South Treatment Plant Peak Flow and Wasteload Projections

2010–2060

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King County

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1. INTRODUCTION

This report documents the methodology and results of peak flow and wasteload projections for King County's South Treatment Plant (South Plant). 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 South Plant from January 2007 through December 2017. Corrections are made to reflect the flow transfers from Brightwater Treatment Plant (Brightwater).

The collection system model, calibrated to observed flows at many locations in the South Plant 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 2007 to 2017 loading rates at South Plant 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 (RSWP) 2007−2013 comprehensive review, projections of average wet weather flow, 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.

This analysis includes revisions to the 2013 PSRC population and employment forecasts used previously to reflect the higher-than-anticipated growth that has occurred in the region.

Conveyance System Modeling

Wastewater treatment plant flow consists of two components: base wastewater flow (sewage) and infiltration and inflow (I/I). 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]

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:

- The South Plant wastewater service area was separated into 123 model basins based on the placement of flow meters installed during the 2009–2011 Decennial Flow Monitoring Project.
- A hydrologic model (MOUSE RDII) was calibrated using rainfall, evaporation, and sewer flow data collected from 2009 to 2011 to simulate flow response to rainfall in each model basin for this two-year period (“calibration period”).
- To verify model accuracy, modeled flows (both base and I/I) for model basins were grouped and input to a hydraulic model (MOUSE HD) to compare them with measured flows at places where meters had collected data from several basins.
- The model was run for the 2007 to 2012 period for additional calibration/validation. The constant inflow rate in the model was reduced to better match the more accurate flow meters at South Plant.
- Once good calibrations were achieved (i.e., model results closely approximated metered data), hydrologic and hydraulic simulations were done using a 60-year rainfall record.
- The 60-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.

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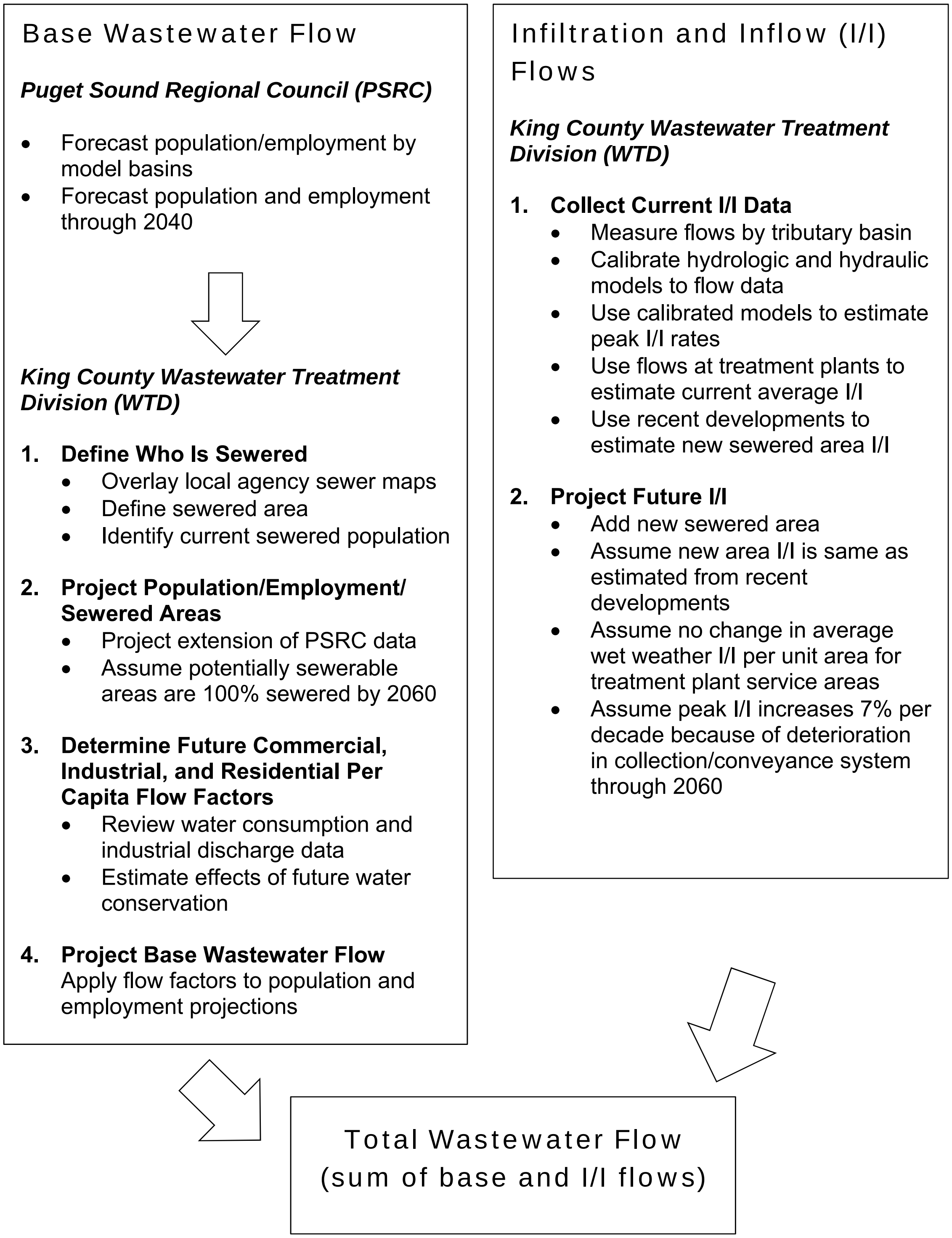
[1] Base flow is wastewater (not including I/I) that originates from homes, businesses, and industries. Infiltration is groundwater that seeps into sewers through holes, breaks, joint failures, defective connections, and other openings; inflow is stormwater that rapidly flows into sewers via roof and 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 RSWP 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 RSWP 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 South Plant 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 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 an average value, 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 2000 gpad, with a 7 percent degradation per decade increase.

In addition, it is assumed that conveyance improvement projects will be completed to allow all flow from the service area to be conveyed to the treatment plant.

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[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 South Plant.

Current (2007–2017) Flows

The collection system model was calibrated to match the observed flow throughout the collection system from 2009 to 2011. South Plant flows were taken from the calculated effluent flow (pi tag: \\SPPISERVER\SP.FB241ETSFLOW.CALC). These flows were then modified to account for flow diversions, as discussed below.

Flow Diversions

The planning basis for South Plant flows was that all flows generated in the service area would be conveyed to the treatment plant. Before Brightwater became fully operational in November 2012, some flows from the Brightwater service area were diverted to South Plant through the York Pump Station (York PS). After Brightwater came online, flows were occasionally diverted because of conveyance or treatment capacity limitations.

The total diverted flow from York PS was obtained from historical records (pi tags: \\SPPISERVER\YORK.FB309111, \\SPPISERVER\YORK.FB309112). Flow through the 48-inch force main was corrected to convert units from cubic feet per second to million gallons per day (mgd). Flows from York PS were averaged to a daily value using the Brightwater sampling day of 06:00 to 06:00. All other flows were averaged to the South Plant sampling day of midnight to midnight.

The current South Plant model does not include the Hollywood/York system. Prior to the completion of the North Lake Sammamish Diversion Project, flow from Hollywood Pump Station (Hollywood PS) to Brightwater was limited to around 13 mgd. Excess flow is transferred to South Plant by the York PS. The North Lake Sammamish Diversion Project is anticipated to be completed prior to 2030 and will convey the current diverted flows to Brightwater. In 2020, flows from York PS will add approximately 0.1 mgd to South Plant’s maximum month flow, 1 mgd to the maximum week flow, and 5 mgd to the maximum day flow. The travel time from York PS to South Plant is sufficient that the peak flow is unlikely to coincide with the peak hour flow at South Plant. As a result, the peak hour flow was not adjusted, although the peak hour flow from York is approximately 10 mgd.

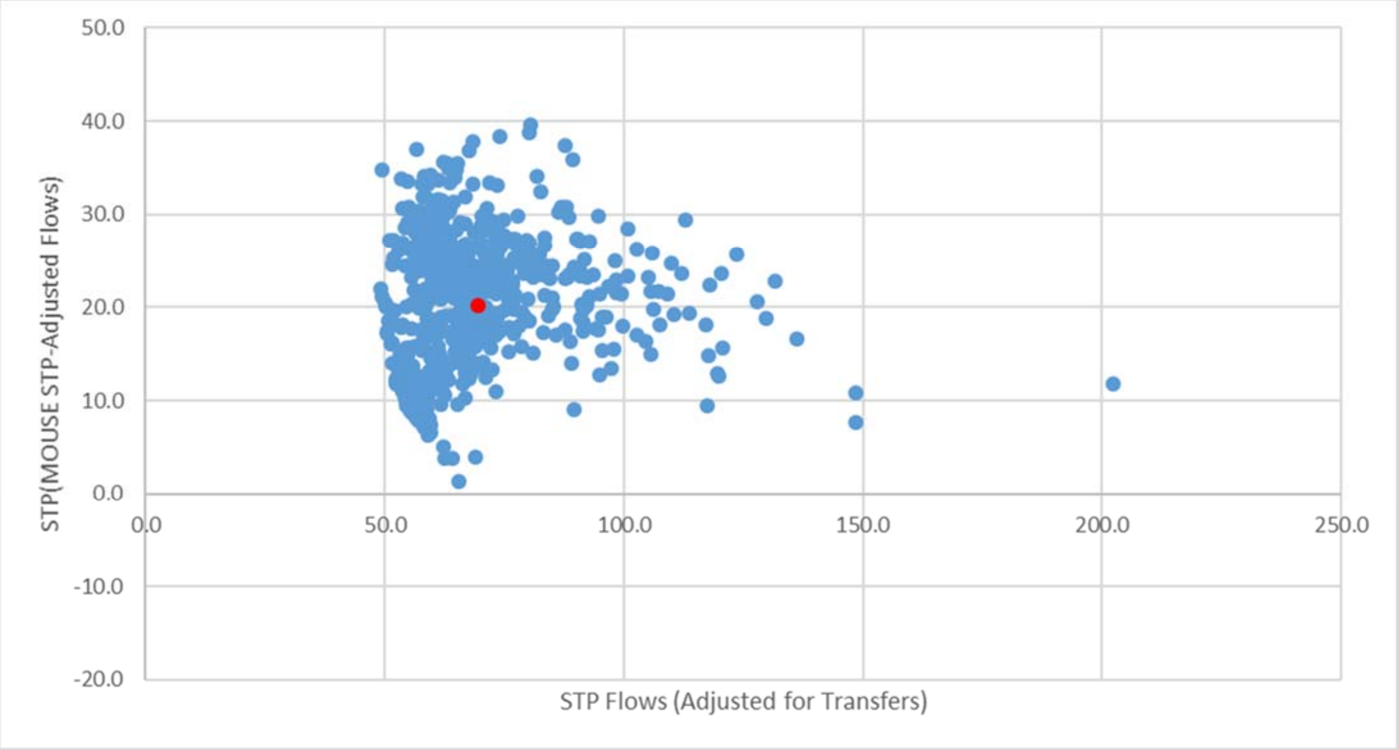
Recycle Streams

South Plant produces reclaimed water, which is predominately used within the plant or for off-site irrigation. On average, about 0.3 mgd of final effluent is fed to the recycled water facility. This effluent is subtracted from the secondary flow meters in the final effluent flow calculation. The reclaimed water facility then produces about 0.2 to 0.25 mgd that goes into South Plant's C2 water system. The filter reject or backwash goes down the sanitary drain back to the influent. The hydraulic model should overpredict the calculated effluent flow by the amount of reclaimed water that goes to the C2 system and is not returned to the plant. Because this is a relatively small amount, no correction was made for to the calculated effluent flow for reclaimed water.

Flow Simulation

The simulated flow from the South Plant service area was averaged to a daily value and compared to the observed flow, adjusted for flow diversions and recycle streams. The South Plant 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 electro-magnetic flow meters and computed flow at South Plant are expected to be much more accurate. The base infiltration in the model was reduced by 20 mgd to match the computed flow at South Plant.

Figure 2 presents the statistical bias in daily flows of the original MOUSE model flows. Figure 3 shows the adjusted model flows together with the South Plant measured flows that are reduced by flow transfers from York PS for the period from October 1, 2009, to October 1, 2011.



STP = South Treatment Plant

Figure 2. Difference between Original MOUSE Model and Observed South Plant Daily Flows (mgd) from September 2009 to May 2011

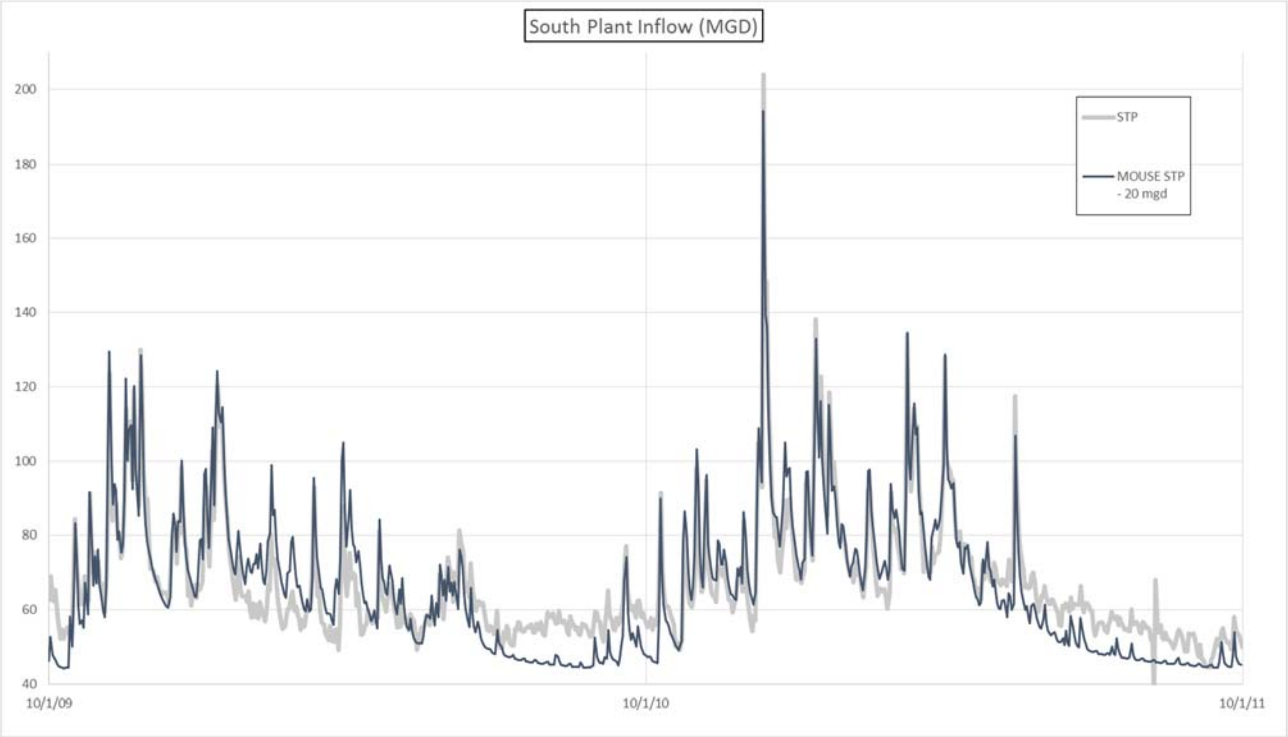


Figure 3. Comparison of Adjusted Hydraulic Model (with 20-mgd Flow Reduction) to Total South Plant Flow from October 1, 2009, to October 1, 2011

Flow Projections

The 2014 RWSP 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. To adjust for current growth, population data were obtained for the South Plant 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. No data were available to verify this assumption in employment growth. The higher-than-anticipated growth since 2010 results in an approximate 5 percent increase to future base wastewater flow projections.

Projections for 2030 and later have been adjusted by the proposed Sammamish Plateau flow diversion to Brightwater, as described in the current Conveyance System Improvement Program plan (King County DNRP, 2017). Flow from the Sammamish Plateau area is proposed to be transferred north to Brightwater in two phases. According to the plan, the Phase 1 diversion would be completed by 2030, and Phase 2 by 2040. Table 1 summarizes the expected population and employment, sewered area, and base wastewater flow for the South Plant service area. The same population and employment assumptions were applied to project the base wastewater flow from the proposed Sammamish Plateau Diversion. With these assumptions, the Phase 1 diversion will transfer 1 mgd of base flow and up to 3 mgd of peak flow to Brightwater in 2030. Phase 2 will transfer an additional 3 mgd of base flow and up to 15 mgd of peak flow to Brightwater in 2040.

Table 1. Projected Growth in the South Plant Service Area

	South Plant Service Area Projections[a,b]					
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Residential Population	681,190	829,586	914,420	967,590	1,060,879	1,156,557
Commercial Employment	407,818	538,794	619,350	706,825	791,590	883,423
Industrial Employment	55,774	61,190	58,578	63,551	65,455	67,360
Sewered Area (acres)	79,205	87,427	94,164	95,926	102,838	109,750
Base Wastewater Flow (mgd)	49	57	60	64	70	76

[a] King County DNRP, 2014a
[b] Adjusted for Sammamish Plateau flow transfers

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

Table 2. Relative Growth of Base Flow and Sewered Area

	South Plant Service Area Projections[a,b]					
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Sewered Area Relative to 2010	1	1.10	1.19	1.21	1.30	1.39
Base Wastewater Flow Relative to 2010	1	1.16	1.21	1.30	1.42	1.54

[a] King County DNRP, 2014a
[b] Adjusted for Sammamish Plateau flow transfers

A 60-year flow time series was generated from the hydraulic model for 2010 conditions and a 60-year long-term rainfall record. This time series was used as the basis for flow projections. The following steps were used to develop flow projections:

1. Model output was separated into two components: the base sewage 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 South Plant model, this was the rainfall week of 1944-09-24 to 1944-09-30.
    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 60-year period.
    d. The I/I component was calculated as the total model flow less the base wastewater for the entire 60-year time series.
2. The 60-year hydrograph of I/I flows was analyzed to determine flows representing the average December, the maximum calendar year, maximum calendar month, maximum seven-day period (week), maximum calendar day, and peak hour. Other than the average December, all maximum/peak flows were taken as corresponding to a 20-year recurrence interval based on a regression of the peak values in the 60-year simulation.
3. 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 1 and Table 2). Additional detail on the development of current base flow estimates can be found in *Updated Planning Assumptions for Wastewater Flow Forecasting* (King County DNRP, 2014b).
4. I/I flows were scaled according to the expected growth in sewered areas, reduced by the lower I/I flow from newly sewered areas. Newly sewered areas were assumed to contribute 2,000 gpad to the peak hour 20-year I/I (King County DNRP, 2014b) in the first decade after that area was assumed to be sewered. I/I from the newly sewered areas was assumed to increase (degrade) by 7 percent per decade in subsequent decades. I/I from newly sewered areas was assumed to be proportional to the ratio of the modeled I/I to peak 20-year I/I. Thus, the projected peak I/I flow was estimated as:

    $$I/I_{2020} = I/I_{2010\ \text{model}} * \left(1.07 + \frac{\text{newly sewered area}}{\text{2010 sewered area}} * \frac{\text{2,000 gpad}}{\text{2010 peak 20-yr I/I (gpad)}}\right)$$

    Where $I/I_{2010\ \text{model}}$ is the peak week, day, or hour I/I determined in step 2, and I/I_{2020} is the corresponding peak I/I flow a decade later. Projections for the annual average I/I and the maximum month I/I flows did not include an I/I degradation factor, consistent with the planning assumption of no increase in AWW I/I.
5. Total flow was estimated by adding the population/employment-derived base flow (Table 1) to the I/I flows. The peak hour flow was estimated assuming the sewage flow was 1.35 times the population/employment-derived base flow plus the peak hour I/I flow.

Table 3 tabulates the base sewage flow, peak I/I, and peak flow estimates by decade. The existing conveyance system does not have adequate capacity to convey the projected peak flows to South Plant. The following assumptions were made on future changes to conveyance facilities in the South Plant service area:

- Interurban Pump Station (Interurban PS) will remain at its current capacity (28 mgd). Increases in flow will result in less flow being diverted to South Plant at the Allentown diversion and more flow continuing to West Point by way of Norfolk and the Elliott Bay Interceptor.

- Facilities to convey flows to Brightwater in excess of the current Hollywood PS capacity will be constructed by 2030 (North Lake Sammamish Flow Diversion Project).
- Sammamish Plateau Diversion Phase 1 will be constructed by 2030 to maintain a 5-year level of service in the Issaquah Interceptor Section 1. This will divert flow from model basins M_SAM016A, M_SAM021A, and 20 percent of M_SAM005, reducing South Plant's 2060 service area by 2500 acres and 1 mgd of base flow.
- Sammamish Plateau Diversion Phase 2 will be constructed by 2040 to maintain a 5-year level of service in the Issaquah Interceptor Section 1. This will divert flow from model basins M_SAM023, 89 percent of M_ISSAQ033, and the remainder (80 percent) of SAM005, reducing South Plant's 2060 service area by an additional 8,000 acres and 3.6 mgd of base flow.
- A capacity upgrade of the East Side Interceptor (ESI) Section 1 will be constructed by 2050. Before that, the flow through ESI Section 1 will be limited to approximately 190 mgd. Increasing the capacity of ESI Section 1 will move the capacity constraint upstream to ESI Section 3 and increase the peak flow to South Plant by 63 mgd.
- Capacity upgrades to the Cedar River Interceptor are assumed to not occur before 2060. Improvements to the Cedar River Interceptor could increase the peak hour flow by 9 mgd.

Based on the assumed capacity limitations of Interurban PS, the maximum day and hour flows were reduced by the amount the projected flows exceeded the 28-mgd capacity. No adjustment was made to peak weekly or monthly flows.

Prior to completion of the North Lake Sammamish Flow Diversion Project, capacity constraints in the Sammamish Valley Interceptor limit the flow at Hollywood PS to around 13 mgd. Flows above this capacity flow to York PS and are pumped into the ESI to South Plant. In 2020, the transfer would add approximately 0.1 mgd to South Plant's maximum month flow, the maximum week by 1 mgd, and the maximum day by 5 mgd. The travel time from York PS to South Plant is sufficient that the peak flow is unlikely to coincide with the peak hour flow at South Plant. As a result, the peak hour flow was not adjusted, although the transfer could contribute up to 10 mgd.

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)	49	66	116	57	71	128	60	74	134
Maximum Week (20-yr Recurrence)	49	77	151 (152[a])	57	87	170 (171[a])	60	97	182
Maximum Day (20-yr Recurrence)	49	152	226 (229[a])	57	173	255 (260[a])	60	193	278
Maximum Hour (20-yr Recurrence)	67	240	330 (331[b])	78	273	347 (374[b])	81	305	364 (410[b])
	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)	64	77	141	70	81	151	76	86	162
Maximum Week (20-yr Recurrence)	64	105	194	70	116	210	76	127	227
Maximum Day (20-yr Recurrence)	64	208	297	70	229	324	76	251	351
Maximum Hour (20-yr Recurrence)	87	329	383 (439[b])	95	362	436 (480[b])	103	396	445 (522[b])

[a] Includes flow transfer from Brightwater Service Area

[b] Peak flow without upstream storage facilities or capacity limitations

Projected Flows Through 2060

Table 4 summarizes the projected flow forecasts for the South Plant service area, including adjustments in 2030 and 2040 for Phase 1 and Phase 2 of the Sammamish Plateau Diversion to Brightwater.

Table 4. Projected Flows for South Plant, 2010–2060

Flow Condition	Flow (mgd)					
	2010	2020	2030	2040	2050	2060
Average annual	68	78	82	86	94	102
Average dry weather	59	68	71	76	82	90
AWW	76	87	92	97	105	114
Maximum month	116	128	134	141	151	162
Maximum week	151	170	182	194	210	227
Peak day	226	255	278	297	324	351
Peak hour	331	374	410	439	480	522
Peak hour with anticipated conveyance capacity (see text)	330	347	364	383	436	445

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 South Plant 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) Loadings

A daily composite sample is collected at South Plant 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 South Plant service area (i.e., adjusted for diversions from Brightwater). 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, unless an influent concentration was measured at Brightwater. When Brightwater influent concentration data were available, that concentration was applied to any flows transferred to South Plant on that day.

The discharge of deicing fluid to the conveyance system from SeaTac International Airport is a significant load on days with high discharges. This load is measured and reported daily, and was subtracted from the South Plant influent BOD load to develop an estimate of the sanitary load. Separating the deicing load enables the contribution of deicing BOD load to be quantified and allows different growth rates to be used in projecting future loads.

Figure 4 presents the corresponding monthly average BOD and TSS load along with the projected loading rates from the 2014 analysis.

Process drains from within South Plant are returned to the influent sewer upstream of the influent sampler. Abnormally high influent BOD and TSS loads beginning in September 2012 led to the identification of leaking tank drains. These leaks were believed to have been corrected by January 2015. An analysis of the frequency daily loads occurred in excess of two standard deviations above the mean of the data set, corrected for temporal trends (Figure 5), suggested that this leakage may have occurred between May 2012 and November 2015. Plant influent data for TSS and BOD were excluded from the analysis during the period from May 2012 through October 2015.

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

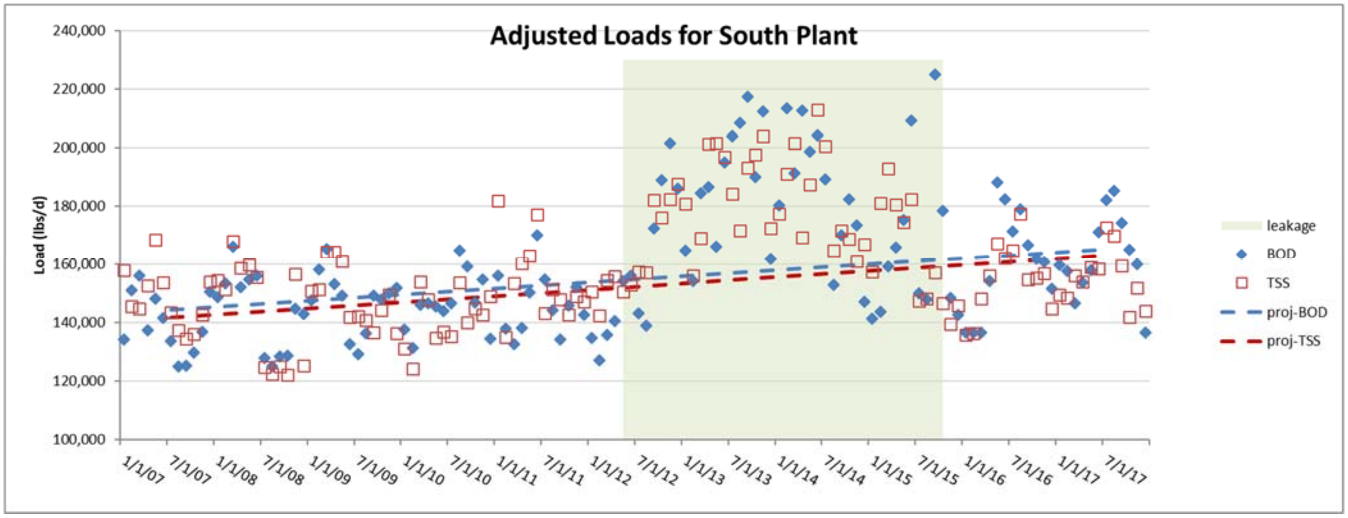

Figure 4. Monthly Average BOD, TSS Loads. Shaded Area from May 2012 through October 2015 Is Influenced by Recycle Stream Leakage.

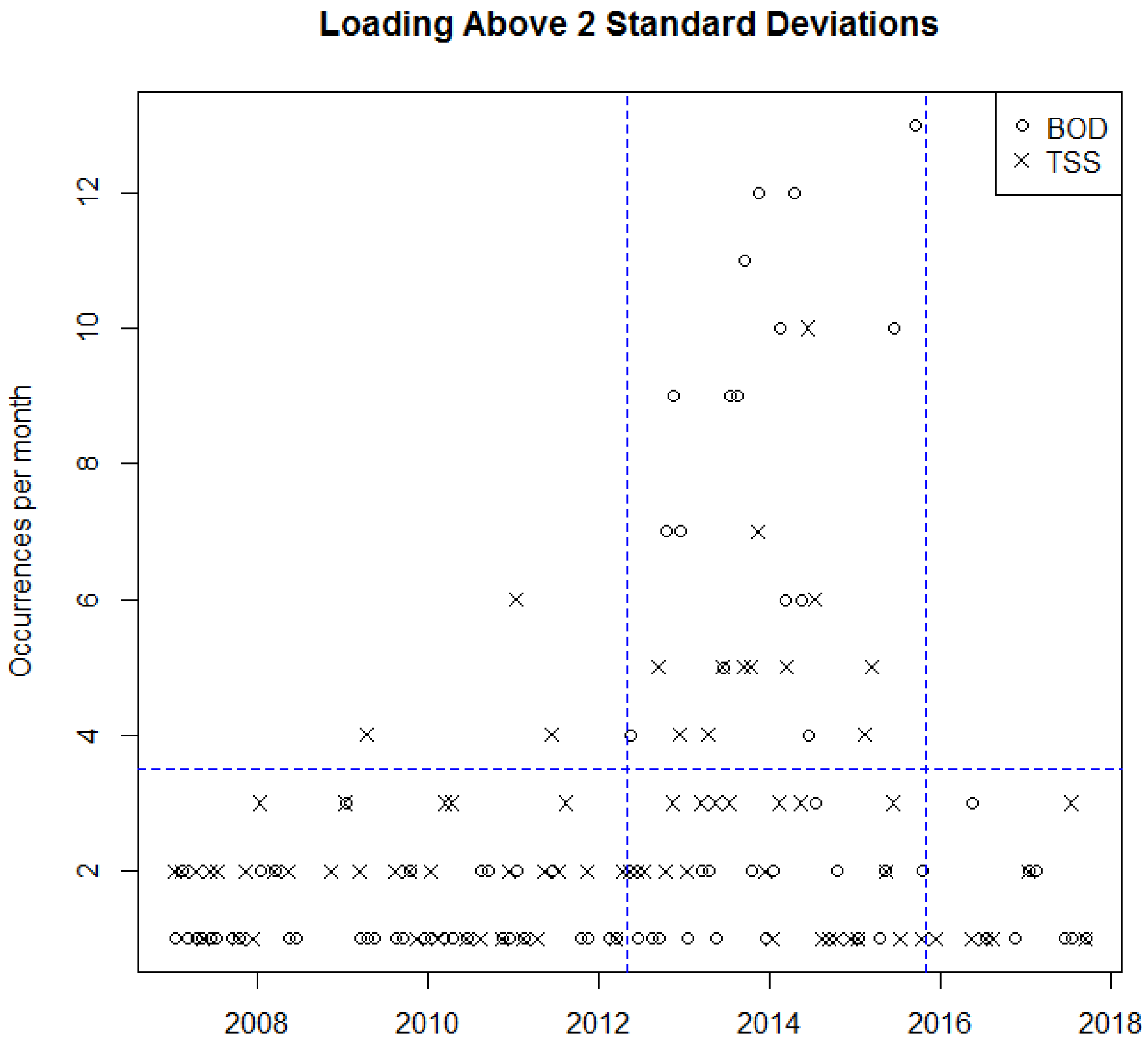

Figure 5. Days per Month Loading Exceeded Two Standard Deviations Above Mean

Influent Loading Data Validation

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):

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

There was little correlation between influent BOD and influent VSS, suggesting that this assumption may have significant uncertainty associated with it. A ratio of 0.8 was used. West Point analysis found a ratio of 0.6.

At South Plant, primary effluent BOD, primary effluent VSS, and primary sludge VSS are typically not measured every day. Correlations between these parameters and primary effluent TSS or primary sludge TSS were developed and used to supplement the measured data in order to assess the primary clarifier mass balance.

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 0.95 (TSS) and 0.98 (BOD), using a primary sludge BOD/VSS ratio of 0.8. Presumably, the values slightly below unity reflect the addition of internal plant recycle streams or sample bias.

It was assumed that solids were not stored in the primaries, so the mass balance was created on a daily basis 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, 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 South Plant 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 x3 65.25 days.

Adjustment to 2010

The first steps 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. May 2012 through October 2015 are excluded because of leaking tank drains that are returned upstream of the influent samplers (shaded green). Figure 6 presents the observed monthly South Plant influent loads.

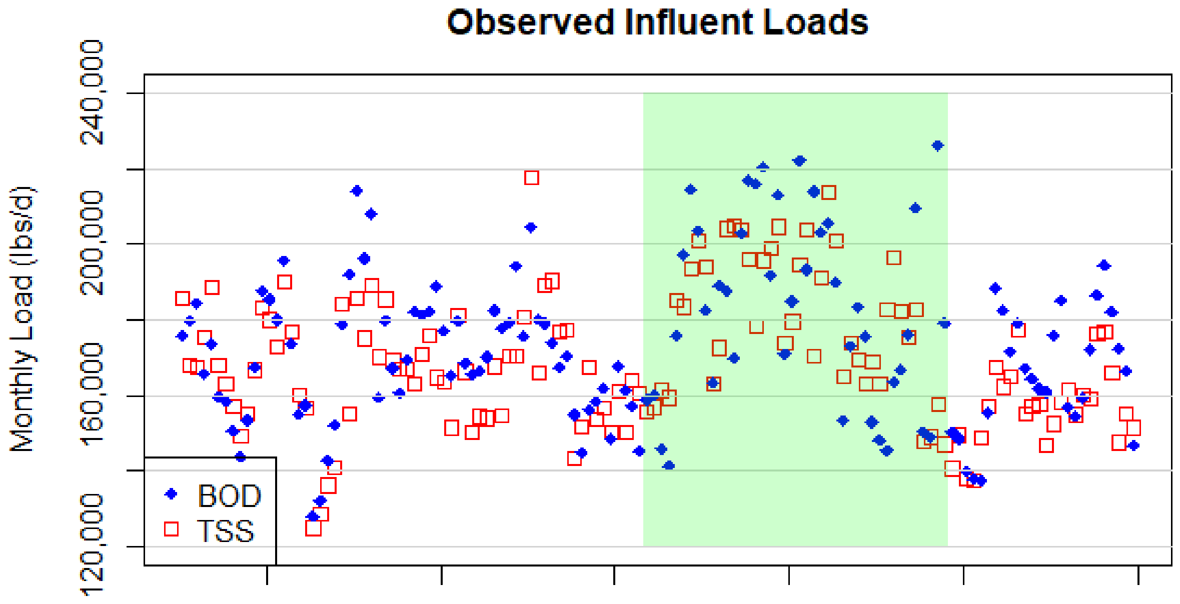

Figure 6. Observed South Plant Influent Loading Rates

Removing the additional days identified as questionable data from the primary clarifier mass balance, Figure 7 presents the monthly South Plant influent loads. Comparison shows a slight reduction in monthly loadings, as expected.

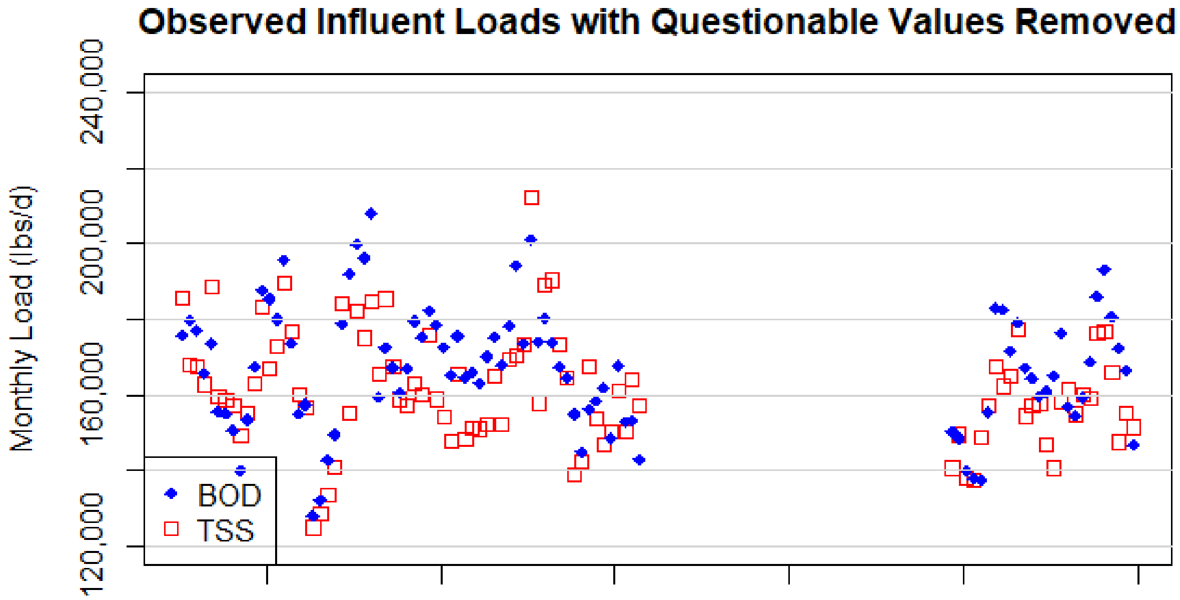

Figure 7. Observed South Plant Influent Loading Rates with Questionable Values Removed

Next, loadings are adjusted to account for flow transfers. This is primarily a reduction of loads prior to 2013 for flows that are now treated at Brightwater. The reported deicing load from SeaTac airport is also removed. Figure 8 presents the resulting loads and the best linear fit to the data. An increasing trend over time is apparent. The linear regression of the data against time is given by:

- BOD_5 = 142,920 + 6.012*(days after 2010-01-01) (lb/day)
- TSS = 144,800 + 3.351*(days after 2010-01-01) (lb/day)

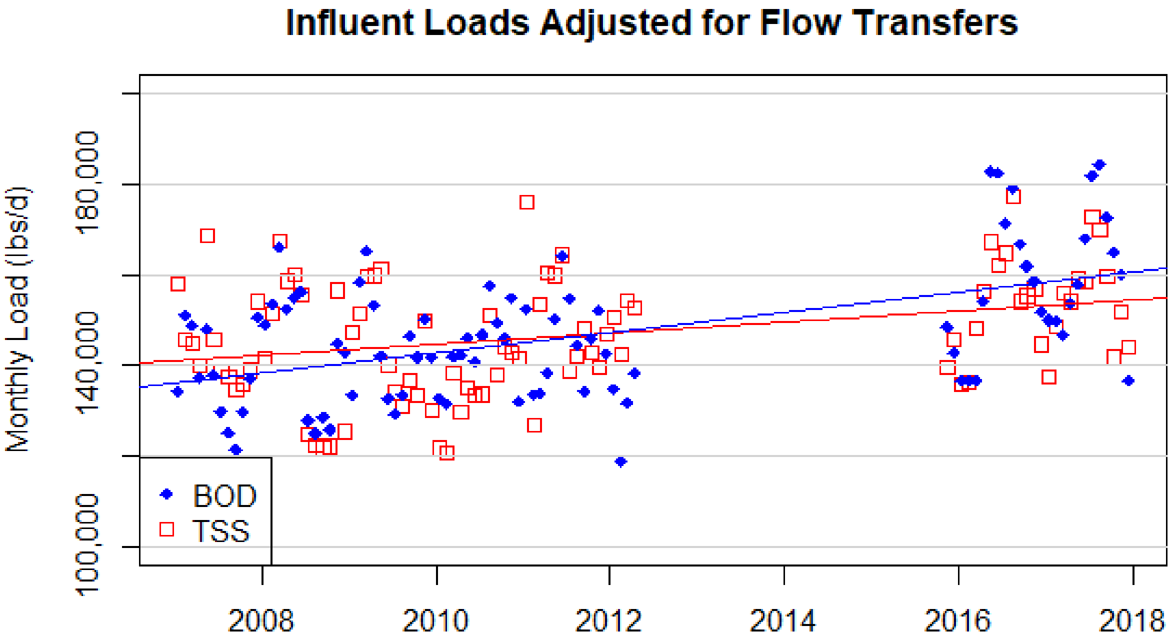

Figure 8. South Plant Influent Loading Rates Adjusted for Flow Transfers

The loading data are adjusted to a 2010 baseline by removing this trend with time from the data, as shown in Figure 9. These data adjusted to the 2010 baseline are used to evaluate the peaking factors.

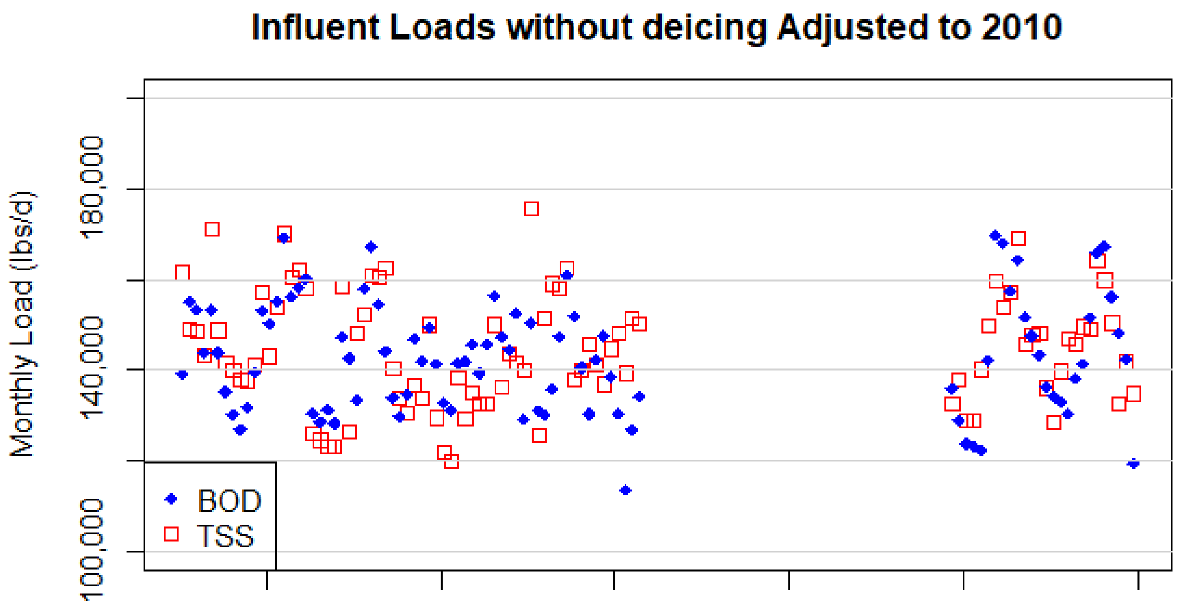

Figure 9. South Plant Influent Loading Rates after removal of linear trend in time

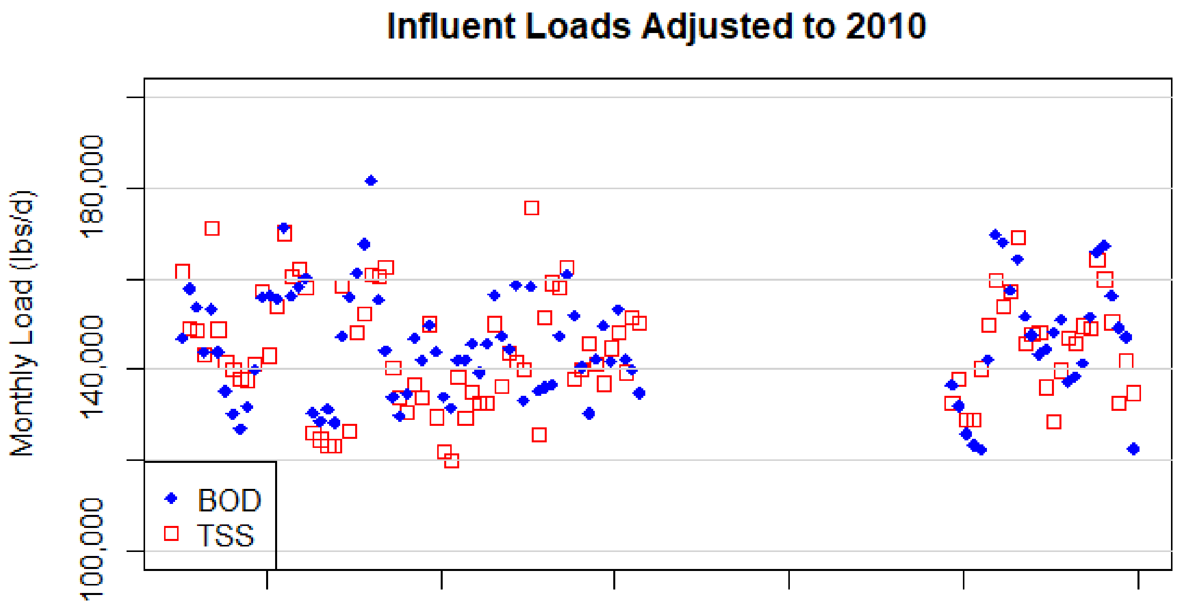

Figure 10. South Plant Influent Loading rates, including deicing loads, adjusted to 2010

Figure 11 shows the ratio of influent loads to primary effluent plus sludge loadings, averaged by month, after the identified questionable data have been removed. Conceptually, this ratio should not exceed one, and would drop below one if additional (in-plant) loads were added to the primary clarifiers. Reasons for the long-term variation in this ratio have not been investigated.

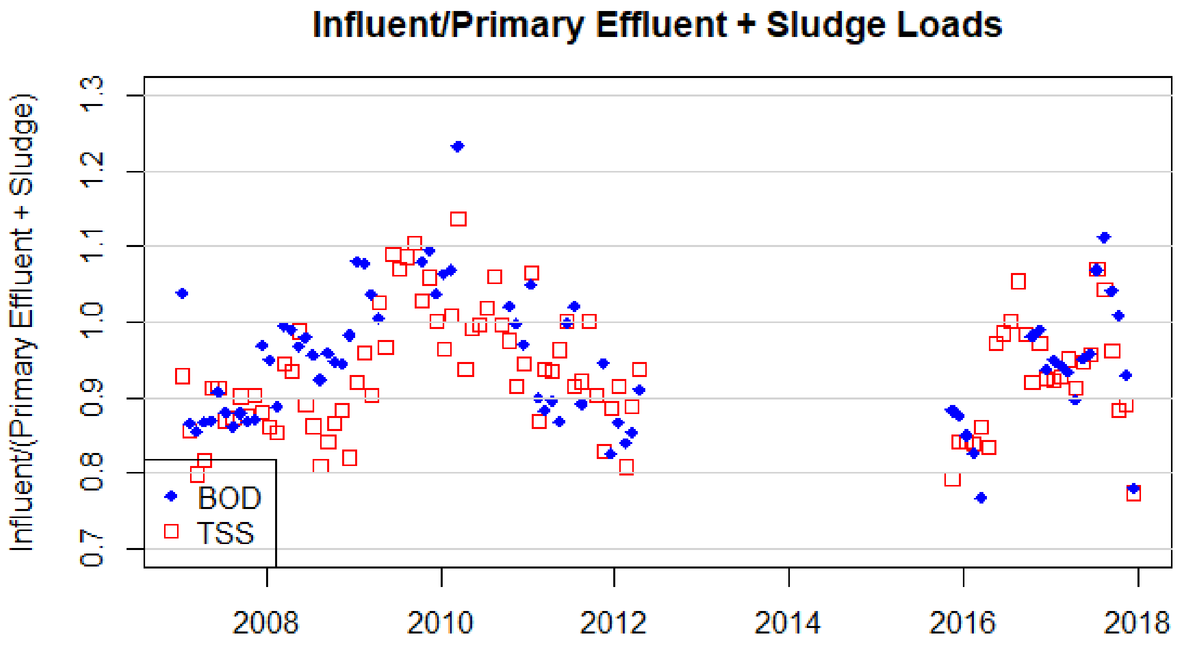

Figure 11. Ratio of Influent to Primary Effluent and Sludge Loading Rates

Day of Week Variation

The loading rates were analyzed for a dependence on the day of the week. Table 5 and Figure 12 shows lower loading rates occurring on Saturday and Sunday. Inspection of the monthly average loading rates did not indicate a consistent seasonal pattern.

Table 5. Average Variation of South Plant Influent Loads by Day of Week

Day of Week	Influent BOD (lb/day)	Influent TSS (lb/day)
Monday	-730	-10
Tuesday	6480	6320
Wednesday	6920	5490
Thursday	5730	4460
Friday	-370	1990
Saturday	-6670	-7830
Sunday	-11,400	-10,400

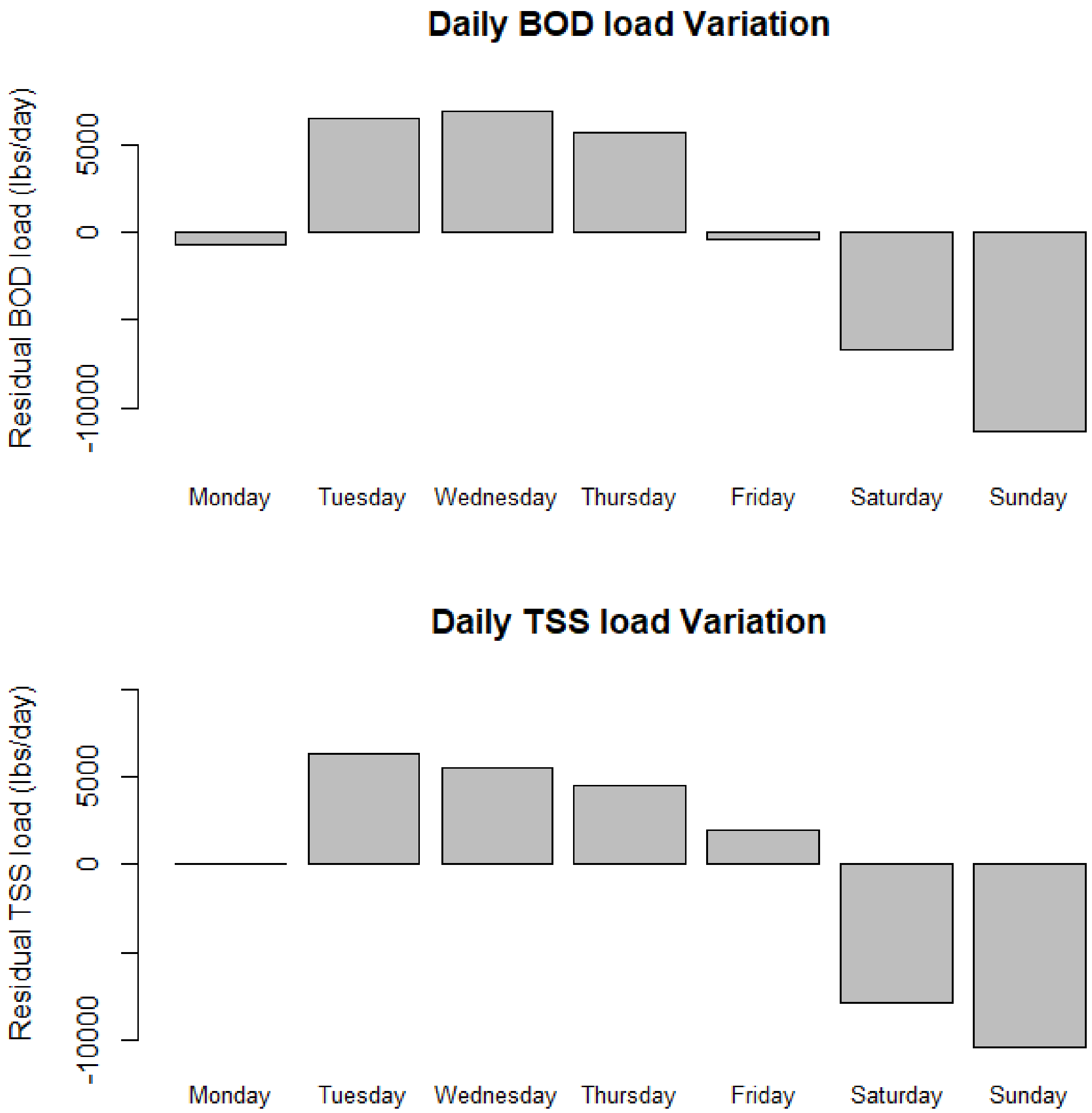

Figure 12. Average Weekday Variation in BOD and TSS Loading Rates. Residual Is Mean Load on Each Weekday Minus Average Loading Rate.

Flow Variation

Variation in loading rates after removing the temporal trend did not show a significant relationship with the daily flow (Figure 13, Figure 14). Note that while the regression line has a non-zero slope, it is not statistically significant (r^2 = 0.00, 0.04). As a result, this dependence is not included in the analysis and was not separated from the loading data.

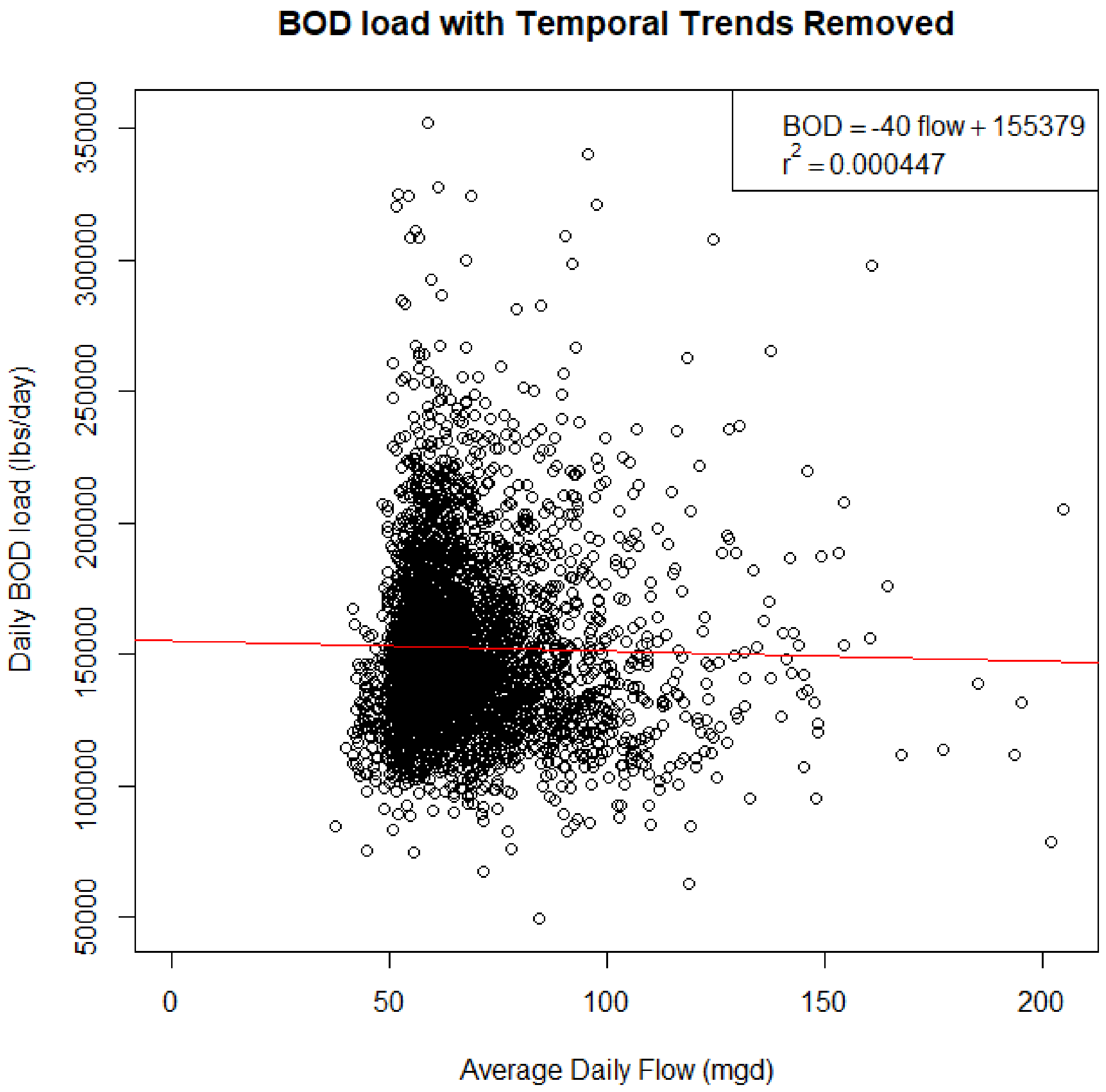

Figure 13. Regression of South Plant Daily BOD Loading Residual after Subtraction of Temporal Trend to Average Daily Flow for January 2007 to May 2012, November 2015 to December 2017

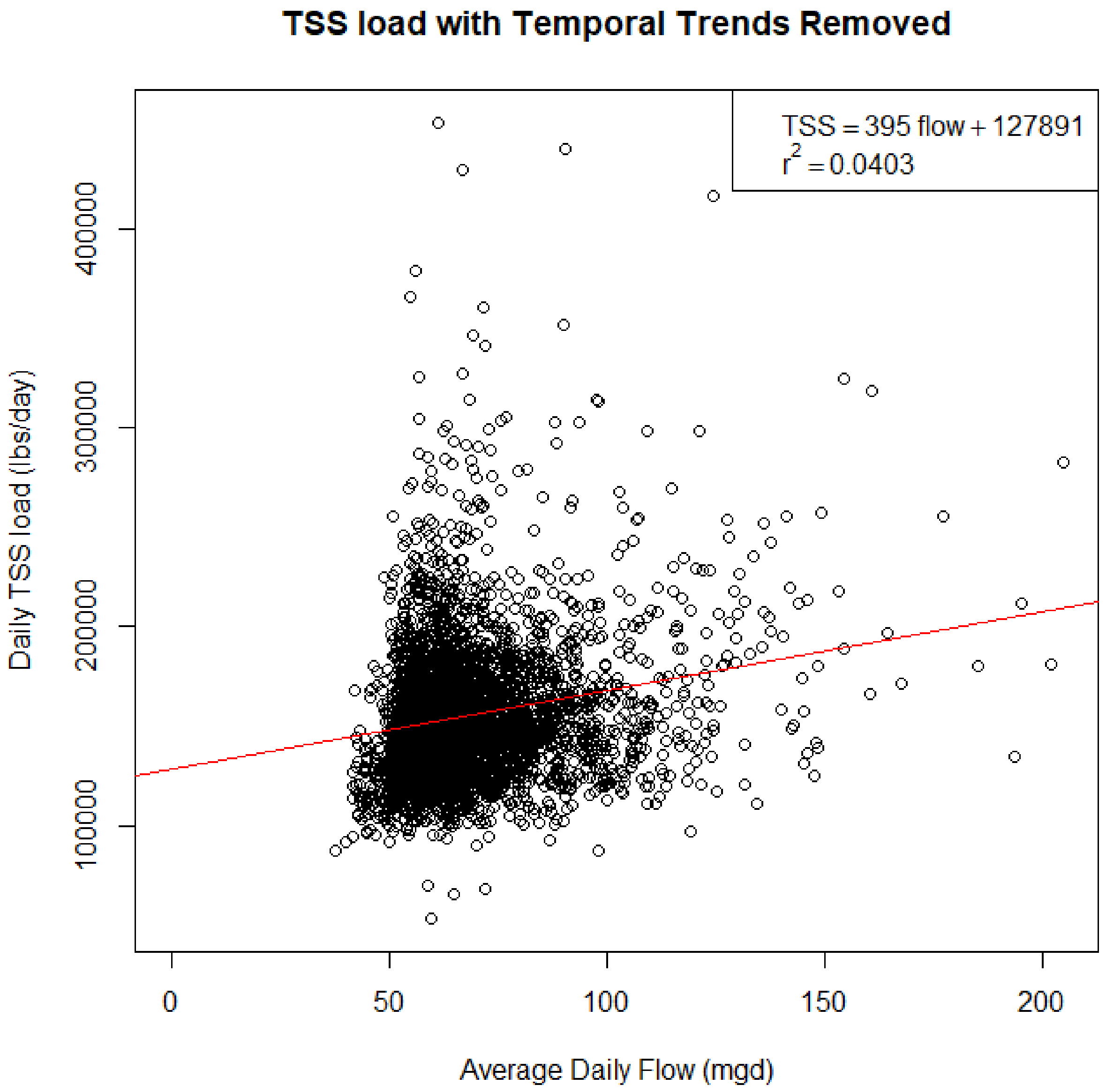

Figure 14. Regression of South Plant Daily TSS Loading Residual after Subtraction of Temporal Trend to Average Daily Flow for January 2007 to May 2012, November 2015 to December 2017

Peak Loading Rates

The daily loading rates were averaged to monthly and weekly loading rates using calendar months and a seven-day running mean, respectively. The distribution of the daily residual loading rates followed a skewed distribution. Loadings from the deicing discharge are not independent of time, occurring during periods of cold weather. Because the residual loading rates were not a random, normally distributed fluctuation about the mean, the peak loading rates were estimated from the empirical distribution of loads corresponding with a once-in-20-year occurrence. To estimate the loads associated with a 20-year recurrence, a bootstrapping approach was used as follows:

- The temporal trend was subtracted from the observed loads to create a distribution of loading values around the 2010 mean load.
- The deicing BOD load and weekday variation were subtracted.
- The daily, weekly, and monthly loads less the weekday variation were each combined into a cumulative probability distribution, and a spline curve was fit through each distribution and used to extrapolate the probability distribution curve.
- For each of the daily, weekly, and monthly loadings, the 2010 loading and deicing spline curves were randomly sampled 10 million times.
- Each sample from the daily loading splines was assigned a day of the week and summed with the corresponding weekday variation in load.
- The 20-year recurrence loading rate was obtained from the resulting sum 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.
- The corresponding peaking factor was calculated by dividing the load by the average annual 2010 loading rate.
- For BOD, a deicing time series was created by repeating the 2007–2017 daily series and added to the series created from sampling the 2010 loading curve, along with the corresponding day of week variation. The 20-year recurrence loading rate and peaking factors were calculated as above.
- The deicing load contribution to the 20-year peak load was estimated as the difference between the 20-year load with the deicing time series and the load estimated without the deicing time series.

Table 6 summarizes the calculated peaking factors (pf) as peak load = mean * (pf).

Figure 15 plots all of the data (adjusted to 2010), including deicing BOD loads, as cumulative distribution curves for daily, weekly, and monthly loading rates. The 20-year recurrence values are indicated in red.

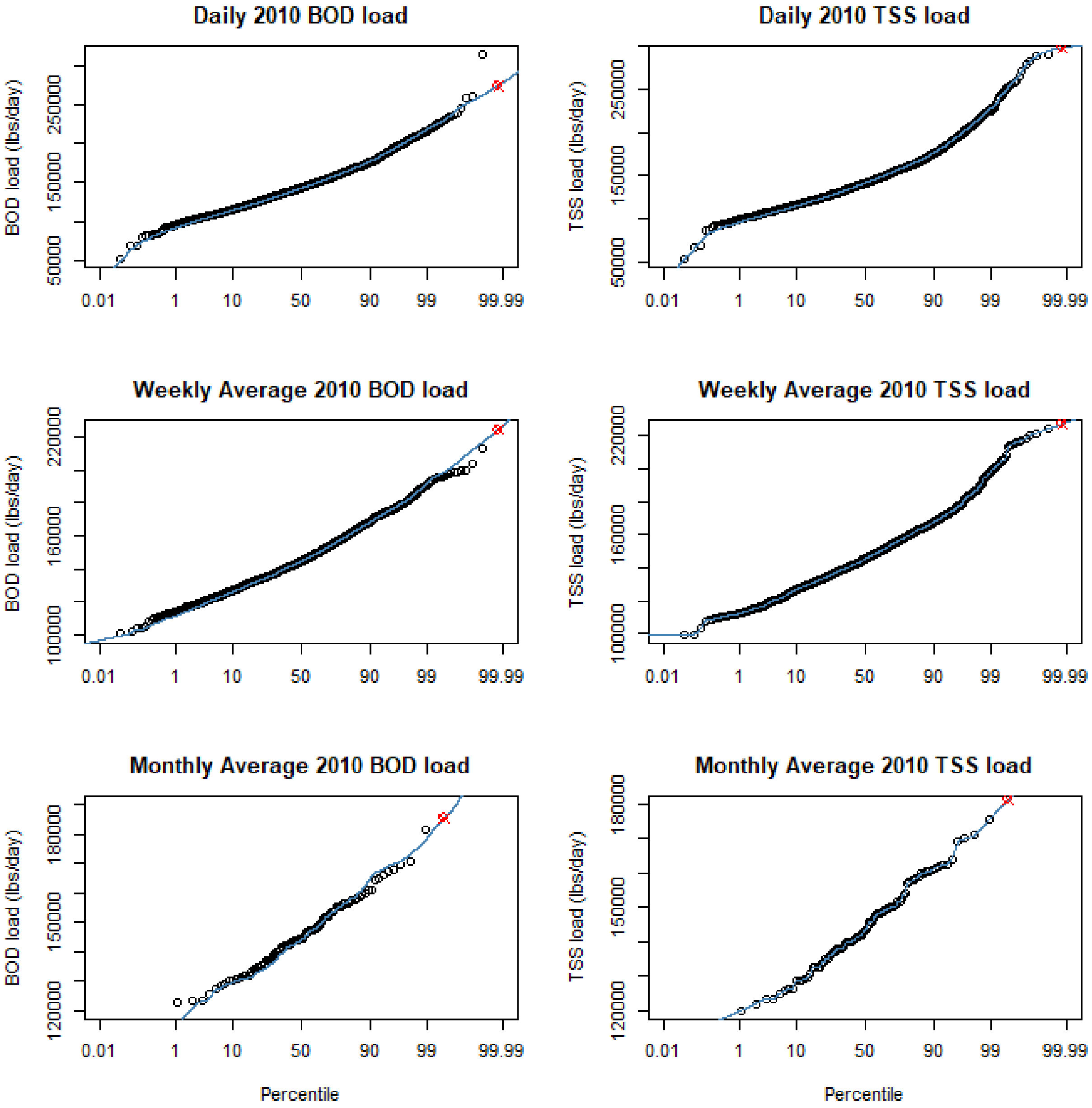

Figure 15. Cumulative Probability Plots of Daily, Weekly, and Monthly BOD and TSS Loads. Twenty-year Recurrence Value Denoted by Red Marker.

Table 6. Peaking Factors for 20-year Peak Loading Rates

Influent BOD			
	South Plant Current Analysis 2007–2017	**South Plant 1997–2002 Average[a]**	**South Plant Design[b]**
Peak Month/Average Annual	1.19 (1.30 with deicing)	1.29	1.14
Peak Week/Average Annual	1.41 (1.57 with deicing)		
Peak Day/Average Annual	1.84 (1.92 with deicing)	2.48	1.61
Peak Day/Peak Month	1.54	1.91	1.41
Influent TSS			
	South Plant Current Analysis 2007–2017	**South Plant 1997–2002 Average[a]**	**South Plant Design[b]**
Peak Month/Average Annual	1.25	1.18	1.17
Peak Week/Average Annual	1.57		
Peak Day/Average Annual	2.05	2.36	1.71
Peak Day/Peak Month	1.64	2.0	1.46

[a] South Plant Capacity and Re-Rating Evaluation, prepared by Brown and Caldwell, June 2004
[b] Enlargement III Facility Plan

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 since 2010. 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 through 2020. No data were available to verify this assumption in employment growth. The higher-than-anticipated population growth results in an approximate 5 percent increase to future TSS and BOD loading projections (see Appendix A, Future Population Projection).

The peaking factors estimated for current loadings were applied to these revised loading projections, adjusted for the proposed Sammamish Plateau Flow Diversion Project, to estimate future peak loading rates, as shown in Table 7. Table 8 presents the estimated loads that will be transferred to Brightwater from the flow transfer.

A King County Industrial Waste Discharge Permit began to limit deicing discharges to 60,000 lb/day beginning in 2016. By 2020, the discharge is to be limited to 45,000 lb/day, with an average of 25,000 lb/day. The Port of Seattle is to submit a plan on how this will be accomplished in 2019. As a conservative assumption, deicing BOD loads were assumed to remain similar to historical levels. Deicing discharges have the greatest impact on the peak weekly BOD loads, increasing by 24,000 lb/day, corresponding to the tendency for the duration of high discharge rates to be around a week. The influence on peak daily loads (12,000 lb/day) is less because of the greater variation of the daily loads and the reduced probability of a high deicing load occurring on the same day as a high load from the sewershed. Peak monthly loads are increased by 15,000 lb/day.

Table 7. Projected Loads for South Plant, 2010–2060

Flow Condition	BOD Load (lb/day)						TSS Load (lb/day)					
	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
Average annual	151,300	181,500	196,000	209,600	227,700	246,400	148,800	179,400	195,800	208,600	227,300	246,600
Average dry weather	151,300	181,500	196,000	209,600	227,700	246,400	148,800	179,400	195,800	208,600	227,300	246,600
AWW	151,300	181,500	196,000	209,600	227,700	246,400	148,800	179,400	195,800	208,600	227,300	246,600
Maximum month	196,700	232,900	250,300	266,700	288,400	310,800	186,000	224,300	244,700	260,800	284,100	308,200
Maximum week	239,100	281,900	302,500	321,900	347,500	374,100	233,600	281,700	307,400	327,600	356,800	387,100
Peak day	290,600	346,000	372,700	397,800	431,100	465,500	306,500	369,600	403,300	429,800	468,200	508,000

Table 8. Transferred Loads from South Plant, 2010–2060

Flow Condition	BOD Load (lb/day)						TSS Load (lb/day)					
	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
Average annual Sammamish Plateau Diversion Phase 1			1,900	2,400	2,700	3,000			2,100	2,600	2,900	3,200
Average annual Sammamish Plateau Diversion Phase 2				8,600	9,600	10,800				8,900	10,000	11,200

Projected Influent Concentrations Through 2060

The projected flow and influent loads are combined to provide estimated influent concentration, given in Table 9.

Table 9. Projected Influent Concentrations for South Plant, 2010–2060

Load Condition	Flow Condition	Influent BOD (mg/l)					
		2010	2020	2030	2040	2050	2060
Average annual	Average annual	268.0	280.7	288.4	291.8	291.3	291.0
Maximum month	Average dry weather	399.8	411.3	422.0	423.0	419.6	416.6
Maximum month	Maximum month	203.7	218.3	223.6	227.4	229.0	230.1
		Influent TSS (mg/l)					
		2010	2020	2030	2040	2050	2060
Average annual	Average annual	263.5	277.5	288.1	290.4	290.8	291.2
Maximum month	Average dry weather	378.0	396.1	412.6	413.7	413.4	413.1
Maximum month	AWW	192.6	210.2	218.6	222.4	225.6	228.2

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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

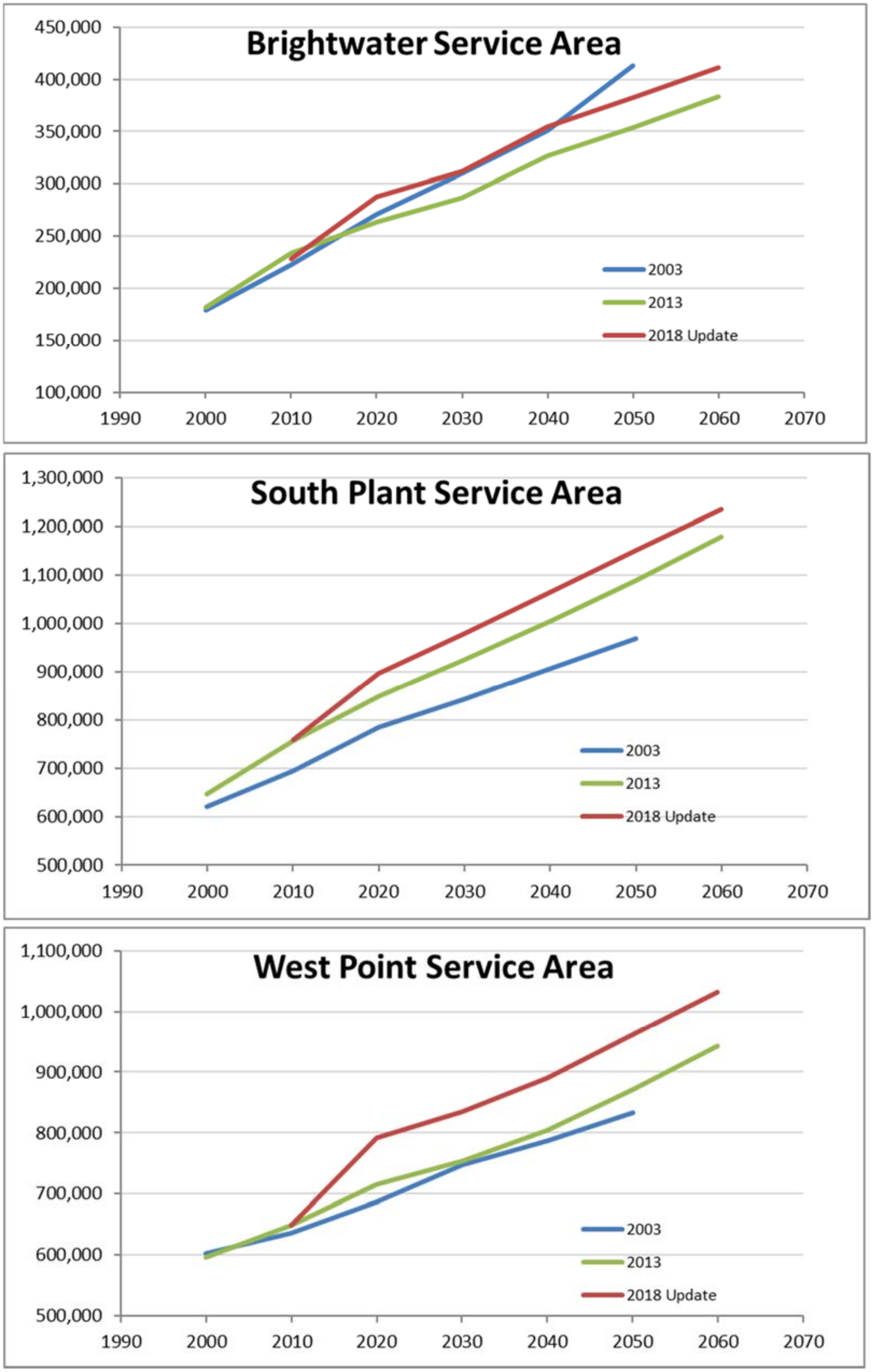

Figure A1. Total Population Projections for Each Service Area from Estimates Made in 2003, 2013, and 2018

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