King County

Department of
Natural Resources and Parks
Wastewater Treatment Division

ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE WEST POINT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT (WEST POINT NITROGEN REMOVAL STUDY)

FINAL REPORT

March 2011

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03/23/2011

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KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS

ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE WEST POINT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

(WEST POINT NITROGEN REMOVAL STUDY)

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ABBREVIATIONS

AACE	Association for the Advancement of Civil Engineering
BAF	Biological Aerated Filter
BOD_5	Biochemical Oxygen Demand (5-day)
CO_2	Carbon Dioxide
DNF	Denitrifying Filter
Ecology	Department of Ecology
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
gpd/sf	gallons per day per square foot
gpm/sf	gallons per minute per square foot
HPO	high purity oxygen
IFAS	Integrated Fixed Film Activated Sludge
MBR	membrane bioreactor
MG	million gallons
mg/L	milligrams per liter
mgd	million gallons per day
mL/g	milliliter per gram
MLE	Modified Ludzak-Ettinger
MLR	mixed liquor return
MLSS	mixed liquor suspended solids
N	nitrogen
NPDES	National Pollutant Discharge Elimination System
NR	Nitrogen Removal
O&M	Operation and Maintenance
ppd	pounds per day
ppd/kcf	pounds per day per thousand cubic foot
SF	square foot
SRT	solids residence time
STP	South Treatment Plant
SVI	sludge volume index
TIN	total inorganic nitrogen
TKN	total kjeldahl nitrogen
tpd	tons per day
TSS	total suspended solids
WAS	waste activated sludge
WWTP	Wastewater Treatment Plant

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ES.1 INTRODUCTION

In 2010 King County and Carollo Engineers completed a report evaluating potential strategies and consequences of implementing nitrogen removal (NR) at King County's South Treatment Plant (STP) (Carollo 2010). This report extends the work by evaluating the same potential for the West Point Treatment Plant (WPTP).

King County's two largest treatment plants are similar in some ways. Both provide secondary wastewater treatment using the activated sludge process. Both treat residual solids from primary and secondary sedimentation using similar processes (thickening, anaerobic digestion, and dewatering), and both discharge through deep outfalls to Puget Sound.

But there are also significant differences between the facilities that impact their ability to achieve NR. The WPTP uses a high purity oxygen (HPO) process, which is less likely to achieve reliable NR than air activated sludge. The STP was designed for air activated sludge treatment using a design solids residence time (SRT) of approximately 2.5 days. The WPTP was designed for high purity oxygen treatment with a SRT of only 1 day. NR processes require SRTs that are significantly greater than these values. The minimum aerobic SRT for nitrogen removal at the WPTP has been identified in the range of 9 to 13 days (average of 11) based on applying a safety factor to published washout SRTs for nitrifying bacteria. This means that the inventory of treatment organisms maintained in the aeration basins must increase by a factor of 11 to 1 at the WPTP, which can only be achieved through significant addition of tank volume (aeration basins and/or clarifiers). It is for this reason that a membrane bioreactor process (MBR) was considered for upgrade of the WPTP for NR; the MBR process allows for an increase of approximately 8-10 times over the concentration currently maintained at the WPTP HPO process. This translates into the needed SRT increase with the smallest increase in tank size which translates into the smallest tank size to meet the required SRT.

Another significant difference between the STP and the WPTP is in the available land area for expansion. At the STP the available land area for treatment plant expansion is in the neighborhood of 10 acres. The WPTP, however, is built at the edge of Puget Sound and surrounded by steep embankments from City parkland with only 1.5 acres of land dedicated for plant expansion.

Initially alternatives for NR for the WPTP were the same as used for the STP study. Development of preliminary alternatives demonstrated that the WPTP had insufficient site land area to accommodate the parallel NR processes selected as representative technologies for the STP. In order to identify processes that would be potentially viable for NR at the WPTP, an important criterion used for evaluation of alternative process for the earlier study needed to be abandoned; namely, the criterion that alternatives must make use of existing unit processes on the treatment plant site to the maximum extent possible.

This study demonstrates that the only processes that could potentially fit within the footprint of available land area at the WPTP site are those that require demolition of major portions of the existing secondary treatment plant. Furthermore, even with the important criterion of avoiding stranded assets not considered, the planning level evaluation has been unable to conclusively confirm that construction of new facilities at WPTP for NR of the entire 139 mgd summer flow or the entire 215 mgd annual average flow is feasible. Much more detailed evaluation is required to reach this conclusion. This study demonstrates that it may be possible to fit the necessary process tanks on the WPTP site to achieve a 3 milligrams per liter (mg/L) total inorganic nitrogen (TIN) (year round) limit. Once more detailed studies are completed, it may be concluded that implementation of NR at the WPTP site would be practically limited due to constructability and site access constraints, including most significantly the need to maintain reliable operation during construction. In this case, the WPTP capacity would be significantly reduced, creating the need for new facilities at another site.

This report is divided into three chapters. Chapter 1 describes project assumptions and evaluates how much flow the existing WPTP could treat if required to comply with a summer seasonal limit of 8-mg/L TIN or a maximum monthly limit of 3-mg/L TIN on a year round basis. Chapter 1 also establishes process modifications required for nitrogen removal. Chapter 2 evaluates the potential consequences (e.g., on tankage, footprint, cost, and greenhouse gas emissions) of meeting the assumed seasonal or year round limits while maintaining current rated capacity (215 million gallons per day (mgd) max month year round and 110 mgd average flow during the summer). Chapter 3 evaluates the consequences that implementing NR would have for reclaimed water production at the WPTP.

ES.2 EFFECT OF N-LIMITS ON EXISTING WPTP CAPACITY

To evaluate the consequences of potential future nitrogen limits on the capacity of the WPTP, a full-plant model was developed and calibrated to operating data collected at the plant. The project team for the STP study had decided upon two effluent nitrogen scenarios representing potential permitting scenarios, and these were followed for the WPTP analysis:

1. Summer effluent limit of 8 mg/L TIN;
2. Year round effluent limit of 3 mg/L TIN.

Both of these limits were assumed to be applied during any month of the permit period. As part of STP study project workshop, the project team decided that the capacity rating of the STP to meet the two target nitrogen effluent scenarios would be determined with one aeration basin and one secondary clarifier out of service. For the WPTP it was determined that reliability criteria would be met with all reactor tanks in service, but one secondary sedimentation tank out of service.

Based on the work presented in Chapter 1, the modeled maximum month capacity of the current WPTP to meet the summer effluent limit of 8 mg/L TIN is 47 mgd and 65,000 pounds per day (ppd) of five-day biochemical oxygen demand (BOD_5). This capacity rating was based on operating the existing HPO tanks in an anoxic/aerobic (Modified Ludzak-Ettinger [MLE]) configuration. To meet this effluent limit, tank modifications would be needed including addition of baffle walls, mixed liquor return (MLR) pumps and a chemical delivery system. It was also assumed that the existing HPO aeration system would be replaced with new blowers and diffused aeration piping. Major construction would be needed (onsite or off-site) to meet the current maximum summer month flow of 139 mgd and replace the capacity lost as a result of the NR modifications. If the existing system were expanded as currently anticipated by adding two more HPO reactor tanks and two more sedimentation tanks, the modeled maximum month capacity would increase to 61 mgd and 85,000 ppd BOD_5.

Based on the assumptions developed in Chapter 1, the modeled maximum month capacity of the current WPTP to meet the year round effluent limit of 3 mg/L TIN was determined to be 44 mgd and 47,000 ppd BOD_5. The ultimate site maximum month capacity for a year round 3 mg/L TIN standard was judged to be 61 mgd and 64,000 ppd BOD_5. This capacity rating was based on operating the modified reactor basins in a dual anoxic/aerobic (Bardenpho) configuration. To meet this effluent limit, modifications would be needed at the current plant including the addition of baffle walls, MLR pumps, and a chemical delivery system. Offsite construction would be needed to provide facilities for treatment of the remainder of the current maximum month design flow of 215 mgd, replacing the capacity lost as a result of the NR modifications.

ES.3 MODIFICATIONS NEEDED TO ACHIEVE NITROGEN REMOVAL

Four general classes of nitrogen removal alternatives were evaluated in the STP study:

1. Land-based;
2. Aquatic;
3. Chemical;
4. Biological.

In the STP Study, a variety of potential alternatives within each of these classes was considered and four biological nitrogen removal alternatives were selected for further evaluation for each nitrogen removal scenario. These selected alternatives represent a range of alternatives including suspended growth, attached growth, and hybrid processes. For the 8 mg/L TIN (summer only) scenario, the selected processes were:

1. MLE;
2. MLE – MBR;
3. MLE – integrated fixed-film activated sludge (IFAS);
4. Biological aerated filter (BAF)/denitrifying filter (DNF).

For the 3 mg/L TIN (year round) scenario, the selected processes were:

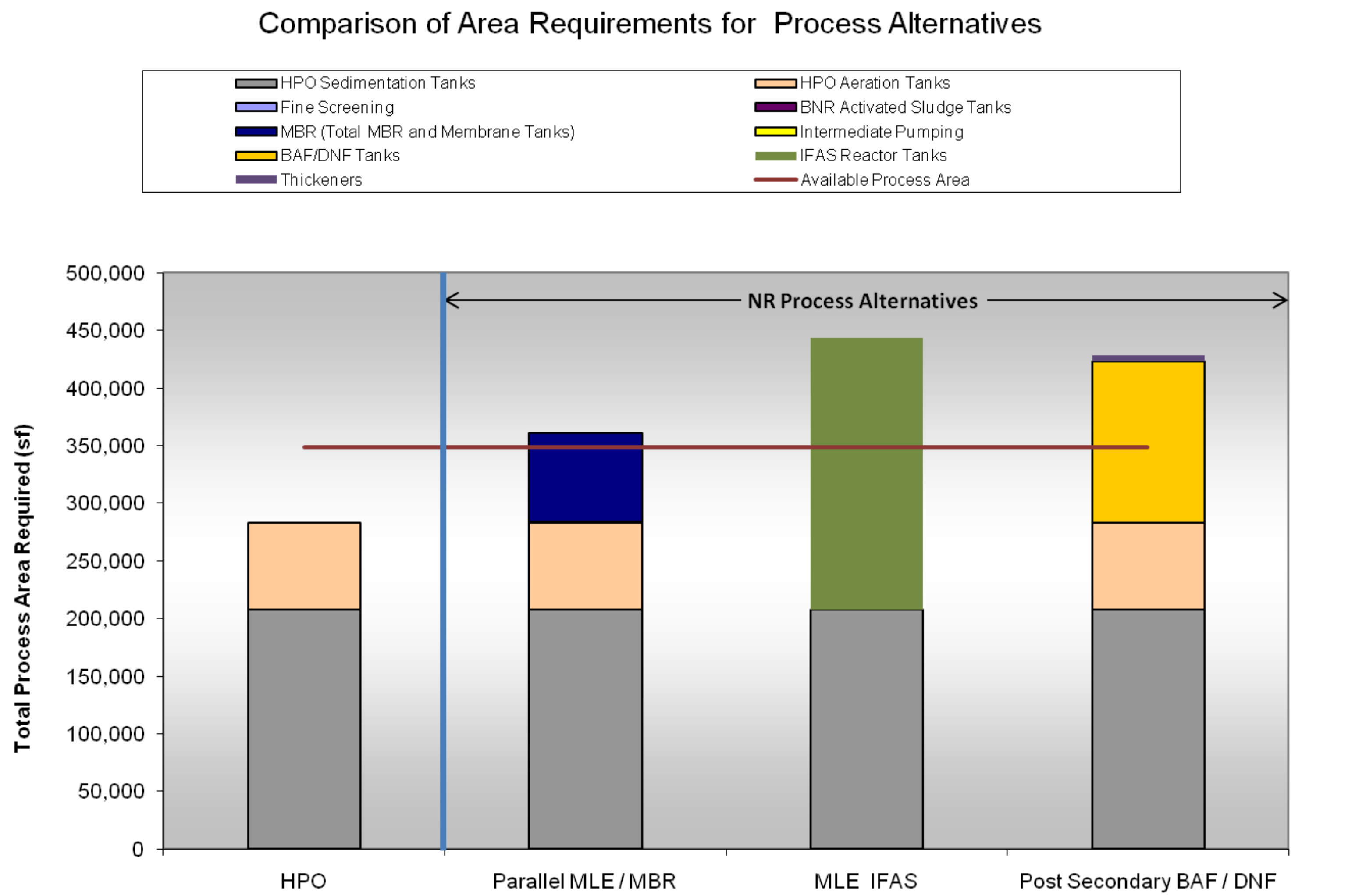
1. Bardenpho;
2. Bardenpho – MBR;
3. Bardenpho – IFAS;
4. BAF/DNF.

For each representative alternative, side stream treatment was evaluated to determine whether this could reduce the footprint and cost of the alternative. For the current study the first of these alternatives were removed from the project scope due to the small amount of available land area for plant expansion at the WPTP site. The remaining three alternatives were initially evaluated.

Figure ES.1 summarizes the footprint requirements of each of these alternatives for the WPTP for the effluent limit scenario of 8 mg/L TIN during the summer. It is seen that none of the initial alternatives provide a process footprint within the available land area for future expansion on the WPTP site. Based on this finding, additional alternatives were considered including:

1. Post-secondary MBR;
2. Replacement MBR;
3. Replacement BAF/DNF.

Figure ES.2 presents footprint requirements for this next series of alternatives. It is seen that only the Replacement MBR and Replacement BAF/DNF alternatives may potentially fit on the WPTP site. The replacement MBR alternative requires demolition of the existing secondary sedimentation tanks and replacement of these with membrane separation tanks. The replacement BAF/DNF alternative requires demolition of both the existing secondary sedimentation tanks and the existing HPO tanks. In either of these alternatives, the strategy of operating the existing HPO process during the winter months would not be available. As a result, either of these alternatives would need to be considered year round operations.



FOOTPRINT COMPARISON OF INITIAL ALTERNATIVES FOR THE 8 MG/L TIN (SUMMER ONLY) PERMIT SCENARIO

FIGURE ES.1

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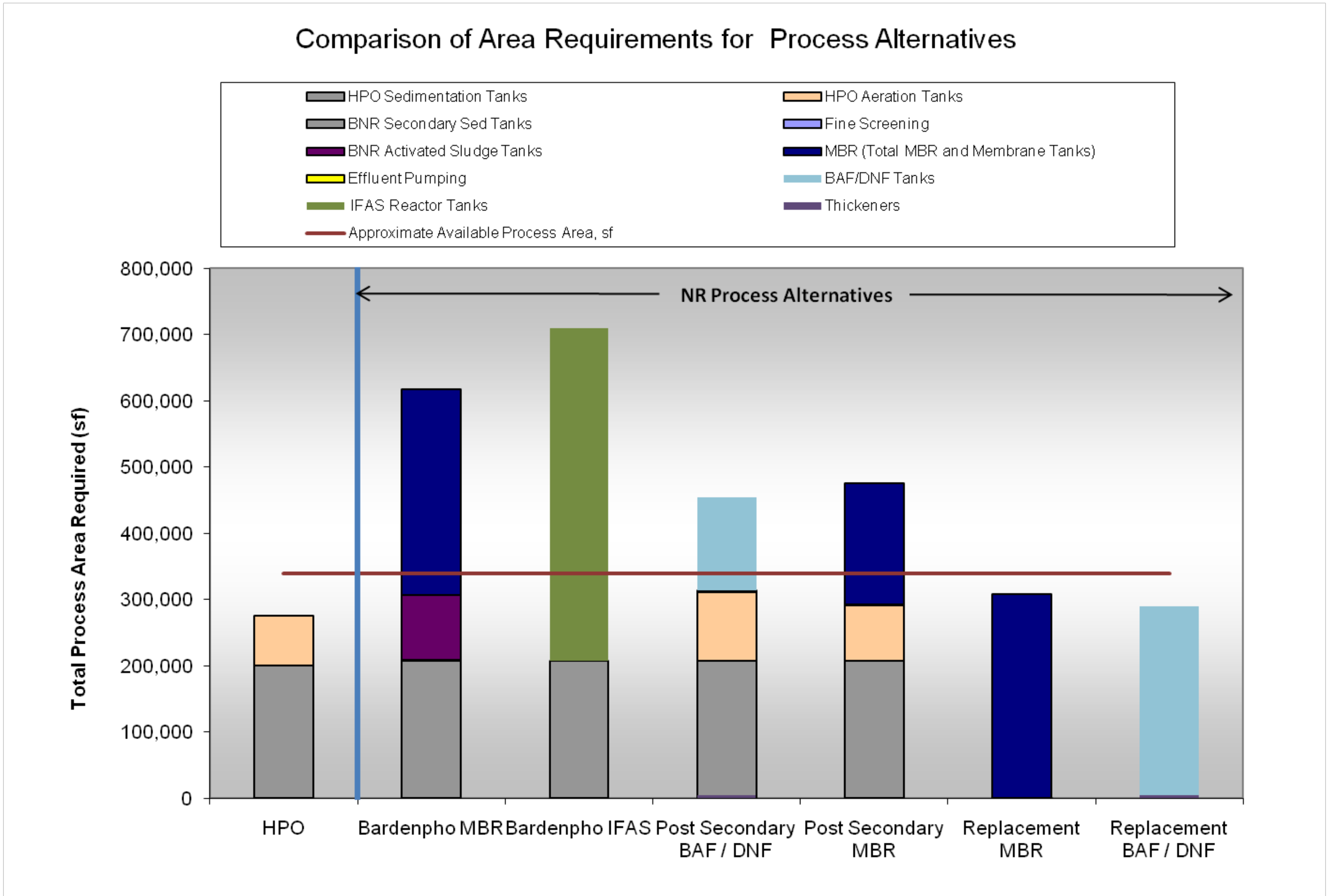
WEST POINT NITROGEN REMOVAL STUDY



FOOTPRINT COMPARISON OF ALTERNATIVES FOR THE 3 MG/L TIN (YEAR ROUND) PERMIT SCENARIO

FIGURE ES.2

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

Different TIN limits could be achieved during the summer and winter periods, but facilities required would be similar to the facilities identified for the 3 mg/L TIN (year round) permit strategy for both operating periods. As discussed above, the current study was not intended to confirm that a construction sequencing would allow for reliable treatment throughout the construction period. Temporary or permanent flow diversion from the WPTP collection system to another treatment plant may be required with either of these alternatives, which may be infeasible. For this study, replacement MBR was selected as the most representative alternative to achieve NR at the WPTP.

Table ES.1 presents a summary of estimated costs for the representative alternative (replacement MBR). The cost estimates were based on conceptual estimates for major items of cost, including excavation, concrete, and equipment. Allowances were added for piping and miscellaneous mechanical equipment, electrical equipment, instrumentation, site work, contingency, general conditions, contractor overhead, and profit, sales tax, allied costs (planning, design, construction management, permits, etc.). Operation and Maintenance (O&M) costs were estimated based on an Environmental Protection Agency (EPA) database for unit process labor, estimated power requirements and chemical consumption, and allowances for structural and equipment maintenance.

Costs were indexed to estimated unit prices for December 15, 2010. This type of estimate is defined by the Association for the Advancement of Cost Engineering (AACE) as a Level 5 - Order of Magnitude Estimate, and has an expected accuracy range of +50 to -30 percent. As shown in the table, implementing NR at the WPTP would cost approximately $1,500 million.

Greenhouse gas (GHG) emissions of the representative alternative were also estimated based on factors developed in the STP study. The result indicates that implementing a year round effluent permit level of 3 mg/L TIN would be to increase the GHG emissions from the WPTP by approximately three times over operation of the HPO process for secondary treatment (from approximately 6,000 metric tons per year of equivalent CO_2 emissions to approximately 20,000 metric tons per year). The primary source of increased GHG emissions is additional electricity from Puget Sound Energy (PSE).

Table ES.1 Estimate Summary for Replacement MBR Upgrade to the WPTP
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Element	HPO	Replacement MBR	Difference
Capital Cost, $			
Fine Screening	$0	$11,380,000	$11,380,000
Demolition of Existing Secondary Sed Tanks	$0	$0	$0
MBR Reactor Tanks	$0	$230,434,000	$230,434,000
MBR Membrane Tanks and Equipment	$0	$821,324,000	$821,324,000
Centrate Treatment Tanks	$0	$6,290,000	$6,290,000
Total Project Cost	$0	$1,069,428,000	$1,069,428,000
Design Max Month Flow (mgd)	215	215	215
Unit Project Cost ($/gpd)	$0.00	$4.97	$4.97
Operation and Maintenance Cost, $/year			
Fine Screening	$0	$2,969,000	$2,969,000
HPO Aeration Tanks	$1,300,000	$0	-$1,300,000
HPO Sedimentation Tanks	$2,183,000	$0	-$2,183,000
MBR Reactor Tanks	$0	$6,763,000	$6,763,000
MBR Membrane Tanks and Equipment	$0	$21,370,000	$21,370,000
Centrate Treatment	$0	$340,000	$340,000
Total	$3,480,000	$31,440,000	$27,960,000
Present Worth Cost, $ Million			
Capital	$0	$1,069	$1,069
Operation and Maintenance	$52	$468	$416
Total Present Worth	**$52**	**$1,537**	**$1,485**

Notes:
(1) Capital cost includes construction cost, contingency (40%), tax, and allied costs (costs of planning, engineering, construction management, permitting, legal and other associated costs (45%)). All costs are in December 2101 dollars.
(2) Present worth O&M values were calculated assuming a 3% discount rate over a 20-year period on calculated current yearly O&M costs.

ES.4 NITROGEN REMOVAL EFFECT ON RECLAIMED WATER PRODUCTION

The WPTP currently provides secondary treatment for up to 215 mgd of flow on a maximum month basis for discharge to Puget Sound. The current HPO process removes a small amount of nitrogen as waste biosolids but substantial nitrogen removal is not achieved. The WPTP has facilities for production and distribution of secondary effluent water for use internal uses at the plant, but the WPTP produces no Class A reclaimed water suitable for unrestricted use off-site. Implementation of BNR at the WPTP could potentially produce a significant effect on reclaimed water availability, potential customers, and quality, depending on the technology selected. If MBR technology is selected, effluent would meet Class A reclaimed water standards, with additional disinfection.

The future average flow of the WPTP during the summer season when reclaimed water could be potentially useful for irrigation is approximately 110 mgd. Coagulation, flocculation, and filtration would be required to implement production of this amount of reclaimed water from the current non-nitrified secondary effluent. Assuming typical detention times and loading rates, approximately 52,000 square foot (sf) of coagulation, flocculation, and filtration facilities would be required.

The estimated present worth cost of media filtration for 110 mgd average flow at the WPTP is approximately $150 million. Media filtration facilities would require approximately one and one-half acre of site land area, which is approximately the remaining land area available on the WPTP for future facilities. Non-cost impacts of implementing reclaimed water at the WPTP as part of a NR project were estimated. The least land-intensive and least energy-intensive way to implement reclaimed water production at the WPTP would be to add media filters to the existing HPO process. If nitrogen removal were to be implemented, however, additional adverse impacts would be minimized if the MBR process is chosen.

ES.5 SUMMARY, FINDINGS, AND CONCLUSIONS

Two potential nitrogen removal permit requirements were evaluated to bracket potential permit limits that could be applied by the Department of Ecology in response to South Puget Sound water quality studies: 1) a “least stringent” potential effluent limit of 8 mg/L TIN for the summer months only; and 2) a “most stringent” potential limit of 3 mg/L TIN year round. The principle findings and conclusions of this report are:

1. The modeled maximum month capacity of the current WPTP to meet the “least stringent” summer effluent limit was estimated at 47 mgd. Major modifications would be needed to meet this capacity, including construction of a new treatment plant at a different site to treat the remainder of the summer maximum month flow (approximately 92 mgd). If land designated for future expansion were used, this

capacity would increase to approximately 61 mgd and approximately 85,000 ppd of BOD_5, reducing the amount of supplemental capacity needed to about 78 mgd.

2. The modeled maximum month capacity of the current WPTP to meet, with modifications, the "most stringent" year round effluent limit was 44 mgd. Major modifications that would be needed to meet this capacity, including construction of a new treatment plant to treat the remainder of the flow (approximately 171 mgd). If land designated for future expansion were used, this capacity would increase to approximately 61 mgd and approximately 64,000 ppd of BOD_5, reducing the amount of supplemental capacity needed to about 154 mgd.

3. Three initial alternatives for NR were evaluated for each permit scenario. Based on evaluation of initial alternatives none were judged able to meet requirements for NR within the land area available for future expansion at the WPTP site. Subsequently, alternatives that require demolition of existing process tanks were developed. Two alternatives: Replacement MBR; and Replacement BAF/DNF, were judged to be potentially feasible at the WPTP. Both alternatives present significant constructability challenges that must be identified and resolved through further analysis. Of these two alternatives, replacement MBR was selected to be the representative alternative for achieving NR at the WPTP.

4. The incremental present worth cost to implement the representative NR alternative is estimated at approximately $1,500 million, as compared to continued operation of secondary treatment with the existing HPO process over the next twenty years.

5. It was concluded that meeting a 3 mg/L TIN year round permit level would result in approximately three times more GHG emissions compared to continuing with secondary treatment at the WPTP.

6. If NR were implemented at the WPTP using the MBR process, up to 215 mgd of effluent would become available that would be suitable for reclaimed water use.

CURRENT CONFIGURATION

1.1 INTRODUCTION

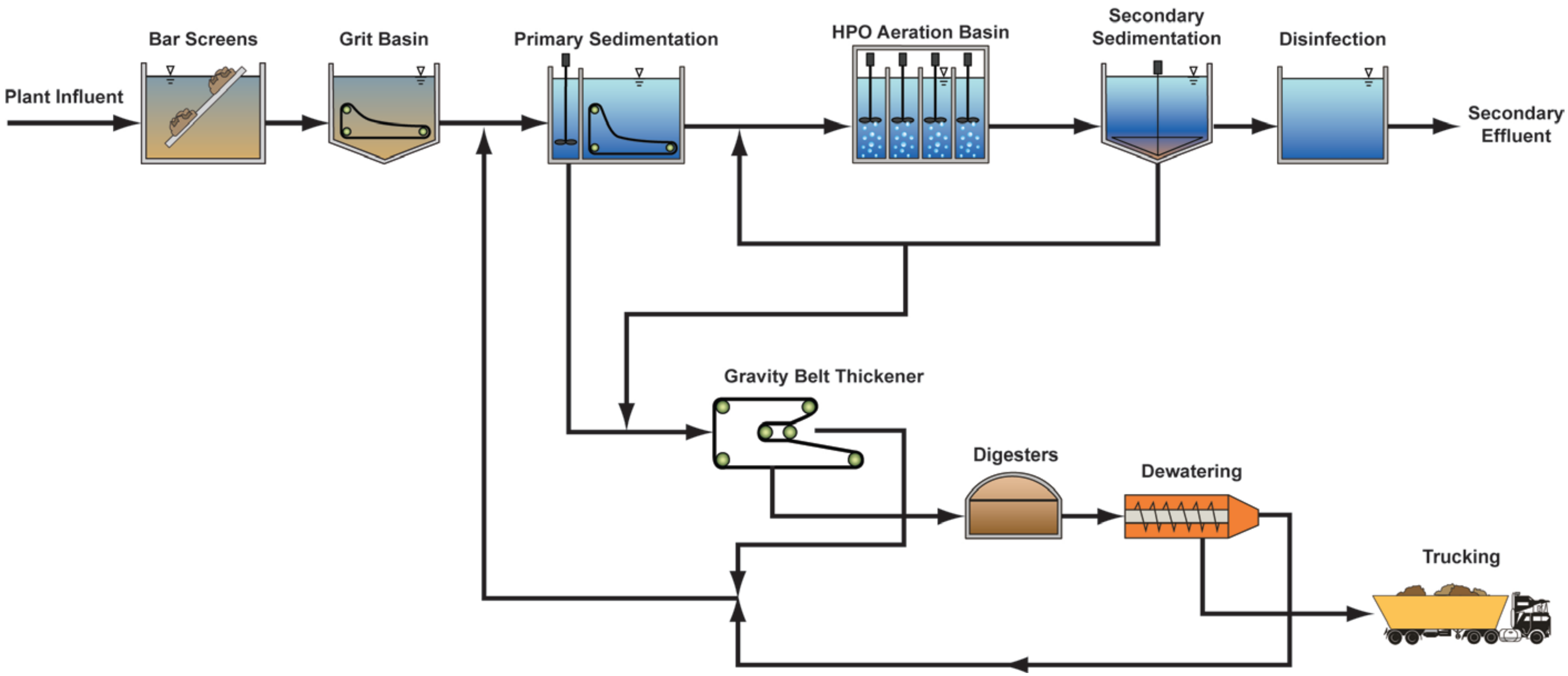
The West Point Treatment Plant (WPTP) provides secondary wastewater treatment by the high purity oxygen (HPO) activated sludge process, and discharges to Puget Sound at the western tip of Discovery Park between Shilshole Bay and Elliott Bay. The plant serves downtown Seattle, northern portions of King County, and portions of Snohomish County. As described in an earlier report for King County's South Treatment Plant (Carollo Engineers 2010) the Washington State Department of Ecology (Ecology) is evaluating the potential need for wastewater treatment plants discharging to Central and South Puget Sound to remove nitrogen compounds. The WPTP discharges to Puget Sound near to the northern boundary of the Central Puget Sound region defined in the Ecology Study (Ecology 2008). This chapter presents introductory material, flow and loading analysis, and results of modeling of the existing process as a basis for establishing the potential capacity of the existing WPTP to achieve nitrogen removal.

1.2 BACKGROUND

1.2.1 Description of Existing Plant

The WPTP went into service in 1965 as a primary treatment plant serving the City of Seattle and adjacent cities and sewer districts in King and Snohomish County. The plant was upgraded and certified by Ecology for secondary treatment operation in December of 1995. The estimated population in the service area was approximately 1,337,000 persons in 2008. The WPTP also serves an industrial flow estimated at approximately 1 million gallons per day (mgd). The design average dry weather flow for the WPTP is 110 mgd and the design average annual flow is 142 mgd. The design maximum month flow during the wet weather season was 215 mgd. The WPTP was designed to provide secondary treatment for flows up to 300 mgd and primary treatment and disinfection for flows exceeding 300 mgd. The plant's rated hydraulic capacity is 440 mgd; however, on December 3, 2007 an instantaneous peak flow of 487 mgd was conveyed through the WPTP. A simplified schematic of the WWTP used for modeling the current process and an aerial view are shown in Figures 1.1 and 1.2.

King County owns approximately 80 acres of land at the WPTP site. Current facilities are located on approximately 25 acres of land. The majority of the site is not available for future process improvements as the site is constrained by a large retaining wall along the south property line and Puget Sound on the east, west, and north sides. The site plan shown in Figure 1.3 shows the limited space allocated on the site for future expansion; approximately 0.6 acres for two new HPO tanks and approximately 1.0 acre for two additional secondary sedimentation tanks. The two additional secondary sedimentation tanks are planned to be constructed adjacent to the existing chlorine contact channel.



GENERAL WPTP PROCESS FLOW SCHEMATIC

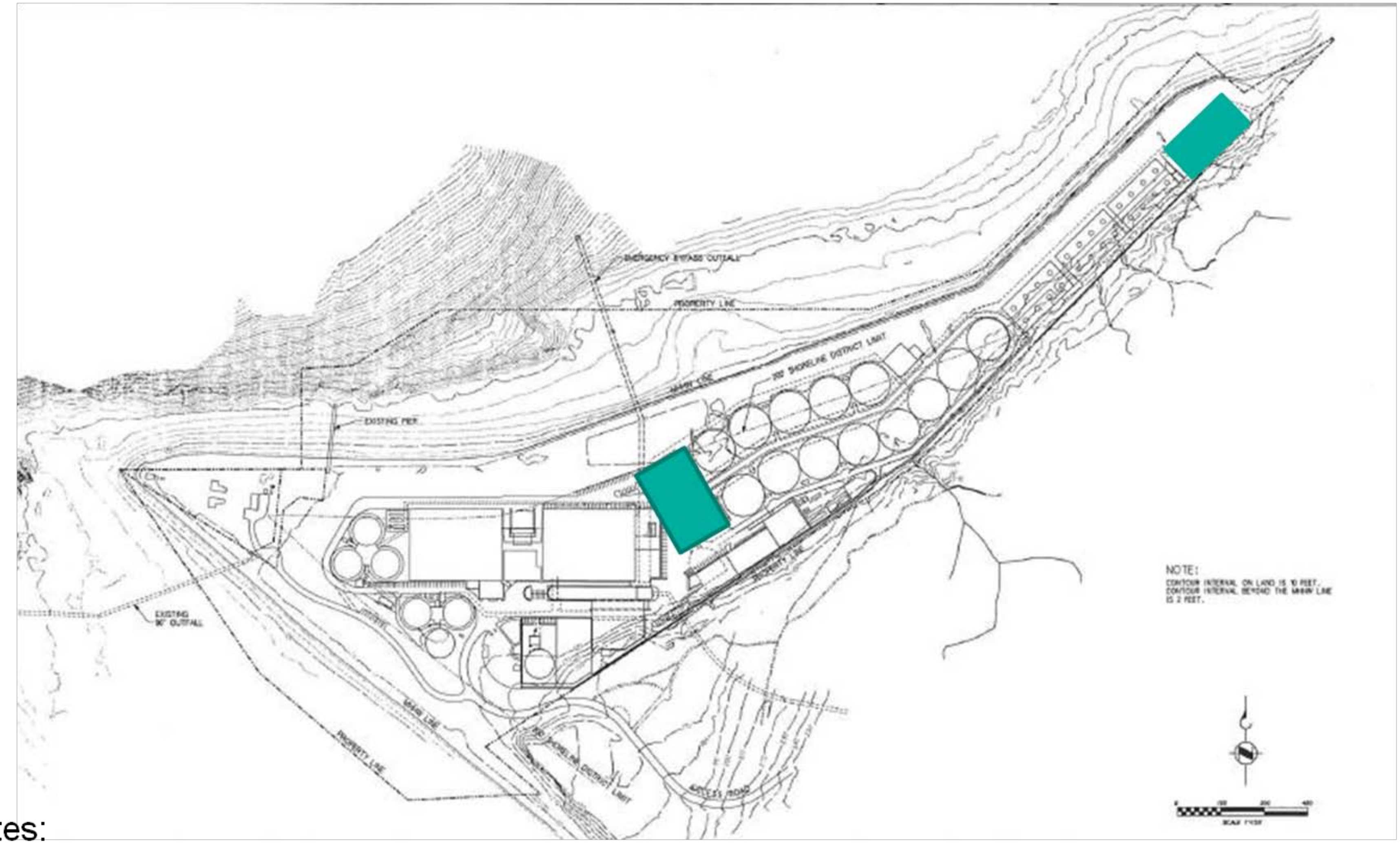
FIGURE 1.1

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

WPTP AERIAL PHOTOGRAPH

FIGURE 1.2

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:

Space available for future expansion

The WPTP has approximately 1.6 acres available for future expansion.

WPTP SITE PLAN

FIGURE 1.3

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

Wastewater enters the plant through a 144-inch influent sewer from the parallel Fort Lawton Tunnels. Preliminary treatment is provided by screens and grit tanks. Screened, degritted wastewater flows to 12 primary sedimentation tanks, which remove approximately 60 percent of influent total suspended solids (TSS). An intermediate pump station lifts primary effluent to six trains of HPO activated sludge aeration basins. Activated sludge is separated in thirteen, 142.5-foot diameter secondary sedimentation tanks. Secondary treated effluent is disinfected in chlorine contact channels prior to discharge to Puget Sound. King County is converting the plant's disinfection system from chlorine gas to sodium hypochlorite. This project was scheduled to be completed by the end of 2010. Disinfected effluent discharges to Puget Sound through a multi-port diffuser located approximately 3,600 feet offshore at a depth of approximately 240 feet below mean lower low water.

Primary and waste activated solids are blended and co-thickened by gravity belt thickeners. The thickened sludge is anaerobically digested and dewatered by centrifuges. The plant produces biosolids used in agriculture and forestry, reclaimed water used for in-plant processes and irrigation, and methane that fuels raw sewage pump engines. Heat recovery systems supply heat to the plant for digester temperature control and space heating.

1.2.2 Summary of Current NPDES Permit

The WPTP's current National Pollution Discharge Elimination System (NPDES) permit was issued in 2009 and expires in 2014. The permit is summarized in Table 1.1 for the main Puget Sound outfall. The current WPTP permit does not regulate effluent nitrogen but does require the plant to monitor the final effluent for total ammonia (concentration and load), nitrate-nitrite, and total Kjeldahl nitrogen (TKN) concentration on a monthly basis.

The current permit lists plant flows and loads as follows:

- Maximum month design flow of 215 mgd;
- Maximum month five-day biochemical oxygen demand (BOD_5) loading of 254,000 pounds per day (ppd);
- Maximum month TSS loading of 274,000 ppd.

Table 1.1 Summary of Current WPTP NPDES Effluent Limits West Point Nitrogen Removal Study King County Department of Natural Resources and Parks		
Parameter	**Average Monthly[1]**	**Average Weekly[2]**
Carbonaceous Biochemical Oxygen Demand (5-day)	25 mg/L, 44,800 ppd	40 mg/L, 71,700 ppd
TSS	30 mg/L, 53,800 ppd	45 mg/L, 80,700 ppd
Fecal Coliform Bacteria[3]	200/100 mL	400/100 mL
pH[4]	Daily minimum is equal to or greater than 6.0 and the daily maximum is less than or equal to 9.0	
Parameter	**Average Monthly[1]**	**Maximum Daily[5]**
Total Residual Chlorine	139 µg/L	364 µg/L

Notes:

(1) Average monthly effluent limit means the highest allowable average of daily discharges over a calendar month. To calculate the discharge value to compare to the limit, you add the value of each daily discharge measured during a calendar month and divide this sum by the total number of daily discharge measured. See footnote 3 for fecal coliform calculations.

During May through October, the average monthly effluent concentration for $CBOD_5$ must not exceed 25 mg/L or 15 percent of the respective monthly average influent concentrations, whichever is more stringent.

During November through April, the average monthly effluent concentration for $CBOD_5$ must not exceed 25 mg/L or 20 percent of the respective monthly average influent concentrations, whichever is more stringent.

During May through October, the average monthly effluent concentration for TSS must not exceed 30 mg/L or 15 percent of the respective monthly average influent concentrations, whichever is more stringent.

During November through April, the average monthly effluent concentration for TSS must not exceed 30 mg/L or 20 percent of the respective monthly average influent concentrations, whichever is more stringent.

(2) Average weekly discharge limitation means the highest allowable average of “daily discharges” over a calendar week, calculated as the sum of all “daily discharges” measured during a calendar week divided by the number of “daily discharges” measured during that week. See footnote 3 for fecal coliform calculations.

(3) To calculate the average monthly and average weekly values for fecal coliforms, you must use the geometric mean. Ecology gives directions to calculate this value in publication No. 04-10-020, *Information Manual for Treatment Plant Operators*.

(4) Indicates the range of permitted values. The Permittee must report the instantaneous maximum and minimum pH monthly. Do not average pH values.

(5) Maximum daily effluent limit means the highest allowable daily discharge. The daily discharge means the discharge of a pollutant measured during a calendar day. The daily discharge is the average measurement of the pollutant over the day. This does not apply to pH.

1.3 NITROGEN LIMIT SCENARIOS

The process used to determine target nitrogen limits for use in project nitrogen removal scenarios was discussed in the South Treatment Plant (STP) Nitrogen Removal Study (Carollo 2010). Two permit scenarios were ultimately selected for evaluation in the STP Nitrogen Removal Study and this report uses the same two scenarios for evaluation of the WPTP. The two permit scenarios given below represent, respectively, the least and most stringent permit scenarios that could reasonably be requested by Ecology:

1. Summer-season (May 1 through October 31) limit of 8 milligrams per liter (mg/L) total inorganic nitrogen (TIN).
2. Year-round limit of 3 mg/L TIN.

It has been further assumed that these permit requirements would be imposed during any month during the permit season, so the permit would be need to be met in the month with the lowest temperature and the highest monthly loading during the permit period. This is a more stringent criterion than, for example, that the limit be imposed as an average over the entire permit season.

1.4 FLOW AND LOAD BASIS

Flows and loadings which formed the basis for design of the existing secondary WPTP are summarized in Table 1.3. These values were derived from the “Design Data” contained in the current record drawings for the West Point Secondary Treatment Facilities Liquids Stream facility drawings originally issued in December 1996 (King County 1996). In the scope of work for the current project it was determined that the design Average Dry Weather Flow of 110 mgd would be used as the design condition for the summer only nitrogen removal permit condition, and that the maximum month design flow of 215 mgd would be used as the maximum month flow for the year round nitrogen removal permit condition. Since design nitrogen loadings were not included in the design documentation for the existing secondary WPTP, and since the relevant peaking factors were not identified in the design documents for the summer condition, data from operation of the WPTP over the last several years were used to establish the concentrations and peaking factors to be used for the current study.

Flow and loading data from the WPTP for the period from 2005 through 2009 were evaluated to establish projected concentrations and peak factors to be used for the current study. During the first three years of the period of record, return flows from solids handling were returned to the influent to the HPO tanks. During the last two years, solids handling return flows were returned to the influent to the treatment plant (upstream of the influent sampler). Average values of loading (and to a lesser extent) flows for this period would not be representative of the true raw sewage influent to the WPTP. Therefore, calibrations of Carollo’s Biotran model included adjustments to the data, such that the model was based on representative flows and loads, with return flows directed to the HPO tanks. Since solid stream return flow and quality data were not available, values for these were calculated using default valves in the Biotran program for solids capture and digester transformations. This calibration approach yielded typical values for calibration parameters, and was used to project future concentrations and peaking factors.

Projected flows and loads used as a basis for this evaluation are presented in Table 1.2. Prior design data for the WPTP are presented in Table 1.3. It should be noted that maximum monthly values for BOD_5 and TSS (201,000 ppd and 218,000 ppd, respectively) in Table 1.3 are less than the design capacity included in the NPDES permit and design documents for BOD_5 and TSS (254,000 ppd and 274,000, respectively). This is because the permit and design documents report the capacity of the WPTP with the addition of two HPO basins and two secondary sedimentation tanks, rather than the capacity of facilities that are currently in operation.

Projected maximum month loadings for BOD_5 and TSS based on the 2009 data analysis (presented in Table 1.2) compare well with prior projections in the design documents, and judged to be reasonable for the basis of this evaluation. Projected BOD_5 loads are within 14 percent of prior projections for year-round conditions, and within 3 percent for summer conditions. Projected TSS loads are within 2 percent of prior projections for year-round conditions, and within 8 percent for summer conditions.

Table 1.2 Projected WPTP Influent Flow and Loads
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks

Description	2009 Summer	2009 Year Round	Projected Summer	Projected Year Round
Flow, mgd				
Average	79	92	110	142
Max Month	100	157	139	215
BOD_5, ppd				
Average	119,000	127,000	167,000	195,000
Max Month	139,000	148,000	**194,000**	**229,000**
TSS, ppd				
Average	131,000	124,000	183,000	192,000
Max Month	143,000	138,000	**200,000**	**213,000**
TKN, ppd				
Average	16,000	15,000	22,000	24,000
Max Month	18,000	17,000	25,000	27,000

Table 1.3	Design WPTP Influent Flow and Loads[1] West Point Nitrogen Removal Study King County Department of Natural Resources and Parks		
Description	**Initial**	**Design**	**Saturation (Future)**
Flow, mgd			
Average Dry Weather	103	110	136
Average Annual	134	142	169
Average Wet Weather (non-storm)	125	133	159
Maximum month	200	215	254
Peak Combined Sewer Flow	281	300	358
Maximum Secondary Flow	440	440	440
Combined Sewer Overflow	300	300	358
	140	140	82
BOD_5, ppd			
Average Annual	156,000	168,000	212,000
Maximum Month	187,000	**201,000**	254,000
Maximum Week	234,000	252,000	317,000
Maximum Day	327,000	352,000	444,000
TSS, ppd			
Average Annual	168,000	181,000	228,000
Maximum Month	202,000	**218,000**	274,000
Maximum Week	252,000	272,000	342,000
Maximum Day	504,000	543,000	684,000

Notes:
(1) King County (1996).

1.5 POTENTIAL NITROGEN REMOVAL CAPACITY ANALYSIS

Treatment plant models were developed by Carollo for this report and calibrated to existing plant data to confirm the capacity of the existing plant. As part of the work, Carollo prepared two models: a proprietary steady state model (Biotran); and a commercial process analysis model from Envirosim (BioWin). Both models included primary treatment, activated sludge reactors, secondary sedimentation tanks, solids thickening, digestion, and dewatering unit process return flows. Figure 1.1 presents the schematic of the model developed in BioWin.

These calibrated models were used to define the potential capacity of the current treatment plant process tanks (with modifications) to meet the summer season limit of 8 mg/L of TIN and the year round limit of 3 mg/L of TIN. The analysis of the current treatment plant described in this report was based on maximum month flows and loads. The analysis assumed that all aeration basins were in service and one secondary clarifier was out of service (i.e., 12 out of the 13 existing clarifiers would be in service at reduced flows to meet the more stringent effluent limits). This decision was documented in an earlier memorandum, Project Memorandum 1, and allows operation at higher mixed liquor suspended solids (MLSS) concentrations while still maintaining the current solids loading rates on the clarifiers. This section describes the analysis of the WPTP data, the model calibration process, and the model results for the two effluent scenarios.

1.5.1 Data Analysis

1.5.1.1 Flow

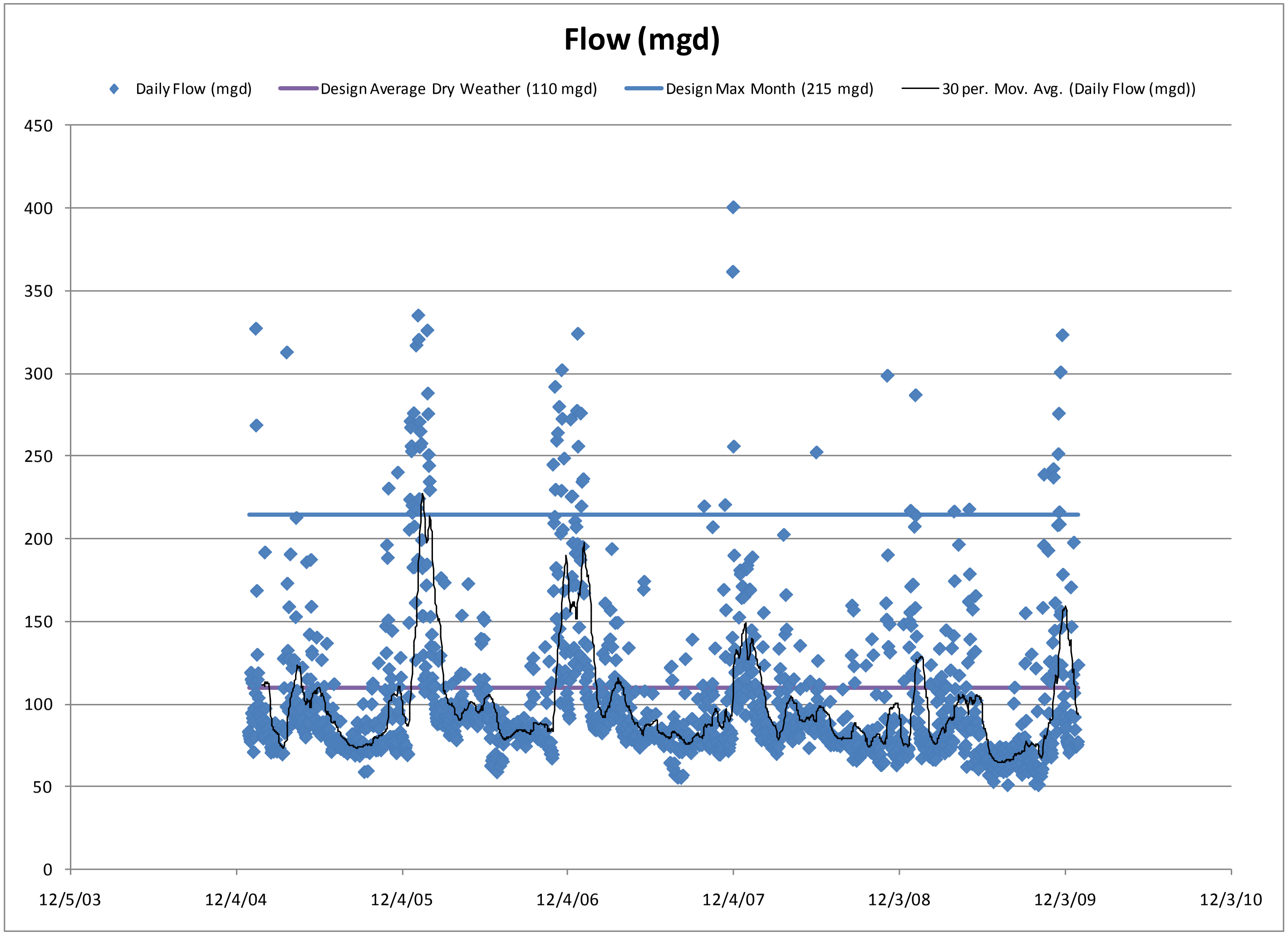
In preparing the model analysis, operating data for the period from 2005 through 2009 were reviewed. Figure 1.4 presents a time-series graph of flow at the WPTP for the period. Flow measurement represents plant effluent, rather than raw sewage influent. The graph presents daily average flow values over the period of record. The design average dry weather flow of 110 mgd and the design maximum month flow of 215 mgd are shown for reference. It is seen that current dry weather flows are approximately 75 mgd. During the five years of record, the 30-day average flow reached design maximum month flow (215 mgd) one time during the winter of 2005/2006.

A full year of data for 2009 was assumed to be representative of the current conditions and was used for calibration of the Biotran model. The average and maximum month flows for 2009 were 92.0 mgd and approximately 154 mgd, respectively.

Figure 1.5 presents peak flow data for the period from 2006 to 2009. The design peak secondary flow of 300 mgd is shown for reference. It is seen that the 300 mgd threshold is experienced frequently. Peak flows in excess of 300 mgd have occurred during the May through October permit season.

1.5.1.2 BOD_5

Figure 1.6 presents influent BOD_5 loadings in tons per day (tpd) for the five-year period of record. The design maximum month BOD_5 loading of 201,000 ppd (approximately 100 tpd) is shown for reference. The 30-day average BOD_5 loading has never approached this value during the period of record. As previously discussed, the values shown represent raw sewage values for the period from 2005 through 2007 and the combined raw sewage plus solids handling return flows for 2008 and 2009. A linear trend line is also shown on the graph. It is seen that this line is essentially flat, indicating that there was no significant growth in BOD_5 loading during the period. Considering that data from the last two years included return flows the data may indicate a slight decrease in BOD_5 loading over the period.

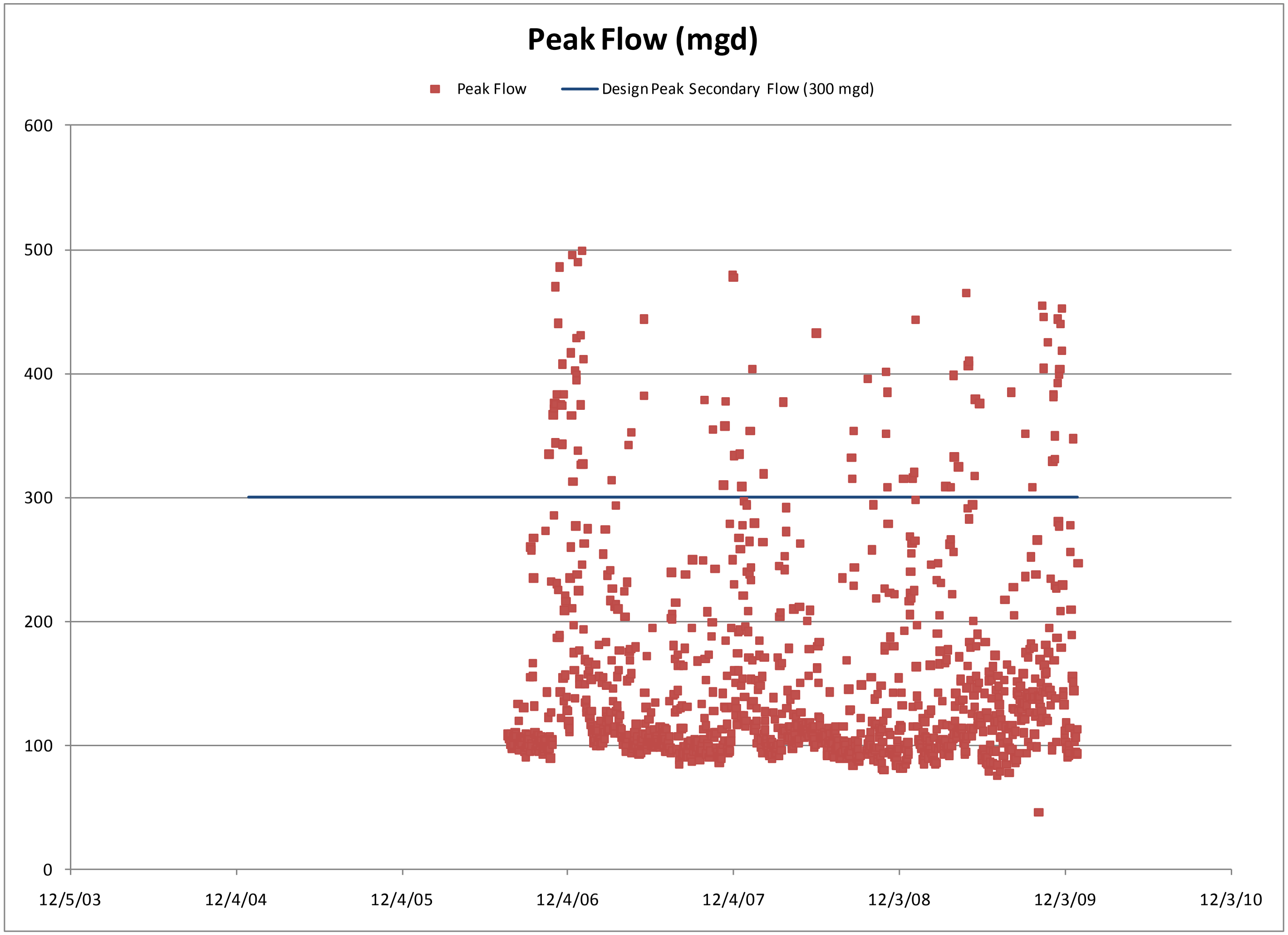


RAW SEWAGE FLOW FOR THE PERIOD FROM 2005 TO 2009

FIGURE 1.4

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

pw://Carollo/Documents/Client/WA/King County/7683G00/Deliverables/Figures/Fig1.4 (A)



PEAK SEWAGE FLOW FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.5

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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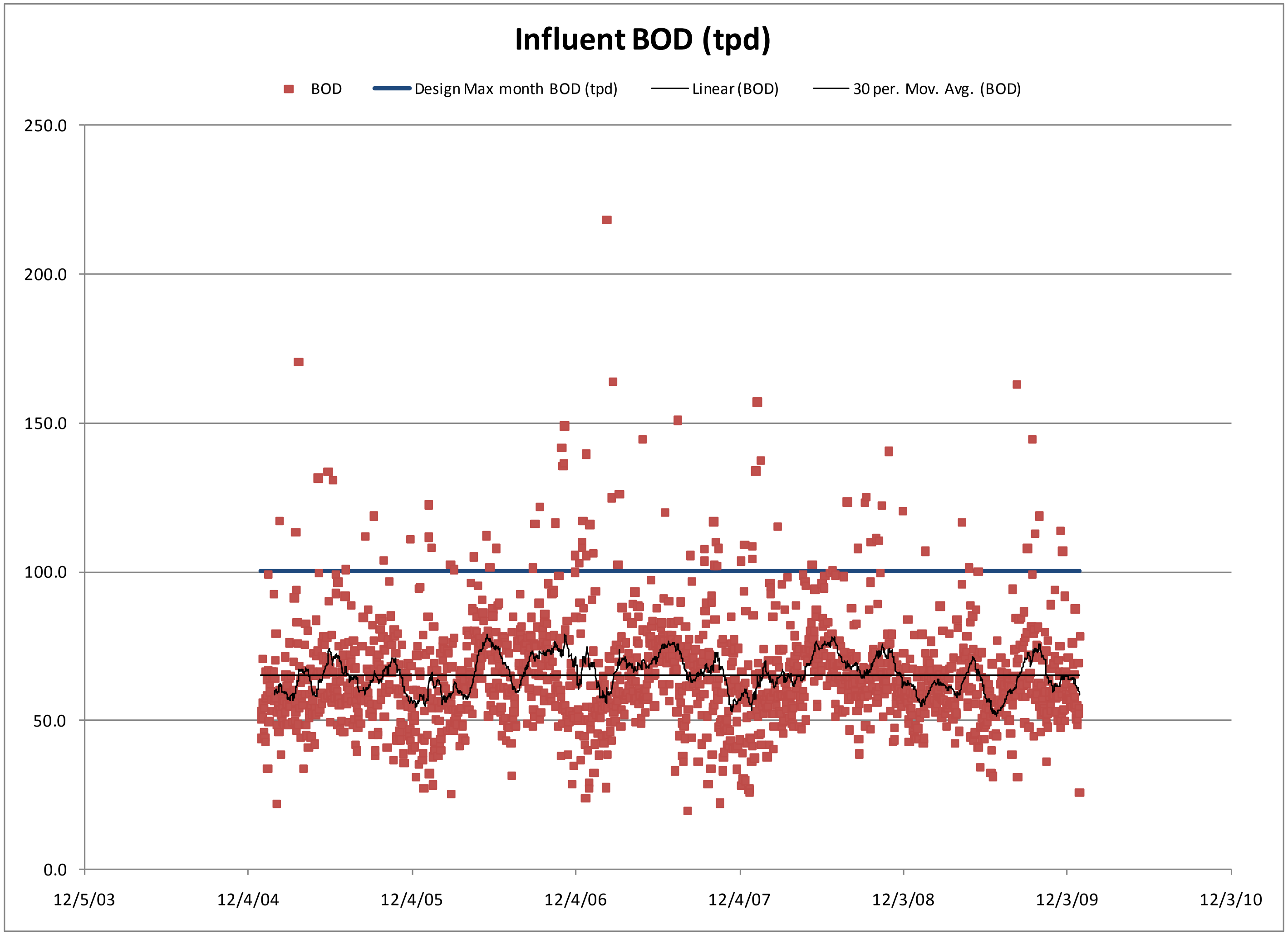


BOD FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.6

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

pw://Carollo/Documents/Client/WA/King County/7683G00/Deliverables/Figures/Fig1.6 (A)

1.5.1.3 TSS

Figure 1.7 presents data for TSS for the period of record. Like the BOD_5 data, it is seen that the 30-day average trend line never exceeded approximately 75 percent of the design influent TSS loading of 218,000 ppd.

1.5.1.4 TKN

Figure 1.8 presents data for total Kjeldahl nitrogen (TKN) for the period of record. Design values for TKN were not identified in the WPTP design documentation since nitrogen control was not a goal of the design. The 30-day average trend line indicates a somewhat stronger seasonal variation than for BOD_5 and TSS. The linear trend line has remained relatively constant at approximately 20,000 ppd (10 tpd).

1.5.1.5 Primary Sedimentation Performance

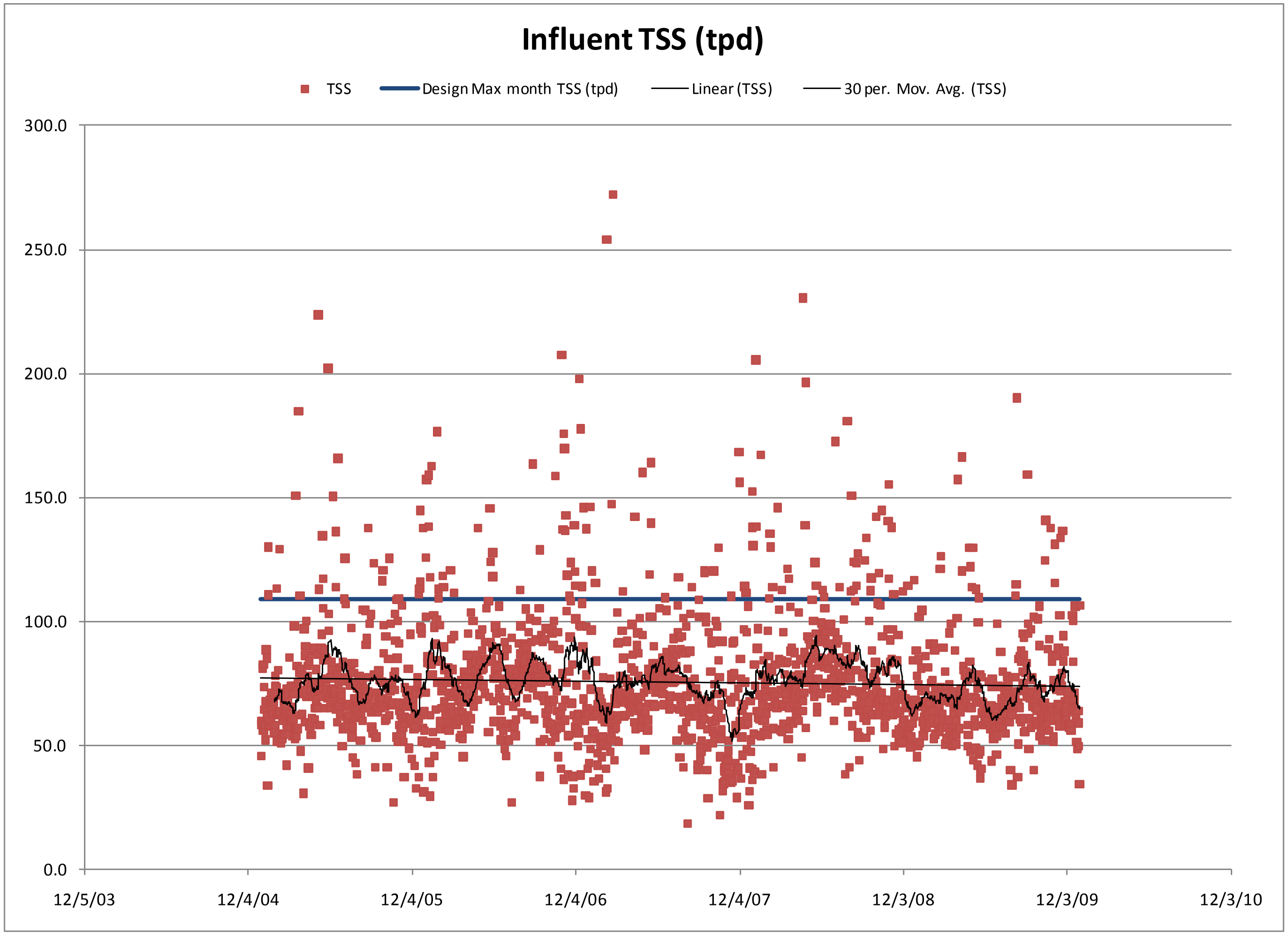
Figures 1.9 and 1.10 present data for removal of BOD_5 and TSS, respectively, through primary sedimentation at the WPTP. These data are for the period from 2007 through 2009. Figure 1.10 includes a typical relationship based on limited data taken by the Water Pollution Control Federation in 1985 which was included in a recent Water Environment Federation (WEF) Wastewater Treatment Design Manual of Practice (WEF and ASCE, 1998). Comparison of WPTP data to the WEF relation indicates that performance of the WPTP primary sedimentation tanks has been better than typical. There is wide scatter in the data, reflecting differences in settling properties from day to day and season to season, which is typical. For analysis of future primary treatment performance, logarithmic equation fits similar to those shown in the figures were used. A fit prepared for the year of 2009, was used for calibration of the model.

1.5.1.6 Activated Sludge Process Parameters

Four parameters are especially important for successful activated sludge operation and model calibration: temperature; alkalinity; solids residence time (SRT); and sludge settleability. Data analysis for these parameters is summarized in sections below.

1.5.1.6.1 *Temperature*

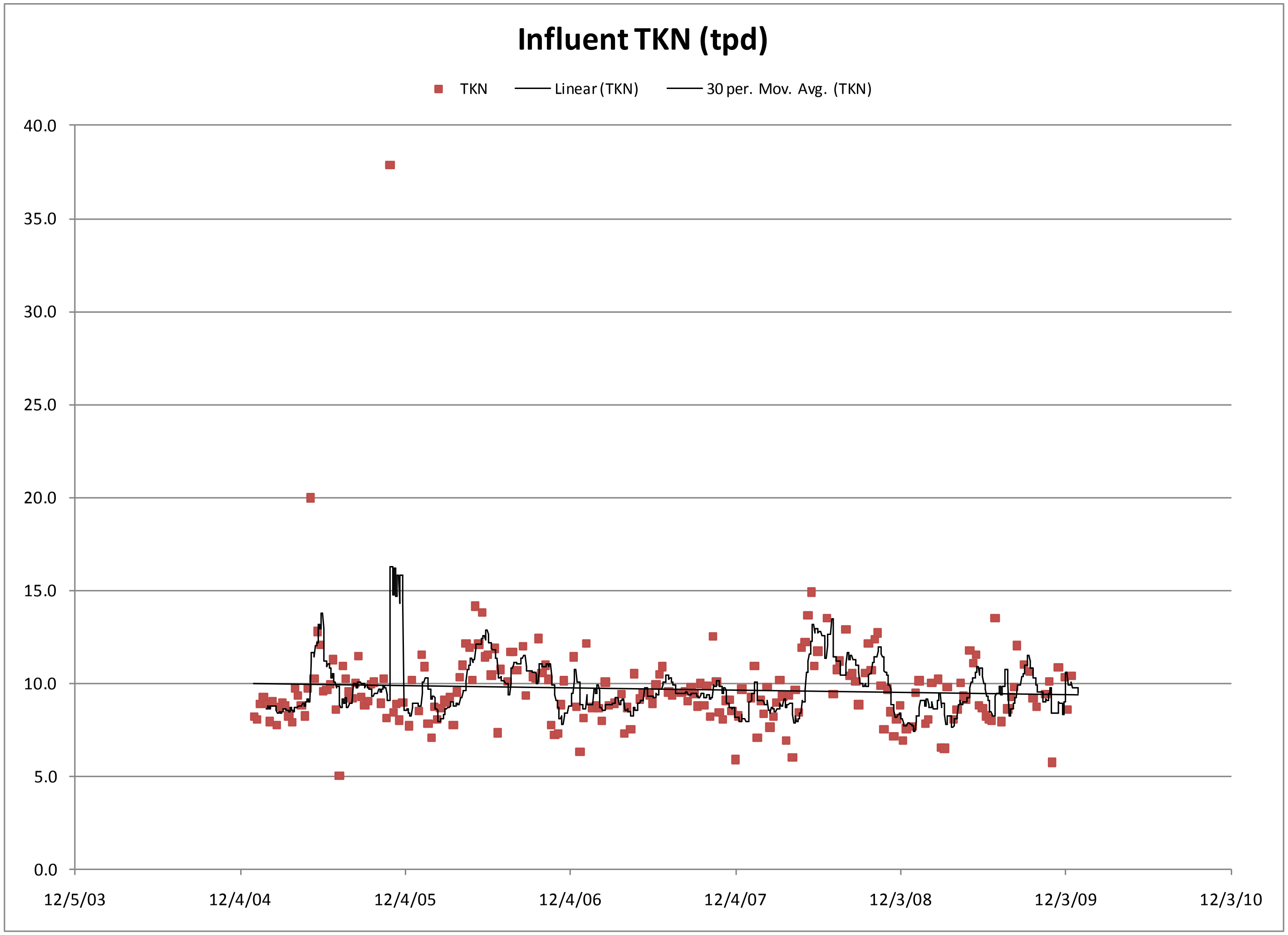
Temperature data from plant records for the period from 2007 to 2009 are shown in Figure 1.11. The data present a variation in temperature from a seasonal 30-day moving average low of just under 15 degrees Centigrade (degrees C) to as high as 24 degrees C during the summer of 2007. During the summer period the 2009 data indicate a minimum month temperature of approximately 16 degrees C, and a minimum week temperature of approximately 15 degrees C. Year round temperatures are approximately 14 degrees C (minimum month) and 12 degrees C (minimum week).



TSS FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.7

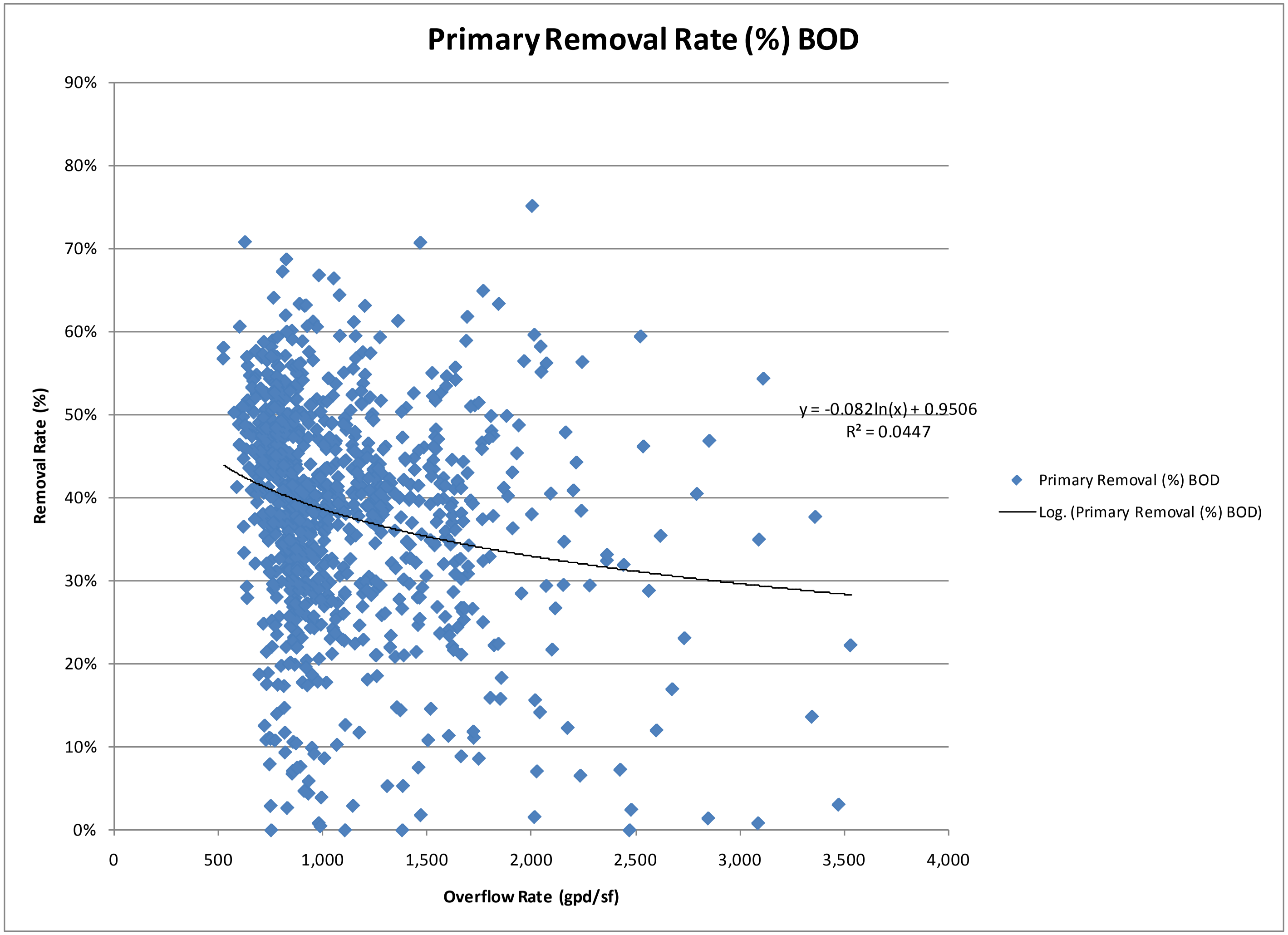
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



TKN FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.8

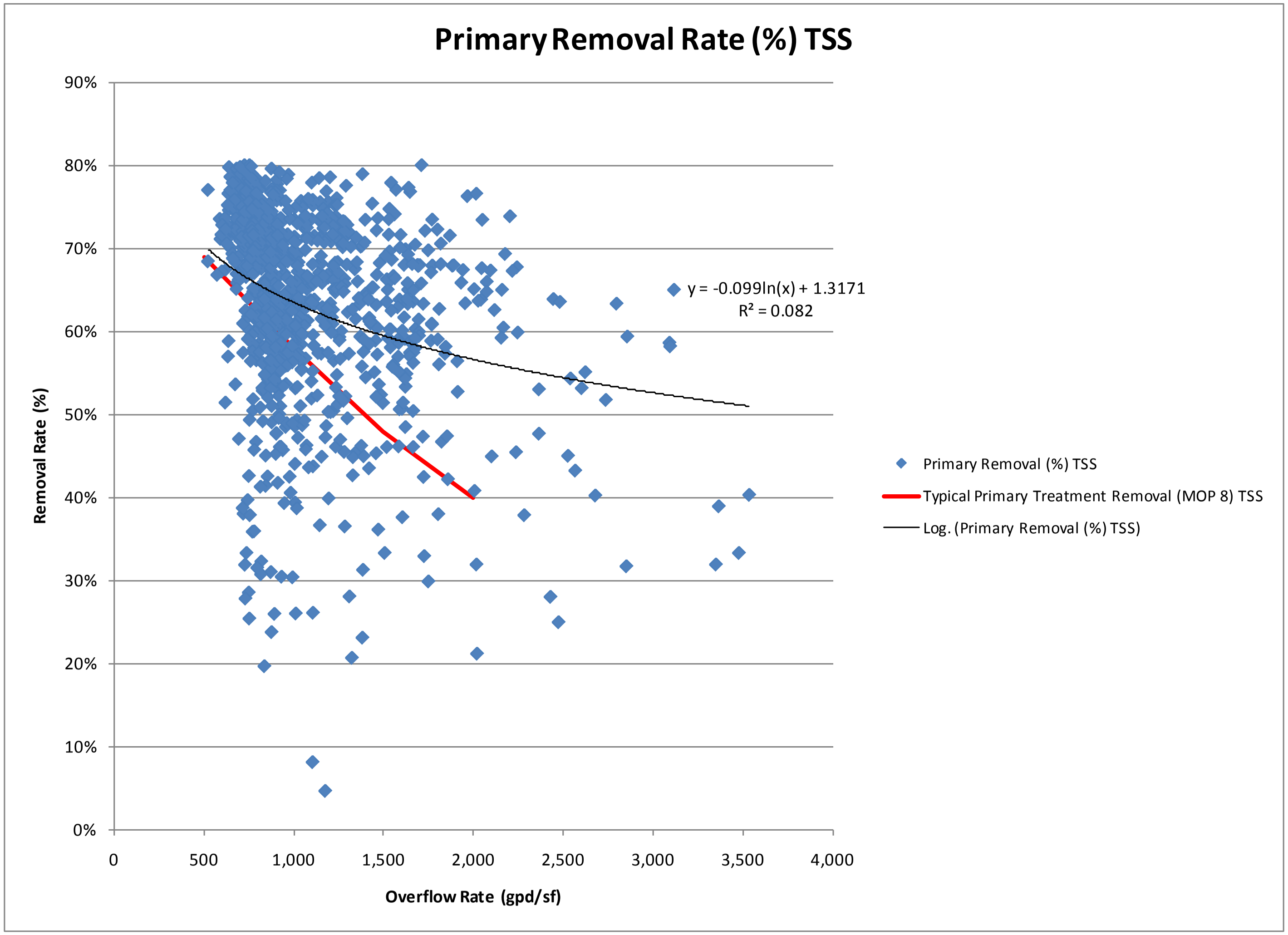
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



PRIMARY BOD REMOVAL DATA FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.9

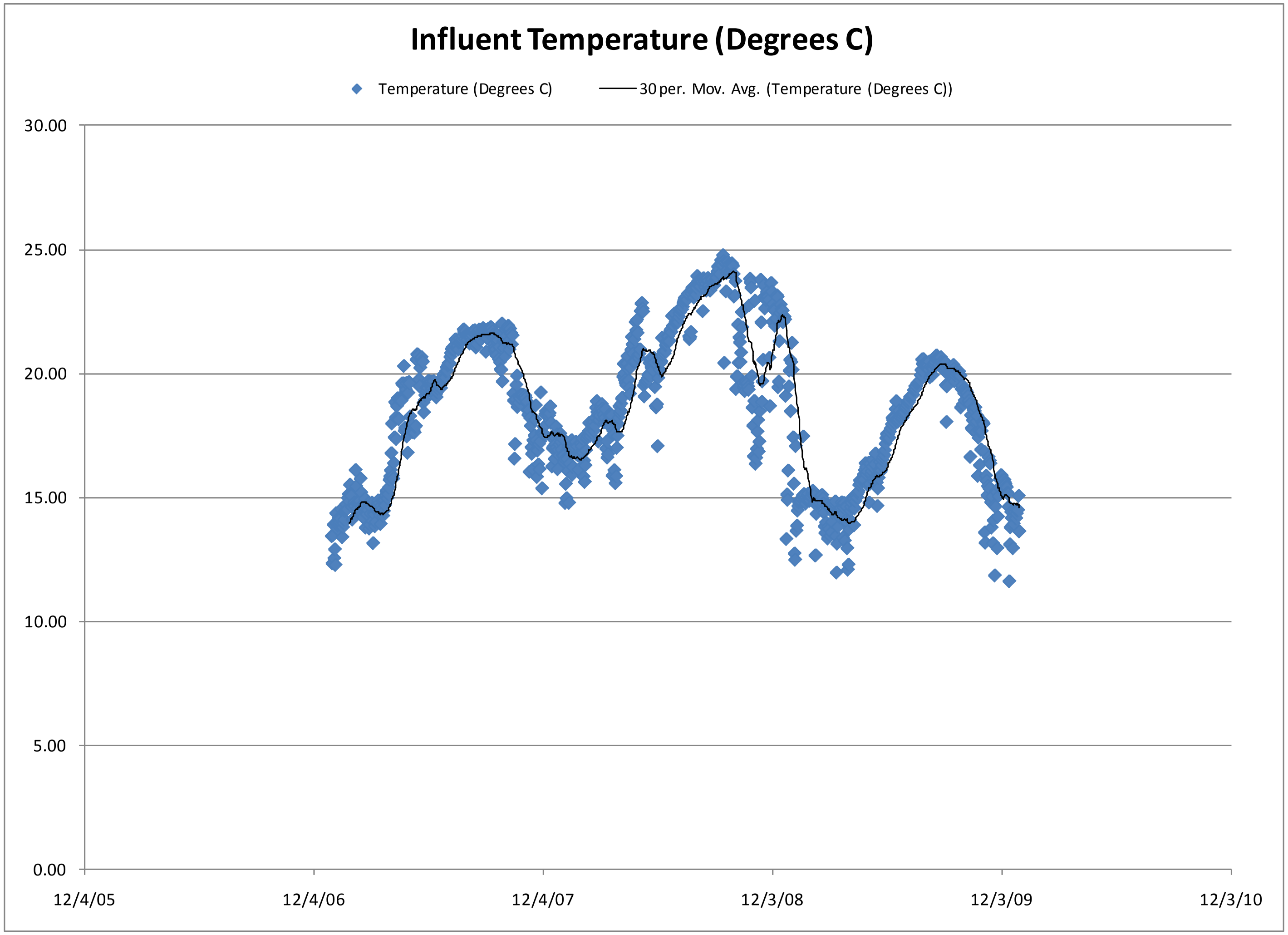
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



PRIMARY TSS REMOVAL DATA FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.10

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



TEMPERATURE FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.11

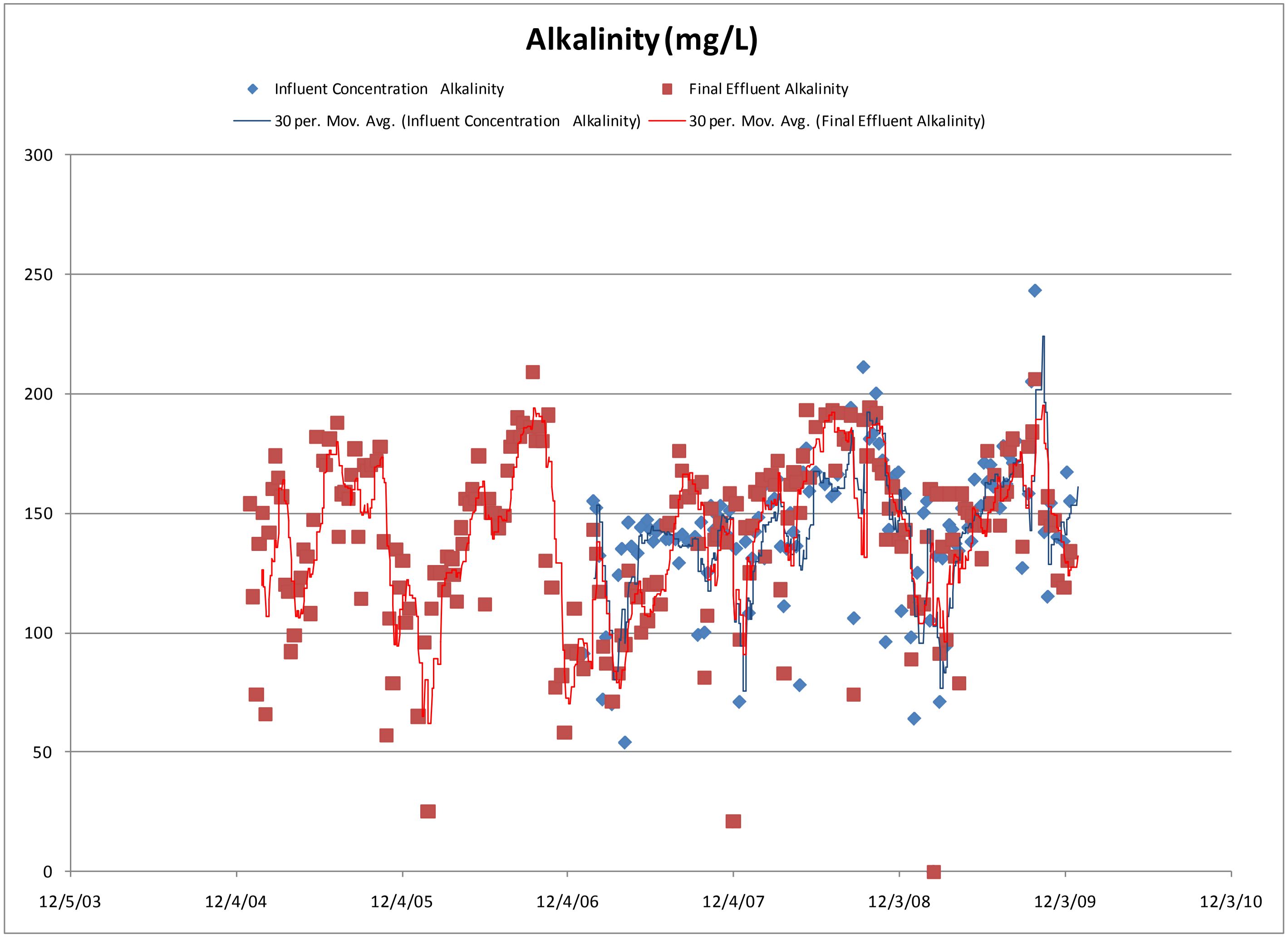
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

At a meeting at the WPTP to discuss these data it was pointed out that the data are unusual in that each year shows a different pattern, with 2007 showing much higher summer temperatures than either of the other two years in the record. It was proposed that these data may have been faulty due to a calibration problem with the temperature measurement probe located in the influent pump wet well. Data from the STP indicated a minimum week low winter temperature of approximately 12 degrees C for this same period. It was agreed to use this value for analysis of year-round nitrogen control alternatives in the WPTP study. For the summer period, the minimum week temperature of approximately 15 degrees was selected.

1.5.1.6.2 *Alkalinity*

Since nitrogen removal requires nitrification (conversion of ammonia to nitrate), which consumes alkalinity, influent alkalinity is a very important parameter for nitrogen control. Figure 1.12 shows the dramatic seasonal variation in influent alkalinity, from low values of less than 50 mg/L during winter storm events to peak values over 200 mg/L during the summer months. The figure shows both influent alkalinity and (for 2006 through 2009) effluent alkalinity.

A drop from influent to effluent alkalinity would be an indicator of at least partial nitrification. The 30-day average trend lines for both indicate little alkalinity drop in current plant operation. During the summers of 2006 and 2007 small drops occurred, but the pattern indicates that there has not been substantial nitrification during operation of the WPTP during the period of record. This is not surprising, since HPO plants like the WPTP typically have low mixed liquor pH due to accumulation of carbon dioxide (CO_2) under the HPO tank covers, which inhibits growth of the organisms which produce nitrification. These data indicate that supplemental alkalinity in the form of caustic soda (sodium hydroxide), sodium bicarbonate, or magnesium oxide would likely be required for nitrification at the WPTP in the current HPO mode.



ALKALINITY FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.12

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

pw://Carollo/Documents/Client/WA/King County/7683G00/Deliverables/Figures/Fig1.12 (A)

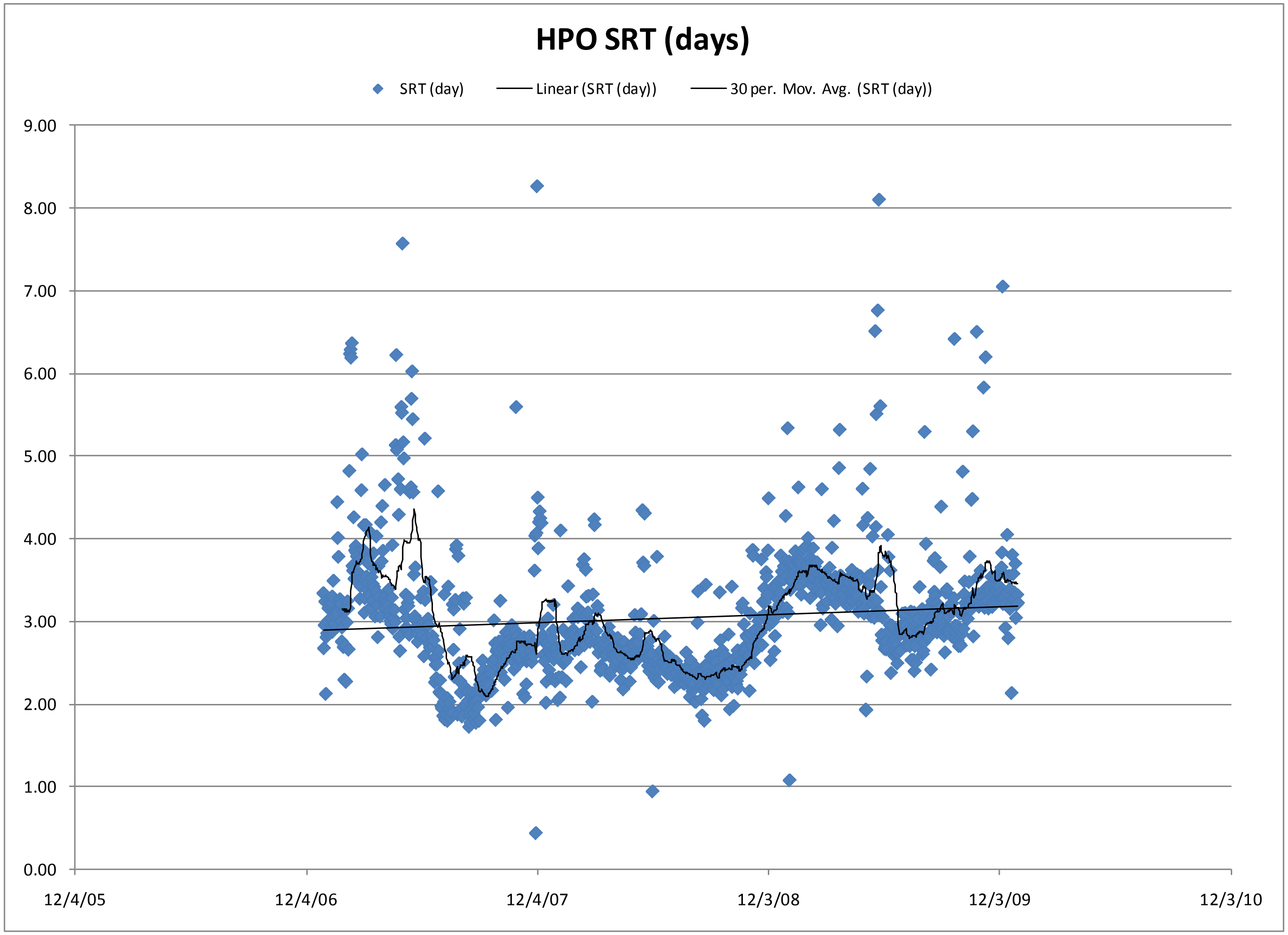
1.5.1.6.3 *Solids Residence Time*

The SRT of the activated sludge system is a key parameter for model calibration and plant operation as it determines bacterial growth rates, which in turn determine oxygen consumption and sludge production for the system. Figure 1.13 presents data for HPO tank total SRT provided by the County. The SRT varied from a minimum of just under 2 days to a maximum of 6 to 8 days over the period of record. The 30-day average SRT (also shown on the figure) has varied from a minimum of approximately 2 days to a maximum of approximately 4 days. The figure shows a gradual trend of increase in SRT over the period of record. It should be noted that the SRT presented in the figure is calculated at the WPTP by dividing the entire HPO system inventory of solids by the sum of the waste activated sludge pumping rate, accounting for the loss of solids over the secondary clarifier weirs. In calculating the HPO system inventory, plant staff also include estimates of the inventory resident in the secondary clarifier tanks. The estimated ratio of solids inventory in the HPO tanks compared to the total system inventory is approximately 60 percent, indicating an SRT range of approximately 1.2 to 2.4 days within the HPO tanks.

A key group of organisms for this evaluation are the nitrifiers. These organisms are sensitive to temperature as is illustrated in Figure 1.14. This graph shows the washout, or minimum, SRT for the nitrifiers as presented by Jenkins, et al. 2004. At the minimum week summer temperature of approximately 15 C, nitrifying organisms are washed out of the system when the aerobic SRT is less than approximately 5 days. At the minimum week year-round temperature of approximately 12 C, nitrifying organisms are washed out of the system when the aerobic SRT is less than approximately 9 days. Based on these minimum washout SRT values, the target aerobic SRT for the summer effluent scenario of 8 mg/L TIN will be 9 days and the target aerobic SRT for the year-round effluent scenario of 3 mg/L TIN will be 13 days. These design SRT values allow for a safety factor to account for uncertainty in operation and diurnal loading effects.

1.5.1.6.4 *Sludge Settleability*

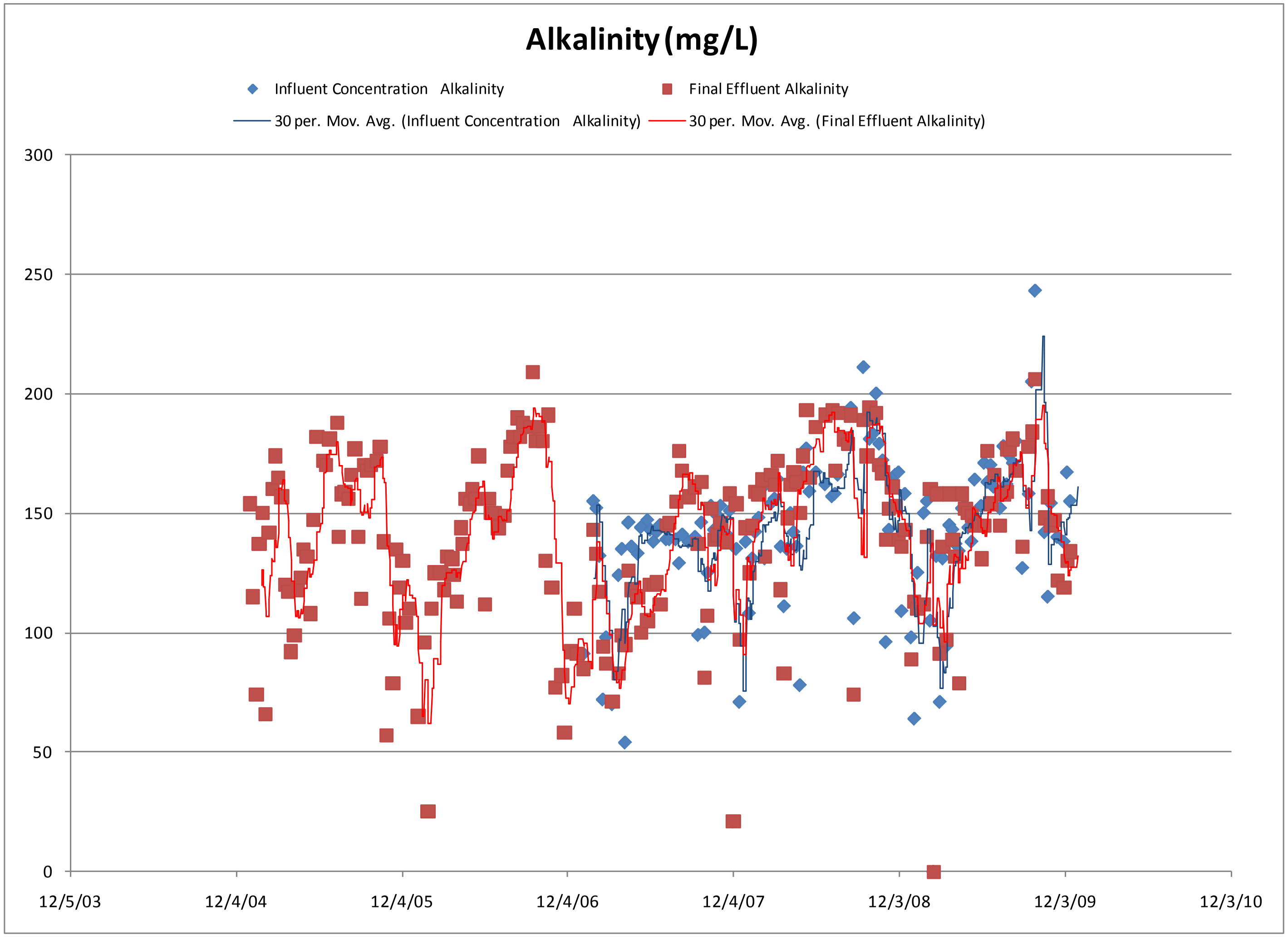
The sludge volume index (SVI) gives an indication of sludge settling rates, which determine the capacity of secondary sedimentation tanks. Figure 1.15 shows a time-series plot of SVI data for the WPTP since the beginning of 2007. The data indicate SVI values below 150 milliliter per gram (mL/g) for most of the period prior to the middle of 2008. A linear plot of the data, however, shows a steady pattern of increase. The average SVI during 2007 was 114 mL/g but the average during 2009 was 173 mL/g. Future settling velocity values will be estimated from the Daigger equation (Daigger 1995) using a value of 150 mL/g.



HPO SRT DATA FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.13

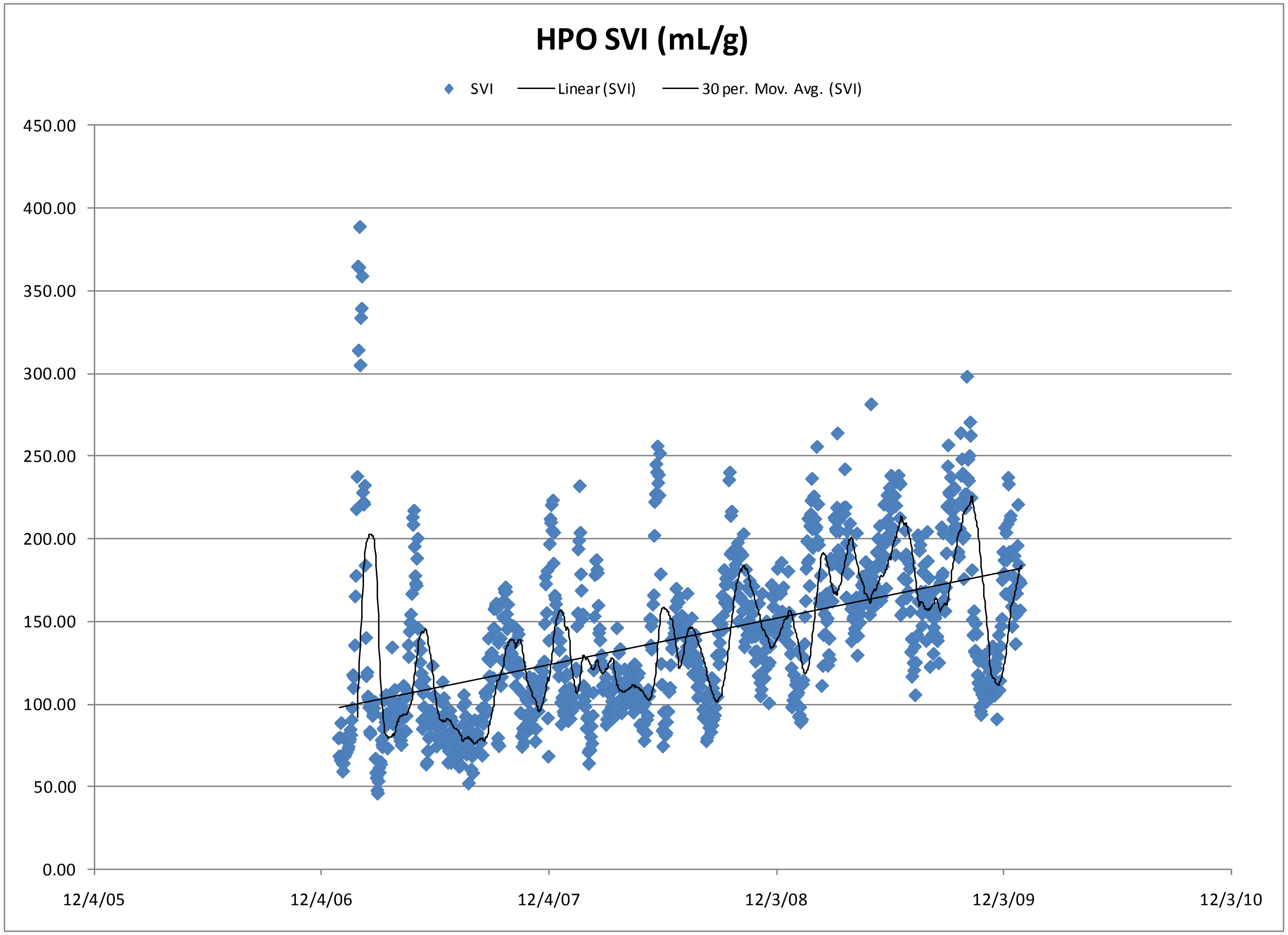
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



WASHOUT AEROBIC SRT FOR NITRIFYING ORGANISMS

FIGURE 1.14

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



HPO SVI DATA FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.15

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

1.5.1.7 <u>Secondary Effluent Performance</u>

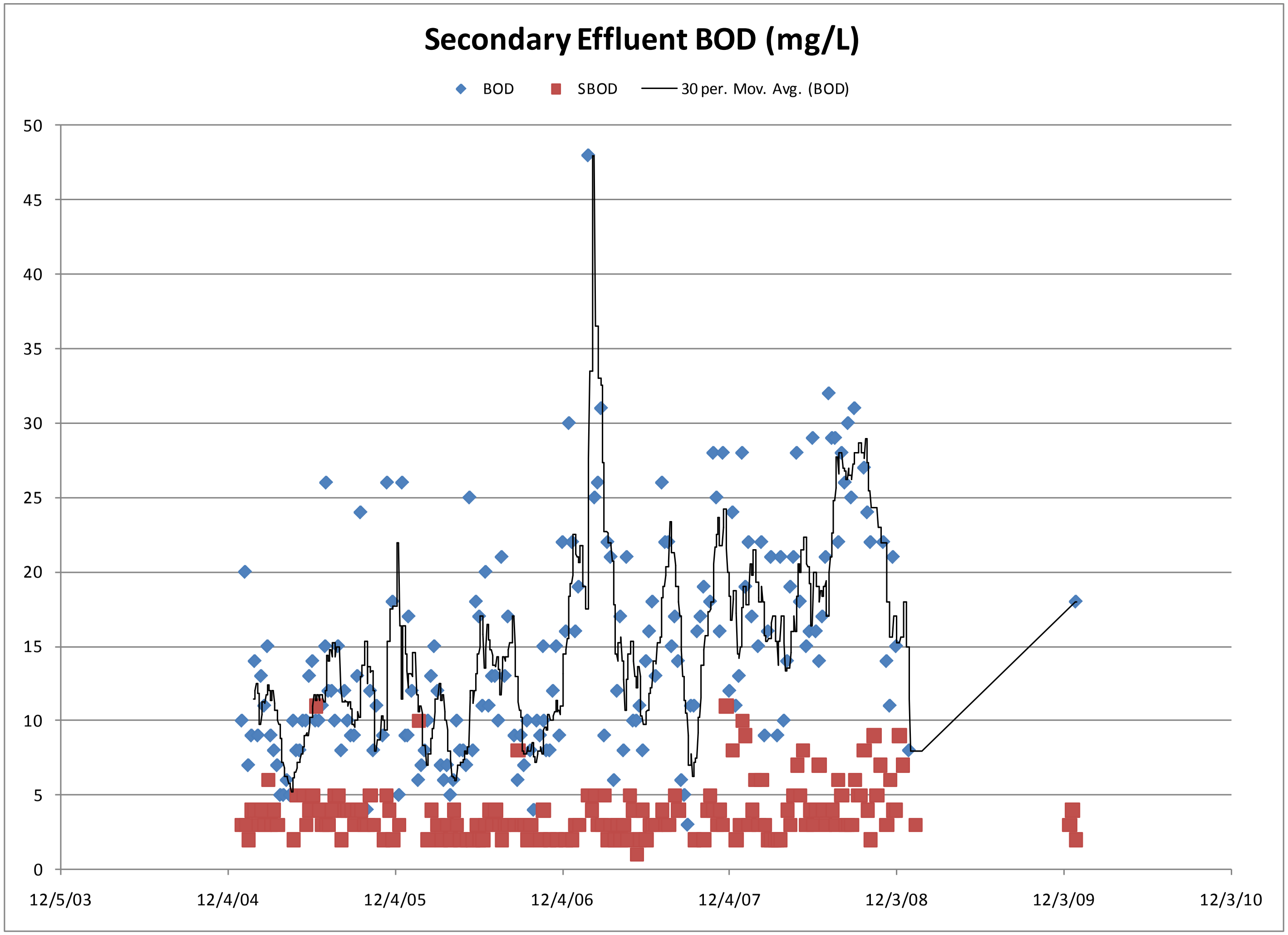
Figures 1.16 and 1.17 show recorded effluent data for BOD_5 and TSS (respectively) from the WPTP data records for the period from 2005 through 2008, plus a small amount of data from the end of 2009. The average BOD_5 concentration over the period has been approximately 15 mg/L. As shown in Figure 1.16 daily values have varied widely from under 5 mg/L to nearly 50 mg/L. The standard deviation of the effluent BOD_5 data was approximately 7 mg/L (50 percent). The 30-day moving average effluent BOD_5 value briefly exceeded the 30 mg/L permit limit during the winter of 2006 and approached the permit limit during late 2007. Effluent TSS values over the same period averaged approximately 10 mg/L with a standard deviation of approximately 7 mg/L (67 percent).

1.5.2 Model Calibration

Modeling of biological wastewater treatment processes requires estimation of several wastewater influent parameters that are typically not monitored at wastewater treatment plants. Key parameters include the distribution of the influent organic material in soluble and particulate fractions and the character of the volatile suspended solids. In Carollo's Biotran model, the parameter Fbf represents the soluble portion of the influent sewage. The parameter Fvu represents the non-volatile ratio of the influent volatile suspended solids. The WPTP monitors the Fbf parameter, but not the Fvu parameter. To determine this parameter a wastewater characterization process was conducted using the following procedure:

1. With Fpf and other calibration parameters fixed, calibrate primary removal performance to replicate existing primary treatment BOD_5 and TSS removal.
2. Adjust Fvu parameter to match measured waste activated sludge (WAS) solids production.
3. Iterate as required to match measured primary effluent BOD_5 and TSS and WAS.

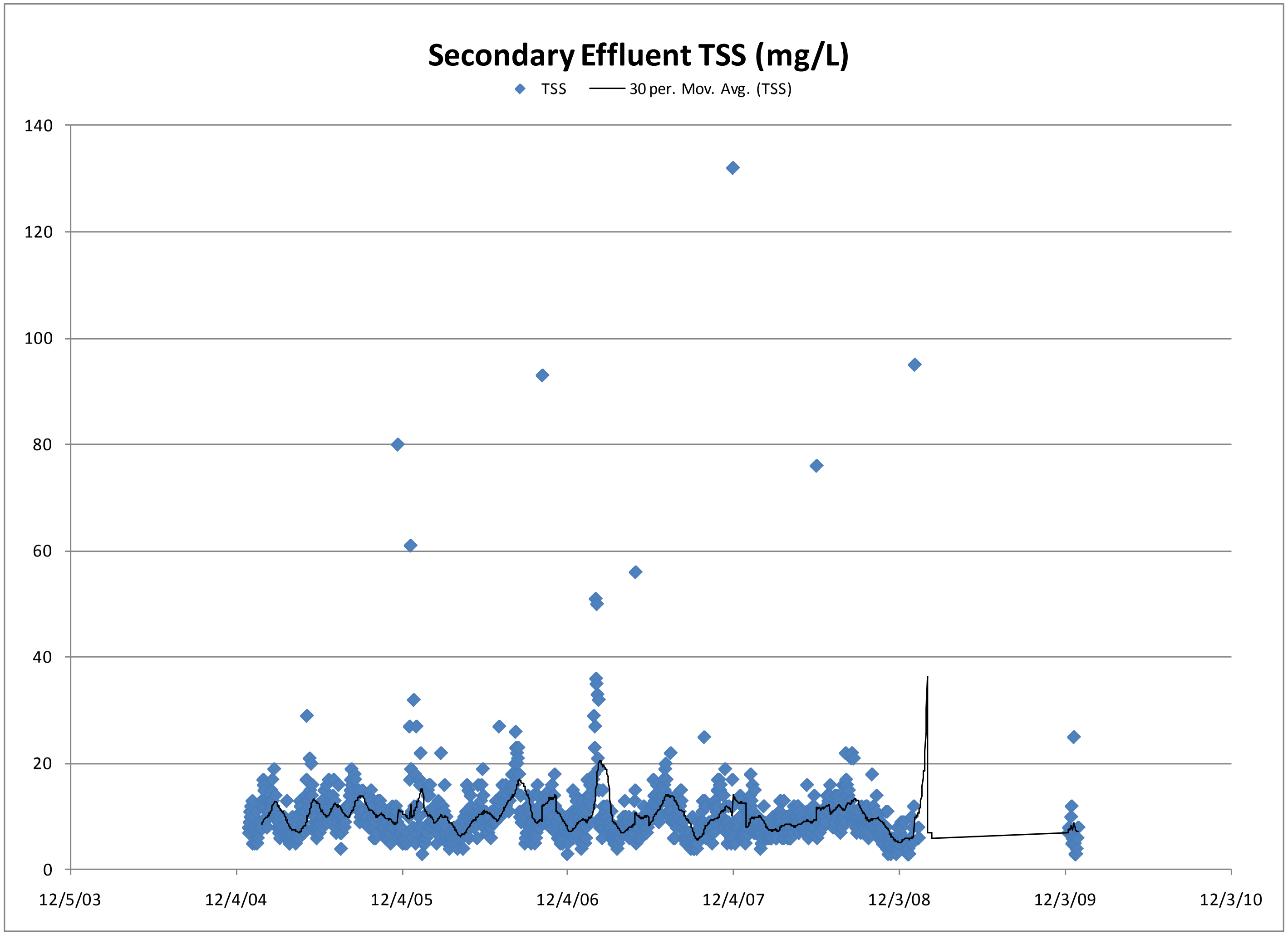
The five years of record had different influent feed conditions, so it was not possible to calibrate to the entire period of record. During the first three years of record return flows from solids handling were directed to the influent to the HPO system. During the last two years of record return flows from solids handling were directed to the influent sewer upstream of the influent wastewater sampler. The wastewater treatment industry normally calibrates primary treatment removal to overflow rate. Overflow rate data were only available for the last three years of record. Considering these facts, 2009 was selected as the period for calibration. Since solids handling return flows were included in the influent concentrations for this year, adjustments were made to influent flows and loadings based on estimated strength and flow of the return stream.



SECONDARY EFFLUENT BOD_5 DATA FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.16

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



SECONDARY EFFLUENT TSS DATA FOR THE PERIOD FROM 2006 TO 2009

FIGURE 1.17

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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Results of the calibration are shown in Figure 1.18 and Table 1.4. Figure 1.18 presents predicted primary treatment solids and BOD_5 removal as a function of overflow rate. The primary treatment model in Biotran includes a model for a composite of slowly settleable and rapidly settleable solids. The respective contributions of each are shown in the charts. Fit parameters were adjusted to match experienced removal rates. These fit parameters were then imported into the main Biotran model. The models matched the solids production and SRT values shown in Table 1.4, which also includes key calibration parameters used as the basis for modeling capacity under future conditions.

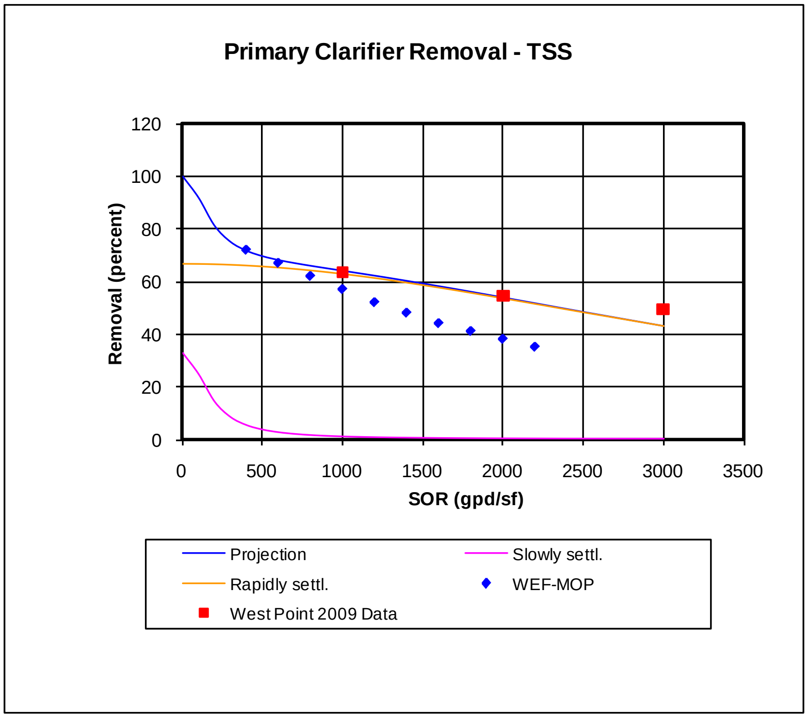
Table 1.5 presents calculated wastewater characteristic values for the input parameters for the BioWin commercial model, that were used to confirm capacity requirements for future nitrogen removal. A schematic of the simplified BioWin model for the WPTP is presented in Figure 1.19.

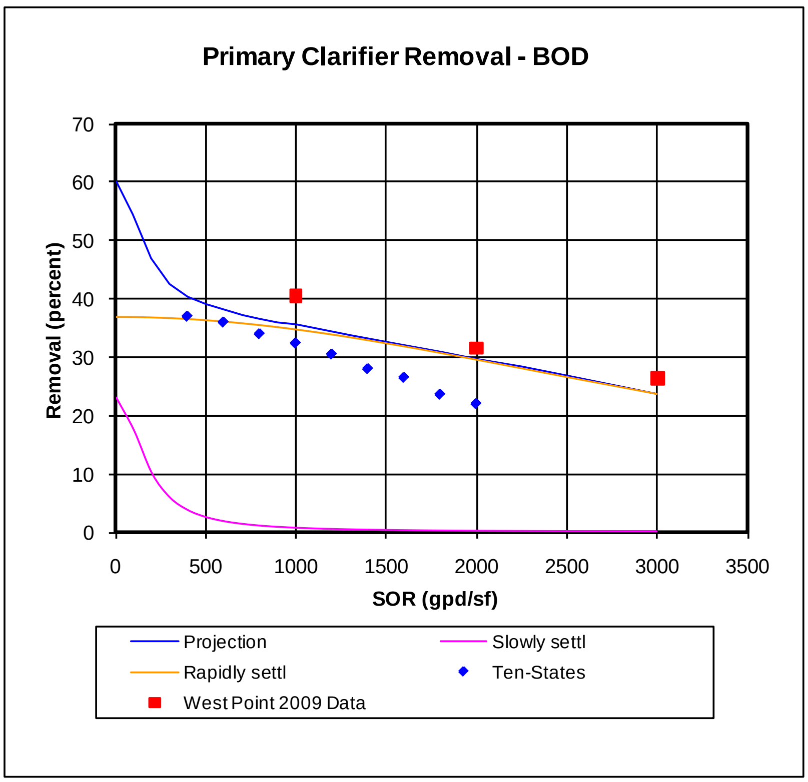
Table 1.4 Calibration Parameters for 2009
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks

Parameters	Model Summer (May - Oct)	Model Ave Annual	Data Summer (May - Oct)	Data Ave Annual
Fbf	0.24	0.28	0.24	0.28
Fvu	0.30	0.30	N/M	N/M
Primary Removal, %				
BOD5	47	44	45	45
TSS	67	66	69	69
Primary Effluent Concentration, mg/L				
BOD5	102	99	114	107
TSS	75	63	66	62
Excess Solids Produced, tons DS / day				
WAS	26.3	28.3	26.8	28.2
Effluent	3.3	3.9	N/A	5.9
Total	29.6	32.1	N/A	34.1
Total, lb/lb Secondary BOD Loaded	0.86	0.83		
Total SRT, days (Plant data includes clarifier inventory)	2.19	2.22	3.20	3.40

Table 1.5 Primary Effluent Characteristics for BioWin Input
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks

Parameter Name	Primary Effluent BioWin Default	2009 Calibration Summer (May-Oct)	2009 Calibration Ave Annual
Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]	0.27	0.21	0.23
Fac - Acetate [gCOD/g of readily biodegradable COD]	0.15	0.15	0.15
Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]	0.50	0.82	0.81
Fus - Unbiodegradable soluble [gCOD/g of total COD]	0.08	0.13	0.11
Fup - Unbiodegradable particulate [gCOD/g of total COD]	0.08	0.05	0.05
Fna - Ammonia [gNH3-N/gTKN]	0.75	0.78	0.77
Fnox - Particulate organic nitrogen [gN/g Organic N]	0.25	0.25	0.29
Fnus - Soluble unbiodegradable TKN [gN/gTKN]	0.02	0.02	0.02
FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]	0.04	0.01	0.02
Fpo4 - Phosphate [gPO4-P/gTP]	0.75	0.75	0.70
FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]	0.01	0.01	0.01
FZbh - Non-poly-P heterotrophs [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbm - Anoxic methanol utilizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZaob - Ammonia oxidizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZnob - Nitrite oxidizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZamob - Anaerobic ammonia oxidizers [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbp - PAOs [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbpa - Propionic acetogens [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbam - Acetoclastic methanogens [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04
FZbhm - H2-utilizing methanogens [gCOD/g of total COD]	1.00E-04	1.00E-04	1.00E-04





PRIMARY SEDIMENTATION CALIBRATION FOR 2009

FIGURE 1.18

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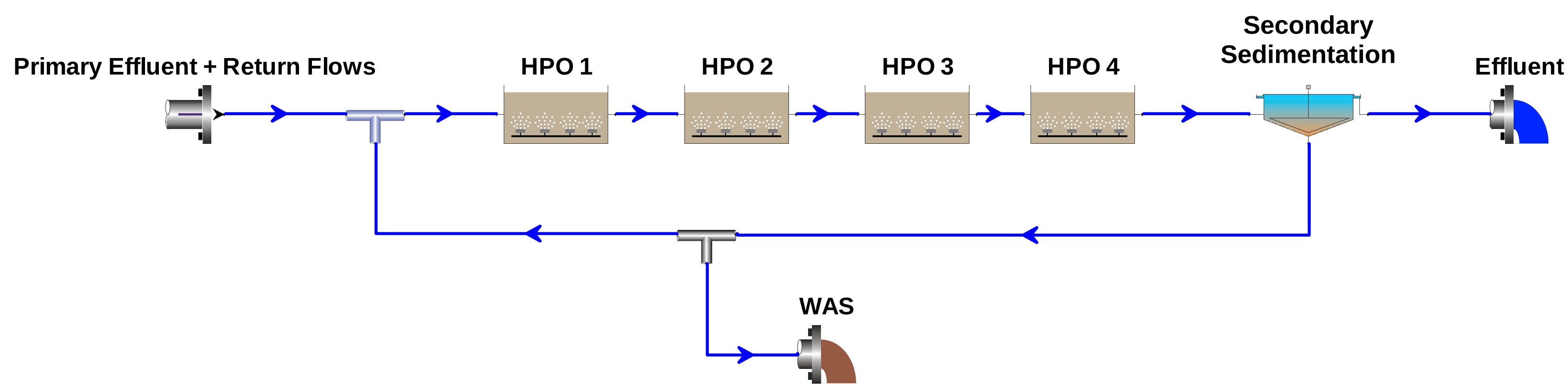
WEST POINT NITROGEN REMOVAL STUDY



PRIMARY EFFLUENT BIOWIN SCHEMATIC

FIGURE 1.19

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

1.5.3 Modeling Results TIN 8 mg/L (Summer only)

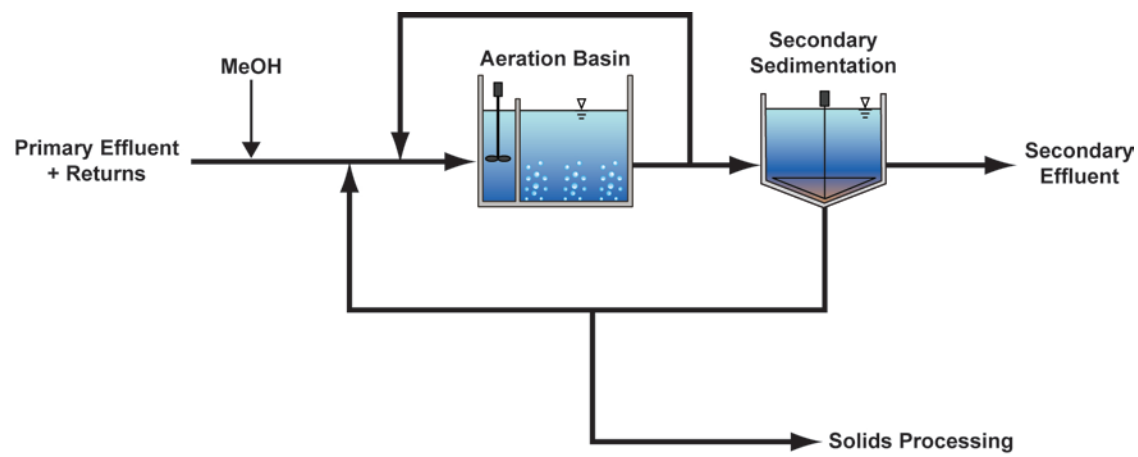
1.5.3.1 Capacity with Existing Process Tanks

Using these calibration parameters, Biotran and BioWin models were prepared for conversion of the existing process tanks at the WPTP to a configuration for nitrogen removal. For the summer-only, 8 mg/L TIN permit scenario, it was assumed that the existing HPO tanks would be converted to an anoxic/aerobic flow pattern using the Modified Ludzak-Etttinger (MLE) process. A schematic of the proposed MLE process is shown in Figure 1.20. In this configuration, the entire first pass would be unaerated and mixed resulting in an unaerated fraction of 25 percent. The unaerated fraction would serve as the anoxic zone where denitrifying bacteria would convert nitrate to nitrogen gas. Additional nitrate would be returned to the anoxic zone by a mixed liquor return (MLR) pump. Based on the modeling, the optimal flow rate for this MLR pump would be 300 percent of the influent flow (or 900 mgd).

The remaining 75 percent of the activated sludge basin would be aerated. It is in this portion of the basin that nitrifying bacteria would convert ammonia to nitrate. Experience with nitrification in HPO plants is limited. As previously discussed, low pH in HPO mixed liquor typically reduces the growth rates for nitrifying bacteria inhibiting nitrification. Furthermore, as tank sizes increase to achieve longer SRTs needed for nitrification, previous studies have shown that diffused aeration becomes more economical than HPO. For these reasons this analysis assumes the existing HPO tanks will be converted from HPO to fine bubble diffused aeration as a part of any nitrogen removal upgrade.

It has been the experience of the wastewater industry that a BOD_5 to TKN (C/N) ratio of at least 4 is required for denitrification (Randall et al., 1992). The C/N ratio of the WPTP primary effluent in 2009 was approximately 4.5 for the summer period and approximately 4.8 for the year round data. It is often found that a lower C/N ratio requires a higher anoxic tank percentage for nutrient removal. To conserve on tank volume it was decided that a target C/N ratio over 5 should be maintained for the WPTP nitrogen removal alternatives. This can be achieved by addition of a carbon supplement, such as methanol, and/or by operating primary sedimentation tanks at relatively high overflow rates to reduce BOD_5 removal.

For calculation of nitrogen removal capacity it was assumed that moderately high overflow rates were maintained by taking primary sedimentation tanks out of service. For the 8 mg/L TIN summer-only permit limit it was assumed that only 9 of the existing 12 primary sedimentation tanks were in service. This produced a predicted BOD_5 removal rate of approximately 41 percent at peak month flow overflow rate of approximately 1,600 gallons per day per square foot (gpd/sf) and a C/N ratio of between 5 and 6. This appears to be adequate to achieve the design requirements with modest carbon supplement.



MLE SCHEMATIC

FIGURE 1.20

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

For the 3 mg/L TIN year-round permit limit, with 11 primary tanks in service, the approximate C/N ratio of the primary effluent is above 5 without carbon supplement. It was found that a small amount of carbon supplement was still required to bring effluent TIN under the 3 mg/L limit with all of the primary tanks in service.

Based on the calibrated Biotran and BioWin models and an assumed aerobic SRT of 9 days, the secondary effluent scenario for 8 mg/L TIN during the summer months can be met by reducing the maximum summer month flow capacity to 47 mgd, and by reducing the maximum month BOD_5 capacity to loading of approximately 65,000 ppd.

The resulting BOD_5 capacity represents approximately 34 percent of the total projected loading to the WPTP for the design year flow. Additional plant capacity for the remainder of the summer season in the design year (92 mgd maximum month flow, and 129,000 ppd maximum month BOD_5, would need to be provided through process expansion). This will be addressed in the subsequent chapter.

Table 1.6 summarizes the modeling results for this scenario. In addition to offsetting the flow and BOD_5 capacity lost in the conversion to nutrient removal, the following modifications would be needed to the existing WPTP to meet the TIN limit of 8 mg/L:

- Addition of mixers in the first stage of the existing HPO tanks;
- Addition of MLR pumps capable of delivering 300 percent of the influent flow (900 mgd);
- Addition of methanol (or other carbon source) delivery system and methanol storage (for peak demands);
- Replacement of the existing HPO aeration system with fine bubble diffusers in the second through fourth stages of the existing HPO tanks and low pressure air blowers.

Table 1.6	Design Data for Existing Capacity for 8 mg/L TIN Summer Permit West Point Nitrogen Removal Study King County Department of Natural Resources and Parks

Parameter	Value
Design Maximum Summer Month Flow, mgd	47
Design Maximum Month Summer BOD_5 Loading, ppd	65,000
Primary Sedimentation	
Number of Tanks in Service	9
Overflow Rate, gpd/sf	1,624
BOD_5 Removal, %	41
Aeration Basins	
Aeration Basins in Service	6
Unaerated Fraction	25%
RAS Rate	69%
MLR Rate	300%
MLSS Concentration, mg/L	2,840
Aeration Air Requirement, cfm	13,050
Methanol Feed, gpd	600
Secondary Sedimentation	
Secondary Clarifiers in Service	12
Secondary Effluent, mg/L	
Ammonia	0.11
Nitrate	5.05
Nitrite	0.04
TIN	5.2

1.5.3.2 Capacity with Expanded Process Tanks

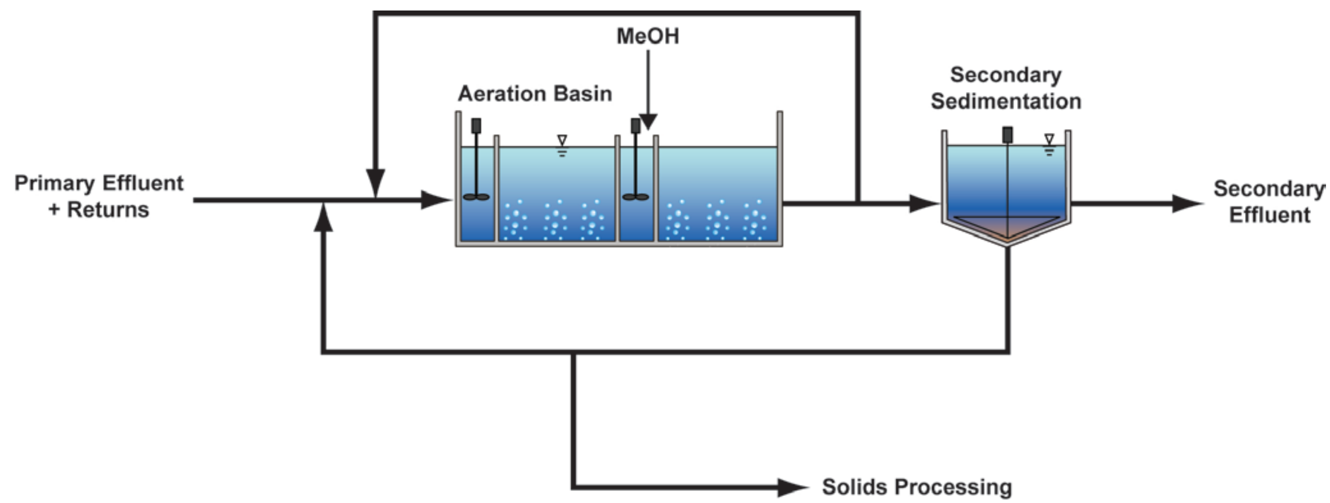
The prior analysis assumed that only existing tank volumes would remain in service when converting to nitrogen removal. The capacity of the WWTP with expanded HPO/secondary sedimentation tanks according to the design build-out plan was also evaluated; namely addition of two more HPO tanks and two more secondary clarifier tanks. Design data for build-out expansion are shown in Table 1.7. In this case the maximum month capacity of the WPTP for summertime nitrogen removal (8 mg/L TIN) would be for approximately 61 mgd and 85,000 ppd BOD_5.

Table 1.7	Design Data for Build-out Capacity for 8 mg/L TIN Summer Permit West Point Nitrogen Removal Study King County Department of Natural Resources and Parks
Parameter	**Value**
Design Maximum Summer Month Flow, mgd	61
Design Maximum Month Summer BOD_5 Loading, ppd	85,000
Primary Tanks	
Number of Tanks in Service	12
Overflow Rate	1,594
Predicted BOD_5 Removal, %	42
Aeration Basins	
Aeration Basins in Service	8
Unaerated Fraction	25%
RAS Rate	78%
MLR Rate	300%
MLSS Concentration, mg/L	2,940
Aeration Air Requirement, cfm	17,040
Methanol Feed, gpd	777
Secondary Sedimentation	
Secondary Clarifiers in Service	14
Secondary Effluent, mg/L	
Ammonia	0.11
Nitrate	4.85
Nitrite	0.04
TIN	5.0

1.5.4 Modeling Results 3 mg/L TIN (Year round)

For the year round season with a maximum month flow of 215 mgd, the capacity of the existing WPTP process to meet a 3-mg/L TIN permit limit was determined to be approximately 44 mgd and 47,000 ppd of BOD_5.

This rating is based on calibrated Biotran and BioWin models with an assumed aerobic SRT of 16 days, and assumes all aeration basins in service and one secondary clarifier out of service. For this scenario the HPO tanks would be converted to operate in the Bardenpho configuration shown in Figure 1.21, a process that incorporates both pre-anoxic and post-anoxic denitrification. It was assumed that the first stage would be unaerated, the second and third stages would be aerated, 60 percent of the fourth stage would be unaerated, and 40 percent of the fourth stage would be aerated. This configuration would produce a total unaerated fraction of 40 percent.



BARDENPHO SCHEMATIC

FIGURE 1.21

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WEST POINT NITROGEN REMOVAL STUDY

The resulting capacity represents approximately 20 percent of the projected future flow and loading capacity. Additional plant capacity for the remainder of the design year (171 mgd maximum month flow, and 182,000 ppd maximum month BOD_5, would be needed through process expansion). This will be addressed in the subsequent chapter.

Table 1.8 summarizes the modeling results for this scenario. In addition to offsetting the flow and BOD_5 capacity lost in the conversion to nutrient removal, the following modifications would be needed to the existing WPTP to meet the TIN limit of 3 mg/L:

- Additional baffle walls in the fourth stage of the existing HPO basins;
- Addition of mixers to the first and fourth stages of the existing HPO basins;
- Mixed liquor return pumps capable of delivering 400 percent of the influent flow (1,200 mgd);
- Methanol delivery system and methanol storage (for peak needs);
- Conversion of the existing HPO delivery system to a system of fine bubble diffusers and low pressure air blowers.

Table 1.8 Design Data for Existing Capacity for 3 mg/L TIN Year Round Permit
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks

Parameter	Value
Design Maximum Summer Month Flow, mgd	44
Design Maximum Month Summer BOD_5 Loading, ppd	47,000
Primary Sedimentation	
Number of Tanks in Service	11
Overflow Rate, gpd/sf	1,882
BOD_5 Removal, %	36
Aeration Basins	
Aeration Basins in Service	6
Unaerated Fraction	40%
RAS Rate	54%
MLR Rate	500%
MLSS Concentration, mg/L	3,500
Aeration Air Requirement, cfm	8,460
Methanol Feed, gpd	300
Secondary Sedimentation	
Secondary Clarifiers in Service	12
Secondary Effluent, mg/L	
Ammonia	0.41
Nitrate	1.63
Nitrite	0.13
TIN	2.2

1.5.4.1 Capacity with Expanded Process Tanks

Design data for the case where two more HPO tanks and two more secondary clarifier tanks were added to the WPTP, in accordance with the original expansion plan, are shown in Table 1.9. In this case the capacity of the WPTP for nitrogen removal would be for approximately 61 mgd and 61,000 ppd BOD_5 to meet an 3-mg/L TIN Year-round permit limit.

Table 1.9 Design Data for Build-out Capacity for 3 mg/L TIN Year Round Permit
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks

Parameter	Value
Design Maximum Summer Month Flow, mgd	61
Design Maximum Month Summer BOD_5 Loading, ppd	64,200
Primary Tanks	
Number of Tanks	12
Overflow Rate	1,951
Predicted BOD_5 Removal, %	34
Aeration Basins	
Aeration Basins in Service	8
Unaerated Fraction	40%
RAS Rate	58%
MLR Rate	500%
MLSS Concentration, mg/L	3,500
Aeration Air Requirement, cfm	11,630
Methanol Feed, gpd	0
Secondary Sedimentation	
Secondary Clarifiers in Service	14
Secondary Effluent, mg/L	
Ammonia	0.52
Nitrate	1.41
Nitrite	0.18
TIN	2.1

1.6 CONCLUSIONS

This analysis was initiated based on the Ecology's South Puget Sound Study findings that suggest that the South Puget Sound may have excess nitrogen. The capacity of the WPTP was evaluated, assuming conversion to nitrogen removing processes. A full-plant model was developed and calibrated to operating data collected at the plant. Two effluent nitrogen scenarios were developed representing the anticipated "least stringent" and "most stringent" permitting scenarios. As documented in a separate project memorandum, it was also decided that the capacity rating of the current plant to meet the two target nitrogen effluent scenarios would be determined with all aeration basins in service and one secondary clarifier out of service.

The potential modeled maximum month capacity of the current WPTP to meet the "least stringent" summer effluent limit of 8 mg/L TIN was 47 mgd and 65,000 ppd of influent BOD_5. To meet this effluent limit, modifications would be needed at the current plant including the addition of tank mixers, MLR pumps, a chemical delivery system, and conversion of the existing aeration system from HPO to fine bubble diffused aeration. Major construction at the existing site or at a new site would be needed to treat the remainder of the maximum month summer flow (approximately 92 mgd). Were two reactor tanks and two secondary clarifier tanks added to the current plant, bringing it to the planned build-out WPTP footprint, this influent capacity would increase to approximately 61 mgd and 85,000 ppd BOD_5. In this case, 78 mgd of additional maximum month flow capacity would be needed.

The potential modeled capacity of the current WPTP to meet the "most stringent" year round effluent limit of 3 mg/L TIN was 44 mgd and approximately 47,000 ppd of BOD_5. To meet this effluent limit, modifications would be needed at the current plant including the addition of mixers and baffle walls, MLR pumps, a chemical delivery system, and replacement of the existing HPO aeration system with a system of fine bubble diffused aeration. Major construction at the existing site or at a new site would be needed to treat the remainder of the maximum month flow (approximately 173 mgd). If the plant were expanded to its planned build-out plant footprint, the nitrogen removal capacity would be increased to approximately 61 mgd and 64,000 ppd of BOD_5. In this case, 156 mgd of additional maximum month flow capacity would be needed.

WEST POINT NITROGEN REMOVAL SCENARIOS

2.1 INTRODUCTION AND SUMMARY OF FINDINGS

Chapter 1 described project assumptions and evaluated how much flow the existing West Point Treatment Plant (WPTP) could process if required to comply with a summer seasonal limit of 8-milligrams per liter (mg/L) total inorganic nitrogen (TIN) or an annual limit of 3-mg/L TIN. This chapter describes potential effects on the WPTP (e.g., tankage, footprint, cost) if it were required to meet the assumed seasonal or year round limit while maintaining its current rated capacity (215-million gallons per day (mgd) max month year round and 110-mgd average during summer).

Based on a prior analysis at the STP, three nitrogen (N) removal alternatives were initially selected for evaluation under each assumed permit limit; however none of these alternatives met the goal of providing nitrogen removal capacity within available land area on the WPTP site. Therefore, three additional treatment schemes were developed. Of these additional strategies, two strategies met the goal of providing nitrogen removal within available land area, although each required abandonment of significant existing assets at the WPTP. Two representative alternatives, one each for the seasonal limit and annual limit, were subsequently selected for a more detailed cost estimate and sensitivity analysis. The cost estimates are considered to be order of magnitude estimates, i.e., in the +50 to -30 percent accuracy range. It should be noted that a representative alternative is the approach that best met the weighted evaluation criteria developed for each nitrogen removal scenario. It is intended to be an approach by which the costs and effects of implementing nitrogen removal at WPTP may be assessed, and may or may not be viable pending more detailed analysis.

2.2 ALTERNATIVES SCREENING

2.2.1 Broad-range Nitrogen Removal Alternatives

Essentially all of the nitrogen influent to the WPTP enters the plant in the reduced form of ammonia and organically bound nitrogen. The maximum month summer concentration of total Kjeldahl nitrogen (TKN – the sum of the ammonia and organic nitrogen species in the wastewater) for the WPTP was 41 mg/L in 2009. To meet an 8-mg/L TIN limit would require removal of in excess of 80 percent of the influent nitrogen. Similarly, the average annual concentration of TKN for 2009 was approximately 30 mg/L. To meet a 3-mg/L TIN limit would require removal of in excess of 90 percent of the influent nitrogen during a maximum month of loading.

Table 2.1 summarizes four different classes of broad-range nitrogen removal alternatives that were considered in the South Plant Nitrogen Removal Study (Carollo, 2010).

Table 2.1 Broad Range Nitrogen Removal Alternatives West Point Nitrogen Removal Study King County Department of Natural Resources and Parks			
Land Based	**Aquatic**	**Chemical**	**Biological**
Infiltration Basins	Wetlands	Ion Exchange	Suspended Growth
Overland Flow	Wetlands	Ion Exchange	Hybrid
Spray Irrigation	Floating Aquatic Plants	Crystallization	Fixed film
		Breakpoint Chlorination	Side Stream

In the South Plant study it was decided that biological treatment alternatives were most likely to be able to meet effluent permit requirements economically and with a relatively small footprint. These alternatives were further narrowed to the following four biological treatment scenarios for each permit target:

- 8 mg/L Summer-only TIN
  - Modified Ludzak-Ettinger (MLE) process
  - Parallel MLE/membrane biological reactor (MBR) process
  - Parallel MLE integrated fixed-film activated sludge (IFAS) process
  - Post-secondary biological aerated filter (BAF)/denitrifying filter (DNF) process
- 3 mg/L Year round TIN
  - Bardenpho process
  - Parallel Bardenpho/MBR process
  - Parallel Bardenpho IFAS process
  - Post-secondary BAF/DNF process

For the WPTP it was concluded as part of the project scoping process that the first of these alternatives (MLE or Bardenpho conversion) would not be feasible because of the very limited land area available for future expansion on the WPTP site. Therefore, initial alternatives for the WPTP were limited to the last three of these alternatives:

- 8 mg/L Summer-only TIN
  - Parallel MLE/MBR process
  - Parallel MLE IFAS process
  - Post-secondary BAF/DNF process
- 3 mg/L Year round TIN
  - Parallel Bardenpho/MBR process
  - Parallel Bardenpho IFAS process
  - Post-secondary BAF/DNF process

General descriptions of the MLE, Bardenpho, IFAS, BAF, and DNF processes were included in the South Plant Nitrogen Removal Study (Carollo 2010).

2.2.2 Initial Alternatives Evaluation

The following section discusses evaluation of initial nitrogen removal alternatives for the WPTP. For each alternative, side stream treatment was assumed to be necessary to reduce the footprint and cost of the alternative. The three initial alternatives for each nitrogen limit scenario were evaluated to determine a relative cost and footprint for each alternative.

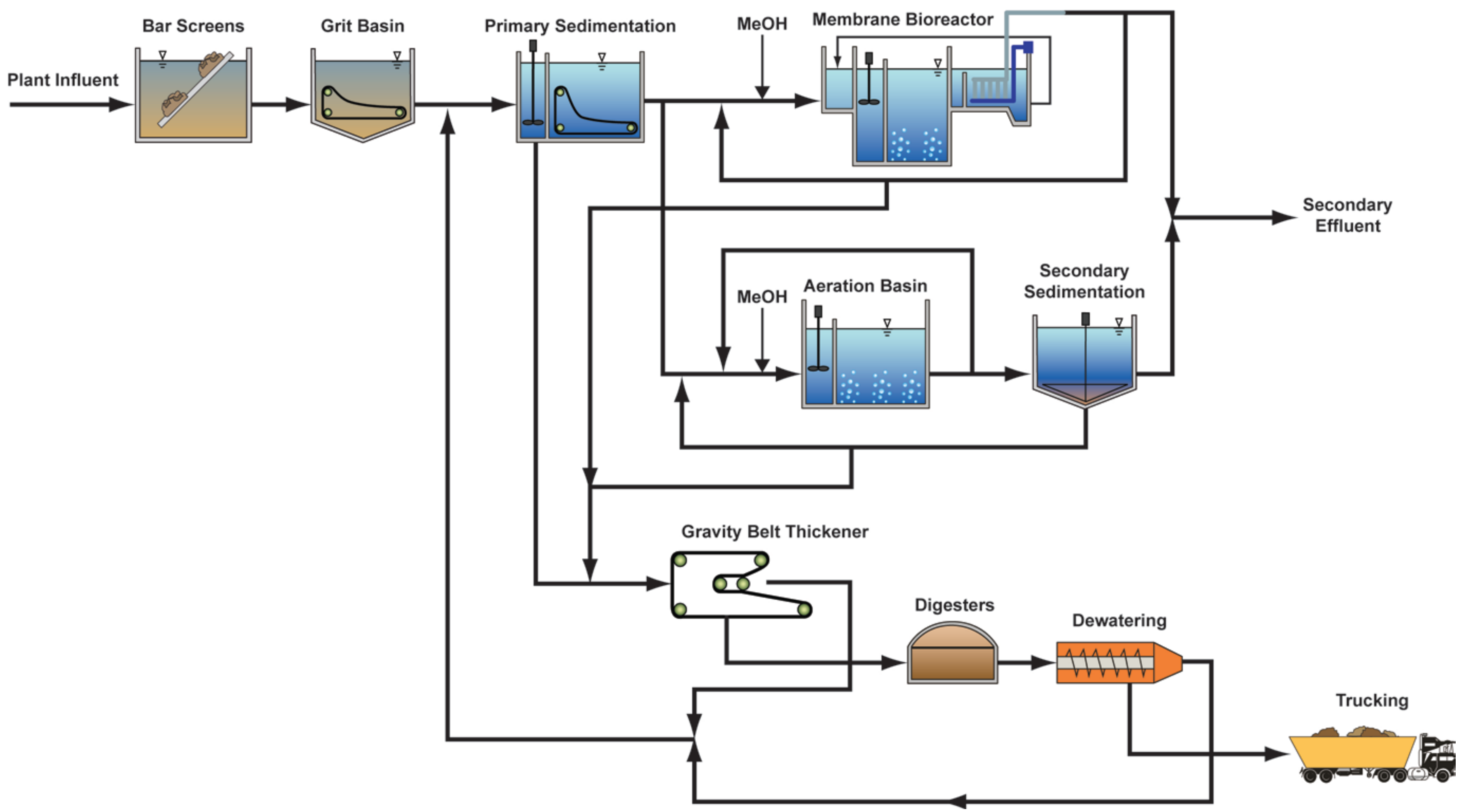
2.2.2.1 8 mg/L TIN (Summer only) Permit Scenario

2.2.2.1.1 *MLE/MBR Alternative*

A schematic of the MLE/MBR alternative is presented in Figure 2.1. In this alternative existing high purity oxygen (HPO) tanks would be modified for nitrogen removal by constructing baffles and installing internal recirculation pumping. As discussed in Chapter 1, evaluation of nitrogen removal alternatives at the WPTP assumed replacement of the HPO aeration system with a diffused aeration system. For each of the suspended growth alternatives (MLE and MBR) evaluated under the 8 mg/L TIN (summer-only) scenarios, it was assumed that the aeration basins would operate with a 9-day aerobic SRT during maximum summer month flows (139 mgd), with all basins in service. Additionally, it was assumed that new aeration tanks would be the same dimensions as the current HPO tanks.

As discussed in Chapter 1, the capacity of the existing tankage for nitrogen removal is for a maximum month flow of approximately 47 mgd. The remainder of the design summer primary-treated secondary influent flow would be treated by a MBR process operated in parallel to the existing treatment process. This alternative provides treatment of 92 mgd by MBR, requiring two reactor tanks equivalent in size to the existing HPO tanks and two membrane tanks with a total volume of approximately 8 million gallons (MG). In addition, space would be required for membrane cleaning equipment and new aeration blowers. Significant, space would also be needed for internal piping to transport recirculation flows of 1,200 mgd.

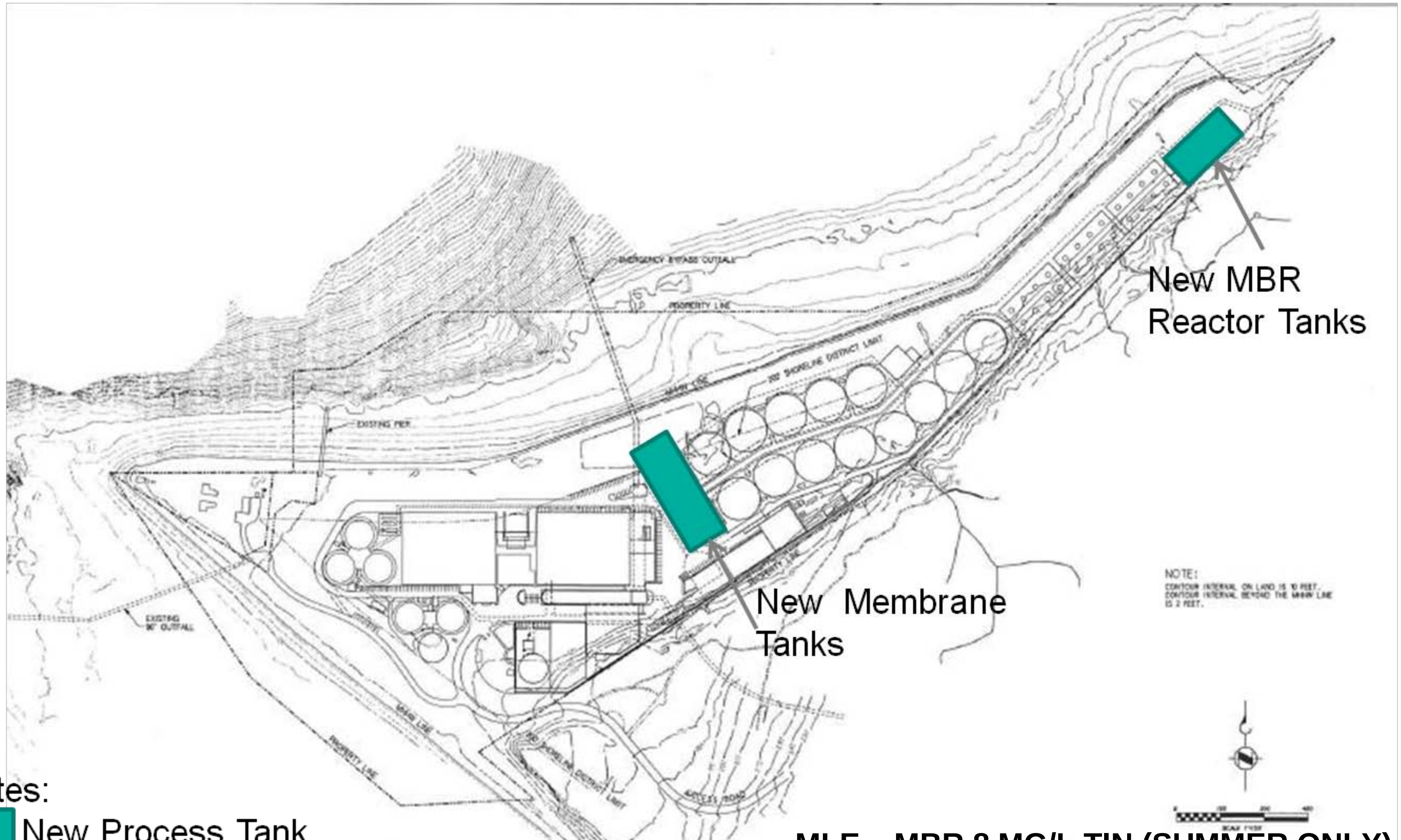
This would require a single pipeline, 22 feet in diameter, or multiple smaller pipes. A schematic site plan for this alternative is shown in Figure 2.2. The figure illustrates that this alternative would not fit at the WPTP.



8 MG/L TIN SUMMER-ONLY - PARALLEL MLE / MBR SCHEMATIC DIAGRAM

FIGURE 2.1

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:

New Process Tank

Existing HPO would be converted to air activated sludge and operated in MLE mode during the summer season. Existing secondary clarifiers would be retained.

MLE – MBR 8 MG/L TIN (SUMMER ONLY) SCHEMATIC SITE PLAN

FIGURE 2.2

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

2.2.2.1.2 *MLE - IFAS Alternative*

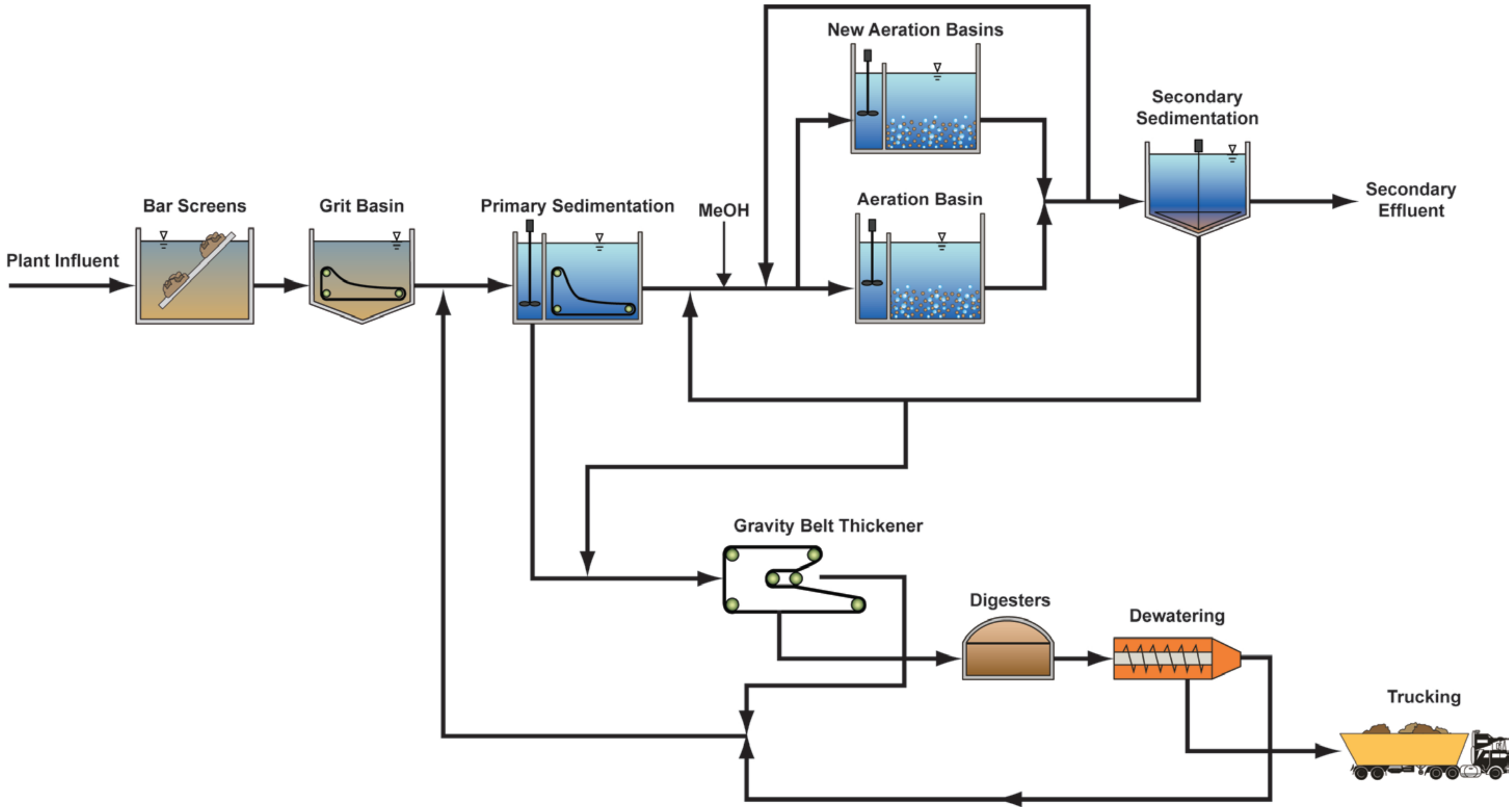
A schematic of the MLE-IFAS alternative is presented in Figure 2.3. In this alternative existing HPO tanks would be converted for anoxic/aerobic treatment by the MLE process with free-floating IFAS media installed in the aerobic portions of the tank. It was assumed that existing tankage would be converted to fine bubble aeration in the aerobic portions of the tank with new IFAS media and media control screens installed in the tank. For this study process sizing was obtained from Kruger, Inc. for an installation using Kaldnes freely-suspended media. The information assumed a total of 33.75 MG of combined anoxic and aerobic IFAS tank volume for the winter condition with a temperature of 12 degrees Centigrade, but with a MLSS concentration of 4,000 mg/L. To keep the secondary clarifiers from failing at 300 mgd secondary treatment flow, however, a maximum MLSS concentration of approximately 1,800 mg/L would be required during the summer season.

Tank sizing for an IFAS system, based on the Kruger information, would need to be almost 75 MG or 32 tanks of a size equivalent to the existing HPO tanks, with 26 of those tanks being new construction. Kruger did not estimate required tank size for the summer condition of 17 degrees C. It was estimated that approximately 18 additional IFAS-equipped aeration basins would be required for the summer condition with a volume of 2.35 MG each to meet the 8 mg/L TIN permit limit. As shown in Figure 2.4, this alternative would not fit at the WPTP.

2.2.2.1.3 *BAF/DNF Alternative*

A schematic diagram of the BAF/DNF alternative is presented in Figure 2.5. For this alternative, the existing plant would be operated in the same manner as it is currently operated, resulting in no change in capacity. To achieve the 8 mg/L TIN (summer only) limit post-secondary BAF and DNF units would be added. Sizing was based on having 28 BAF units including two standby units and 20 DNF units including 2 standby units to accommodate maximum month flows of 139 mgd and peak day flows of 300 mgd for this permit scenario. Sizing data was received from one major manufacturer of this equipment. In the manufacturer's sizing, tank size was limited by hydraulic loading rate on the nitrification filters on a maximum day. This sizing produced an ammonia loading rate of approximately 12 pounds per day per thousand cubic foot (ppd/kcf) of filter volume.

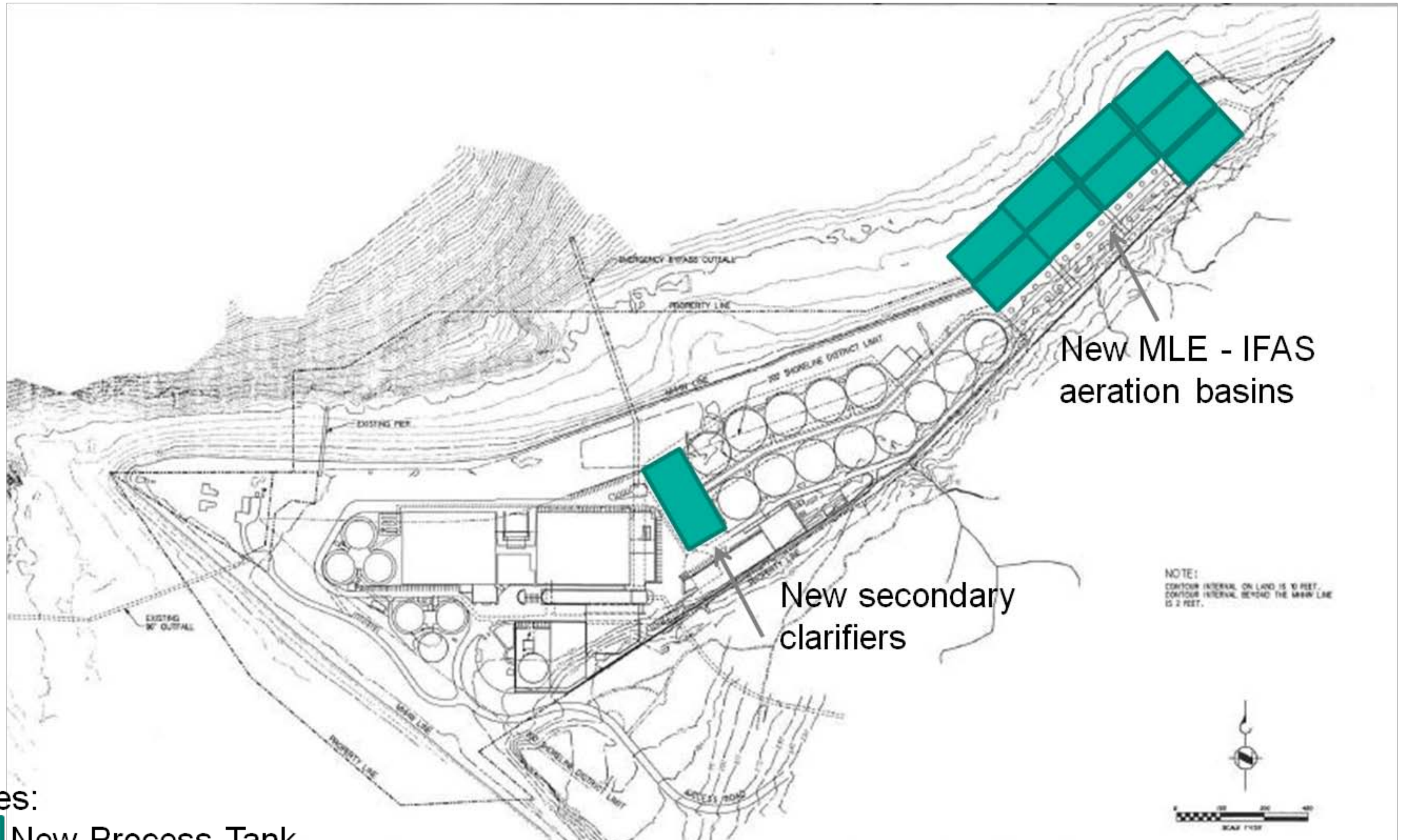
For the denitrification, tanks sizing was based on a maximum day hydraulic loading rate, which led to a nitrate loading of approximately 55 ppd/kcf. Methanol addition would be required prior to the DNF. As is shown in Figure 2.6, this alternative does not fit at the WPTP.



MLE – IFAS SCHEMATIC

FIGURE 2.3

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:

New Process Tank

Existing HPO would be converted to IFAS and operated in MLE mode during the summer season. Existing secondary clarifiers would be retained.

MLE – IFAS SCHEMATIC SITE PLAN

FIGURE 2.4

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

carollo

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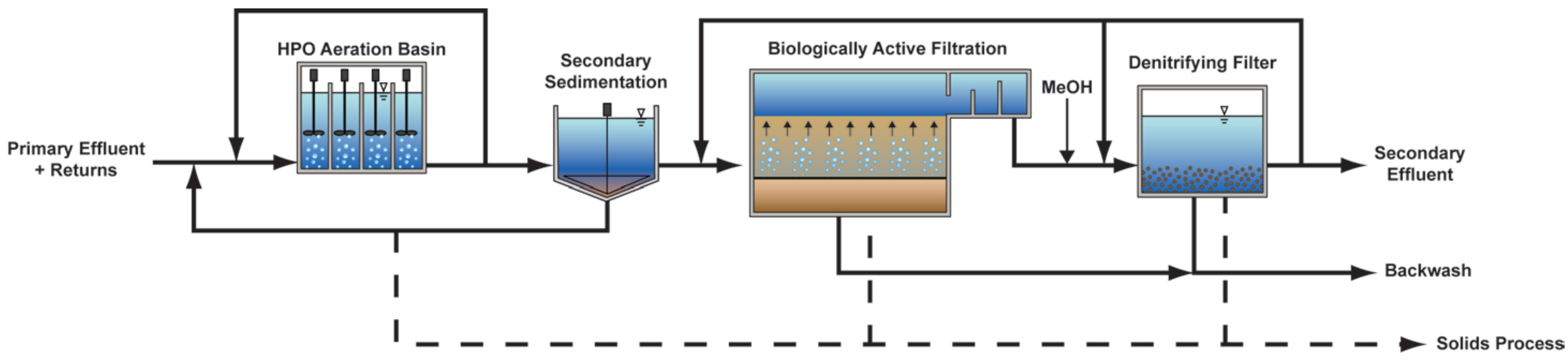
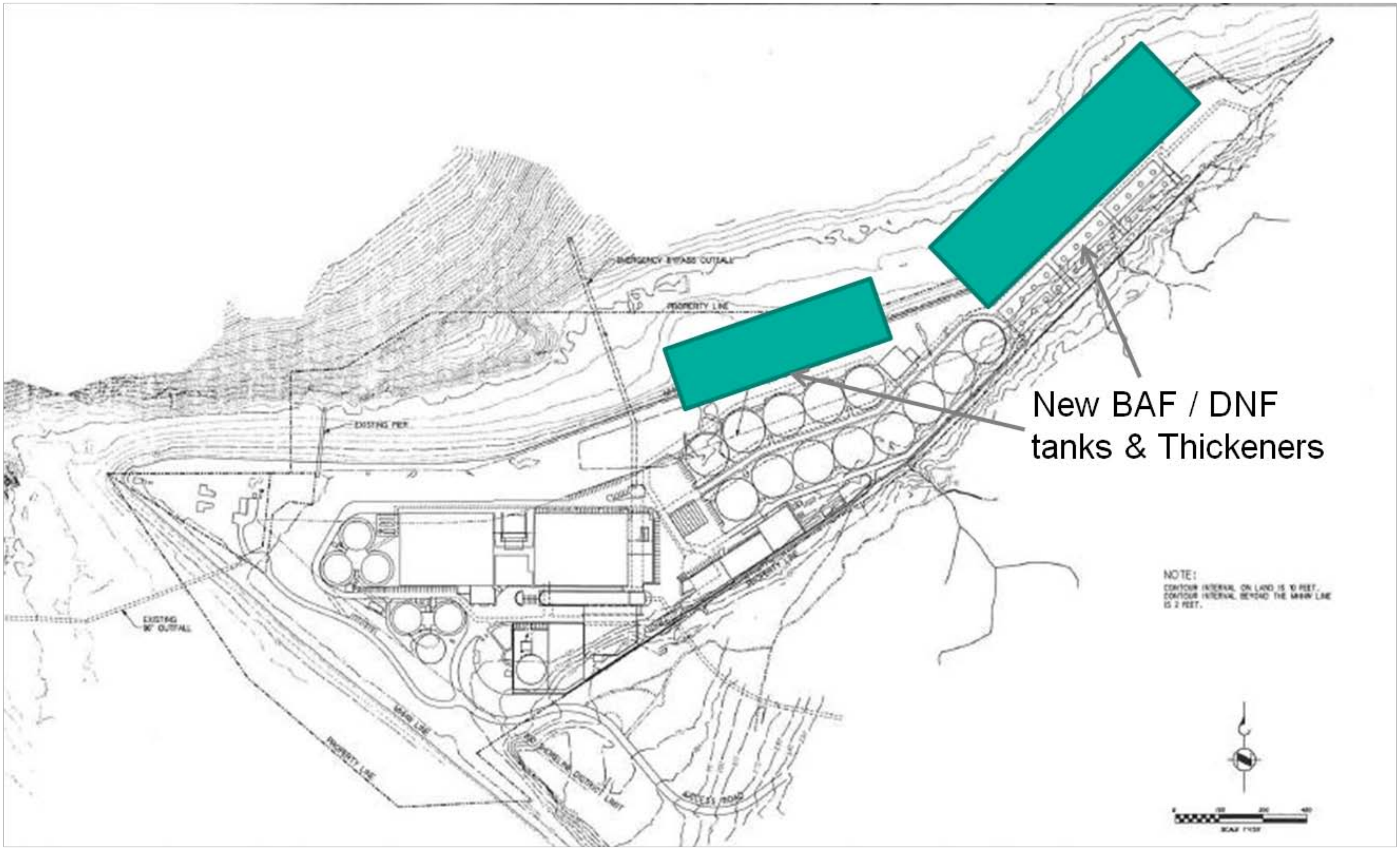


BAF/DNF SCHEMATIC DIAGRAM

FIGURE 2.5

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:

New Process Tank

Continue HPO treatment.

BAF/DNF 8 MG/L TIN (SUMMER ONLY) FOOTPRINT

FIGURE 2.6

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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2.2.2.1.4 *8 mg/L TIN Permit Summary*

Figure 2.7 summarizes the footprint requirements of each alternative. Footprint estimates are primarily for comparative purposes and do not account for some features that can consume footprint such as roads, odor control equipment, chemical feed equipment, and other ancillary equipment. As can be seen from the figure, all three of the alternatives under consideration require more space than is available at the WPTP. As a result, additional alternatives were developed as presented in Section 2.2.3.

2.2.2.2 <u>3 mg/L TIN (Year Round) Scenario</u>

Based on the analysis of alternatives at the STP, the three initial alternatives were developed for the 3 mg/L TIN (year round) Permit scenario:

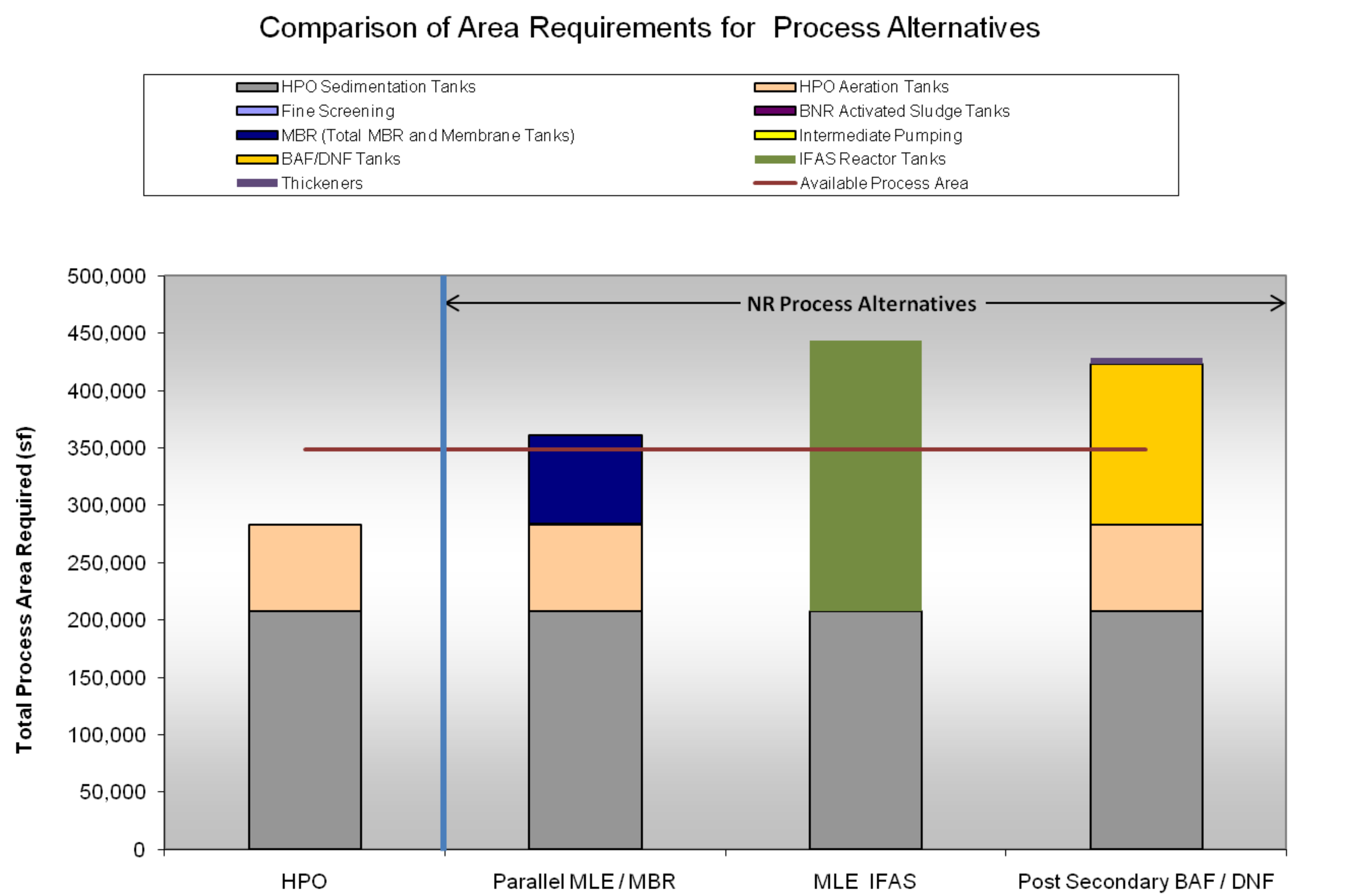
1. Parallel Bardenpho/MBR;
2. Bardenpho IFAS;
3. BAF/DNF.

2.2.2.3 <u>Parallel Bardenpho/MBR</u>

A schematic diagram of the Parallel Bardenpho/MBR alternative is shown in Figure 2.8. This alternative includes two stages of anoxic and aerobic treatment designed for an aerobic solids residence time of 13 days. Existing HPO tanks would be converted by addition of mixers, internal recycle pumping systems, baffle walls, and a new aeration system. New parallel MBR facilities would be built to operate in parallel with the converted existing tanks. New MBR facilities would use the same Bardenpho configuration used for the existing tank conversion, as shown in the schematic. The sizing procedure used for this study resulted in the need for an additional 12 reactor tanks, equal in size to the existing 6 HPO tanks. A schematic site plan is shown in Figure 2.9. It is seen from the site plan that this alternative would not fit at the WPTP.

2.2.2.4 <u>Bardenpho IFAS</u>

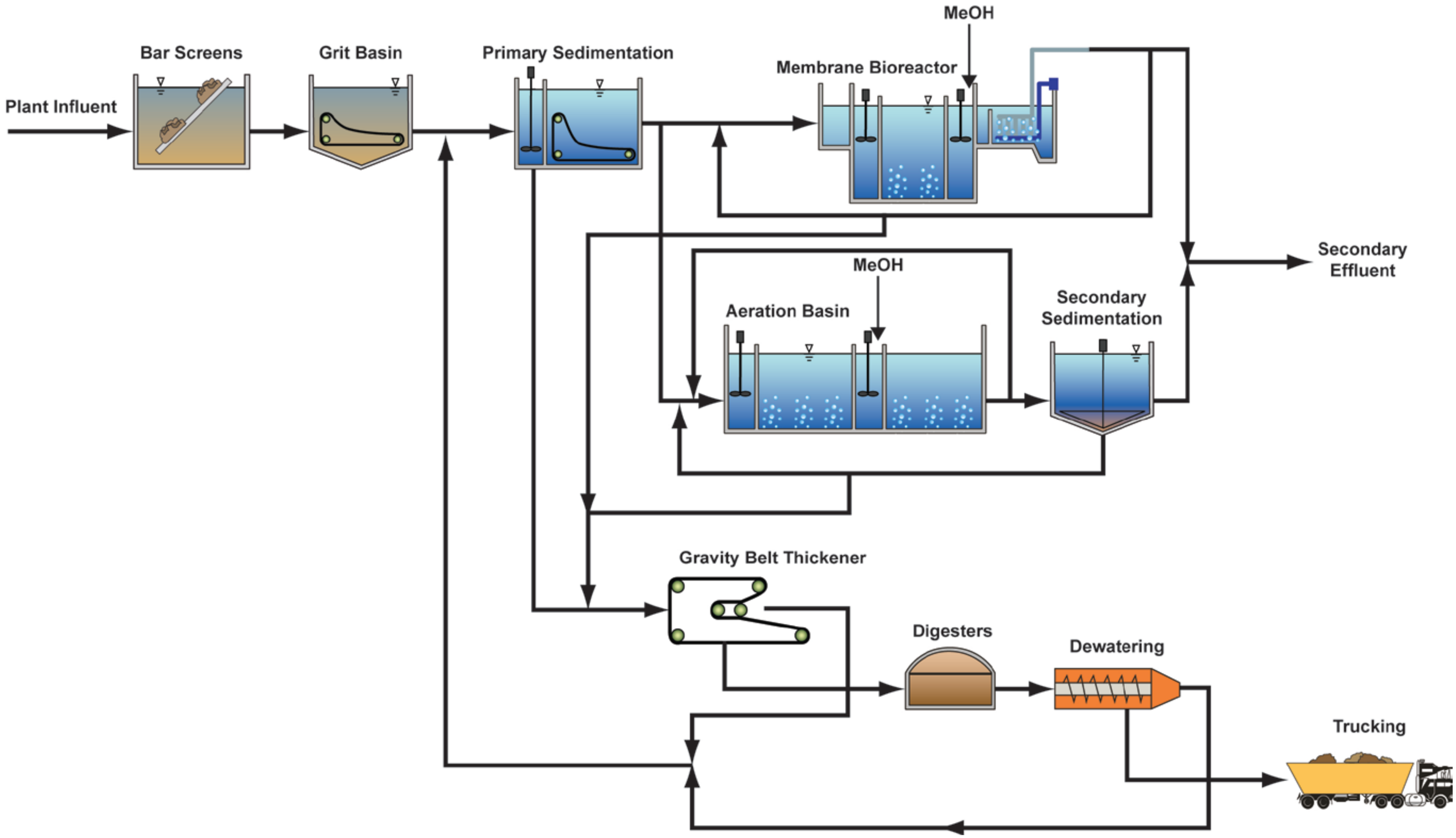
In the Bardenpho-IFAS alternative, the existing aeration basins would be converted to IFAS basins. A schematic diagram of the Bardenpho-IFAS alternative that was considered is shown in Figure 2.10. Process sizing was obtained from Kruger, Inc. for an installation using Kaldnes freely-suspended media. Kruger information indicated a total of 33.75 MG of combined anoxic and aerobic IFAS tank volume for the design winter temperature of 12 degrees Centigrade, but with a MLSS concentration of 4,000 mg/L. To keep the secondary clarifiers from failing at 300 mgd secondary treatment flow, however, a maximum MLSS concentration of approximately 1,400 mg/L would be required for the WPTP.



8 MG/L TIN (SUMMER ONLY) FOOTPRINT COMPARISON

FIGURE 2.7

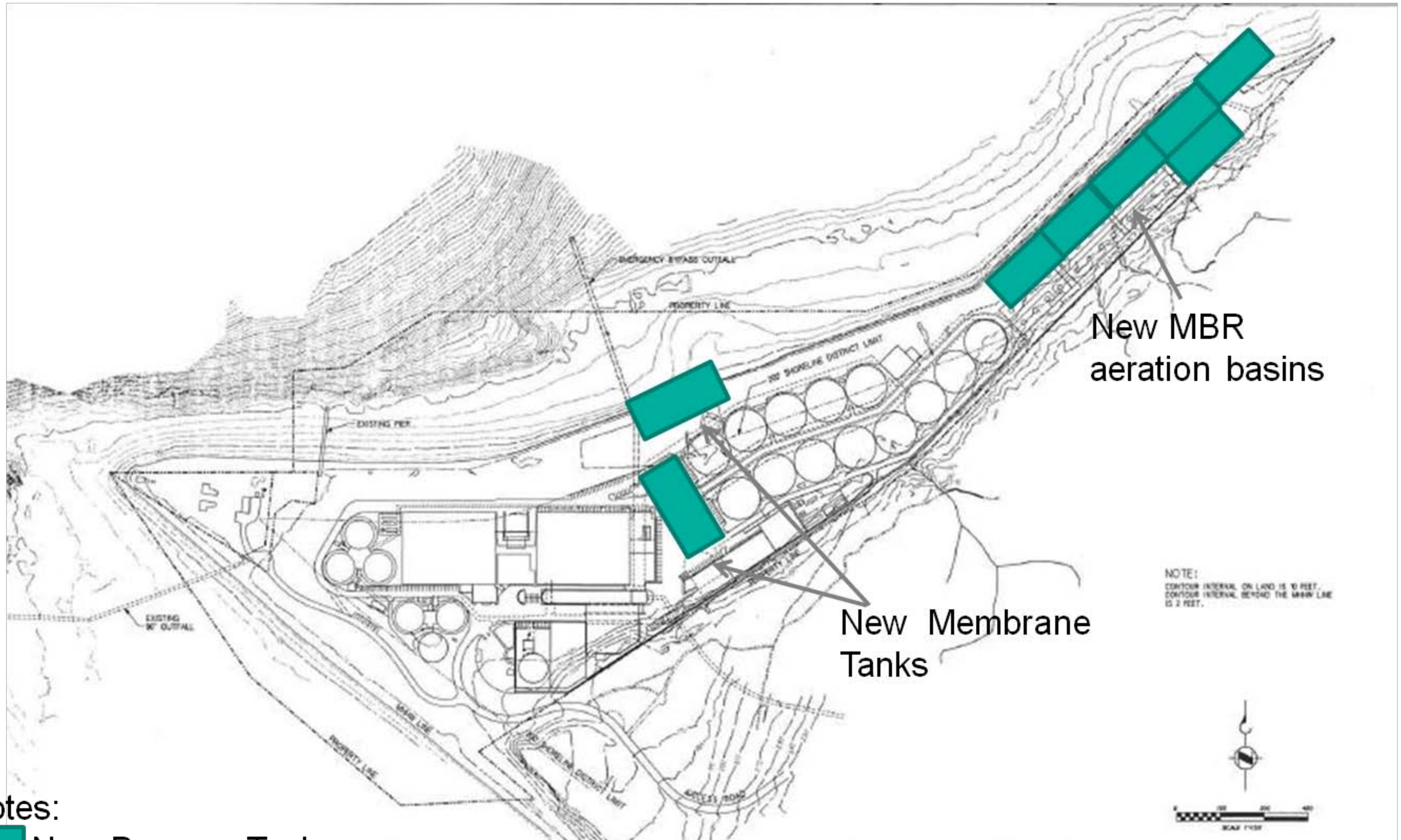
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



PARALLEL BARDENPHO MBR 3 MG/L TIN (YEAR ROUND) SCHEMATIC DIAGRAM

FIGURE 2.8

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:

New Process Tank

Existing HPO would be converted to air activated sludge and operated in Bardedenpho mode year round. Existing secondary clarifiers would be retained.

BARDENPHO-MBR 3 MG/L TIN (YEAR ROUND)
SCHEMATIC SITE PLAN

FIGURE 2.9

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

carollo

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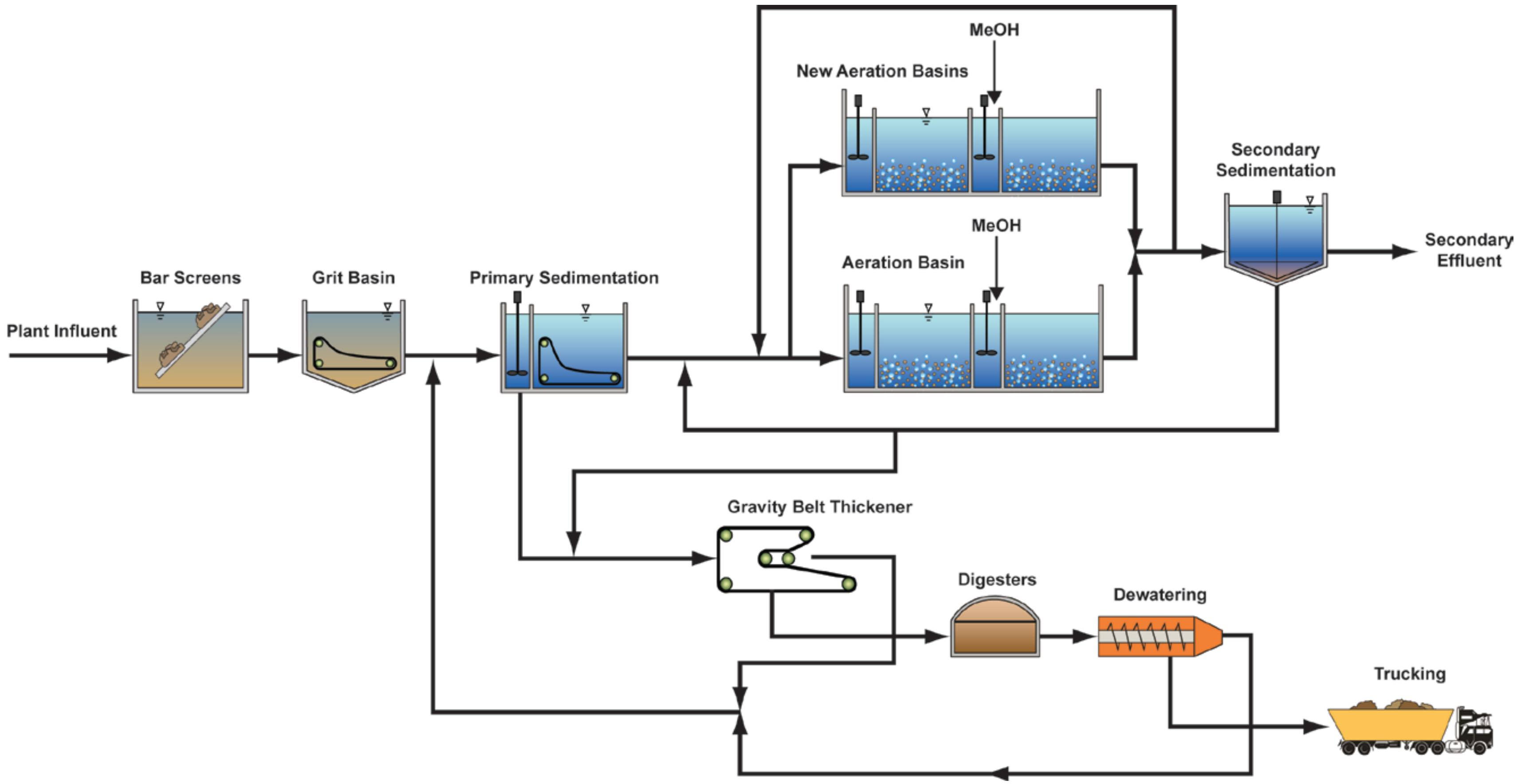

BARDENPHO IFAS 3 MG/L TIN (YEAR ROUND) SCHEMATIC DIAGRAM

FIGURE 2.10

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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Thus tank sizing for an IFAS system for the full-year WPTP design would need to be almost 96 MG, or a total of 41 tanks of the size equivalent to the existing HPO tanks. Thirty-five of those tanks would be new construction. With this sizing, as shown in Figure 2.11, the IFAS alternative would not fit at the WPTP.

2.2.2.5 BAF/DNF

Kruger, Inc. provided information for new BAF/DNF process tanks as described above for the 8 mg/L TIN (summer only) permit scenario. Kruger proposed the same tank volume for the 3 mg/L TIN (year round) permit level as for the 8 mg/L TIN (summer-only) scenario, but with additional carbon required for denitrification. Tank sizing was for 28 nitrification (BAF) tanks and 20 denitrification (DNF) tanks, limited by hydraulic loading, with a total filter area of 72,296 square foot for nitrification and 51,640 sf for denitrification. The process schematic for this alternative would be the same as that shown in Figure 2.5 and the site layout the same as shown in Figure 2.6, which shows that the process would not fit at the WPTP.

2.2.3 Refined Alternatives Evaluation

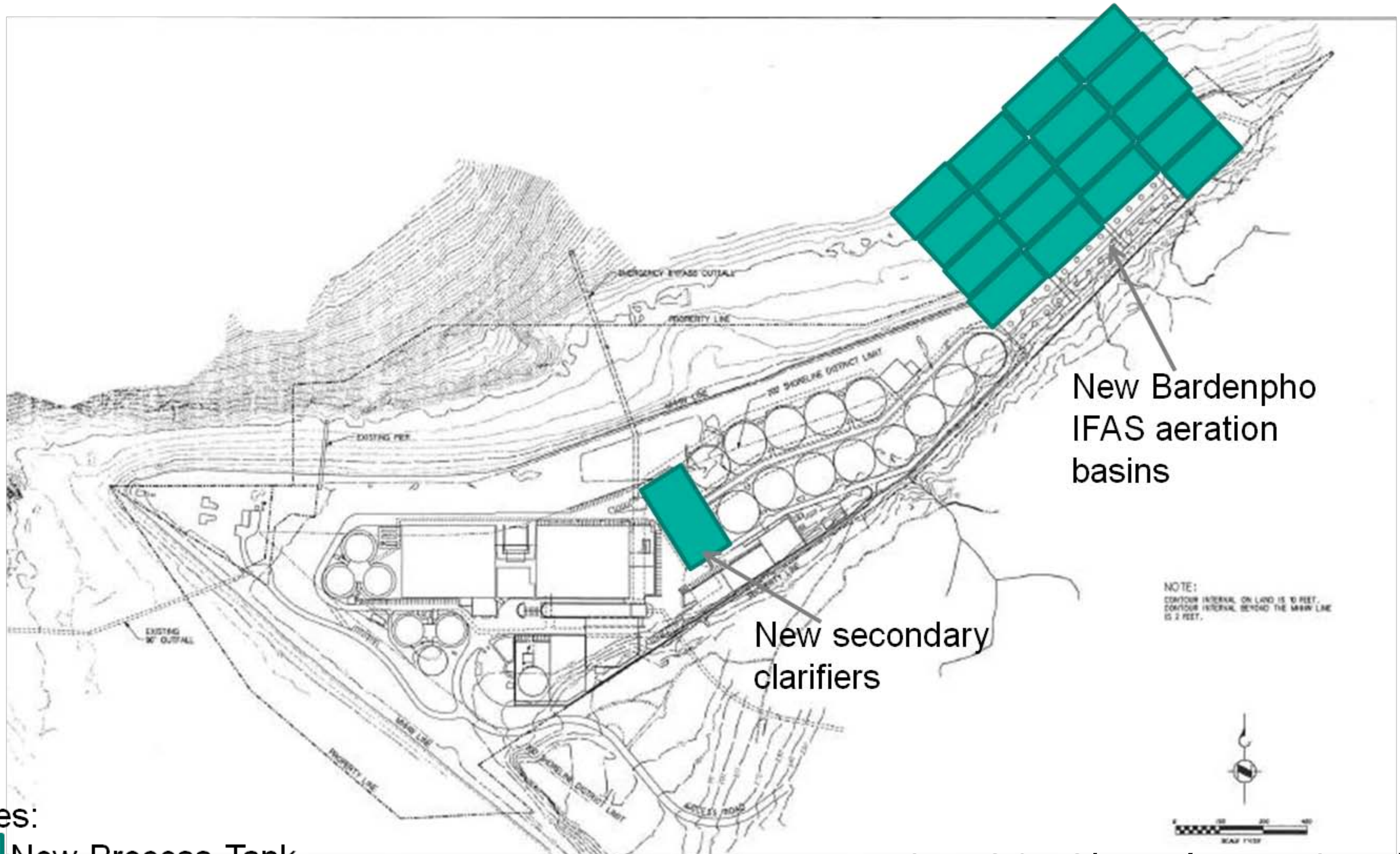
Considering that preliminary alternatives developed for both permit scenarios would not fit at the WPTP, additional alternatives were developed including:

1. Post Secondary MBR;
2. Replacement MBR;
3. Replacement BAF/DNF.

In these alternatives the selection criterion that existing assets at the WPTP be maintained as much as possible was eliminated. In the case of the replacement MBR alternative, it was assumed that existing secondary sedimentation tanks would be removed and replaced by membrane separation equipment in separate tanks. In this alternative the existing HPO tanks would be modified for operation as a Bardenpho process with aeration by atmospheric air. In the replacement BAF/DNF alternative both existing secondary sedimentation tanks and HPO tanks would be replaced by new BAF/DNF tanks.

2.2.3.1 Post-secondary MBR

In this alternative MBR aeration tanks and MBR separation tanks would be added downstream of the existing HPO process for nitrification and denitrification using methanol or another supplemental carbon source. A schematic diagram of required processes to meet an 8 mg/L TIN (summer only) permit level is presented as Figure 2.12. A schematic site plan for this alternative is shown in Figure 2.13. A schematic diagram of required processes to meet a 3 mg/L TIN (year round) permit level is presented as Figure 2.14. A schematic site plan for this alternative is shown in Figure 2.15. As shown in the site plan, this process would not fit at the WPTP site for either permit scenario.



Notes:

New Process Tank

Existing HPO would be converted to IFAS and operated in Bardenpho mode year round. Existing secondary clarifiers would be retained.

BARDENPHO IFAS 3 MG/L TIN (YEAR ROUND)
SCHEMATIC SITE PLAN

FIGURE 2.11

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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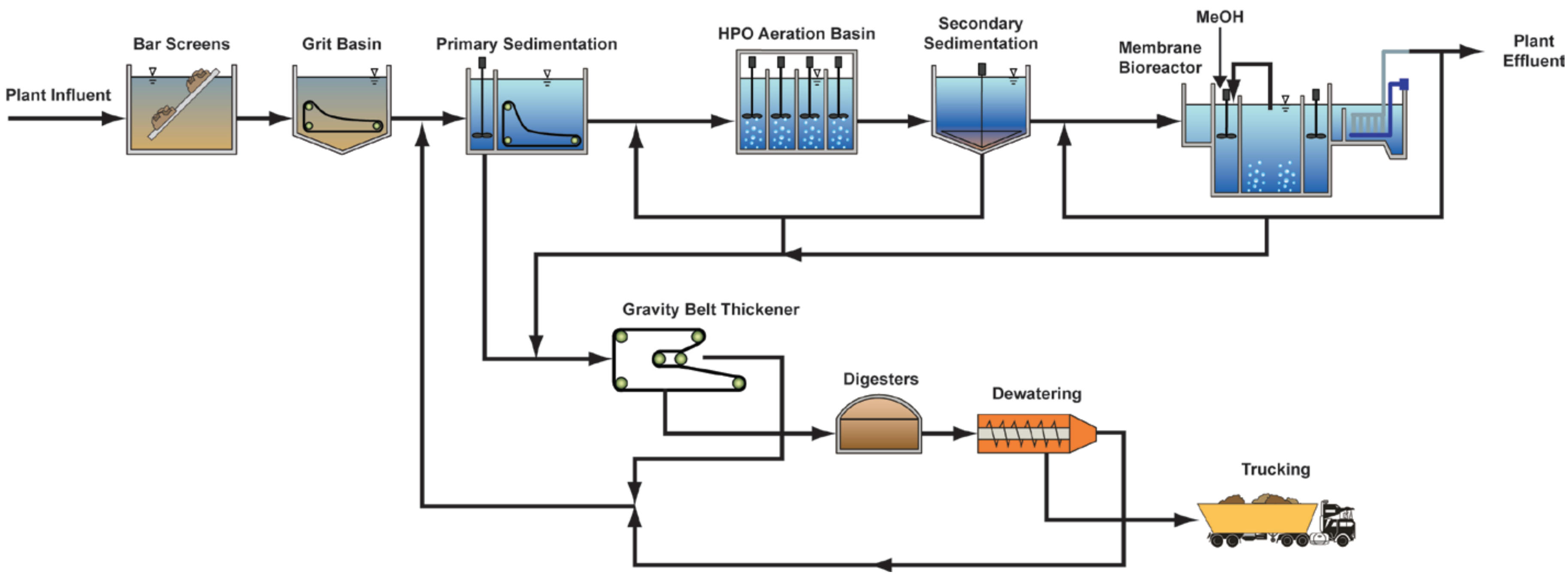
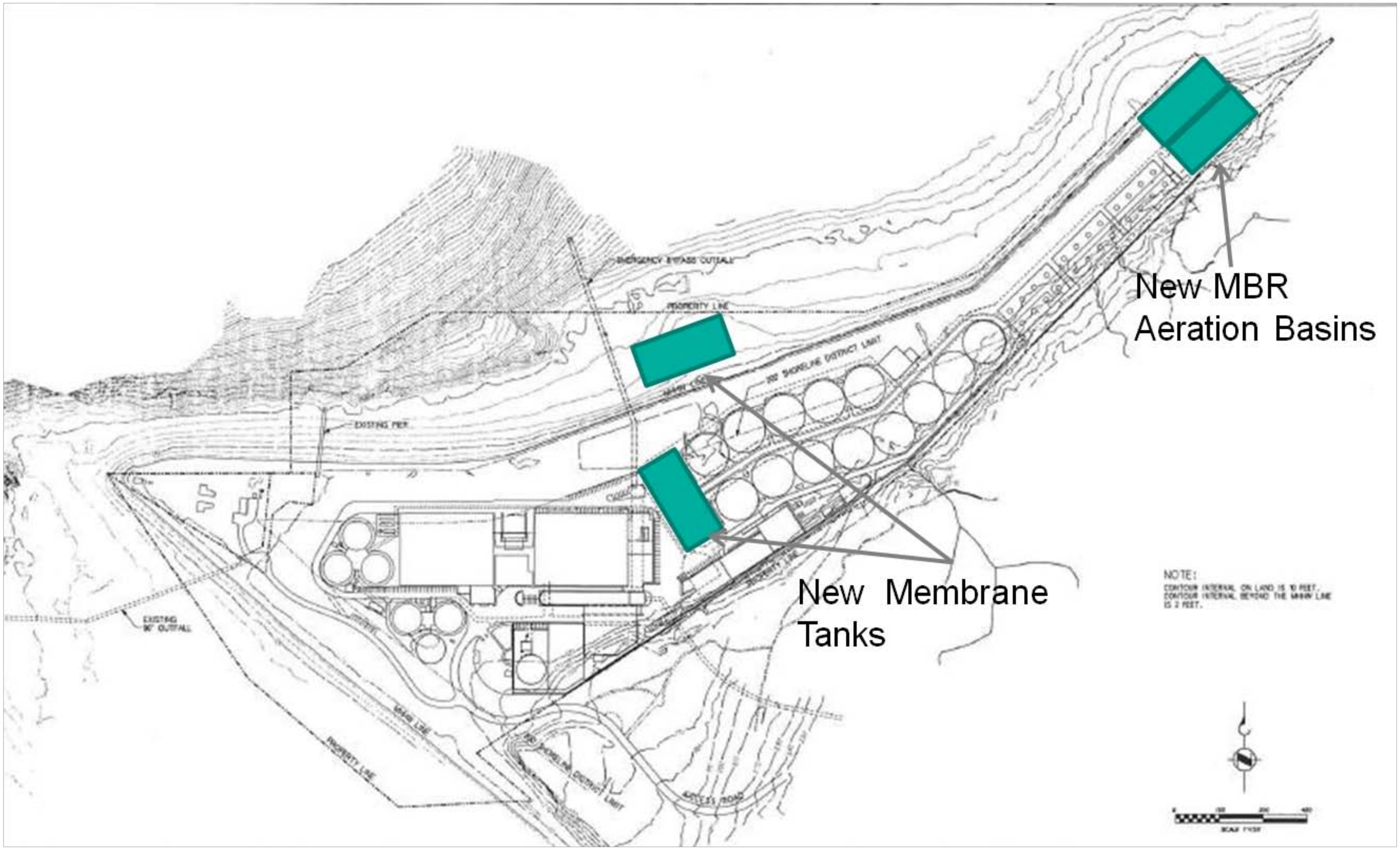


SCHEMATIC DIAGRAM OF THE POST-SECONDARY MBR ALTERNATIVE TO MEET THE 8 MG/L TIN (SUMMER-ONLY) PERMIT

FIGURE 2.12

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:

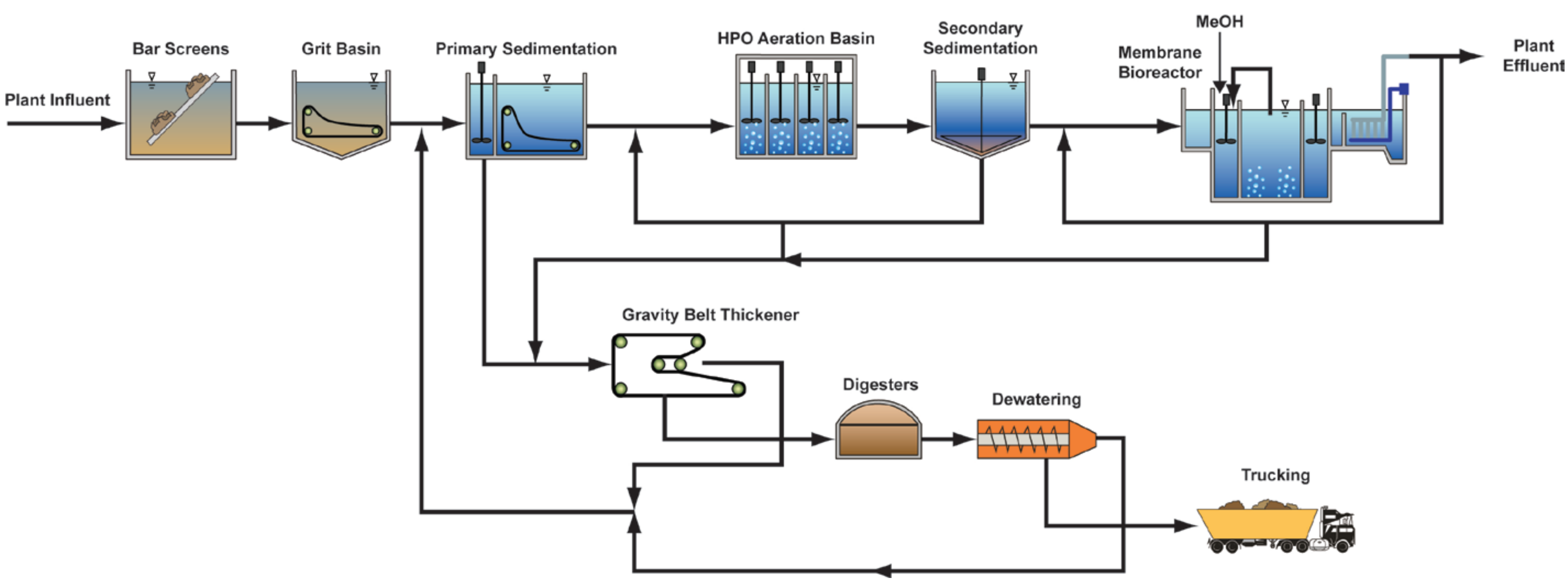
New Process Tank

Continue HPO treatment. Existing secondary clarifiers would be retained.

SCHEMATIC SITE PLAN FOR THE POST-SECONDARY MBR ALTERNATIVE TO MEET THE 8 MG/L TIN (SUMMER-ONLY) PERMIT

FIGURE 2.13

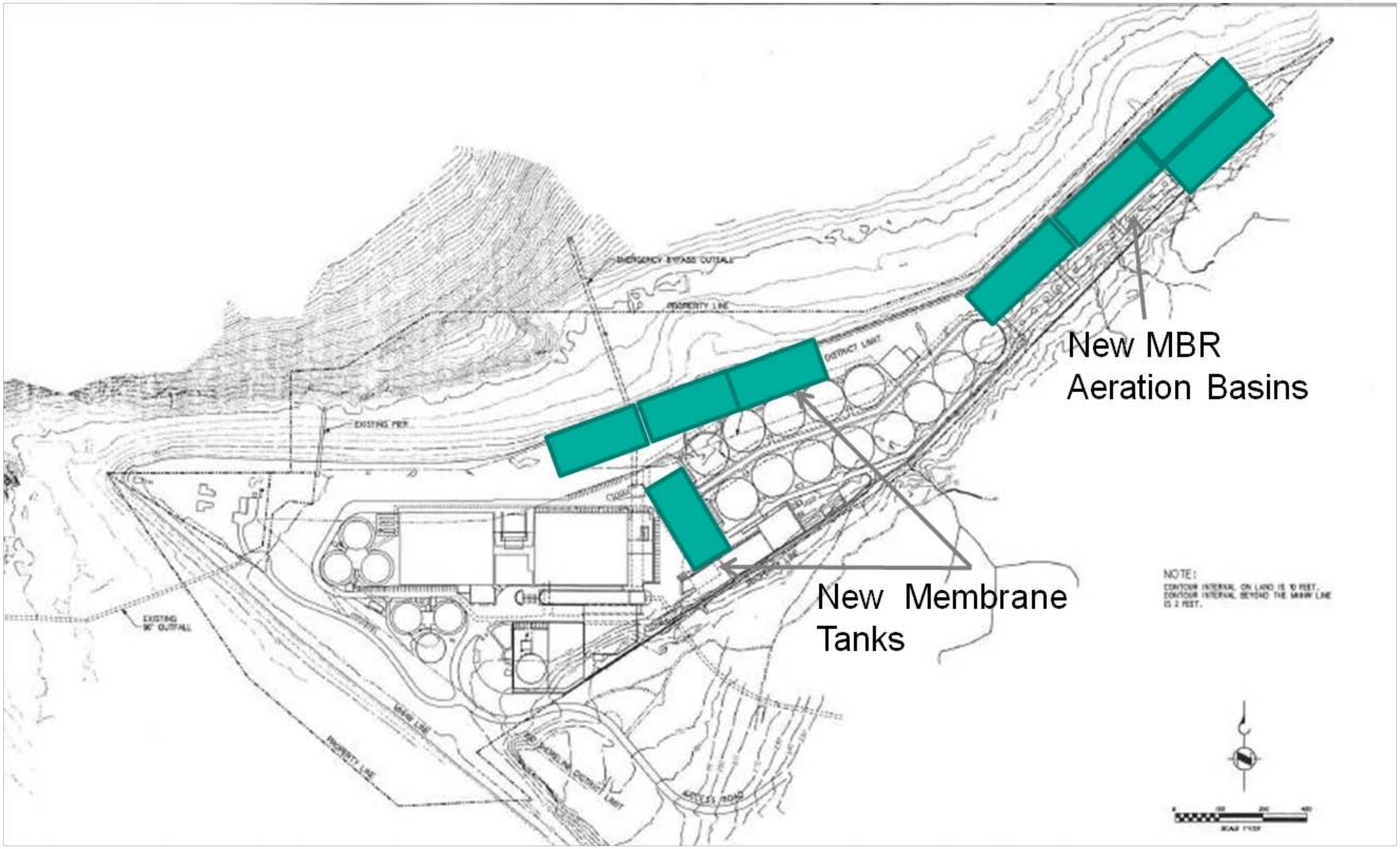
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



SCHEMATIC DIAGRAM OF THE POST-SECONDARY MBR ALTERNATIVE TO MEET THE 3 MG/L TIN (YEAR-ROUND) PERMIT LIMIT

FIGURE 2.14

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



Notes:
New Process Tank
Continue HPO treatment. Existing secondary clarifiers would be retained.

SCHEMATIC SITE PLAN FOR THE POST-SECONDARY MBR ALTERNATIVE TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT LIMIT

FIGURE 2.15

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

2.2.3.2 Replacement MBR

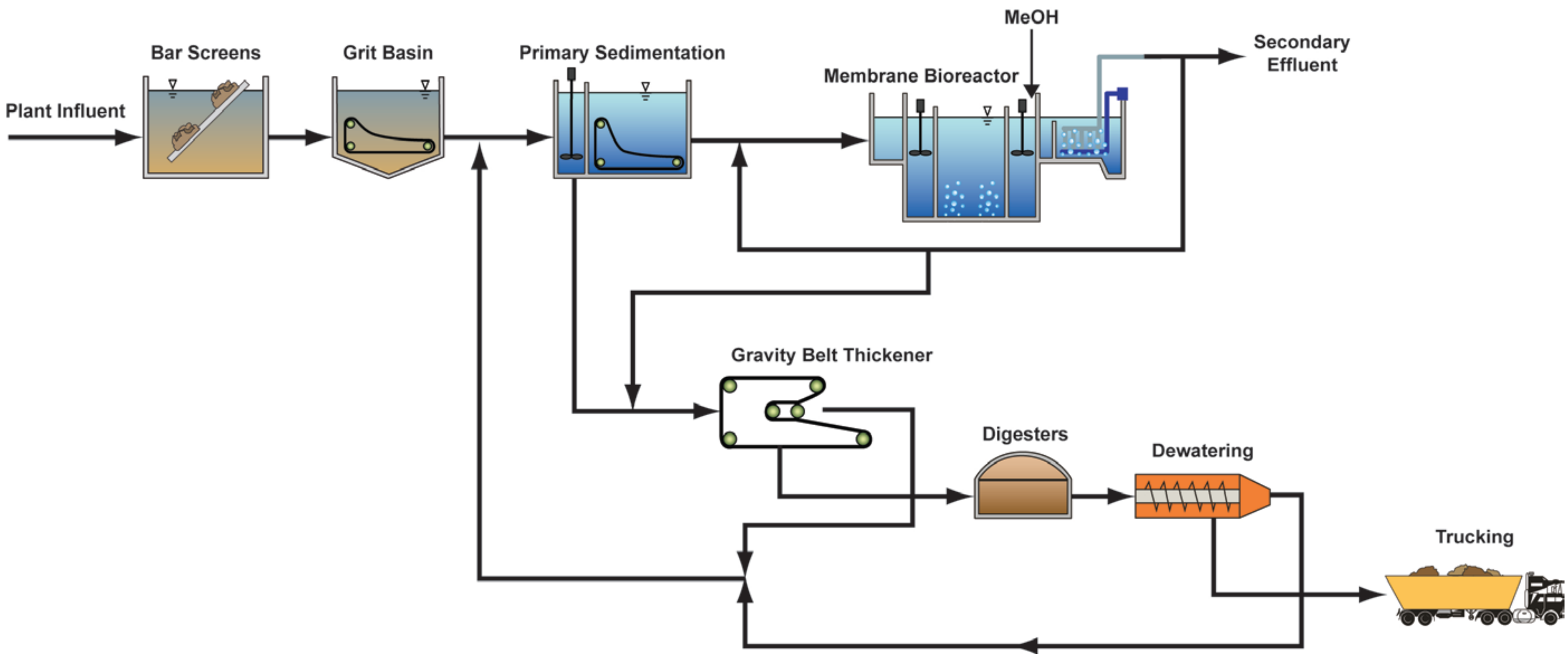
In this alternative existing HPO tanks would be converted to anoxic tanks and aerobic treatment tanks using atmospheric air with addition of internal recirculation to bring nitrate into contact with carbonaceous materials. Tanks would achieve denitrification in the anoxic zones and nitrification in the aerobic zones. Mixing would be required in the anoxic zones for denitrification. Existing secondary sedimentation tanks would be destroyed and replaced by MBR separation tanks. As a result, this strategy would require the WPTP to operate in MBR mode year round, even if the 8 mg/L TIN limits were only applicable in the summer, therefore this strategy was only developed for the year round permit limit scenario.

For a 3 mg/L TIN (year round) permit limit a dual anoxic/aerobic treatment sequence (Bardenpho process) would be required. A schematic diagram for this process is shown in Figure 2.16. A schematic site plan is shown in Figure 2.17 This scenario would sacrifice assets currently in use (secondary clarifiers) but it could potentially be made to fit within the land area available for existing and planned future process units at the WPTP site. Because existing process units would need to remain in service during construction of new units, however, construction sequencing would be extremely challenging for this alternative. New membrane tanks would need to be constructed while a substantial number of existing secondary sedimentation tanks remained in service. This sequence would require extensive flow transfer within the WPTP collection system to minimize flows to the WPTP during construction, which may make this alternative practically infeasible.

2.2.3.3 Replacement BAF/DNF

In this scenario BAF and DNF tanks would be constructed in place of existing HPO tanks and secondary sedimentation tanks. The entire asset base for secondary treatment at the WPTP would be demolished. Because the waste biosolids from the BAF and DNF processes is typically much more dilute than the waste activated sludge from the HPO process, implementation of the BAF/DNF process on the WPTP would require additional biosolids thickening prior to further solids handling.

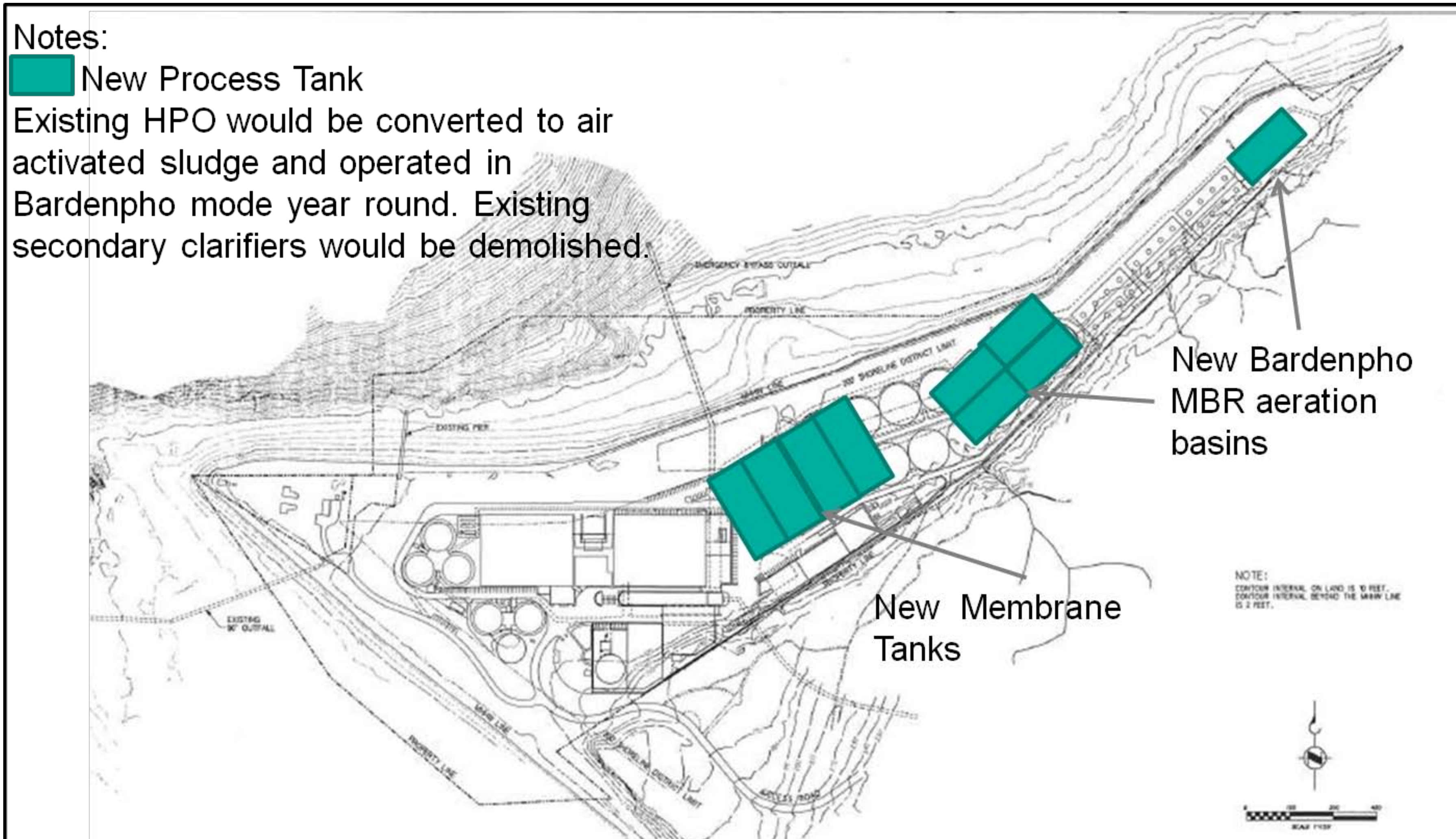
Figure 2.18 presents a process schematic for the BAF/DNF process at the WPTP. Implementation of this process at the WPTP would require construction of clearwell tanks for backwash storage, backwash tanks, and multiple pumping systems for the entire WPTP process flow. A schematic site plan for the BAF/DNF process at the WPTP is shown in Figure 2.19. It appears that this process alternative may theoretically fit within the available process area of existing and future planned process tanks. However, construction sequencing requirements for this alternative would be even more severe than for the MBR replacement alternative since HPO tanks would need to be demolished in addition to secondary sedimentation tanks and would not be available for interim secondary treatment during the construction period.



SCHEMATIC DIAGRAM OF THE REPLACEMENT MBR ALTERNATIVE TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT LIMIT

FIGURE 2.16

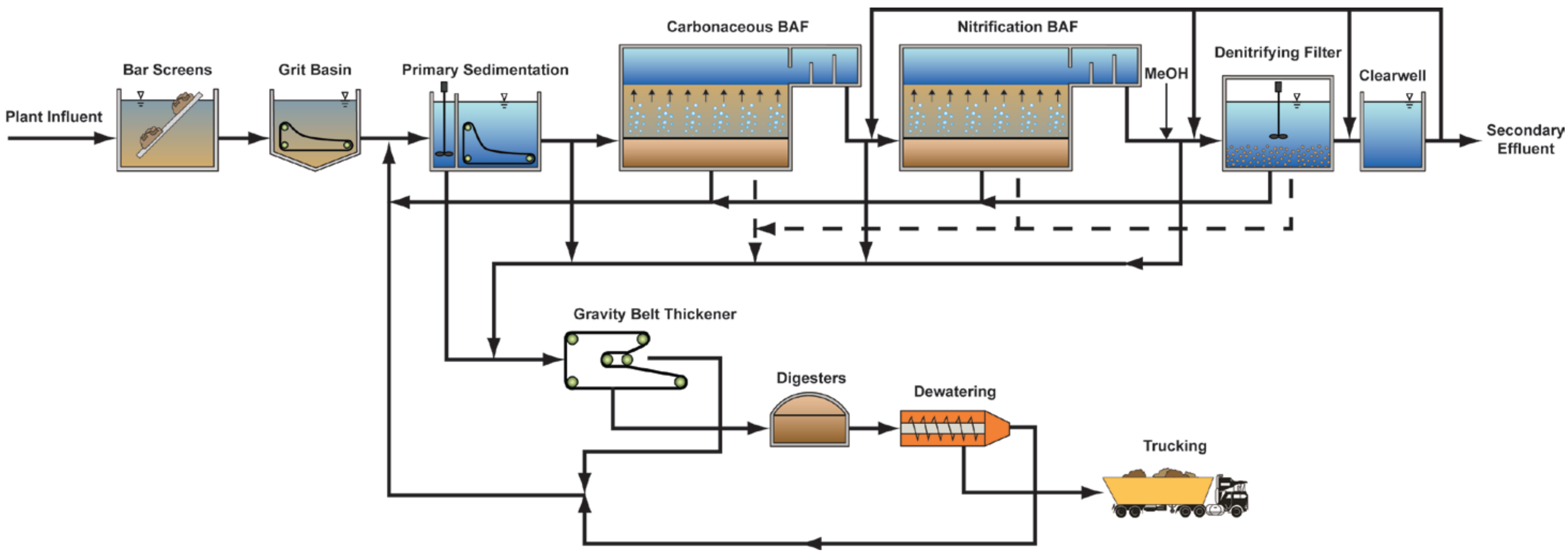
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



SCHEMATIC SITE PLAN FOR THE REPLACEMENT MBR ALTERNATIVE TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT LIMIT

FIGURE 2.17

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

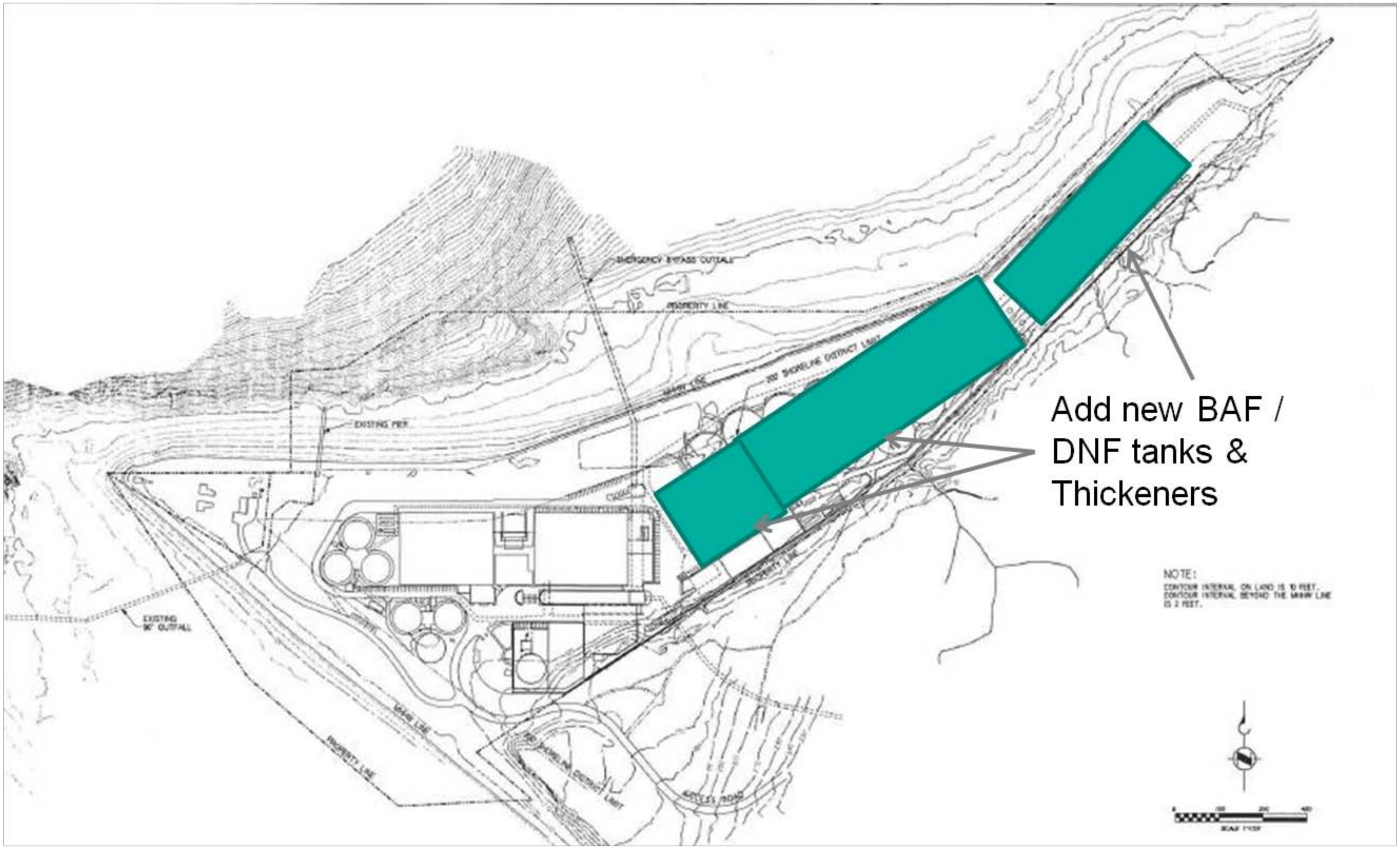


SCHEMATIC DIAGRAM OF THE REPLACEMENT BAF/DNF ALTERNATIVE TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT LIMIT

FIGURE 2.18

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

carollo



Notes:

New Process Tank

Demolish existing HPO tanks and clarifiers.

SCHEMATIC SITE PLAN FOR THE REPLACEMENT BAF/DNF ALTERNATIVE TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT LIMIT

FIGURE 2.19

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

2.2.3.4 Summary of Refined Alternatives

Figure 2.20 presents a summary of the process footprint requirements of the alternatives considered for meeting a 3 mg/L TIN (year round) permit limit scenario. It is seen that only two of the alternatives, the replacement MBR and the replacement BAF/DNF alternatives are theoretically feasible. As previously discussed, both of these alternatives may be practically infeasible due to constructability constraints.

2.3 REPRESENTATIVE ALTERNATIVE

2.3.1 Alternative Selection

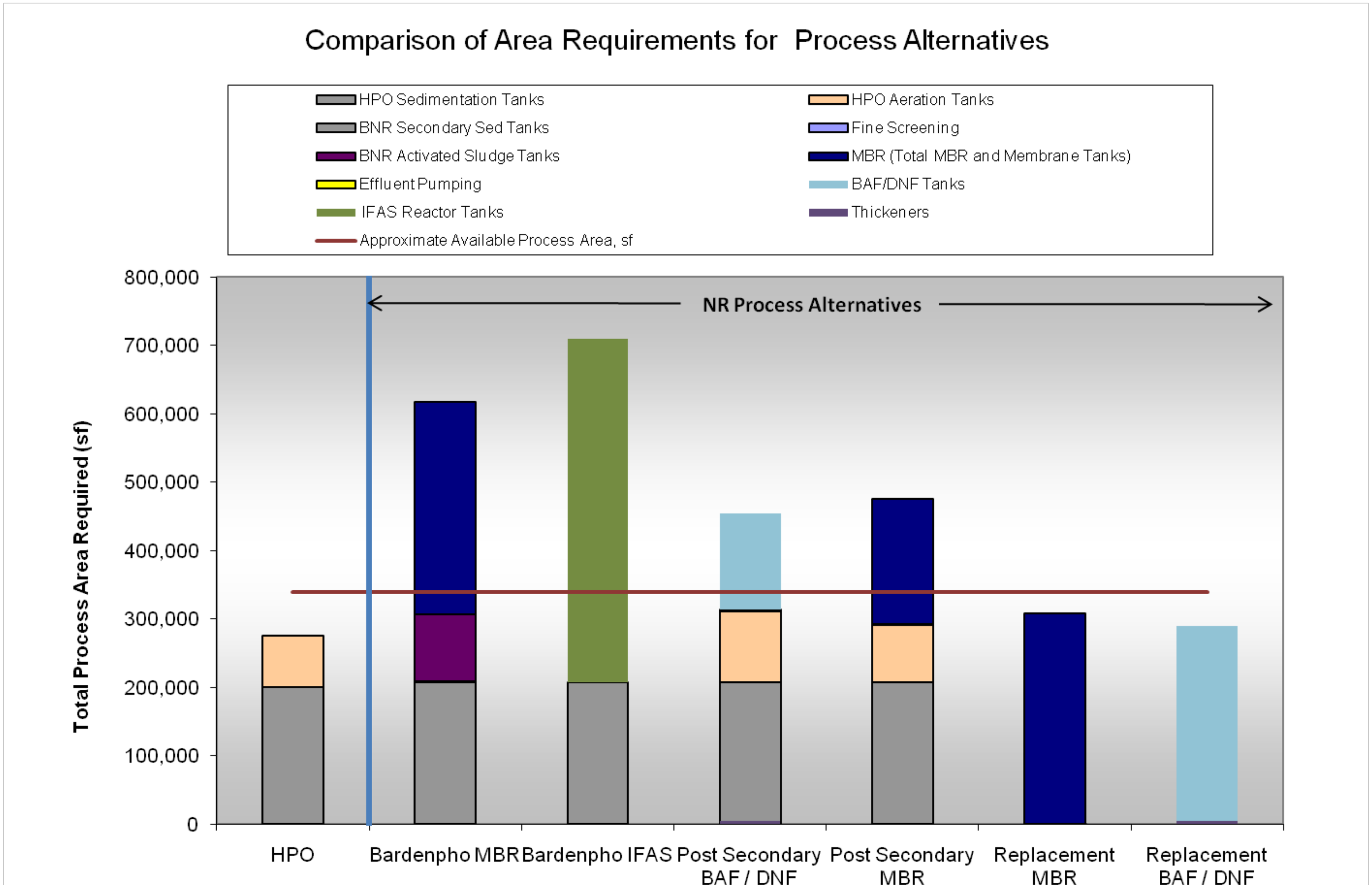
It was determined that no feasible alternatives exist for upgrade of the WPTP for nitrogen removal during a summer period only that would allow retaining existing HPO treatment facilities in service during the remainder of the year. Upgrade of the WPTP, if required to meet future permit conditions, would require demolition of existing secondary sedimentation tanks as a minimum, which would preclude operation of an HPO process during the summer. Two year round alternatives were determined to be theoretically feasible:

- Replacement MBR process;
- Replacement BAF/DNF process.

The replacement MBR process was selected for further development. Significant features of this alternative are summarized below.

2.3.1.1 Replacement MBR process

In this alternative the existing HPO tanks would be retained, but secondary sedimentation tanks would be demolished. This would require a phased process and a significant reduction in flow treated at the WPTP for the entire duration of construction. HPO tanks would be modified to provide for pumped internal recycle of mixed liquor to unaerated zones, which would be operated in anoxic mode for denitrification. In addition, aerobic zones of the existing aeration tanks would be converted to diffused aeration. A new system of medium-pressure blowers and aeration diffusers would be installed in the aerobic zones of the modified tanks. Methanol feed would also be required. A series of immersed membrane separation tanks would be constructed to replace existing sedimentation tanks. These tanks would include provisions for regular membrane scour and periodic chemical backwash and cleaning. With a maximum month flow of 215 mgd to the WPTP, the new MBR process would accommodate the current peak hour secondary flow of 300 mgd. During peak storm events, excess primary effluent flows beyond this flow would be directed to the chlorine contact channel for disinfection and blending with MBR treated flows.



SUMMARY OF PROCESS ALTERNATIVE FOOTPRINT REQUIREMENTS TO MEET THE 3 MG/L TIN (YEAR-ROUND) PERMIT LIMIT

FIGURE 2.20

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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Major elements of the upgrade include:

- Upgrade of existing aeration tanks:
  - Installation of internal recycle pumps and piping
  - Odor control facilities for the aeration tanks
  - Odor treatment equipment
  - Installation of additional mixers in the first and third stages of the aeration tanks
  - Additional baffle walls
- Replacement of the HPO aeration system with new blowers and aeration tank diffuser grids
- New unaerated and aerated aeration tanks with mixers and diffusers, odor control covers, and odor treatment equipment
- New membrane tanks:
  - New blowers for membrane scour
  - New membrane equipment building
  - Chemical feed building
  - Membrane tank odor control covering
  - MBR tank roof
  - Membranes and support equipment

2.3.2 Site layout

The schematic site layout for the representative alternative is presented in Figure 2.17.

2.3.3 Cost

The cost estimate was for the representative alternative was based on conceptual estimates for major items such as excavation, concrete, and equipment. Allowances were added to these costs for piping and miscellaneous mechanical equipment, electrical equipment, instrumentation, site work, contingency, general conditions, contractor overhead ,and profit, sales tax, allied costs (planning, design, construction management, permits, etc.). Operation and Maintenance (O&M) costs were estimated based on an EPA database for unit process labor, estimated power requirements and chemical consumption, and allowances for structural and equipment maintenance. Costs were indexed to estimated unit prices for December 15, 2010. The expected accuracy range for this type of estimate is defined by the American Academy of Cost Engineers (AACE) as a Level -5 Order of Magnitude Estimate and has an expected accuracy range of +50 to -30 percent. Cost assumptions are summarized in Appendix B.

Table 2.2 presents a summary of the estimated costs. The table compares the cost of continuing secondary treatment by the HPO process with upgrades to achieve nitrogen removal. The cost estimates summarized in Table 2.2 will be significantly impacted by constructability issues that can not be quantified at this time.

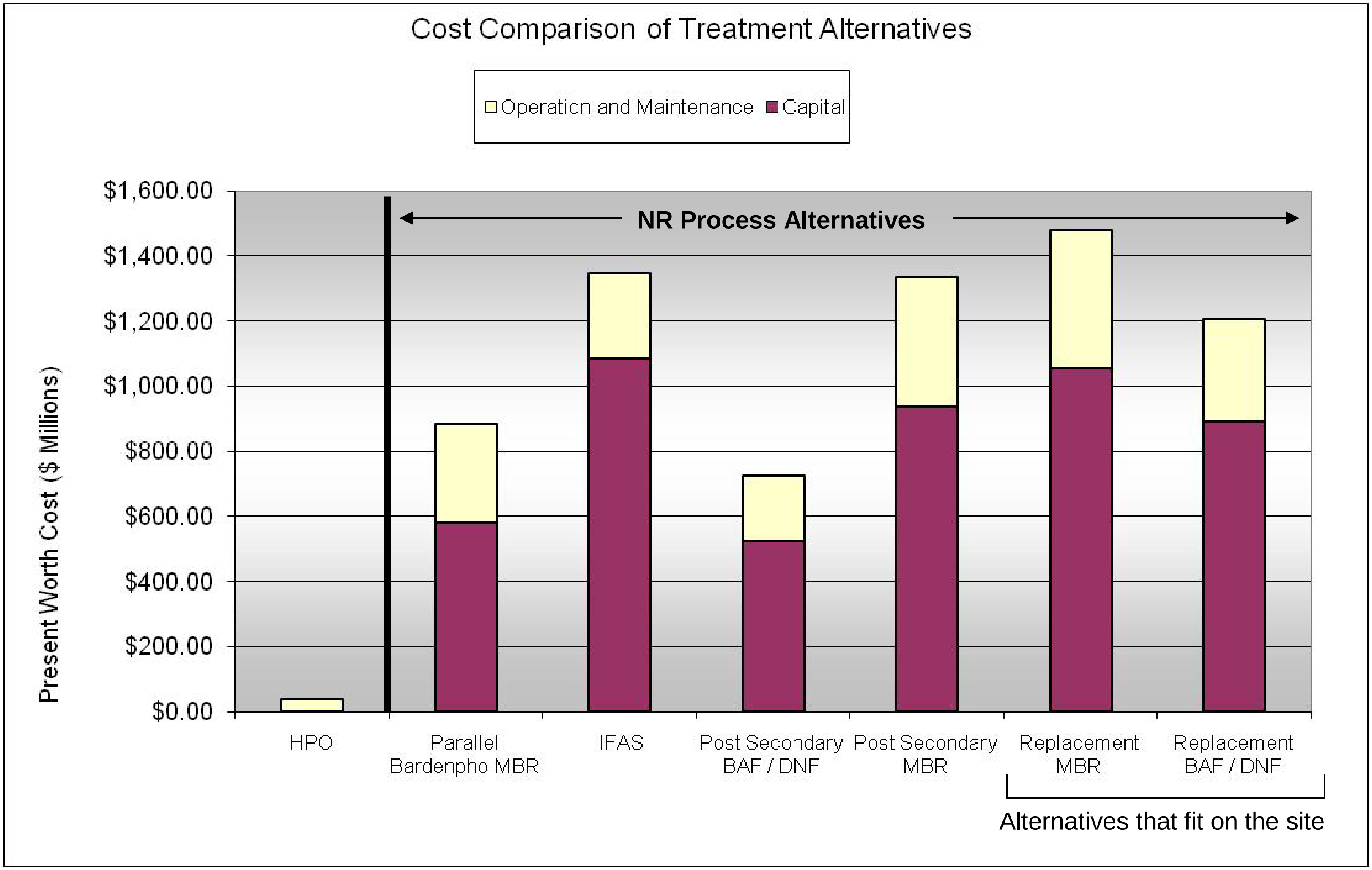
The table shows the difference between the estimated cost of capital expenditure, plus the present worth of operating and maintenance costs for nitrogen removal upgrade minus the present worth cost of operation and maintenance for the existing HPO process.

Table 2.2 Estimate Summary for 3 mg/L TIN (Year round) Permit Level Upgrade
West Point Nitrogen Removal Study
King County Department of Natural Resources and Parks

Treatment Element	HPO	Replacement MBR	Difference
Capital Cost, $			
Fine Screening	$0	$11,380,000	$11,380,000
Demolition of Existing Secondary Sed Tanks	$0	$4,560,000	$4,560,000
MBR Reactor Tanks	$0	$230,434,000	$230,434,000
MBR Membrane Tanks and Equipment	$0	$821,324,000	$821,324,000
Centrate Treatment Tanks	$0	$6,290,000	$6,290,000
Total Project Cost	$0	$1,073,988,000	$1,073,988,000
Design Max Month Flow (mgd)	215	215	215
Unit Project Cost ($/gpd)	$0.00	$5.00	$5.00
Operation and Maintenance Cost, $/year			
Fine Screening	$0	$2,969,000	$2,969,000
HPO Aeration Tanks	$1,300,000	$0	-$1,300,000
HPO Sedimentation Tanks	$2,183,000	$0	-$2,183,000
MBR Reactor Tanks	$0	$6,763,000	$6,763,000
MBR Membrane Tanks and Equipment	$0	$21,370,000	$21,370,000
Centrate Treatment	$0	$340,000	$340,000
Total	$3,480,000	$31,440,000	$27,960,000
Present Worth Cost, $ Million			
Capital	$0	$1,074	$1,074
Operation and Maintenance	$52	$468	$416
Total Present Worth	**$52**	**$1,542**	**$1,490**

Notes:
(1) Capital cost includes construction cost, contingency, tax, and allied costs (costs of planning, engineering, construction management, permitting, legal and other associated costs). All costs are in December 2010 dollars.
(2) Present worth O&M values were calculated assuming a 3% discount rate over a 20-year period on estimated current yearly O&M costs.

Figure 2.21 shows how the preliminary and selected representative alternatives compare on cost basis.



SUMMARY OF PROCESS ALTERNATIVE PRESENT WORTH COST ESTIMATE TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT

FIGURE 2.21

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

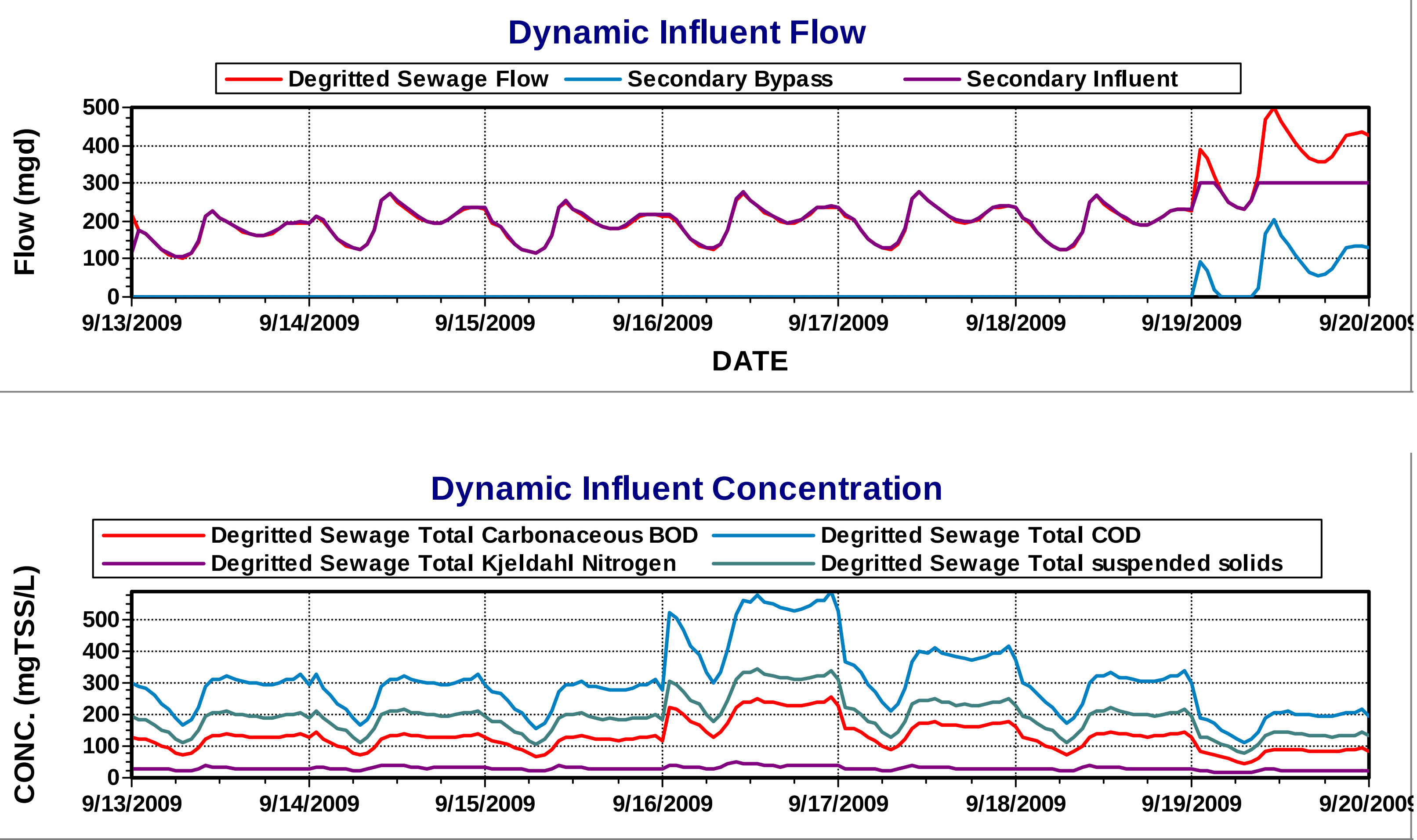
2.3.4 Sensitivity Analysis

Following selection of the representative alternative for nitrogen removal, a sensitivity analysis was performed to determine the response of the representative alternative to potential changes in dynamic loads, including the potential treatment of dewatering return flows. Dynamic models were prepared assuming input of one week of data with varying average daily flows and loadings.

Data were taken from the WPTP record for the week of September 13, 2009 through September 19, 2009. Flows and concentrations from the 2009 period were corrected by factors to adjust daily flows to conditions expected for the maximum month at a design maximum month flow of 215 mgd. This period in 2009 included a day during which influent sewage flows reached nearly 300 mgd, the flow beyond which primary treated flow is blended with secondary treated flow. The adjusted flows result in one day during the simulation week with influent flows exceeding the 300 mgd level. It was assumed in the simulation that primary flows in excess of this limit would continue to be blended with biologically treated flows.

Hourly variations in flow and concentration was taken from Carollo data gathered at the Central Contra Costa Sanitary District, a King County peer agency. Dynamic influent flows and concentrations used for the simulations are presented in Figure 2.22. Figure 2.23 presents the dynamic influent total nitrogen mass rate as a time series during the simulation week. It is seen that most of the influent mass rate of nitrogen comes from the degritted sewage influent, rather than from dewatering return flows which amounts to less than 10 percent of the total loading. Temperatures were maintained constant during the simulated week of loading at 12 degrees C.

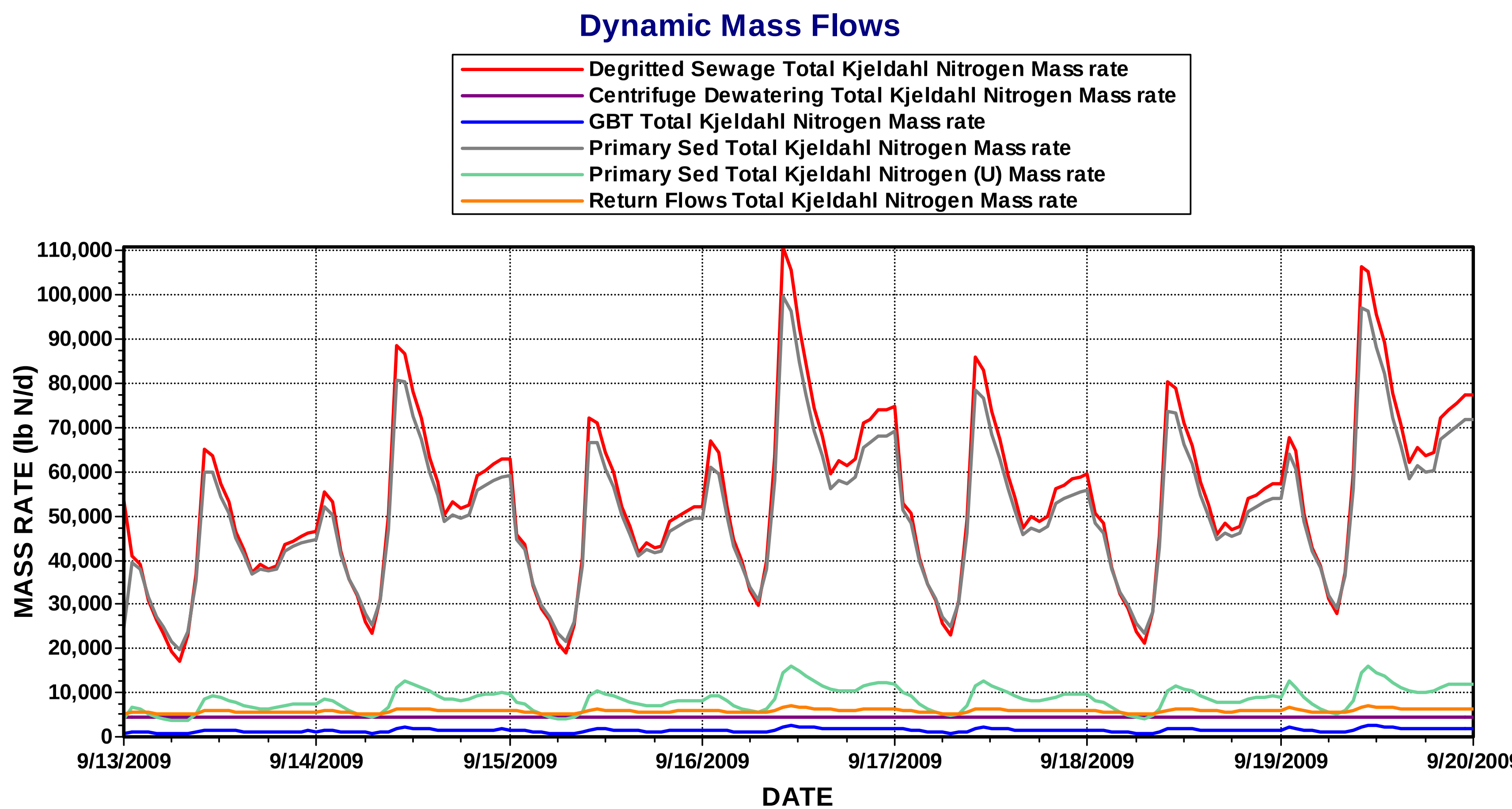
Since dewatering biosolids at the WPTP is continuous, this was the condition monitored for return flows. Figure 2.24 presents the schematic of the process tank configuration assumed for the simulations. A full plant model was configured as shown with waste primary and activated biosolids discharged to thickening and digestion and dewatered on a 7-day per week, 24-hour basis. Figure 2.25 shows the predicted effluent flow and concentration time series for the simulation week. Predicted effluent TIN varies from a low of approximately 2 mg/L to a high of over 8 mg/L during the first three days of the simulation. During the fourth day of the simulation effluent TIN rises to over 10 mg/L as a result of a dramatic increase in loading that was experienced during the model week in 2009.



DYNAMIC INFLUENT CONDITIONS

FIGURE 2.22

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



DYNAMIC INFLUENT NITROGEN MASS RATE

FIGURE 2.23

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

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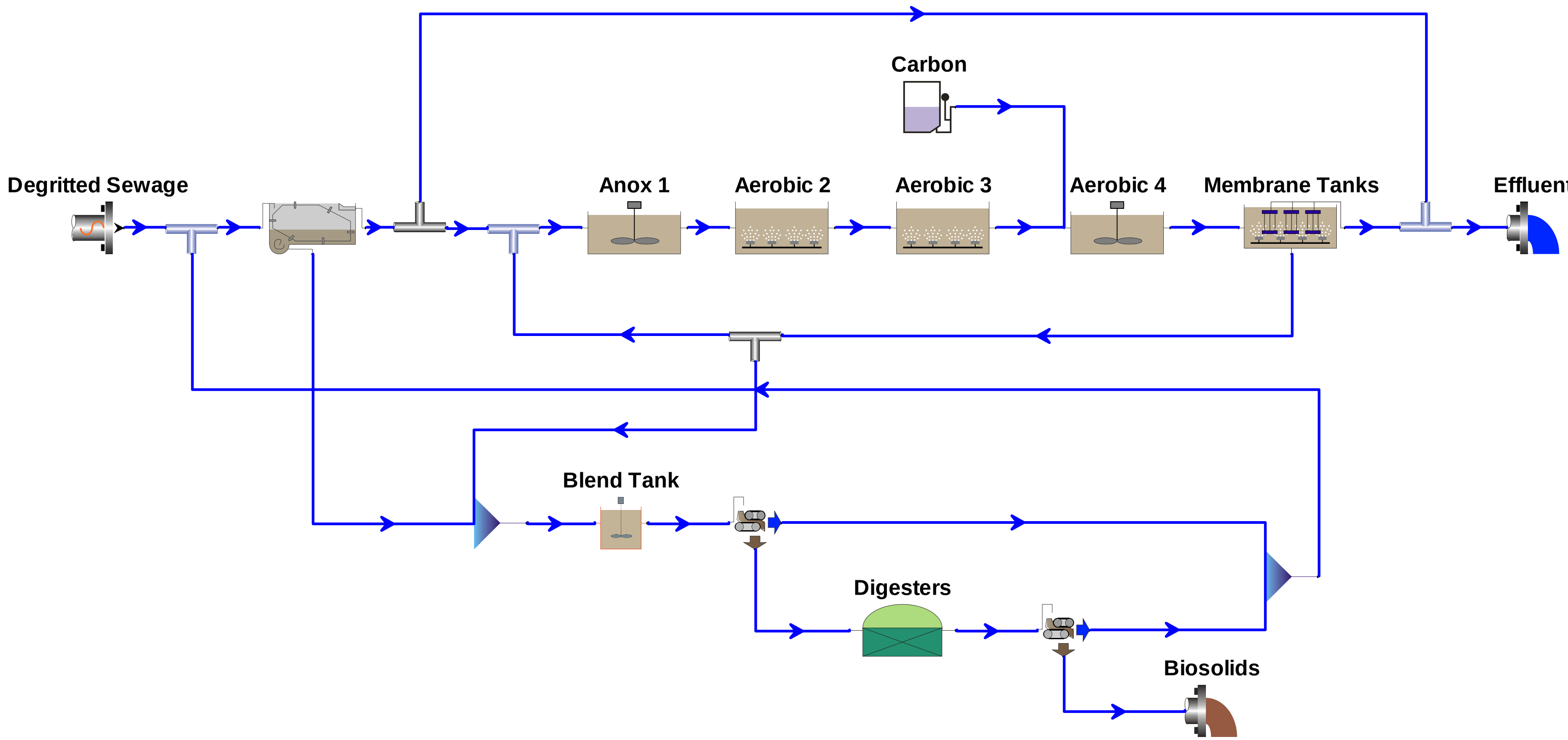
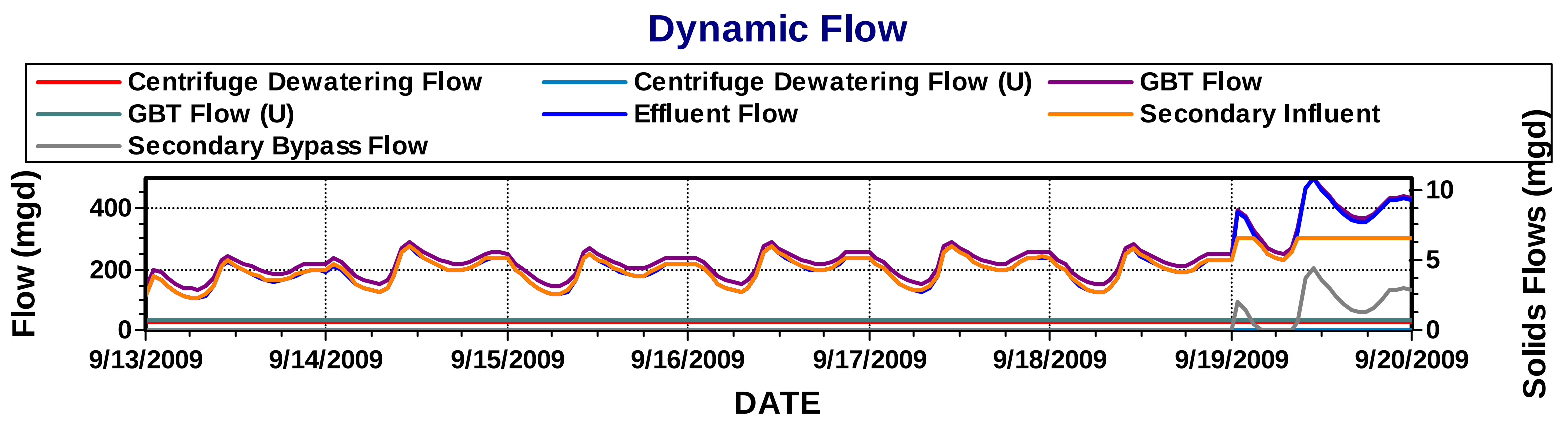
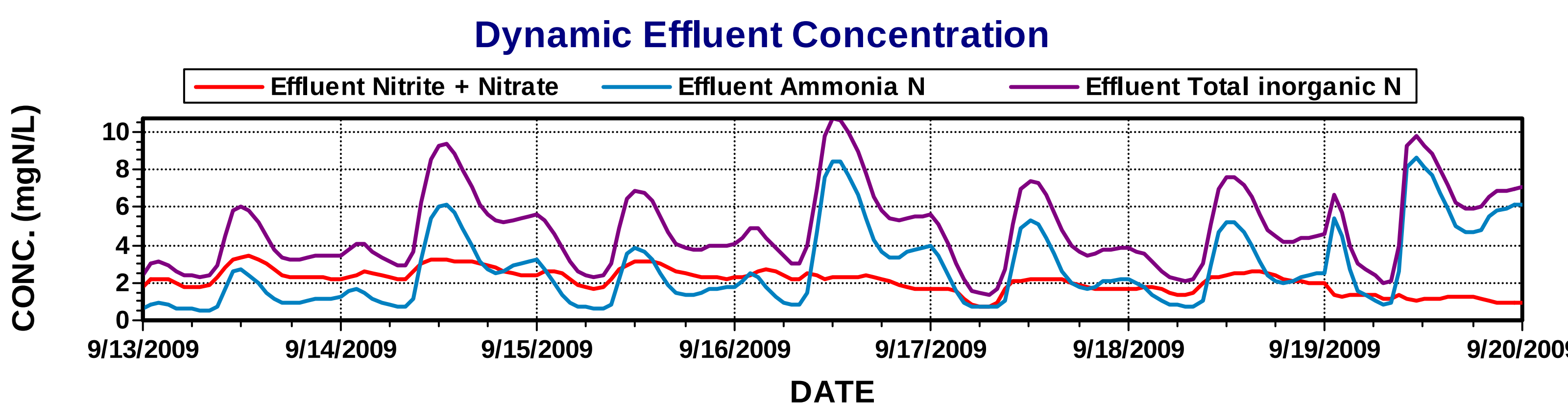


BIOWIN SCHEMATIC – 3 MG/L (YEAR ROUND) PERMIT LEVEL WITHOUT CENTRATE TREATMENT

FIGURE 2.24

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY





DYNAMIC EFFLUENT CONDITIONS – UNTREATED RETURN FLOWS

FIGURE 2.25

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

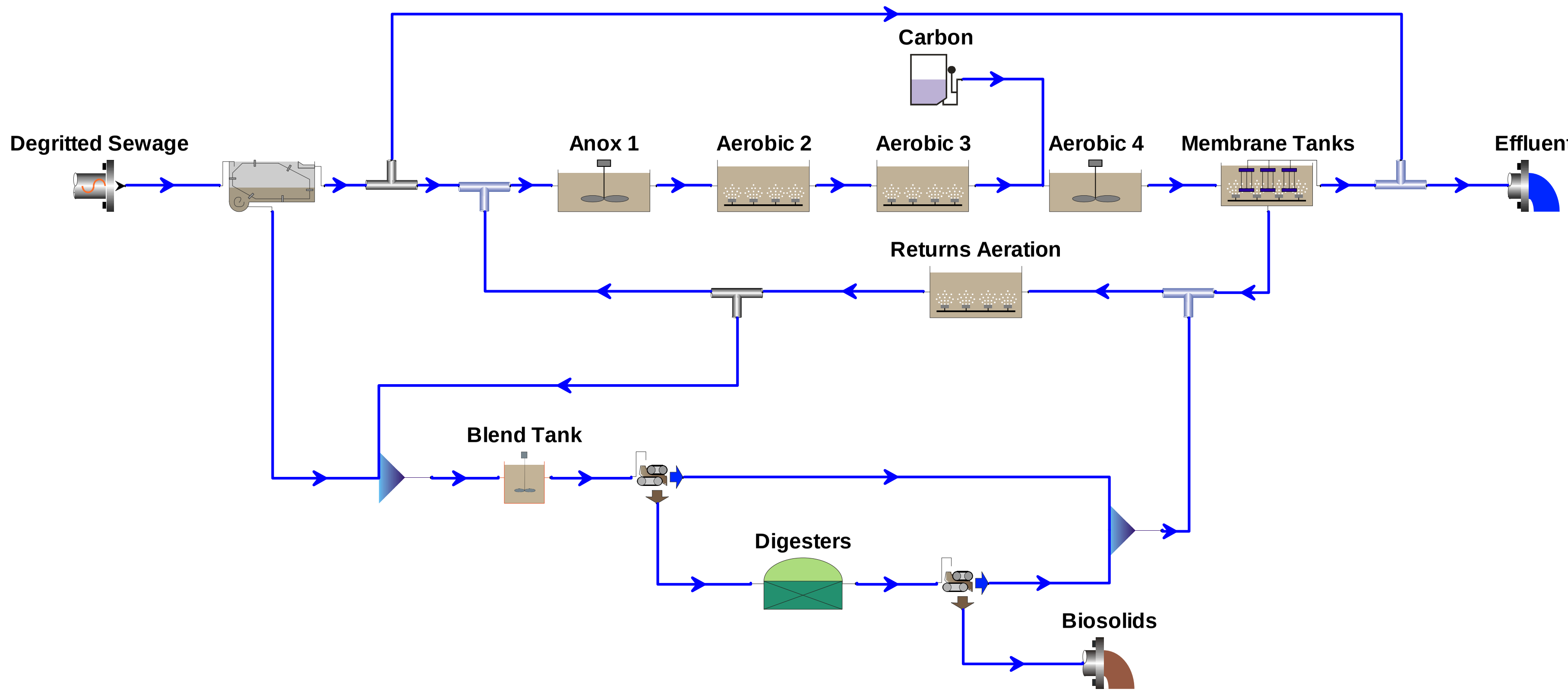
Figure 2.26 presents the process schematic developed to represent the case where dewatering flows were treated prior to return to the liquid stream. It was assumed that return flows were mixed with return activated sludge from the membrane tank under aerobic conditions to nitrify these flows. In the simulations the return flows averaged approximately 120 mg/L total Kjeldahl nitrogen. The dewatering return treatment tank was sized to produce an ammonia concentration less than 0.5 mg/L. The predicted effluent flows and concentrations are shown in Figure 2.27. The results indicate that influent sewage peaks could cause peak effluent TIN values to exceed 6 mg/l but that the average effluent TIN during this extreme week of loading would remain at approximately of 3 mg/L.

2.4 GREENHOUSE GAS COMPARISON

Effects of nitrogen removal upgrades on generation of greenhouse gas (GHG) emissions were evaluated as part of the South Plant Nitrogen Removal Study. A detailed evaluation of GHG emissions was not included in the WPTP analysis. In the South Plant study it was found that power consumption can be used as a near surrogate for GHG; approximately 80 percent of the GHG produced for either conventional activated sludge or nitrogen removing activated sludge using MBR was the result of electricity consumption. Using this factor as a guide, approximate GHG emissions from nitrogen removing MBR activated sludge can be estimated.

In the South Plant study, estimated mid-period energy consumption of 61 million kWh/year of power consumption was associated with approximately 27,000 total metric tons of carbon dioxide emissions. Using the same ratio for the WPTP and based on energy consumption shown in Figure 2.28 (approximately 36 million kWh/year for the replacement MBR alternative), the projected GHG emissions for the representative alternative would be approximately 16,000 metric tons.

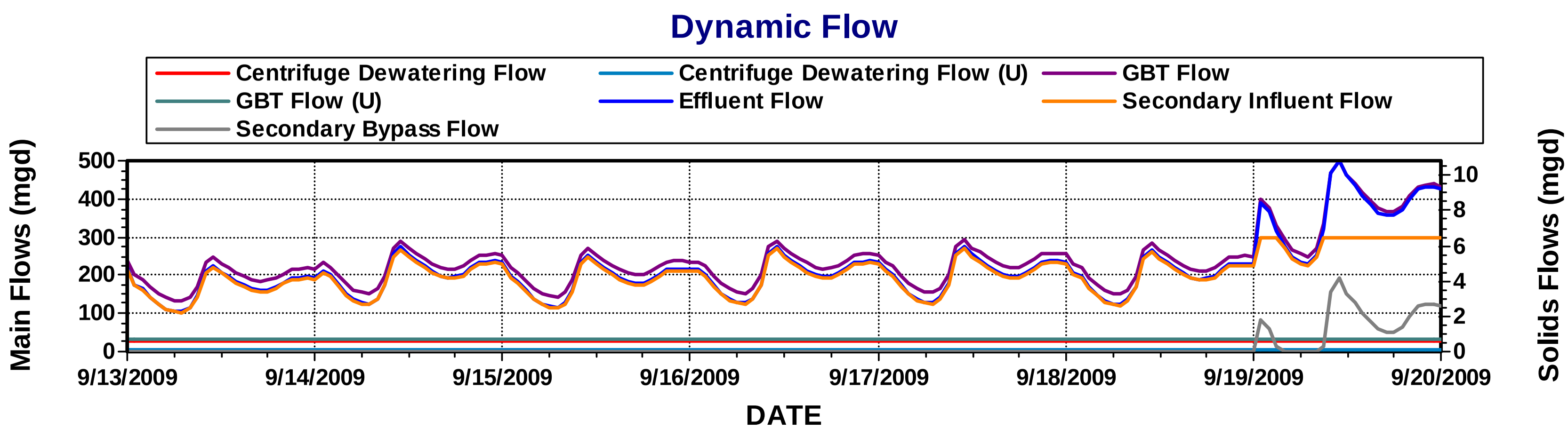
The projected GHG emissions for the WPTP are smaller than for the South Plant. This is explained by the fact that even though projected maximum month flows for the WPTP are greater than the South Plant (215 mgd versus 144 mgd), projected organic and nutrient loadings are less (for example, the projected year round average annual TKN loading for this study was 24,000 ppd for the WPTP compared to 45,000 ppd estimated for the South Plant).

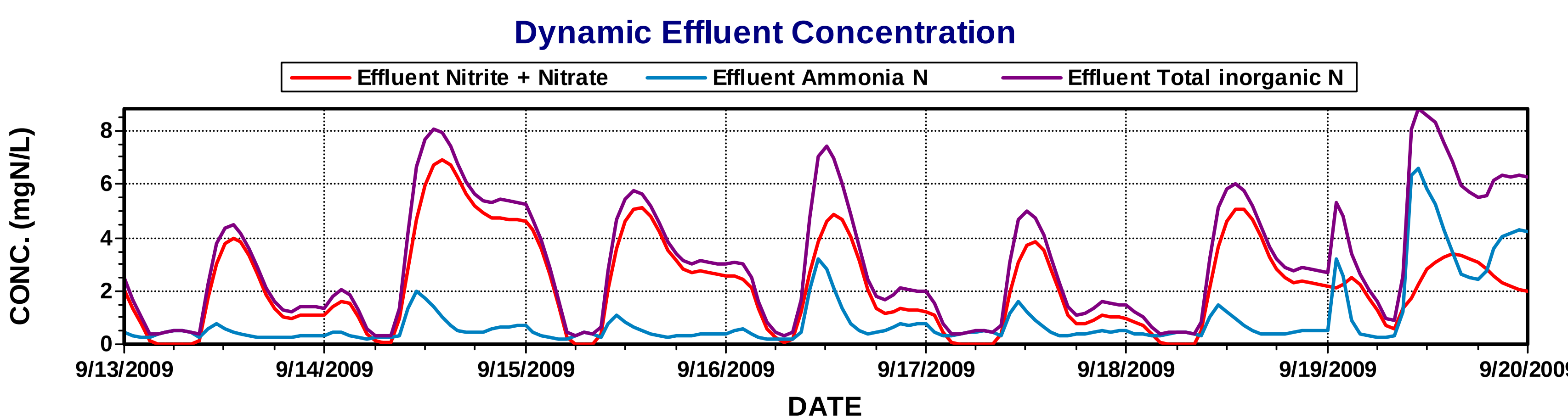


BIOWIN SCHEMATIC – 3 MG/L (YEAR ROUND) PERMIT LEVEL WITH CENTRATE TREATMENT

FIGURE 2.26

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

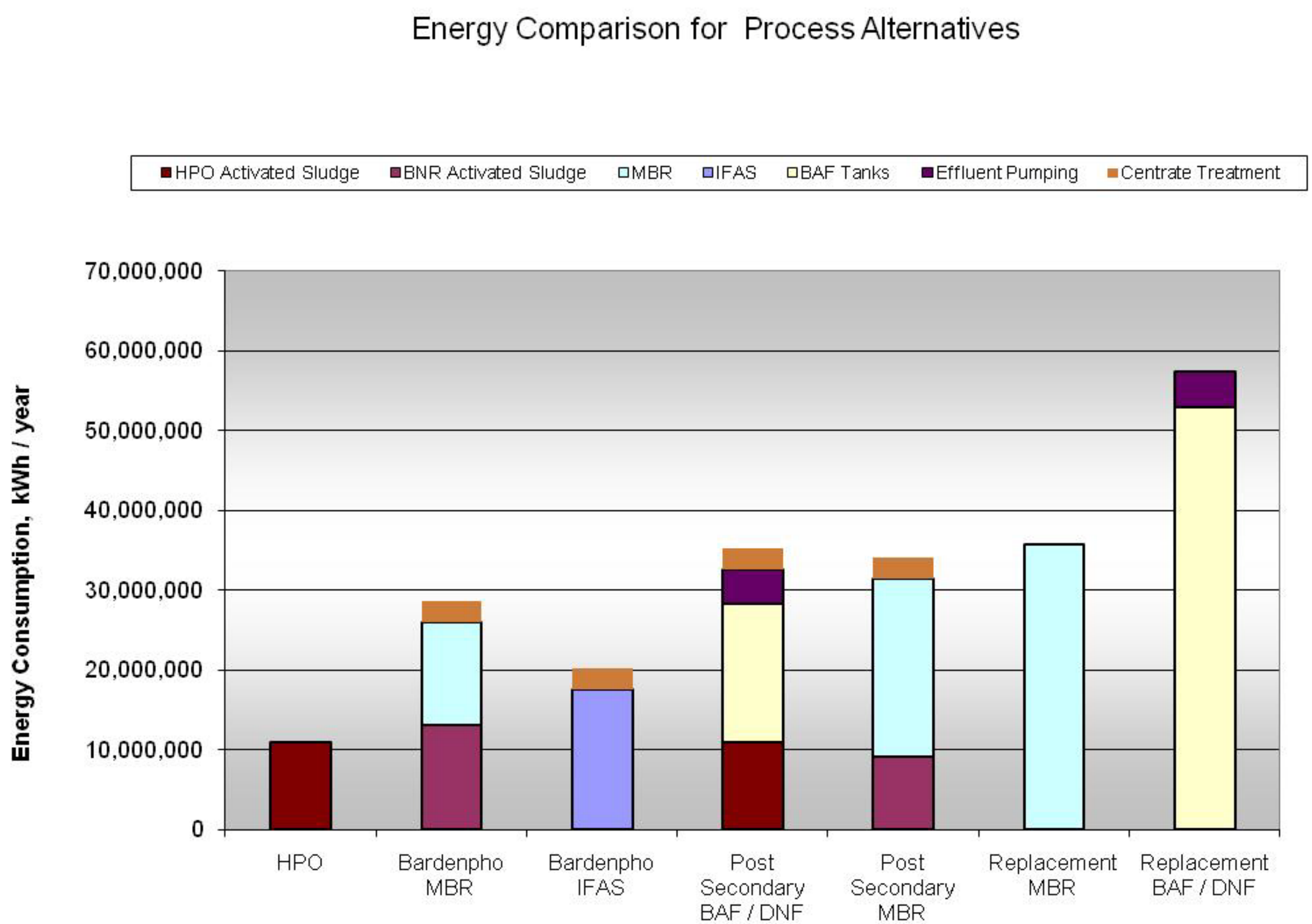




DYNAMIC EFFLUENT CONDITIONS – TREATED RETURN FLOWS

FIGURE 2.27

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



SUMMARY OF PROCESS ALTERNATIVE ESTIMATED ENERGY REQUIREMENTS TO MEET THE 3 MG/L TIN (YEAR ROUND) PERMIT LIMIT

FIGURE 2.28

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY

2.5 FINDINGS AND CONCLUSIONS

This chapter presented the results of evaluations undertaken to determine the effects of an effluent permit requirement for nitrogen removal at the WPTP. Two different potential permit requirements were assessed:

- 8 mg/L TIN for the summer period;
- 3 mg/L TIN year round.

The estimated process tank sizes required to meet these potential future permit requirements were compared to the current operation of HPO to meet a secondary treatment permit for discharge to Puget Sound. Three initial alternatives were considered for each potential permit scenario. These initial alternatives included:

1. Parallel MLE or Bardenpho NR and MBR;
2. MLE or Bardenpho IFAS;
3. Post Secondary BAF/DNF.

For neither the 8 mg/L TIN (summer only) nor the 3 mg/L TIN (year round) permit period, were any of these alternatives judged likely to fit within the available land area for future process units. They failed the initial test criterion: the footprint criterion. These alternatives were initially selected because they did not require demolition of significant assets at the WPTP; in all three of these alternatives existing structures for the HPO tanks and secondary sedimentation tanks would be retained. However, none of these preliminary alternatives were judged to be feasible, due to space constraints at the WPTP. Therefore, several additional alternatives were considered as follows:

1. Post-secondary MBR;
2. Replacement MBR;
3. Replacement BAF/DNF.

The first of these alternatives also will not fit at the WPTP site. The last two, however, may be potentially feasible assuming existing tanks are demolished. In the case of the replacement MBR alternative, existing secondary sedimentation tanks would be demolished and the land area now occupied by these tanks would be used for construction of new MBR aeration basins, membrane separation tanks, and ancillary equipment. The existing HPO tanks would be converted to a nitrogen removal configuration by addition of mixers, baffle walls, and internal recycle pumping systems. The third alternative, replacement BAF/DNF, would require demolition of the existing HPO tanks, as well as secondary sedimentation tanks.

Both of these alternatives would present significant construction challenges in that construction would need to take place while maintaining the current level of treatment for WPTP flows. It is likely that significant flow diversion from the collection system to the South

Plant would be required to minimize flows directed to the WPTP during construction. Development of a detailed construction plan for these alternatives was beyond the scope of the current study. If nitrogen removal is required in the future for WPTP, this plan would need to be investigated in significant detail to confirm feasibility of construction of either of these alternatives.

The replacement MBR alternative was identified as the representative alternative for cost development. Since this alternative requires demolition of secondary sedimentation tanks at the WPTP, continued operation of the existing HPO process for secondary treatment during the summer months is not possible. Therefore, there would be no significant difference in facilities constructed with the 8 mg/L TIN (summer only) as compared with the 3 mg/L TIN (year round) permit scenario. However, since average flows are higher during the winter if an 8 mg/L TIN (summer only) permit were required it may be possible to construct fewer membrane separation tanks than would be required for year round operation. The 3 mg/L TIN (year round) scenario would also require more carbon supplement than an 8 mg/L TIN (summer only) but other costs and impacts would be similar.

Costs of the representative alternative were estimated and compared to the replacement BAF/DNF alternative using a series of criteria including capital cost, O&M cost, risk, flexibility, footprint, energy, odor generation potential, compatibility with existing processes, impact on biosolids quantity, and the amount and quality of reclaimed water produced. The replacement MBR process was preferred; although estimated costs for this alternative were higher, the MBR alternative was judged to be more feasible to construct, and had potential to meet a 3 mg/L TIN (year round) permit limit with less energy consumption. This alternative would require demolition of less existing tankage at the WPTP site.

Another significant factor in the ranking of these alternatives was that the MBR process is a much better known process for King County than the BAF/DNF process. King County will have two operating MBR wastewater treatment plants in the near future (the Brightwater and Carnation treatment plants) while there are very few BAF or DNF processes in North America and none in Washington state. Considering these factors, the replacement MBR process was selected as process best representing the effects that would result from a nitrogen removal requirement for the WPTP.

A sensitivity analysis was conducted to evaluate potential effects of diurnal loading variation and treatment of sludge dewatering return flows on operation of the representative process. It was concluded that sludge dewatering return flow treatment would be necessary to ensure meeting a 3 mg/L TIN (year round) permit limit.

The incremental present worth cost for upgrade of the WPTP to meet an 3 mg/L TIN permit level year round is estimated at a present worth cost of approximately $1,500 million more than continuing operation of secondary treatment over the next twenty years. In addition to evaluation of incremental present worth costs, an estimate of GHG emissions was conducted. It was concluded that meeting a 3 mg/L TIN year round permit level would result in approximately three times more GHG emissions compared to continuing with secondary treatment at the WPTP. GHG emission estimates were approximated based on more detailed estimates prepared for the South Plant Nitrogen Removal Study (Carollo 2010).

EFFECT ON RECLAIMED WATER PRODUCTION

3.1 INTRODUCTION

This study considers possible effects of nitrogen removal (NR) on the availability, cost, and potential for production of reclaimed water from the West Point Treatment Plant (WPTP).

3.2 SUMMARY OF RECLAIMED WATER STANDARDS

The South Plant Nitrogen Removal Study (Carollo 2010) provided a summary of current reclaimed water standards in the State of Washington. New rules are expected to be promulgated in 2012. The key requirement in the currently proposed rules as it would be applicable to the WPTP is the requirement for Class A Reclaimed Water. This means *"reclaimed water that, at a minimum, is at all times an oxidized, coagulated, filtered, disinfected wastewater. The wastewater shall be considered adequately disinfected if the median number of total coliform organisms in the wastewater after disinfection does not exceed 2.2 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed, and the number of total coliform organisms does not exceed 23 per 100 milliliters in any sample."* In the context of this report, it is assumed that for widest possible use, reclaimed water from the WPTP would need to be treated to the Class A level.

3.3 RECLAIMED WATER EVALUATION

3.3.1 Reclaimed Water Effects

The two final alternatives for NR at the WPTP identified in Chapter 2 were the replacement membrane biological reactor (MBR) and biological aerated filter (BAF)/ denitrifying filter (DNF) alternatives. In each of these alternatives, existing secondary sedimentation tanks at the WPTP would be demolished and replaced with new facilities. In the case of the BAF/DNF alternative the existing high purity oxygen (HPO) tanks would also be demolished. The MBR alternative would produce reclaimed water meeting Class A standards without additional filtration. This is probably not the case for the BAF/DNF filter alternative. It is unlikely that the effluent from the DNF would meet Class A turbidity requirements. Therefore it has been assumed that additional coagulation, flocculation, and filtration facilities would be required with this alternative.

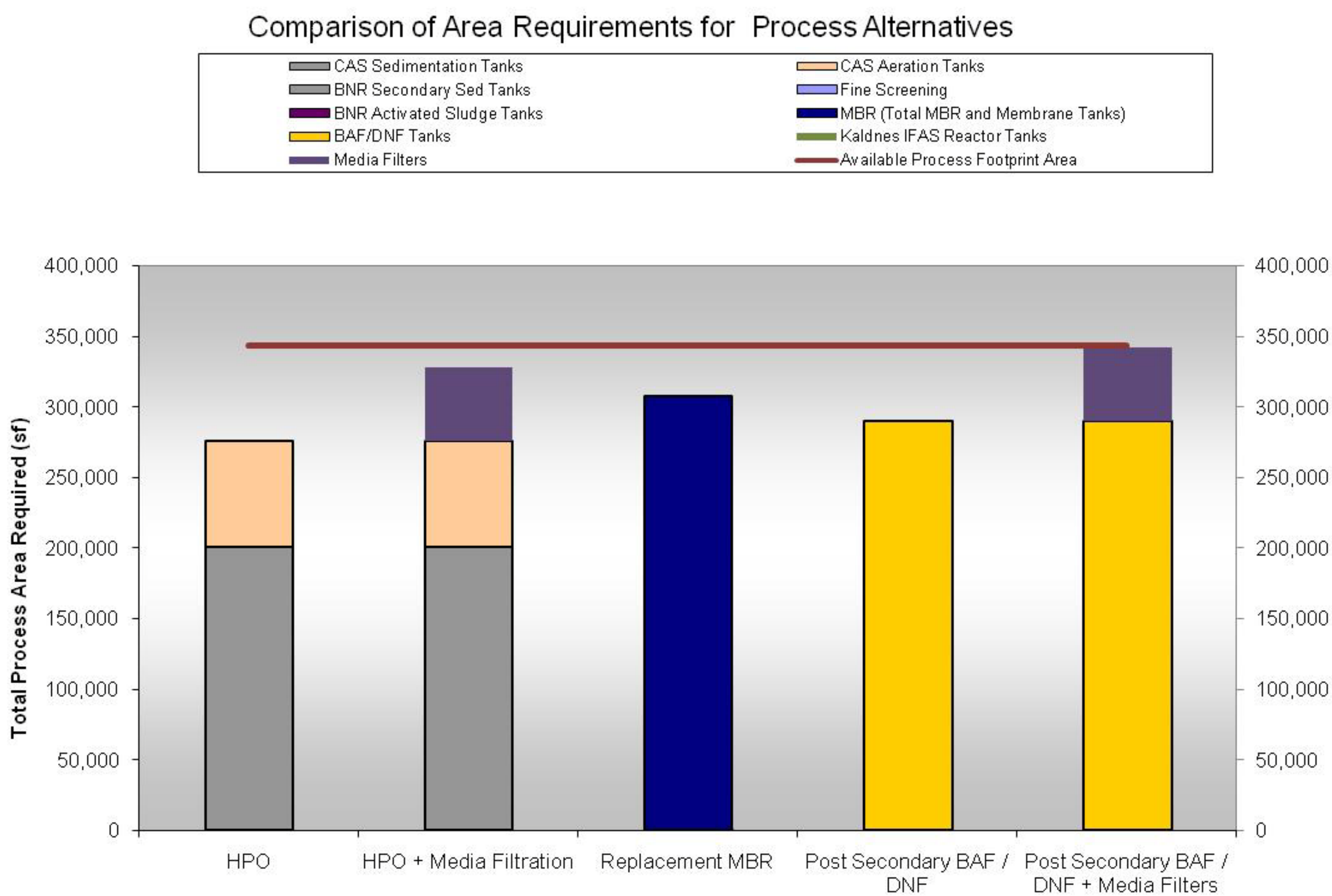
For the WPTP evaluation, it was assumed that coagulation, flocculation, and filtration or membrane filtration would be required for the BAF/DNF alternative for the projected future average annual flow of 110 million gallons per day (mgd) of reclaimed water from with a maximum summer flow of 139 mgd.

Assuming a typical rapid mix detention time of 1 second, flocculation detention time of 30 minutes, and a maximum month hydraulic loading rate of 4 gallons per minute per square foot (gpm/sf) for the rapid sand filters, a total of approximately 52,000 square foot (sf) of coagulation, flocculation, and filtration facilities would be required. This sizing assumes one standby unit out of a total of 61 filters. Figure 3.1 shows a comparison of the site area requirements for the two final NR alternatives with media filtration added to the BAF/DNF alternative. The figure also shows the comparison to the existing HPO process with and without addition of media filtration. The alternative of BAF/DNF without additional filtration is shown as well. The chart indicates that addition of over one acre of filtration facilities would cause the BAF/DNF alternative to be marginal in meeting the footprint criterion for feasibility. It would just barely fit into the land area set aside for existing tanks and future construction at the WPTP site, with no margin of safety. More detailed evaluation would be required to confirm feasibility of this alternative. The chart indicates that addition of media filtration to the existing HPO processes is potentially feasible from the standpoint of footprint.

To achieve Class A reclaimed water standards for disinfection, additional chlorine contact basin volume would likely be required to achieve the 30 minute T_{10} CT. Disinfection with a substantially nitrified effluent following membrane filtration may require chloramination. However, due to the higher quality water, the required chlorine dose may decrease from what would be required following filtration of the non-nitrified effluent. Since the effects of nitrogen removal with a MBR system on the chemical requirements of disinfection are unknown without pilot-scale testing, it has been assumed that costs and other effects of the disinfection system for all scenarios are equal.

3.3.2 Reclaimed Water Costs

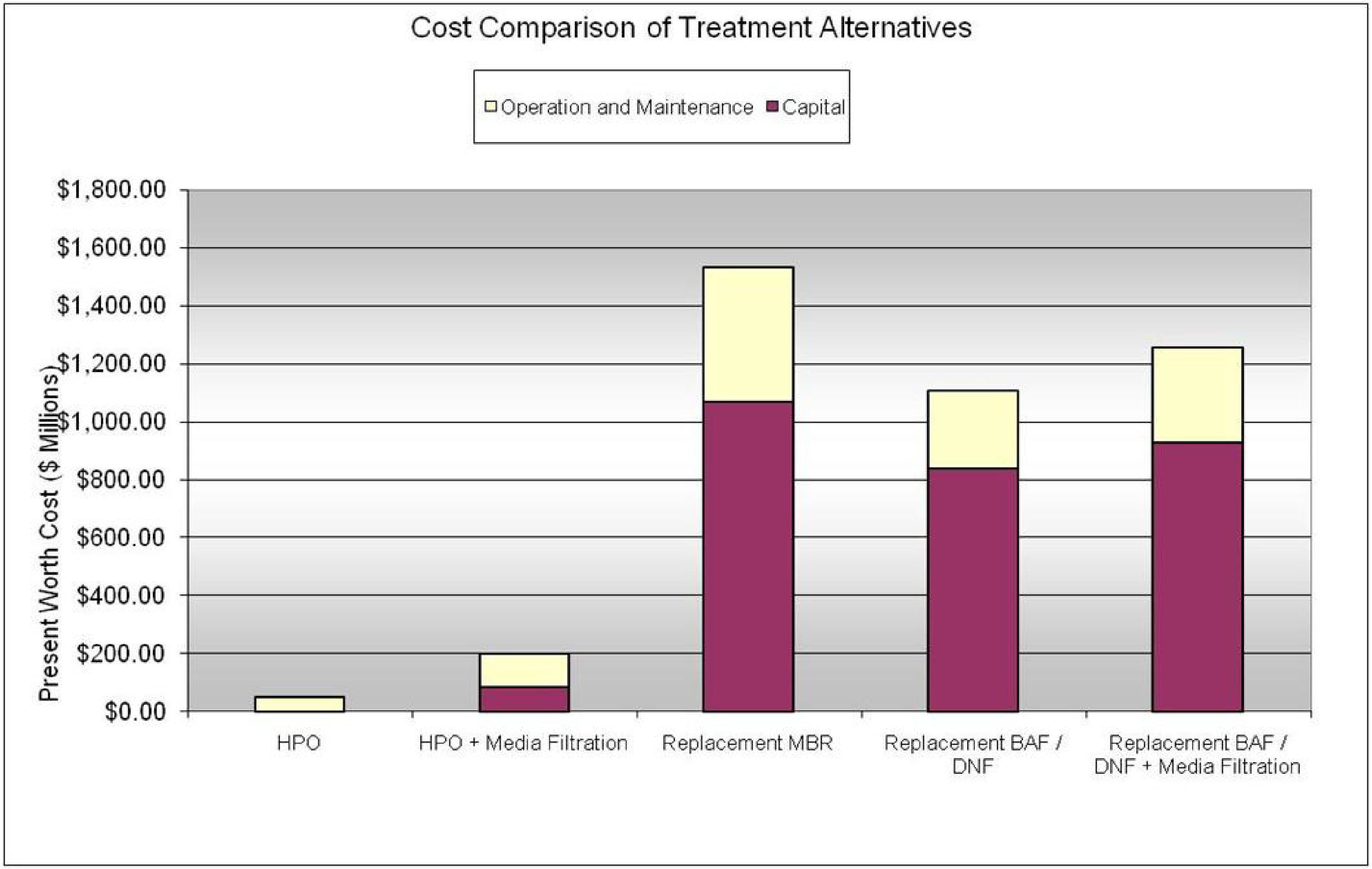
Figure 3.2 compares planning level costs of reclaimed water production for the full 110 mgd summer flow for the future non-nitrified secondary effluent to the requirements for additional filtration assuming nitrogen removal upgrade by a replacement MBR or BAF/DNF processes. As shown in the figure, there would be no additional cost to implement reclaimed water production for the full summer flow of 110 mgd if the MBR project is implemented for NR. The cost of implementing 110 mgd average flow reclaimed water by conventional filtration is estimated to be approximately $150 million in present worth capital and operating and maintenance costs. If a BAF/DNF project were implemented, this additional cost would be required for reclaimed water production facilities.



SITE REQUIREMENTS FOR NR ALTERNATIVES PRODUCING RECLAIMED WATER

FIGURE 3.1

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
WEST POINT NITROGEN REMOVAL STUDY



ESTIMATED COSTS FOR IMPLEMENTING PROJECTS TO PRODUCE RECLAIMED WATER AT 110 MGD AVERAGE FLOW

FIGURE 3.2

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WEST POINT NITROGEN REMOVAL STUDY

3.3.3 Other Effects

In addition to economic effect, there would be other effects of implementing nitrogen removal on potential reclaimed water production. Key effects include additional land use, energy consumption, and greenhouse gas (GHG) consumption. These are summarized in Table 3.1. The table presents estimates of the total effects of implementing reclaimed water assuming either the existing HPO process, a future MBR, or a future BAF/DNF process, including the impacts of implementing secondary and NR treatment. GHG emissions were estimated as a ratio of energy consumption using a factor developed during the South Plant Nitrogen Removal Study (Carollo 2010).

Table 3.1 Summary of Non-cost Reclaimed Water Effects
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks

Element	HPO + Media Filtration (110 mgd treated)	MBR (110 mgd treated)	BAF + Media Filtration (110 mgd treated)
Land area (sf)	*327,000*	*307,000*	*346,000*
Energy consumption (kWh/year)	*11,200,000*	36,400,000	*57,800,000*
GHG Emissions (estimated metric tons of annual eCO_2)	*6,200*	*20,200*	*32,100*

3.4 CONCLUSIONS

The final alternatives for implementation of NR at the WPTP included either membrane filtration following MBR or BAF/DNF. While filtration is integral to the BAF/DNF process, effluent turbidity from the final denitrification step of the process is not guaranteed to meet Class A reclaimed water standards. It was assumed, therefore, that if the BAF/DNF process were used for NR, additional media filtration would be required. If the MBR process is implemented for NR, additional filtration would not be required to meet Class A reclaimed water standards.

The estimated present worth cost of media filtration for 110 mgd average flow at the WPTP is approximately $150 million. Media filtration facilities would require approximately one and one half acres of site land area, which is approximately the remaining land area available on the WPTP for future facilities. Non-cost impacts of implementing reclaimed water at the WPTP as part of a NR project were estimated. The least land-intensive and least energy-intensive way to implement reclaimed water production at the WPTP would be to add media filters to the existing HPO process. If nitrogen removal were to be implemented, however, additional adverse impacts would be minimized if the MBR process is chosen, compared to the BAF/DNF process.

APPENDIX A
RANKING ASSUMPTIONS

	TIN 8 Scoring Explanation		
Criteria	Parallel MBR	IFAS Kaldness	BAF
Capital Cost	<1.5 * Lowest = 2	Lowest = 3	Lowest = 3
Total Cost	$605,506,000	$437,942,000	$422,029,000
Relative Cost	1.43	1.04	1.00
O&M Cost, PW	> 1.5 * Lowest = 1	<1.5 * Lowest = 2	Lowest = 3
Total Cost	$295,764,000	$164,545,000	$147,733,000
Relative Cost	1.8	1.11	1.00
Risk	County familiar with process. Brightwater will be of a similar size range = 3	County not familiar with process. No US installations of a similar size = 1	County familiar with process. 1 US installation of a similar size, 1 additional planned for 2010 = 1
Future Flexibility	No Room for Future = 0	No Room for Future = 0	No Room for Future = 0
Footprint, sf	Does Not Fit = 0	Does Not Fit = 0	Does Not Fit = 0
Total Footprint	413,604	403,756	465,919
Relative Footprint	Failure	Failure	Failure
Energy, kWh/year	< 1.5 * Lowest = 2	> 1.5 * Lowest = 1	Lowest = 3
Total Energy	28,111,000	37,259,000	24,362,000
Relative Energy	1.15	1.53	1.00
Odor	Similar odor impacts = 2	Similar odor impacts = 2	Similar odor impacts = 2
Compatibility with existing processes	No stranded assets = 3	No stranded assets = 3	No stranded assets = 3
Biosolids Quality	No Significant Difference = 2	No Significant Difference = 2	No Significant Difference = 2
RW Quality	Reclaimed water quality effluent = 3	Somewhat better than HPO = 2	Somewhat better than HPO = 2

	TIN 3 Scoring Explanation				
Criteria	Parallel MBR	MLE IFAS	Post-secondary BAF / DNF	Replacement MBR	Replacement BAF / DNF
Capital Cost	<1.5*Lowest = 2	< 1.5 * Lowest = 2	Lowest = 3	> 1.5 * Lowest =1	> 1.5 * Lowest =1
Total Cost	$483,242,000	$608,046,000	$432,729,000	$935,846,000	$762,489,000
Relative Cost	1.12	1.41	1.00	2.16	1.76
O&M Cost, PW	> 1.5* Lowest = 1	< 1.5 * Lowest = 2	Lowest = 3	> 1.5 * Lowest = 1	> 1.5 * Lowest = 1
Total Cost	$273,299,000	$231,940,000	$169,008,000	$378,781,000	$254,554,000
Relative Cost	1.62	1.37	1.00	2.24	1.51
Risk	County has two MBR. Brightwater will be of a similar size range = 3	County not familiar with process. No US installations of a similar size = 1	County not familiar with process. 1 US installation of a similar size, 1 additional planned for 2010 = 1	County has two MBR. Brightwater will be of a similar size range = 3	County not familiar with process. 1 US installation of a similar size, 1 additional planned for 2010 = 1
Footprint, sf	Failure - Does Not Fit on Site = 0	Failure - Does Not Fit on Site = 0	Failure - Does Not Fit on Site = 0	Second Lowest = 2	Lowest = 3
Total Footprint	497,000	460,000	479,000	375,834	276,000
Relative Footprint	Failure	Failure	Failure	1.00	1.01
Energy, kWh/year	< 1.5 * Lowest = 2	> 1.5* Lowest = 1	Lowest = 3	Lowest = 3	< 1.5 * Lowest = 2
Total Energy	28,531,000	57,844,000	24,337,000	25,788,000	31,637,000
Relative Energy	1.17	2.38	1.00	1.06	1.30
Odor	Equal Odor Production = 2	Equal Odor Production = 2	Equal Odor Production = 2	Equal Odor Production = 2	Equal Odor Production = 2
Compatibility with existing processes	No stranded assets = 3	No stranded assets = 3	No stranded assets = 3	Destroys Clarifiers = 2	Destroys Clarifiers and HPO Tanks = 1
Biosolids Quality	No significant Biosolids Impact = 2	No significant Biosolids Impact = 2	No significant Biosolids Impact = 2	No significant Biosolids Impact = 2	No significant Biosolids Impact = 2
RW Quality	Reclaimed water quality effluent = 3	Nitrifying system, better effluent, no room for filters = 2	Nitrifying system, better effluent, no room for filters = 2	Reclaimed water quality effluent = 3	Nitrifying system, better effluent, no room for filters = 2

APPENDIX B
COST ASSUMPTIONS

Client:	**King County**
Project:	**WPTP Nitrogen Removal Study - 3 mg/L Year-round**
Subject:	**Cost Assumptions**
Cost Assumptions	
By :	**RWS**
Estimate Cost Base :	**3/15/2010**
	Bordered Cells are Input Cells
Item	**Value**
Period of analysis, years	**20**
Discount rate, %	**3.0%**
Construction escalation rate, %	**6.0%**
Operations inflation rate, %	**6.0%**
Mid-point construction date	**15-Mar-10**
Operations labor rate, $/hr	**$50**
Diesel oil cost, $/gal	**$3.00**
Power cost, $/kwh	**$0.07**
Biosolids Management, $ / wet ton (with trucking)	**$50.00**
Chemical cost, $/lb	
Chlorine	**$0.62**
Sulfur dioxide	**$0.19**
Citric acid	**$0.50**
Alum	**$0.10**
Ferric chloride	**$0.35**
Sodium hypochlorite	**$0.90**
Methanol	**$0.33**
Cationic polymer	**$1.60**
Structural Annual Replacement Cost, %	**2%**
Equipment Annual Replacement Cost, %	**4%**
Contingency, %	**40%**
Allied Cost (Planning, design, CM, permits, etc.)	**45%**
Construction management, %	**0%**
Sales tax, %	**10.0%**
Present Worth Factor	14.87747