

Forecast Summary

Figure A1 shows previous and current population and employment projections (Table A2) for the WTD service area. The updated projection increases the forecasted population beyond 2020 by 10.7 percent in the West Point service area, 11.9 percent in the Brightwater service area, and 5.3 percent in the South Plant service area compared to the forecast used by WTD in 2014. The sewered population served by each treatment plant is less than the total population, depending on the extent of regions without sewer connections in each area.

Table A1. Total Population Based on ACS Data Clipped to Service Area

Service Area	2010	2011	2012	2013	2014	2015	2016	2017*	2018*	2019*	2020*
West Point	648,664	657,433	667,004	679,863	693,928	709,047	725,643	740,882	756,440	772,326	788,545
South Plant	759,229	764,489	783,172	791,663	811,116	826,815	837,730	851,972	866,455	881,185	896,165
Brightwater	228,504	233,440	238,149	243,400	249,758	255,667	261,809	268,093	274,527	281,116	287,863

* Extrapolated

Table A2. Projected Sewered Population and Employment by Decade

Sewered Population	2010	2020	2030	2040	2050	2060
West Point	642,725	782,992	826,669	883,049	955,619	1,028,474
South Plant	681,190	829,586	926,674	1,029,580	1,130,834	1,234,924
Brightwater	203,202	264,920	293,874	341,990	375,931	410,848
Commercial Employment						
West Point	493,502	672,740	750,392	840,846	941,748	1,051,058
South Plant	407,818	538,794	621,462	741,628	830,570	926,928
Brightwater	55,774	61,190	58,628	64,433	66,365	68,296
Industrial Employment						
West Point	33618	41729	39947	43568	44875	46182
South Plant	96212	139263	162722	188502	211123	235628
Brightwater	15577	17874	17324	20858	21484	22110

* Projections assume current service area boundaries

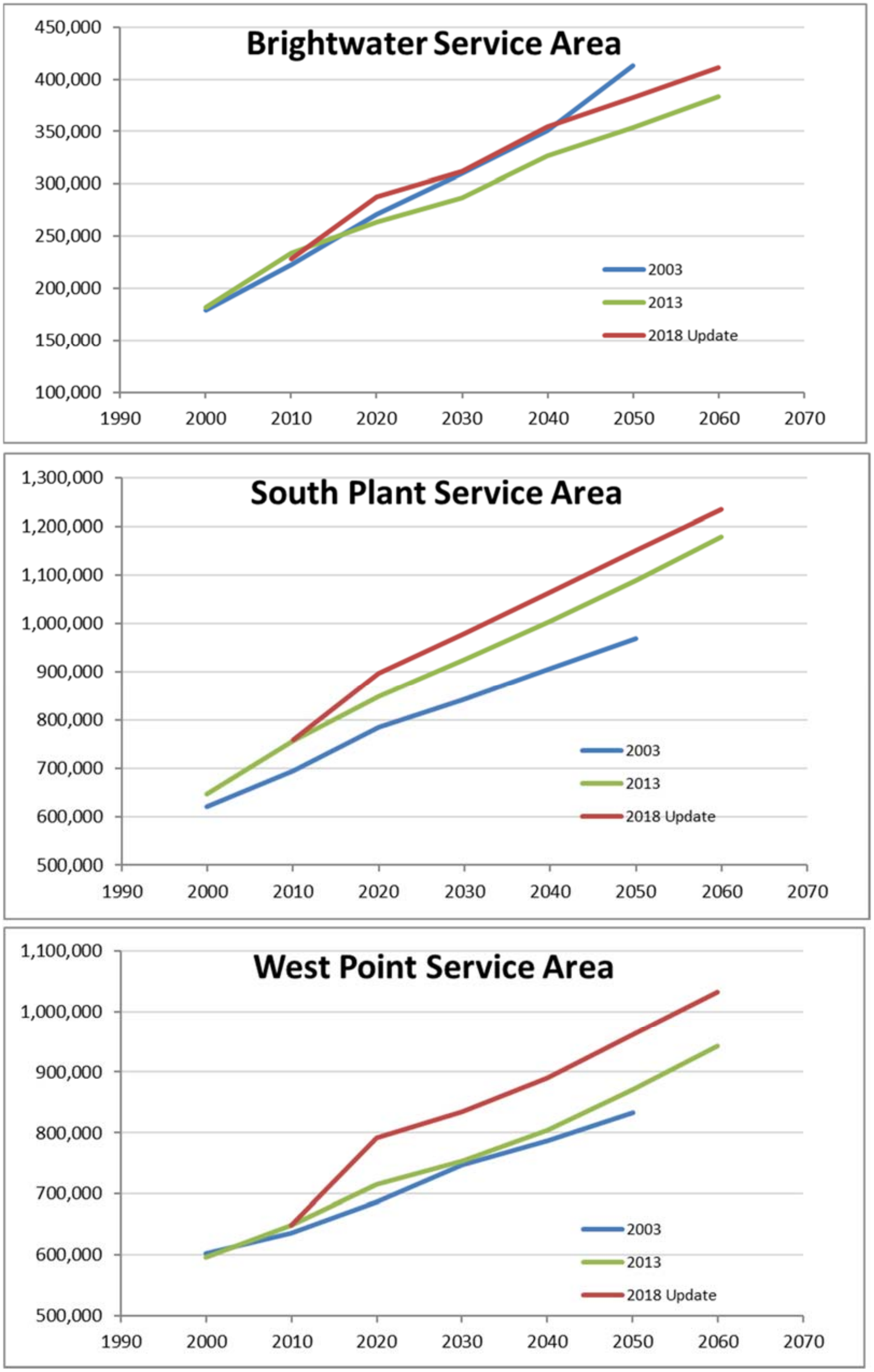

Figure A1. Total Population Projections for Each Service Area from Estimates Made in 2003, 2013, and 2018

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