Brightwater 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 Brightwater Treatment Plant (Brightwater). The projections update those described in *Brightwater Treatment Plant Peak Flow and Wasteload Projections 2010−2040* (King County Department of Natural Resources and Parks [DNRP], 2016).

This analysis uses a calibrated collection system model (MIKE URBAN) along with flow and wasteload data measured at Brightwater from January 2013 through December 2017. Corrections are made to reflect the flow transfers from Brightwater.

The collection system model, calibrated to observed flows at many locations in the Brightwater 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 forecast assumptions used in (King County DNRP, 2014a) to estimate peak flows from 2010 through 2060. Base wastewater flow and annual loading rates are updated with revised population projections to reflect observed growth rates through 2016.

A statistical analysis was applied to the observed 2013 to 2017 loading rates at Brightwater 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 to estimate loading rates from 2010 through 2060.

This report updates the Brightwater Treatment Plant Peak Flow and Wasteload Projections 2010−2040 analysis by:

- Including projections for 2050 and 2060.
- Including additional flow from the proposed Sammamish Plateau Diversion Phase 1 and Phase 2 projects.
- Reducing the estimated 2010 base wastewater flow by 0.4 million gallons per day (mgd), correcting for an erroneous assignment of the SAM016A basin to the Brightwater service area.
- Including treatment plant loadings from 2015 through 2017. The seasonal variation of loads observed in the 2013 to 2014 data do not appear to be significant over the longer period and no seasonal variation is included in this analysis.
- Including additional population and employment growth in the Brightwater service area based on an extrapolation of the American Community Survey (ACS) population estimates from 2010 through 2016 to 2020.

Background

As part of the Regional Wastewater Services Plan (RWSP) 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.

Conveyance System Modeling

Wastewater treatment plant flow consists of two components: base wastewater flow (sewage) and 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 Brightwater service area was separated into 36 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 into 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 2013 to 2014 period for additional calibration/validation. Brightwater was fully operational during this period, enabling flows to be compared with the Brightwater influent flow meters. A scaling factor was applied to the model to better match the more accurate influent flow meters at Brightwater.
- 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.

[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.

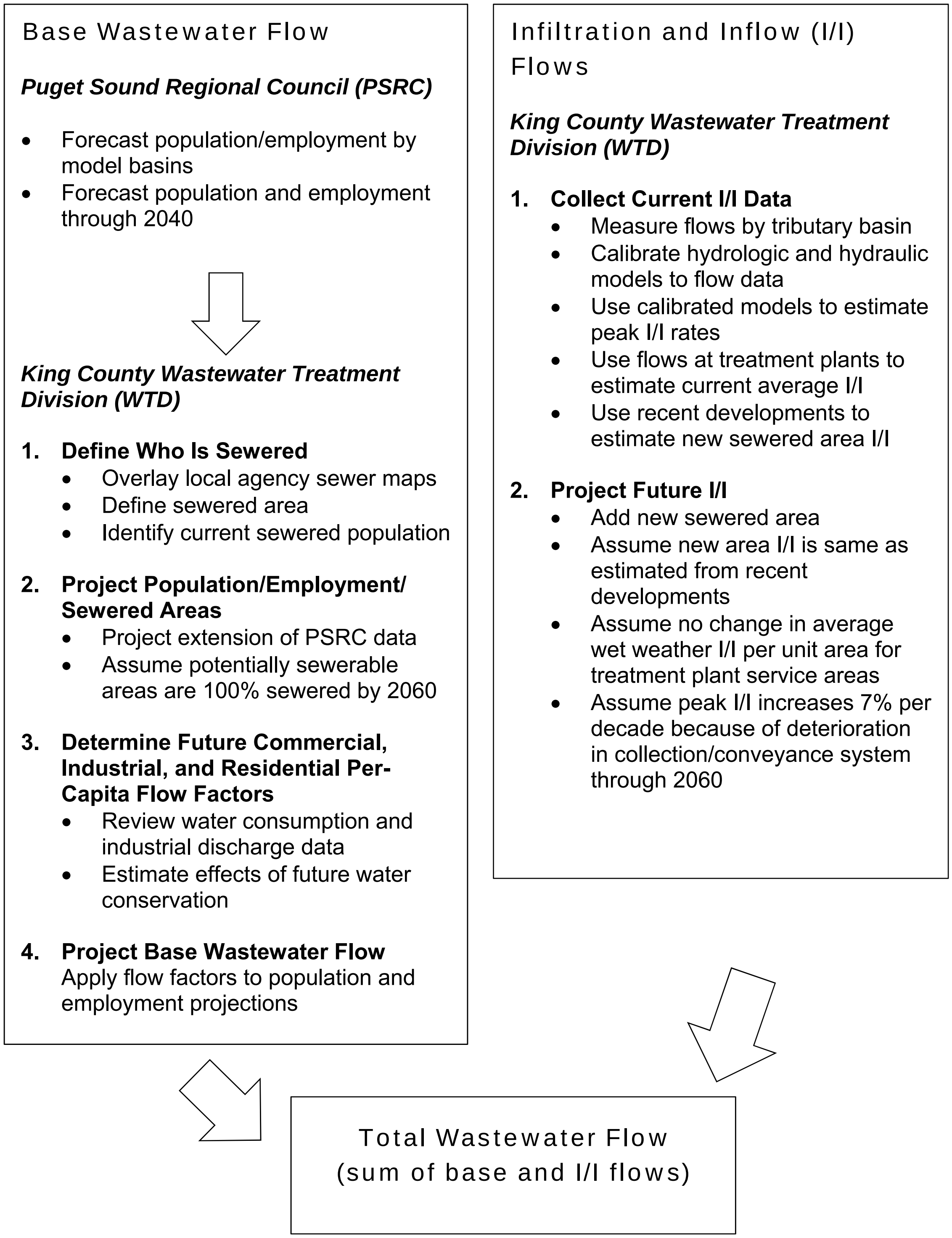

Figure 1. Wastewater Flow Projection Process

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 South Treatment Plant (South Plant) between 1985 and 2012 were reviewed. South Plant data was used due to the longer duration of data and serving a separated conveyance system. 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 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) for forecasting 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.

In addition, it is assumed that the conveyance improvement projects listed in Table 1 will be completed to allow all flow from the service area to be conveyed to the treatment plant.

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

Table 1. Assumed Completion of Future Conveyance Improvement Projects

Future Conveyance Improvement	***Assumed Completed* Before**
N. Lake Sammamish Diversion	2030
Sammamish Plateau Diversion Phase 1	2030
Sammamish Plateau Diversion Phase 2	2040

2. WASTEWATER FLOW PROJECTIONS

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

Current (2013–2014) Flows

The collection system model was calibrated to match the observed flow at Brightwater during the period from 2013 and 2014. Brightwater flows were taken from the sum of the two influent flow meters (pi tag: \\SPPISERVER\BW-30001A-ATOTINFLO). These flows were then modified to account for flow diversions and recycle streams, as discussed below.

Flow Transfers

The planning basis for Brightwater flows was that all flows generated in the service area would be conveyed to the treatment plant. During 2013 and 2014, some flows were diverted because of conveyance or treatment capacity limitations. Flows from the North Lake Sammamish Interceptor enter at the Hollywood Pump Station (Hollywood PS) and are pumped to the Sammamish Valley Interceptor for conveyance northward to Brightwater. This flow can also be diverted to the York Pump Station (York PS). The diverted flows are pumped into the Eastside Interceptor and flow to South Plant. Flow can also be diverted at the North Creek Pump Station and pumped to the York PS, and subsequently pumped into the Eastside Interceptor. Additionally, the Swamp Creek Connection and North Creek Junction can be configured to send flow to West Point Treatment Plant (West Point).

The total Brightwater flow was calculated as the sum of the Brightwater influent flow plus flow from the York PS (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 mgd. No flows were transferred to West Point during this time. Flows were averaged to a daily value using the Brightwater sampling day of 06:00 to 06:00.

The current Brightwater model purposely does not simulate the Hollywood/York diversions; all North Lake Sammamish flows are conveyed to Brightwater. This condition will occur when the N. Lake Sammamish Diversion is completed (Table 1). In accounting for this configuration, reconstructed Brightwater inflow includes flow from the York PS.

Recycle Streams

Brightwater produces reclaimed water that is distributed through a network of reclaimed water pipes. To maintain a minimum flow at the Brightwater influent pump station (IPS) and for a variety of testing purposes, this reclaimed water can be re-introduced into the collection system at certain locations, including the IPS and York PS. These recycled flows were subtracted from the total Brightwater flow. Table 2 summarizes the sources of recycle flow rates.

Table 2. Reclaimed Water Flows Returned to the Collection System

Flow Description	***PI* Tag**
Recirculated reclaimed water through North Creek Diversion Structure	'\\SPPISERVER\NC311FI311017D
Reclaimed water used at IPS for flushing and when reclaimed water is diverted (discharge is to surge chamber)	'\\SPPISERVER\BW240FIT240314
IPS air gap tank (in from variable frequency drive cooling)	'\\SPPISERVER\BW210XLA210229-QO
RW mostly going to South Plant via York PS	'\\SPPISERVER\BW240FIT309501IC

RW = reclaimed water

Flow Simulation

The simulated flow from the Brightwater service area was averaged to a daily value and compared to the observed flow after adjusting for flow diversions and recycle streams. The Brightwater 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 at Brightwater are expected to be much more accurate. A calibration scaling factor of 0.866 was calculated as the ratio of total Brightwater flow (accounting for diversions and recycle streams) to the average model flow for the period from September 1, 2013, to January 1, 2015. Data before September 1, 2013, were excluded because flow rates for some recycle streams were estimated up to that point. Figure 2 presents the calibrated model flows.

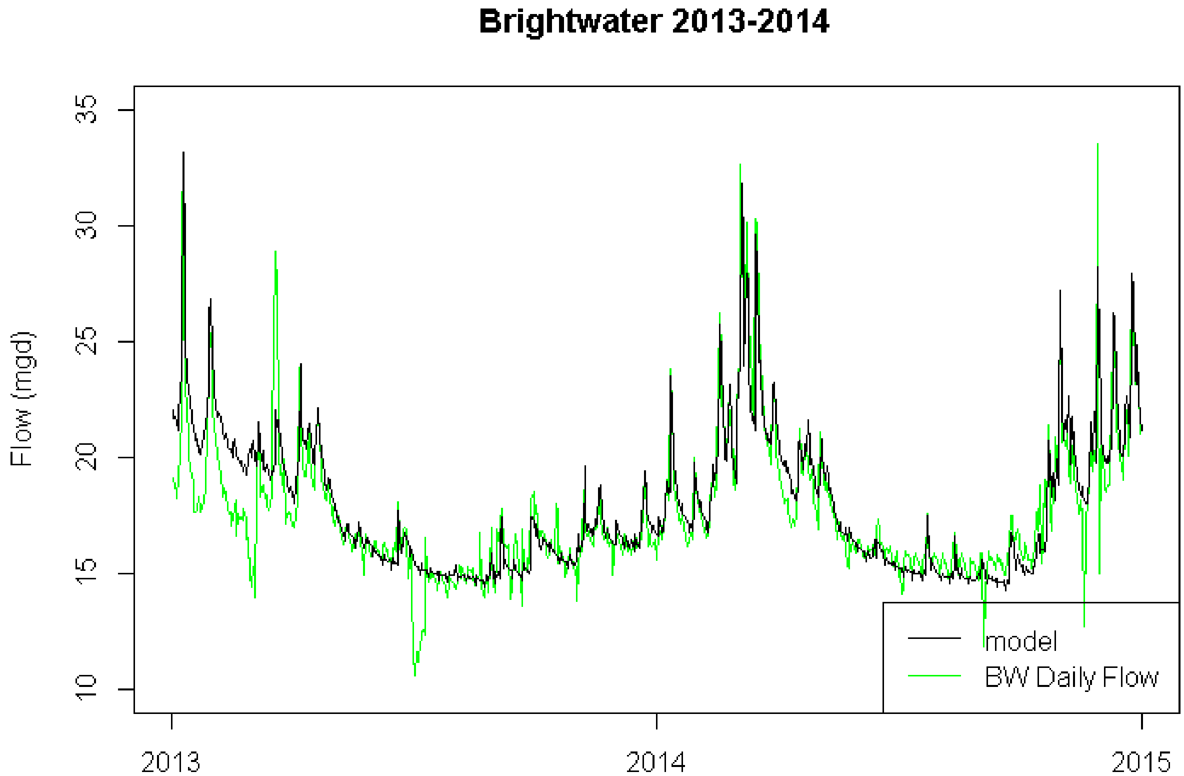

Figure 2. Comparison of Calibrated and Scaled Hydraulic Model to Total Brightwater Flow. Brightwater Flow Has Been Adjusted for Reclaimed Water and Flow Diversions.

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. To adjust for current growth, population data were obtained for both the Brightwater service area and Sammamish Plateau diversion area. These data were used to determine the relative increase in population from 2010. 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 growth since 2010 results in an approximate 12 percent increase to future Brightwater base wastewater flow projections and a 3 percent increase to base wastewater flows from the Sammamish Plateau.

The current Conveyance System Improvement Program plan (King County DNRP, 2017) proposes diverting flow from the Sammamish Plateau area north to Brightwater in two phases. Table 3 summarizes the expected population and employment, sewered area, and base wastewater flow for the Brightwater service area. Projections for 2030 and later have been increased by the Phase 1 diversion, with projections for 2040 and later increased by the expected Phase 2 diversion.

Table 3. Projected Growth in the Brightwater Service Area

Brightwater Treatment Plant Service Area Projections[a,b]						
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Residential Population	203,202	264,920	306,128	403,980	445,887	489,214
Commercial Employment	96,212	139,263	164,834	223,306	250,103	279,133
Industrial Employment	15,577	17,874	17,373	21,741	22,393	23,045
Sewered Area (acres)	21,786	24,333	28,365	37,372	41,229	45,086
Base Wastewater Flow (mgd)	13	17	18	24	27	29

[a] King County DNRP, 2014a

[b] Including Sammamish Plateau Diversion Phase 1 in 2030 and Phase 2 in 2040

To align with the RWSP projections developed for a 2010 base year, the hydraulic model was further adjusted to reflect the difference between 2010 and the 2013 and 2014 period used to scale the flow (Figure 2). The model was scaled back to represent 2010 conditions based on an increase in model flow from 2010 to 2014 of 1.046 (=11.5 percent/decade), obtained from a linear interpolation of the expected growth from 2010 to 2020 estimated for the RWSP projections (King County DNRP, 2014b). Thus, the model flows were scaled by 0.866/1.046 = 0.828 to obtain flows in year 2010. This scaling ratio does not include an adjustment for the 2010 to 2016 growth rates.

Table 4 summarizes the projected growth in sewered area and base flow relative to 2010 for the Brightwater service area.

Table 4. Relative Growth of Base Flow and Sewered Area

	Brightwater Treatment Plant Service Area Projections					
	2010*	**2020**	**2030**	**2040**	**2050**	**2060**
Sewered Area Relative to 2010	1.00	1.12	1.30	1.72	1.89	2.07
Base wastewater Flow Relative to 2010	1.00	1.25	1.36	1.79	1.98	2.17

*Including Sammamish Plateau Diversion Phase 1 in 2030 and Phase 2 in 2040

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 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 Brightwater model, this was the week of 1944-10-08 to 1944-10-15.
    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 following: 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 3 and Table 4). 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 I/I flow was estimated as:

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

Where $I/I_{2010\ model}$ 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 3) 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 5 presents the base sewage flow, peak I/I, and peak flow estimates tabulated by decade. The existing conveyance system does not have adequate capacity to convey the projected peak flows to Brightwater. The following assumptions were made on future changes to conveyance facilities in the Brightwater service area:

- Facilities to convey flows to Brightwater in excess of the current Hollywood PS capacity will be constructed by 2030 (North Lake Sammamish Diversion Project).
- Sammamish Plateau Diversion Phase 1 will be constructed by 2030 to maintain a five-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, increasing Brightwater's 2060 service area by 2,500 acres and 1 mgd of base flow.
- Sammamish Plateau Diversion Phase 2 will be constructed by 2040 to maintain a five-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, increasing Brightwater's 2060 service area by 8,000 acres and 3.5 mgd of base flow.

Before completion of the North Lake Sammamish Diversion Project, capacity constraints in the Sammamish Valley Interceptor limit the flow at Hollywood PS to around 13 mgd. Flows above this flow to York PS and are pumped into the Eastside Interceptor to South Plant. Maximum week, day, and hour flows are reduced by this transfer for 2010 and 2020. In 2020, the transfer reduces the maximum month flow by approximately 0.1 mgd, the maximum week by 1 mgd, the maximum day by 5 mgd, and the peak hour flow by 10 mgd.

Table 5. Components of Projected Flows by Decade to Brightwater

	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 Month (20-yr Recurrence)	13	12	25	17	13	30	18	15	33
Maximum Week (20-yr Recurrence)	13	21	34*	17	24	40*	18	29	47
Maximum Day (20-yr Recurrence)	13	32	45*	17	36	53*	18	49	67
Maximum Hour (20-yr Recurrence)	18	46	64*	23	51	73*	25	72	97
	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 Month (20-yr Recurrence)	24	18	43	27	21	47	29	23	52
Maximum Week (20-yr Recurrence)	24	37	61	27	42	69	29	47	76
Maximum Day (20-yr Recurrence)	24	63	87	27	71	98	29	79	109
Maximum Hour (20-yr Recurrence)	32	92	125	36	105	140	39	117	156

* Peak flow reduced by capacity limitations in Sammamish Valley Interceptor

Projected Flows Through 2060

Table 6 summarizes the projected flow forecasts for the Brightwater service area, including adjustments in 2030 and 2040 for Phase 1 and Phase 2 of the Sammamish Plateau Diversion to Brightwater and reductions in 2010 and 2020 because of capacity constraints in the Sammamish Valley Interceptor.

Table 6. Projected Flows for Brightwater, 2010−2060

Flow Condition	Flow (mgd)					
	2010	2020	2030	2040	2050	2060
Average annual	16	20	22	28	30	33
ADW	14	18	19	25	28	31
AWW	18	22	24	30	33	36
Maximum month	25	30	33	43	47	52
Maximum week	34	40	47	61	69	76
Peak day	45	53	67	87	98	109
Peak hour	64	73	97	125	140	156

3. WASTELOAD FORECASTS

Annual average loading rates of solids (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 Brightwater between 2013 and 2017 to develop peaking factors to relate loading rates for average December, the maximum calendar year, maximum calendar month, maximum week (seven-day running mean), maximum day, and peak hour 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 (2013–2017) Loadings

A daily composite sample is collected at Brightwater to measure the influent BOD and TSS concentrations. The measurements from 2013 through 2017 were multiplied by the total flow from the current Brightwater service area (i.e., adjusted to include flow transferred) to obtain a daily load. Figure 3 presents the corresponding monthly average BOD and TSS loads with their projected loading rates. The projected loading rates are based on the loading factors determined for the annual loading projections (King County DNRP, 2014a), combined with an updated estimate of population growth. ACS population estimates from 2010 to 2016 were extrapolated to 2020. Employment estimates were increased by the same ratio as population. The ACS survey suggests that the population growth rate for the Brightwater service area has been approximately double the PSRC estimate.

The loading rate was examined for a seasonal and flow correlation. The previous analysis based on 2013 and 2014 data had found a slight seasonal correlation, which was approximated by a triangular waveform. This correlation was not significant over the longer 2013 to 2017 data set, and no seasonal correlation was assumed.

The residual after removing the seasonal correlation for the 2013 to 2014 loads did not show a significant relationship with the daily flow (Figure 7, Figure 8). Note that while the regression line has a non-zero slope, it is not statistically significant (r^2 = 0.018, 0.052). A slight increase in loading was associated with daily flow rates between 30 and 35 mgd. No adjustment was made for this correlation.

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

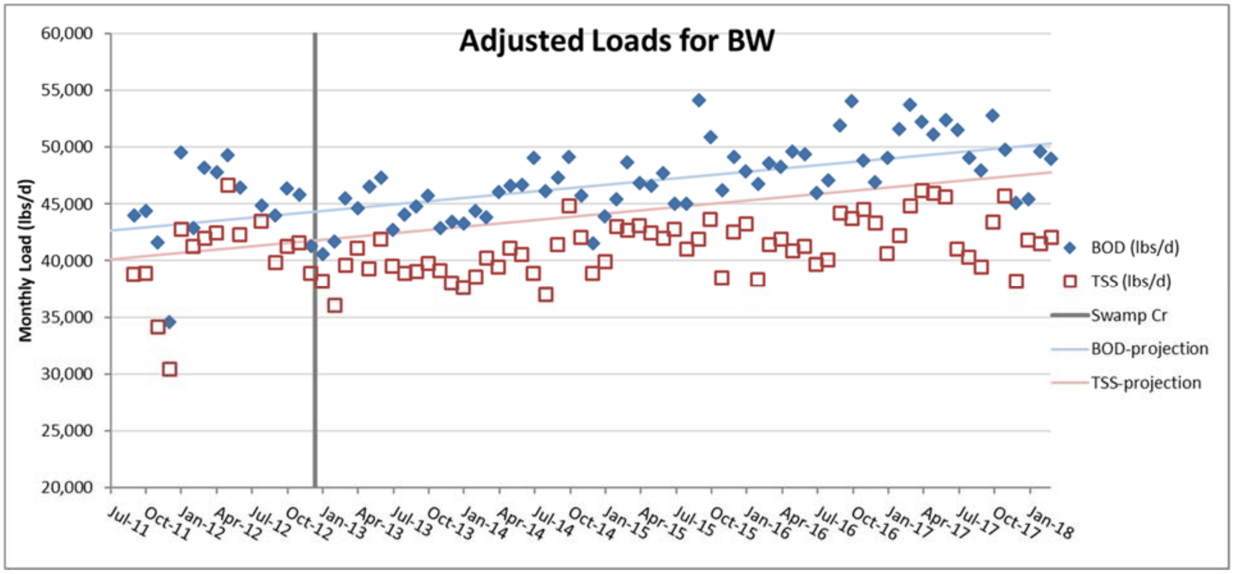

Figure 3. Monthly Average BOD, TSS Loads and Projected Loading Rates

Influent Loading Data Validation

A daily mass balance was attempted around the primary process to identify uncharacteristic influent BOD or TSS concentrations. Unfortunately, primary effluent concentrations are typically measured only three days per week, so a mass balance could not be created. Other load correlations were examined, but none were found to have significant correlation to be suitable for validating the influent loads. Thus, the influent loads were used as reported.

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 Brightwater between 2013 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.

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. January 6, 2016, through January 11, 2016, and December 30 and 31, 2017, were excluded because of influent sampler issues. Figure 4 presents the observed monthly Brightwater influent loads.

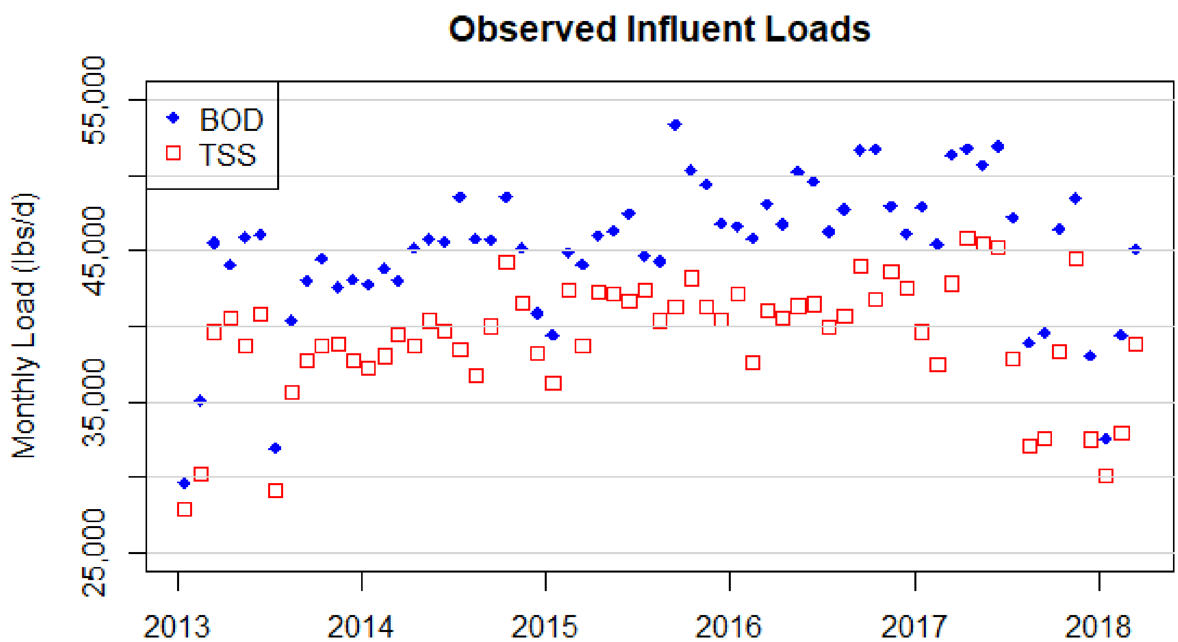

Figure 4. Observed Brightwater Influent Loading Rates

Next, loadings were adjusted to account for flow transfers. This is primarily an addition of loads corresponding to flows transferred at York PS to South Plant. Figure 5 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 = 39,670 + 3.778*(days after 2010-01-01) (lb/day)
- TSS = 36,550 + 2.285*(days after 2010-01-01) (lb/day)

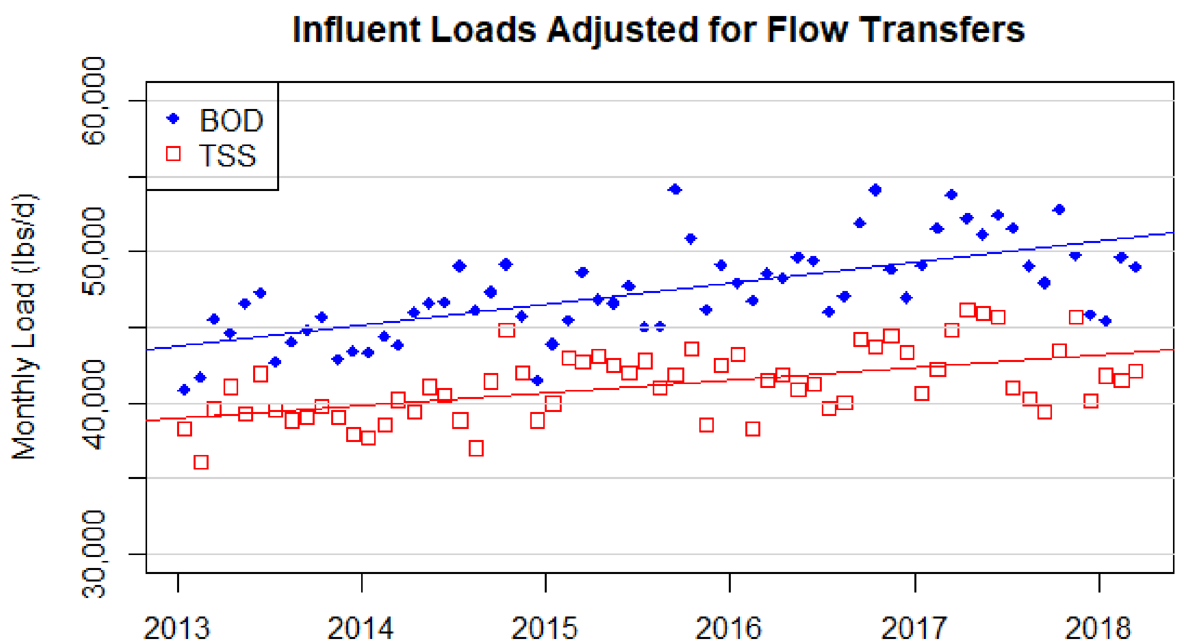

Figure 5. Brightwater Influent Loading Rates Adjusted for Flow Transfers

The loading data are adjusted to a 2010 baseline by removing this trend with time from the data, as shown in Figure 6. These data adjusted to the 2010 baseline are used to evaluate the peaking factors.

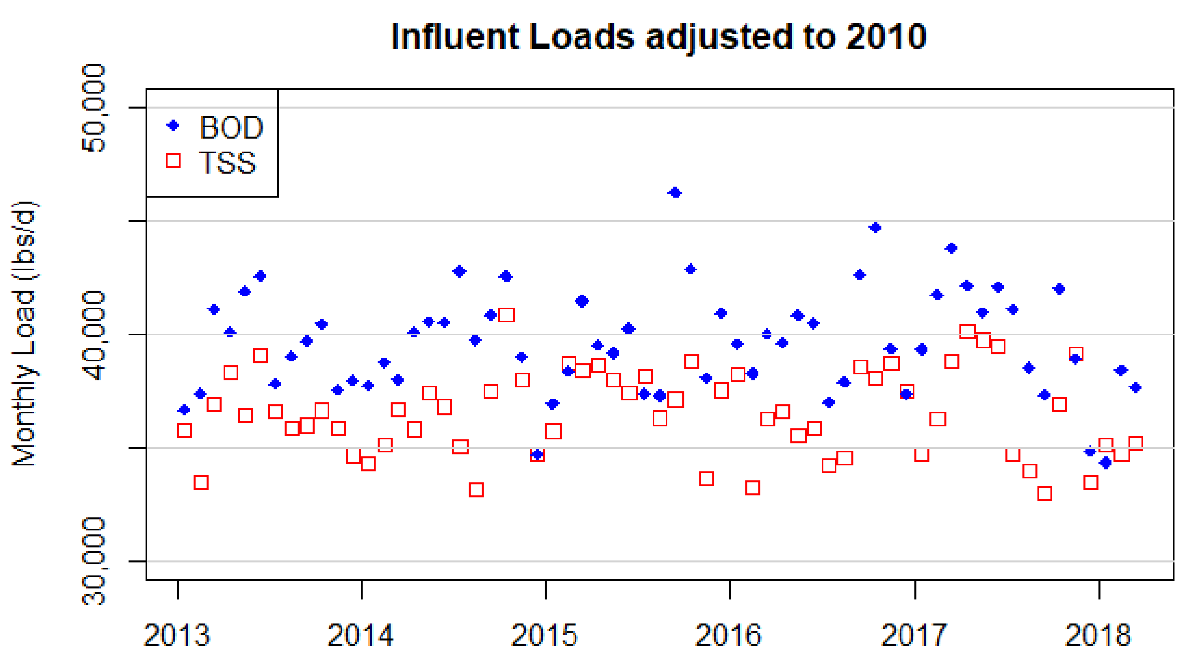

Figure 6. Brightwater Influent Loading Rates After Removal of Linear Trend in Time

Flow Variation

Variation in loading rates after removing the temporal trend did not show a significant relationship with the daily flow (Figure 7, Figure 8). Note that while the regression line has a non-zero slope, it is not statistically significant (r^2 = 0.00, 0.03). As a result, this dependence is not included in the analysis and was not separated from the loading data.

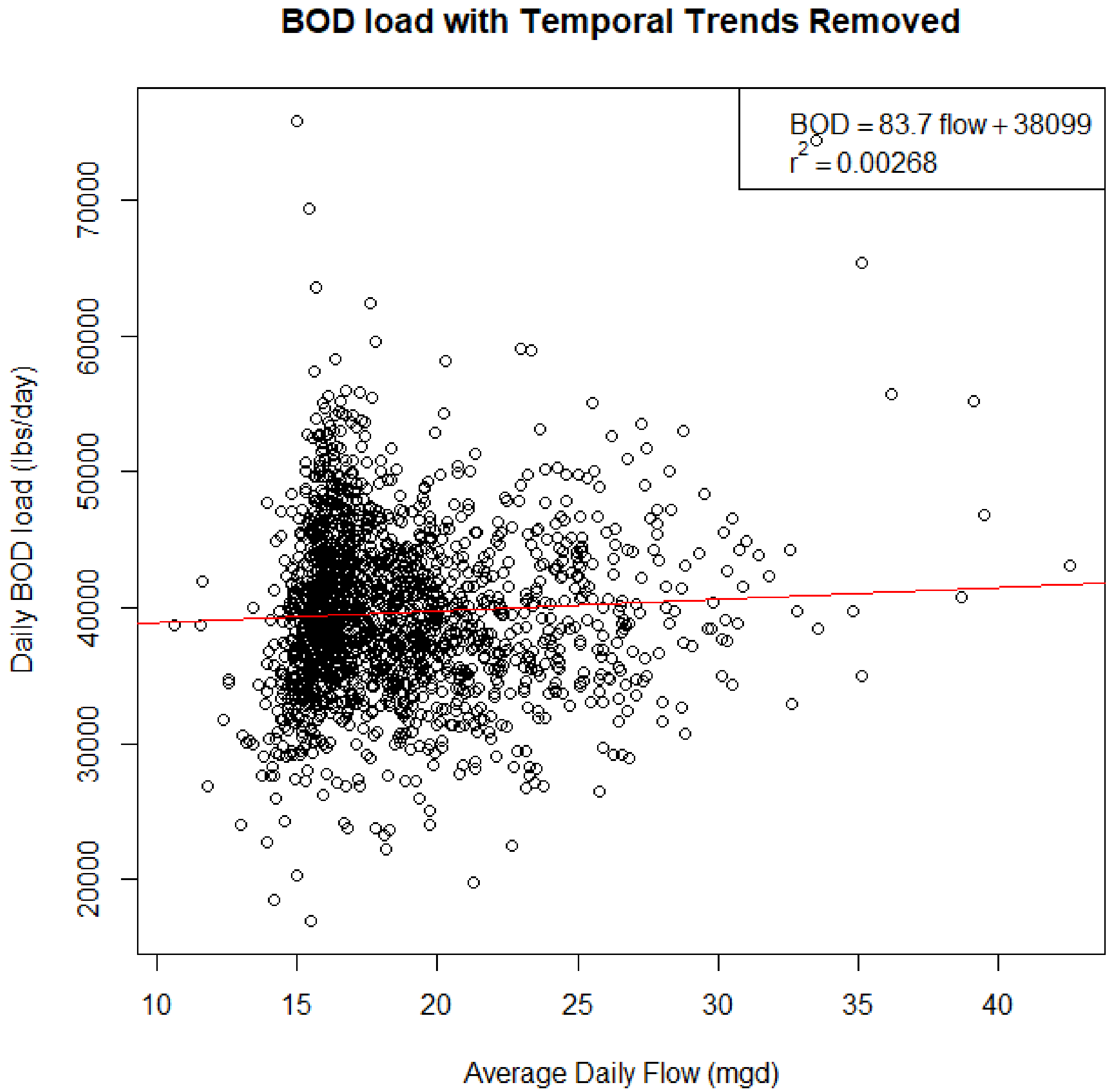

Figure 7. Regression of Brightwater Daily BOD Loads After Subtraction of Temporal Trend to Average Daily Flow for January 2013 to March 2018

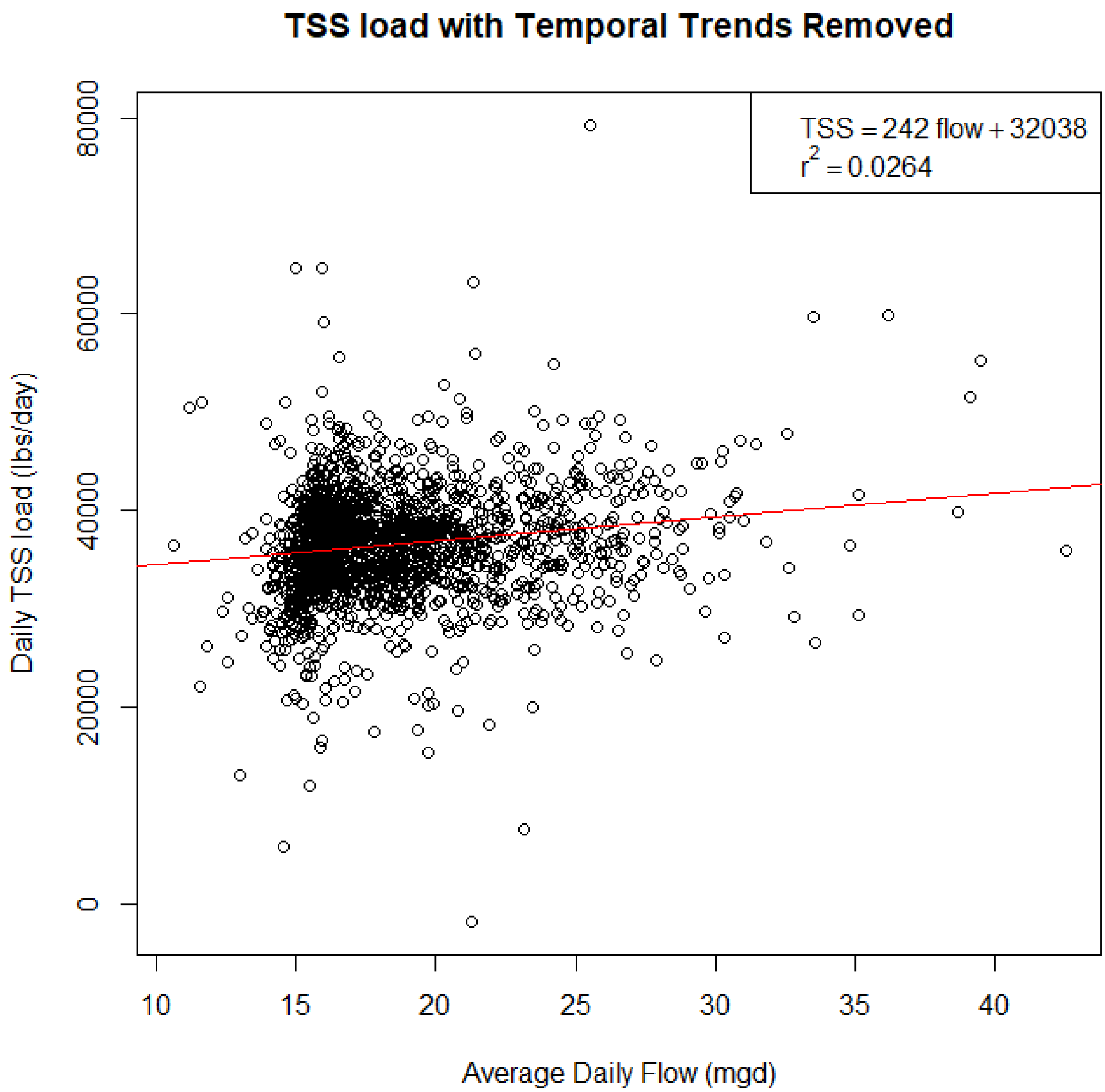

Figure 8. Regression of Brightwater Daily TSS Loads After Subtraction of Temporal Trend to Average Daily Flow for January 2013 to March 2018

Peak Loading Rates

The daily loading rates were then 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 mostly followed a normal distribution, with some skewness at extreme values. To include the observed skewness, 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 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 (Figure 9).
- For each of the daily, weekly, and monthly loadings, the 2010 loading spline curves were randomly sampled 10 million times.
- 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.

Table 7 summarizes the calculated peaking factors (pf) as peak load = mean * (pf).

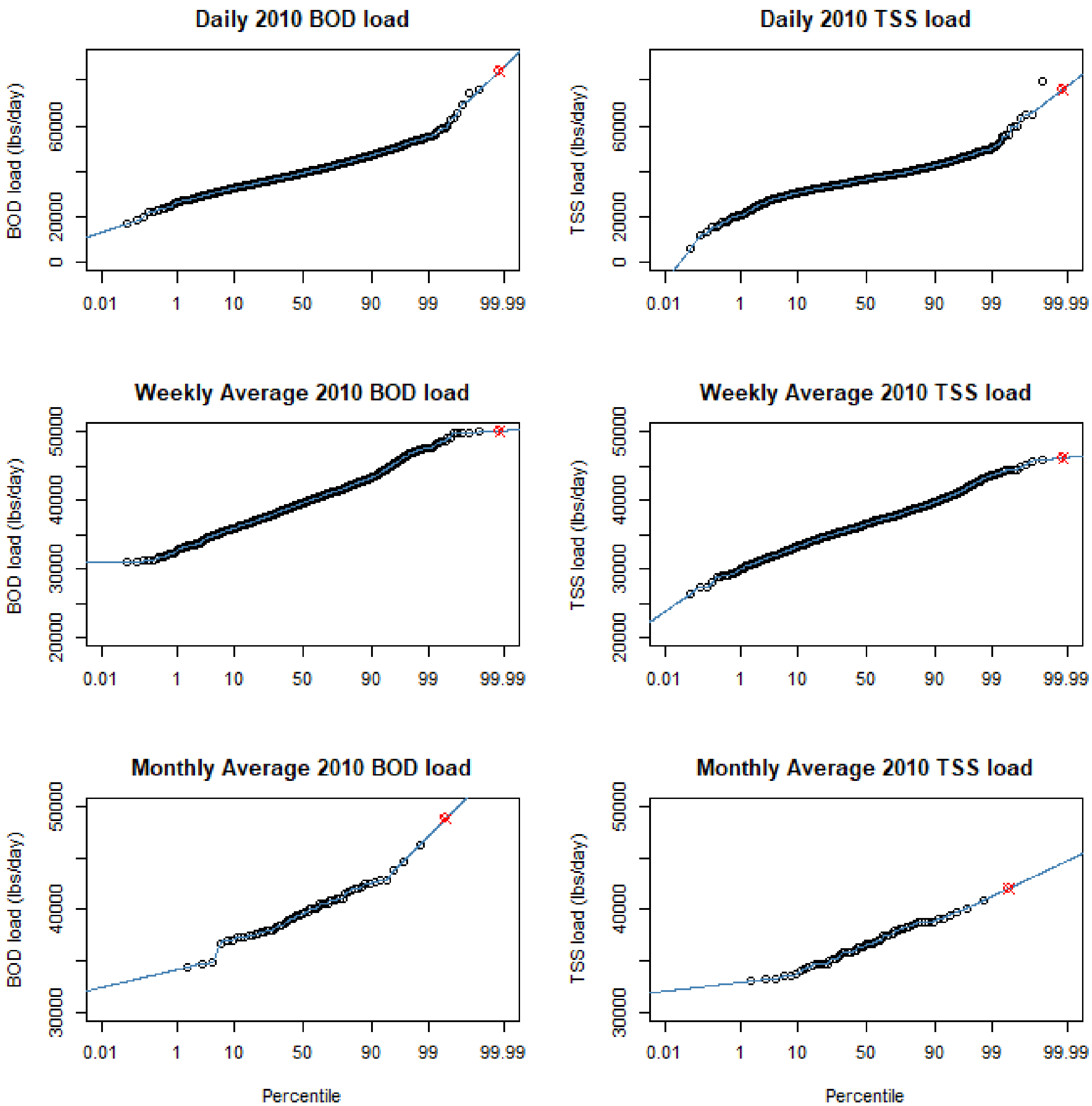

Figure 9. Cumulative Probability Plots of Daily, Weekly, and Monthly BOD and TSS Loads. Twenty-year Recurrence Value Denoted by Red Marker.

Table 7. Peaking Factors for 20-year Peak Loading Rates

Influent BOD			
	Brightwater Current Analysis 2013–2017	**Brightwater Facility Plan Analysis[a] 2013–2014**	**Brightwater Design[b]**
Peak Month/Average Annual	1.23	1.15	1.31
Peak week/Average Annual	1.26	1.24	1.55
Peak Day/Average Annual	2.12	1.54	3.20
Peak Day/Peak Month	1.67 1.72	1.34	2.45
Influent TSS			
	Brightwater Current Analysis 2013–2017	**Brightwater Facility Plan Analysis[a] 2013–2014**	**Brightwater Design[b]**
Peak Month/Average Annual	1.15	1.20	1.22
Peak Week/Average Annual	1.26	1.29	1.45
Peak Day/Average Annual	2.08	1.53	2.68
Peak Day/Peak Month	1.81	1.27	2.20

[a] King County DNRP, 2016

[b] Brightwater Electronic Operations Manual Portal (http://bweomserver/); King County DNRP, 2005

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).

Table 8 presents the projections adjusted for the proposed Sammamish Plateau Flow Diversion Project. Table 9 presents the estimated loads that will be transferred to Brightwater from the flow diversion. No adjustment is made for flow transfers to South Plant.

Table 8. Projected Loads for Brightwater, 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	41,500	53,500	60,400	79,400	87,000	94,900	39,000	51,000	58,500	77,300	85,200	93,400
ADW	41,500	53,500	60,400	79,400	87,000	94,900	39,000	51,000	58,500	77,300	85,200	93,400
AWW	41,500	53,500	60,400	79,400	87,000	94,900	39,000	51,000	58,500	77,300	85,200	93,400
Maximum Month	51,100	65,800	74,300	97,600	107,000	116,700	44,900	58,600	67,300	88,900	97,900	107,400
Maximum Week	52,300	67,400	76,100	100,000	109,600	119,500	49,200	64,300	73,700	97,400	107,300	117,600
Peak Day	88,000	113,400	128,000	168,200	184,300	201,100	81,100	106,100	121,700	160,700	177,100	194,200

Table 9. Loads Transferred to Brightwater, 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 Diversion Phase 1			1,900	2,400	2,700	3,000			2,100	2,600	2,900	3,200
Average Annual Sammamish 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 in Table 10.

Table 10. Projected Influent Concentrations for Brightwater, 2010−2060

Load Condition	Flow Condition	Influent BOD (mg/l)					
		2010	2020	2030	2040	2050	2060
Average Annual	Average Annual	310.8	326.3	337.4	345.0	343.3	341.9
Maximum Month	Average Dry Weather	429.0	445.5	461.3	464.0	461.1	458.6
Maximum Month	Maximum Month	241.8	264.5	269.2	275.1	272.5	269.9
		Influent TSS (mg/l)					
		2010	2020	2030	2040	2050	2060
Average Annual	Average Annual	292.0	311.1	327.0	335.9	336.2	336.5
Maximum Month	ADW	376.7	397.1	417.9	422.4	422.2	422.0
Maximum Month	AWW	212.3	235.7	243.9	250.5	249.5	248.4

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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

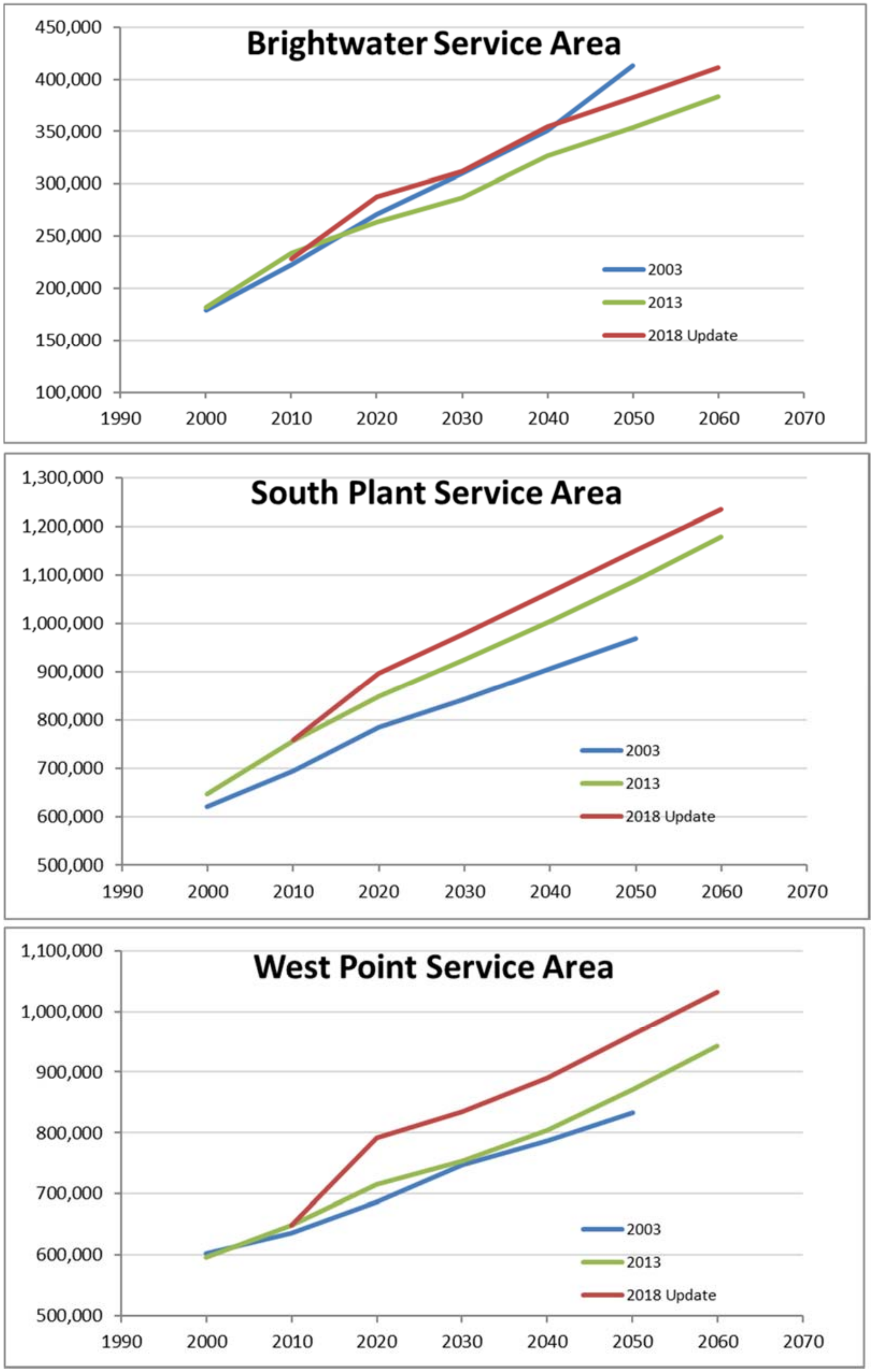

Figure A1. Total Population Projections for Each Service Area from Estimates Made in 2003, 2013, and 2018

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