King County

Department of
Natural Resources and Parks
Wastewater Treatment Division

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

FINAL REPORT

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KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS

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ABBREVIATIONS

AACE	Association for the Advancement of Civil Engineering
AB32	Assembly Bill 32
BAF	Biological Aerated Filter
BNR	Biological Nitrogen Removal
BOD_5	Biochemical Oxygen Demand (5-day)
C	Celsius
CARB	California Air Resources Board
CAS	Conventional Activated Sludge
CCAR GRP	California Climate Action Registry General Reporting Protocol
cfm	Cubic Feet per Minute
CH_4	Methane
County	King County
CO_2	Carbon Dioxide
CO_2e	Equivalent CO_2
DAFT	Dissolved Air Flotation Thickener
DIN	Dissolved Inorganic Nitrogen
DNF	Denitrifying Filter
DO	Dissolved Oxygen
Ecology	Department of Ecology
EPA	Environmental Protection Agency
fbf	Filterable BOD_5 Fraction
fvu	Non-biodegradable Volatile Fraction
GHG	Greenhouse Gas
gpd	Gallons per Day
gpd/sf	Gallons per Day per Square Foot
GWP	Global Warming Potential
HOCl	Hypochlorite
IFAS	Integrated Fixed Film Activated Sludge
IPCC	International Panel on Climate Change
LOTT	Lacey, Olympia, Tumwater, Thurston County
MBBR	Moving Bed Bioreactor
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
MCLG	Maximum Containment Limit Goal
MLR	Mixed Liquor Return
MLSS	Mixed Liquor Suspended Solids
N	Nitrogen
N_2O	Nitrous Oxide
NH_4+	Ammonium Ion
NDN	Nitrification/Denitrification
$NH_4MgPO_4\ 6H_2O$	Ammonium Magnesium Phosphate
NO_3^-	Nitrate Ion
NPDES	National Pollutant Discharge Elimination System
NR	Nitrogen Removal
O&M	Operation and Maintenance
POTW	Publically Owned Treatment Works
ppd	Pounds per Day
ppd/kcf	Pounds per Day per Thousand Cubic Feet
ppd/sf	Pounds per Day per Square Foot
RAS	Return Activated Sludge
SF	Square Foot
SRT	Solids Residence Time
STP	South Treatment Plant
SVI	Sludge Volume Index
TIN	Total Inorganic Nitrogen
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
U.S.	United States
WAS	Waste Activated Sludge
WERF	Water Environment Research Foundation
WWTP	Wastewater Treatment Plant

ES.1 INTRODUCTION

According to the Washington State Department of Ecology (Ecology 2008b), portions of South Puget Sound do not meet Washington State water quality standards for dissolved oxygen (DO). Ecology is concerned that algal growth stimulated by nitrogen loadings to Puget Sound is causing DO depression in near-bottom regions. In 2006 Ecology began a major study to determine the extent of low DO and how nitrogen from a variety of sources affects DO levels. While it is not clear how Ecology will use the results of its studies to establish future regulatory limits, King County (County) has undertaken this project to evaluate potential effects of future nitrogen removal requirements for the King County South Treatment Plant (STP).

This report is divided into three chapters. Chapter 1 describes project assumptions and evaluates how much flow the existing STP could process if required to comply with a summer seasonal limit of 8-milligrams per liter (mg/L) TIN (Total Inorganic Nitrogen) or an annual limit of 3-mg/L TIN and what modifications would be required for nitrogen removal. Chapter 2 evaluates the potential effects (e.g., tankage, footprint, cost, greenhouse gas emissions) to the STP if it were required to meet the assumed seasonal or year-round limit while maintaining its current rated capacity (144-million gallons per day (mgd) max month year-round and 98-mgd max month during summer). Chapter 3 evaluates the effects that implementing nitrogen removal would have on reclaimed water production at the STP.

ES.2 SOUTH PLANT NITROGEN REMOVAL - CURRENT CONFIGURATION

A project team was assembled to evaluate the effects of potential future nitrogen limits on the capacity of the STP. A full-plant model was developed and calibrated to operating data collected at the plant. The project team decided upon two effluent nitrogen scenarios representing potential permitting scenarios: (1) a summer effluent limit of 8 mg/L TIN and (2) a year-round effluent limit of 3 mg/L TIN. As part of a project workshop, the project team also decided that the capacity rating of the current plant to meet the two target nitrogen effluent scenarios would be determined with one aeration basin and one secondary clarifier out of service.

Based on these assumptions, the modeled capacity of the current STP to meet the summer effluent limit of 8 mg/L TIN is 36 mgd. This capacity rating was based on operating the existing aeration basins in a Modified Ludzak-Ettinger (MLE) configuration. To meet this effluent limit, minor modifications would be needed at the current plant including the addition of baffle walls, mixed liquor return (MLR) pumps and a chemical delivery system. However, major construction would be needed (onsite or offsite) to meet the current maximum summer month flow of 98 mgd and replace the 62 mgd of capacity lost as a result of the nitrogen removal modifications.

Based on the assumptions established in the first workshop, the modeled capacity of the current STP to meet the year-round effluent limit of 3 mg/L TIN was determined to be 30 mgd. This capacity rating was based on operating the existing aeration basins in a Bardenpho configuration. To meet this effluent limit, minor modifications would be needed at the current plant including the addition of baffle walls, MLR pumps and a chemical delivery system. However, construction would be needed (onsite or offsite) to meet the current maximum month flow of 144 mgd and replace the 114 mgd of capacity lost as a result of the nitrogen removal modifications.

ES.3 SOUTH PLANT NITROGEN REMOVAL SCENARIOS

There are four general classes of nitrogen removal alternatives:

- Land-based
- Aquatic
- Chemical
- Biological

At the first workshop on October 1, 2009, a variety of potential alternatives within each of the 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 biological 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 – membrane bioreactor (MBR), 3) MLE – integrated fixed-film activated sludge (IFAS) and 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, and 4) BAF/DNF. For each representative alternative, side stream treatment was evaluated to determine whether additional treatment could reduce the footprint and cost of the alternative.

The four selected alternatives for each nitrogen limit scenario were evaluated to determine a relative cost and footprint for each alternative. Tables ES.1 and ES.2 summarize the footprint effects of each alternative for the effluent limit scenario of 8 mg/L TIN during the summer and 3 mg/L TIN year round, respectively. Footprint estimates are primarily for comparative purposes, and do not currently account for other features that can consume land area such as roads, odor control, and ancillary equipment.

The MLE alternative requires the greatest footprint and provides very little space for the plant to expand to treat future flows or to respond to future changes in effluent quality requirements while the BAF-DNF and MLE-MBR alternatives provide the most available space for future expansion. The MLE-IFAS alternative could be very attractive from a footprint standpoint if the most aggressive of the manufacturer’s performance and design criteria could be confirmed.

The Bardenpho alternative requires the greatest footprint and does not fit on the site while the BAF-DNF and Bardenpho-MBR alternatives provide the most available space for future expansion. The Bardenpho-IFAS alternative could be very attractive from a footprint standpoint if the aggressive version of manufacturer's claims and assumed packing densities could be confirmed.

Table ES.1 8 mg/L TIN (Summer-only) Alternative Footprint Analysis South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division

	MLE	MLE-MBR	MLE-IFAS (A)[1]	MLE-IFAS (C)[2]	BAF / DNF
Total added basins, sf[3]	359,900	107,700	39,900	191,600	100,700
Full buildout capacity assuming no expansion on the biosolids site, mgd[1]	144	270	360	210	270

Notes:
(1) IFAS A stands for the aggressive sizing of IFAS.
(2) IFAS C stands for the conservative sizing of IFAS.
(3) Capacity ratings are based on maximum month flows during the summer months. The maximum month flow capacity of the current plant for summer flows is 98 mgd. The assumed density of aeration basins is based on the proposed STP site buildout layout provided by the County. No extra allowances were made for roads or ancillary facilities.

Table ES.2 3 mg/L TIN (Year-round) Alternative Foot Print Analysis South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division

	Bardenpho	Bardenpho - MBR	Bardenpho - IFAS (A)[1]	Bardenpho - IFAS (C)[2]	BAF / DNF
Total added basins, sf	1,009,100	293,700	80,300	505,900	183,300
Full buildout capacity assuming no expansion on the biosolids site, mgd[3]	TL[4]	170	300	TL[4]	240

Notes:
(1) IFAS A stands for the aggressive sizing of IFAS.
(2) IFAS C stands for the conservative sizing of IFAS.
(3) Capacity ratings are based on maximum month flows. The maximum month flow capacity of the current plant is 144 mgd. The assumed density of aeration basins is based on the proposed STP site buildout layout provided by the County. No extra allowances were made for roads or ancillary facilities.
(4) TL = estimated foot print is too large and does not fit on the site.

Based on team input from the first workshop, the four alternatives for each nutrient limit scenario were evaluated based on the following cost and non-cost criteria: (1) onsite capital costs, (2) operation and maintenance (O&M) costs, (3) risk, (4) future flexibility, (5) footprint, (6) energy, (7) odor, (8) compatibility with existing processes, (9) biosolids quality, and (10) reclaimed water quality/quantity. Each of these criteria was scored from 1 (low) to 3 (high). The weighting for each criterion was established by the team at the second workshop on

December 15, 2009. Tables ES.3 and ES.4 present the weighted results for each effluent limit scenario. Based on this analysis, the two leading alternatives for both effluent limit scenarios were the MBR and BAF/DNF. The County decided to select the MBR system as the representative alternative for both effluent limit scenarios. The team concluded that the BAF/DNF system should also be considered in more detail at a facility planning or pre-design level. Since aggressive IFAS sizing potentially offers a very competitive alternative, the County may want to consider pilot testing to determine the optimum kinetic parameters and packing densities.

Table ES.3 8 mg/L TIN (Summer-only) Scoring Matrix
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Criteria	Weight	Score MLE	MBR	IFAS A(1)	IFAS C(2)	BAF
Onsite Capital Cost	1	3	2	3	1	3
O&M Cost	1	3	1	2	2	2
Risk	2	3	3	0(3)	1	2
Future Flexibility	2	1	3	3	1	3
Footprint	3	1	3	3	2	3
Energy	2	3	2	3	1	2
Odor	1	2	2	2	2	2
Compatibility with existing processes	1	3	3	3	3	3
Biosolids Quality	1	2	2	2	2	2
Reclaimed Water Quality/Quantity	1	1	3	2	2	2
Un-weighted Total		22	24	F(4)	17	24
Weighted Total		31	38	F(4)	24	37

Notes:
(1) IFAS A stands for the aggressive sizing of IFAS.
(2) IFAS C stands for the conservative sizing of IFAS.
(3) The aggressive IFAS sizing was determined to be too risky based on the manufacturer's lack of sufficiently demonstrated approach to tank sizing. The County may want to consider pilot testing to further support this consideration.
(4) A score of a "0" on any of the criteria results in a failure of that alternative.

Table ES.4 3 mg/L TIN (Year-round) Scoring Matrix
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Criteria	Weight	Score MBR	IFAS A[(1)]	IFAS C[(2)]	BAF
Onsite Capital Cost	1	2	3	3	2
O&M Cost	1	1	1	3	2
Risk	2	3	0[(3)]	1	2
Footprint	3	2	3	0[(4)]	2
Energy	2	1	3	2	2
Odor	1	2	2	2	2
Compatibility with existing processes	1	3	3	3	3
Biosolids Quality	1	2	2	2	2
Reclaimed Water Quality/Quantity	1	3	2	1	2
Un-weighted Total		19	F[(5)]	F[(5)]	19
Weighted Total		27	F[(5)]	F[(5)]	27

Notes:
(1) IFAS A stands for the aggressive sizing of IFAS.
(2) IFAS C stands for the conservative sizing of IFAS.
(3) The aggressive IFAS sizing was deemed to be too risky based on the manufacturer's lack of an adequate explanation for tank sizing. This alternative should be pilot tested before further consideration.
(4) The conservative sizing of IFAS was given a "0" for footprint since this alternative did not fit on the site.
(5) A score of a "0" on any of the criteria results in a failure of that alternative.

Tables ES.5 and ES.6 present summaries of estimated costs for upgrade of the STP to provide for nitrogen removal for the two potential permit levels. The estimates include the cost of odor control covers and equipment for the reactor tanks. The cost estimates were based on a preliminary quantity estimate for excavation and concrete for new tanks and estimated cost for new equipment. To these direct costs were added allowances 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.). 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 March 15, 2010. The expected accuracy range for 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. The tables present summaries of costs for major project elements in five columns:

1. Costs for conventional activated sludge (CAS) operation

Table ES.5 Estimate Summary for 8 mg/L TIN (Summer-only) Permit Level Upgrade to the STP
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Element	CAS	MLE Upgrade	MLE MBR	Total BNR Upgrade	Difference
Present Worth Cost, $ Million					
Capital Cost[(1)]	$0	$105	$425	$530	$530
Operation and Maintenance[(2)]	$25	$46	$129	$176	$149
Total Present Worth	**$25**	**$151**	**$554**	**$706**	**$679**

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 March 2010 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.

Table ES.6 Estimate Summary for 3 mg/L TIN (Year-round) Permit Level Upgrade to the STP
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Element	CAS	Bardenpho Upgrade	Bardenpho MBR	Total BNR Upgrade	Difference
Present Worth Cost, $ Million					
Capital Cost [(1)]	$0	$188	$779	$967	$959
Operation and Maintenance[(2)]	$25	$128	$394	$522	$475
Total Present Worth	**$25**	**$316**	**$1,173**	**$1,489**	**$1,434**

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 March 2010 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.

2. Upgrade of the existing CAS to provide for biological nitrogen removal (BNR)
3. New Parallel MBR BNR facilities
4. The total estimated cost for the BNR upgrade
5. The difference in cost between the BNR upgrade and the cost of operation of the existing CAS

The greenhouse gas (GHG) emissions of the representative alternative for each permit scenario were compared against the current mode of operation at the STP. A summary of the results of the GHG analysis for the project is presented in Figure ES.1. This figure presents a bar chart representing the total estimated annual production of carbon dioxide (CO_2) equivalents for the three process alternatives:

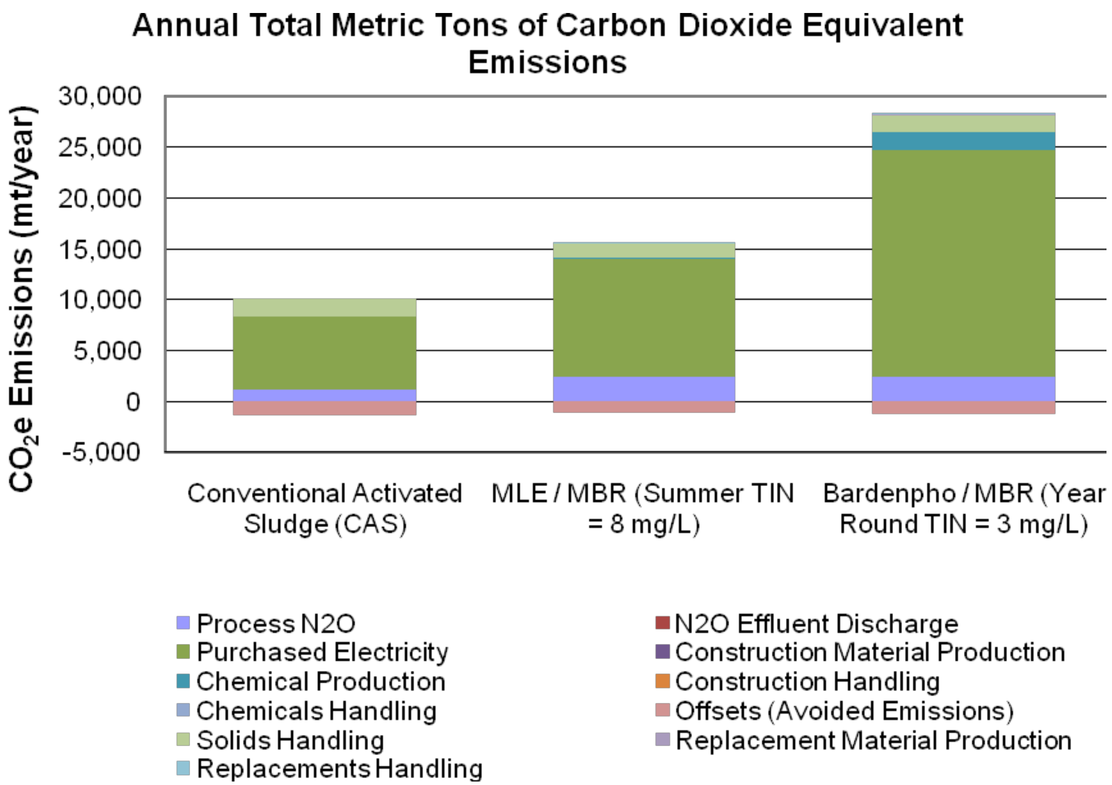
1. CAS
2. BNR with an effluent permit goal of 8 mg/L TIN for the six summer months of the year by conversion of the existing aeration tanks to an MLE process with treatment of the remaining flow by MLE MBR. Operation in CAS the remainder of the year.
3. BNR with an effluent permit goal of 3 mg/L TIN (year-round) by conversion of the existing aeration tanks to a Bardenpho process with treatment of the remaining flow by Bardenpho MBR.

The results indicate that the effect of a summer-only effluent permit level of 8 mg/L TIN would be approximately two thirds more GHG emissions compared to secondary treatment at the STP. Imposition of a 3 mg/L TIN year-round limit would result in approximately three times more emissions of equivalent GHGs. The primary sources of increased GHG emissions are process nitrous oxide (N_2O) and purchased electricity.

ES.4 SOUTH PLANT NITROGEN REMOVAL EFFECT ON RECLAIMED WATER PRODUCTION

The STP currently provides secondary treatment for up to 144 mgd of flow on a maximum month basis for discharge to Puget Sound. Substantial removal of ammonia is not achieved. Reclaimed water filtration facilities for up to 1.5 mgd of secondary effluent are available using coagulation, flocculation, sand filtration, and disinfection. Implementation of BNR at the STP could have a significant effect on reclaimed water availability, potential customers, and quality, depending on the technology selected.

The current flow of the STP during the summer season when reclaimed water could be potentially useful for irrigation is approximately 98 mgd. Coagulation, flocculation, and filtration would be required to implement production of 98 mgd of reclaimed water from the current non-nitrified secondary effluent. Assuming typical detention times and loading ratios, approximately 38,000 square foot (sf) of coagulation, flocculation, and filtration facilities would be required. In calculating effects, current capacity of 1.5 mgd was ignored.



GHG COMPARISON

FIGURE ES.1

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

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The MLE – MBR alternative for operation for an 8 mg/L TIN permit level during the summer would produce up to 62 mgd of MBR effluent water during the summer that would substantially meet the requirements for Class A reclaimed water. To produce reclaimed water equaling the full current dry weather flow of 98 mgd, sand filtration of 36 mgd from the existing secondary clarifiers would be needed resulting in a requirement of approximately 13,000 sf of coagulation, flocculation, and filtration facilities.

The Bardenpho – MBR upgrade strategy would produce up to 114 mgd of MBR effluent year round that would substantially meet the requirements of Class A reclaimed water. This means that during the summer season, the STP could treat the full summer flow through the MBRs, if BNR were implemented.

Table ES.7 compares the costs of reclaimed water production for the full 98 mgd summer flow for the current non-nitrified secondary effluent to the requirements for additional filtration assuming nitrogen removal upgrade by a parallel MBR process for either the 8 mg/L (summer only) or the 3 mg/L (year-round) TIN permit level. As shown in Table ES.7, there would be no additional cost to implement reclaimed water production for the full summer flow of 98 mgd if the 3 mg/L (year-round) TIN permit limit project is implemented.

Table ES.7 shows that the cost of implementing reclaimed water by conventional filtration is approximately $104 million in present worth capital and operating and maintenance costs. If a 3 mg/L (year-round) TIN permit limit project using parallel MBR were implemented, this cost would be avoided.

The relative present worth cost of implementing 36 mgd of reclaimed water production for non-nitrified effluent would be approximately $45 million. This would represent a savings of approximately $45 million over providing full summer reclaimed water production today from non-nitrified STP effluent. This relative savings in reclaimed water production would be realized if the 8 mg/L (summer-only) parallel MBR project were implemented.

Table ES.7 Summary of Relative Reclaimed Water Cost Effects
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Process	Current Approach. Non-nitrified Secondary Effluent. No new facilities. Summer only.	8 mg/l TIN Summer Limit Parallel MLE-MBR Processes		3 mg/l TIN All-year Limit
Add'l Sand Filtration Req'd	98 mgd sand filters	MLE Effluent 36 mgd sand filters	MBR Effluent 62 mgd - no sand filters	MBR Effluent 114 mgd – no sand filters
Capital Cost	$57M	$23M	$0	$0
Annual O&M Cost	$3.1M/yr	$1.4M/yr	$0	$0
Disinfection	Assumed equal cost for all alternatives.			
Present Worth O&M(1)	$47M	$22M		$0
Total Present Worth	**$104M**	**$45M**		**$0**

Notes:
(1) Present worth O&M values calculated assuming a 3% discount rate over a 20-year period on calculated current yearly O&M costs.

ES.5 FINDINGS AND CONCLUSIONS

The principle findings and conclusions of this report are the following:

1. At a project workshop two potential nitrogen removal permit requirements were determined 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.

2. Based on assumptions developed at project workshops, the modeled capacity of the current STP, with minor modifications, to meet the "least stringent" summer effluent limit was 36 mgd. Major modifications that would be needed would be construction of a new treatment plant to treat the remainder of the summer flow (approximately 62 mgd).

3. The modeled capacity of the current STP to meet, with minor modifications, the "most stringent" year-round effluent limit was 30 mgd. Major modifications that would be needed would be construction of a new treatment plant to treat the remainder of the flow (approximately 114 mgd).

4. A large number of potential nitrogen removal alternatives were considered for each potential permit scenario and reduced to four for each permit scenario. Potential effects of each of these upgrade strategies were estimated using a series of criteria

including capital cost, O&M cost, risk, flexibility, footprint, energy, odor generation potential, compatibility with existing processes, effect on biosolids quantity, and the amount and quality of reclaimed water produced. Each of these criteria were scored from 1 (low) to 3 (high) and tallied to determine the ranking. The final ranking indicated that for the 8 mg/L TIN (summer-only) permit level, the most promising upgrade strategy would be to upgrade the existing CAS process at the STP to provide for anoxic and aerobic treatment in two stages by a MLE process and to construct a parallel nitrogen removing MBR process to treat the remainder of the flow. For the 3 mg/L TIN (year-round) discharge alternative a similar strategy was selected, but using a four-stage anoxic and aerobic process (the Bardenpho process). It was concluded that two other processes, BAF/DNF and IFAS processes, were potentially cost-effective and have similar enough other effects that they should be considered for pilot testing in the future.

5. The incremental present worth cost for upgrade of the STP to meet an 8 mg/L TIN permit level during the summer months is estimated at approximately $680 million more than continuing operation of secondary treatment over the next twenty years. The estimated incremental present worth cost for upgrade of the STP to meet a 3 mg/L TIN (year-round) permit level is approximately $1,430 million more than the cost of continuing with secondary treatment.

6. It was concluded that meeting an 8 mg/L TIN summer permit level would result in nearly two thirds more GHG emissions from the STP compared to the currently-used CAS process and that 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 STP.

7. If BNR were implemented at the STP, between 36 and 98 mgd of effluent would be made available that would be suitable for reclaimed water use. Assuming that the costs of production of this water were required for BNR in any case, this water would be available for reclaimed use at a relative savings over the costs of production of the water using conventional gravity sand filtration. Cost savings would be in the range of $45 to $104 million, depending on the level of nitrogen removal implemented. There would also be a savings in land area of between one quarter and one acre and a savings of a small amount in electricity consumption and GHG emissions, compared to production of the same amount of reclaimed water using media filtration if BNR treatment facilities were not available.

SOUTH PLANT NITROGEN REMOVAL - CURRENT CONFIGURATION

1.1 INTRODUCTION

According to the Washington State Department of Ecology (Ecology 2008b), portions of South Puget Sound do not meet Washington State water quality standards for dissolved oxygen (DO). Ecology is concerned that algal growth stimulated by nitrogen loadings to Puget Sound is causing DO depressions in near-bottom regions. The form of nitrogen of greatest interest to Ecology is dissolved inorganic nitrogen (DIN), which is the sum of nitrate, nitrite, and ammonium. In 2006 Ecology began a major study to determine the extent of low DO and how nitrogen from a variety of sources affects DO levels. The primary concern was with South Puget Sound below the Tacoma Narrows, but because it was thought that circulation of nitrogen from the north could cause low DO effects, the Central Puget Sound area north of the Tacoma Narrows and south of Edmonds was included in the study. All of King County's wastewater treatment plants (WWTP) discharge to the Central Puget Sound. The scope of work for the Ecology study includes data collection, developing hydrodynamic and water quality models, and simulating alternative management scenarios.

To date Ecology has completed data collection and hydrodynamic modeling. The last elements of Ecology's scope of work are being completed in 2010. Ecology produced two significant conclusions from its data collection effort (Ecology, 2008a):

- Nitrogen is the main pollutant that causes low dissolved oxygen levels.
- In September 2007, wastewater treatment plants contributed 80 percent of the watershed DIN load to South Puget Sound (nitrogen loads in late summer are particularly important because this is when DO levels are the lowest). Because of the greater population density in the Central Puget Sound study area, the sum of WWTP DIN loadings from the combined Central and South Puget Sound area contributed over 90 percent of the watershed DIN load to the combined Central and South Puget Sound.

Results of the hydrodynamic modeling are available as an external review draft (Ecology, 2009). These results conclude that "Based on predicted dilution levels derived from water column maximum dye concentrations during September 16-30, 2007, dye from South and Central Puget Sound exchanges through the Tacoma Narrows (Figure ES-7). Therefore, we cannot rule out the influence of Central Puget Sound sources on South Puget Sound water quality. However, the results are not sufficient to rule in an influence either given the complexity of nutrient transport and transformation within marine environments. The water quality model is needed to quantify the link between sources and water quality impairments." Results of the water quality transport modeling are expected in 2010.

With this background King County (the County) undertook the current project to "determine the effectiveness and costs of a range of treatment scenarios designed to reduce nitrogen discharged by the South Treatment Plant (STP)" (from scope of work for King County Contract E00025E07). An initial project team workshop was conducted on October 1, 2009 where the project assumptions were established.

Three memoranda were produced as part of this project. The first memorandum evaluated how much flow the existing STP could process if required to comply with two different levels of nitrogen removal and what modifications would be required for each. The second memorandum evaluated the potential effects on the STP (in terms of additional tankage, footprint, cost, and greenhouse gas emissions) if it were required to meet the assumed seasonal or year-round limit while maintaining its current rated capacity (144-million gallons per day (mgd) max month year-round and 98-mgd max month during summer). The third memorandum evaluated effects on the reclaimed water program for the County. These three memoranda have been incorporated, respectively, into Chapters 1, 2, and 3 of this report.

The purpose of this first chapter is to describe the process used to determine target effluent nitrogen limits and the re-rated capacity of the current STP to meet these target nitrogen limits.

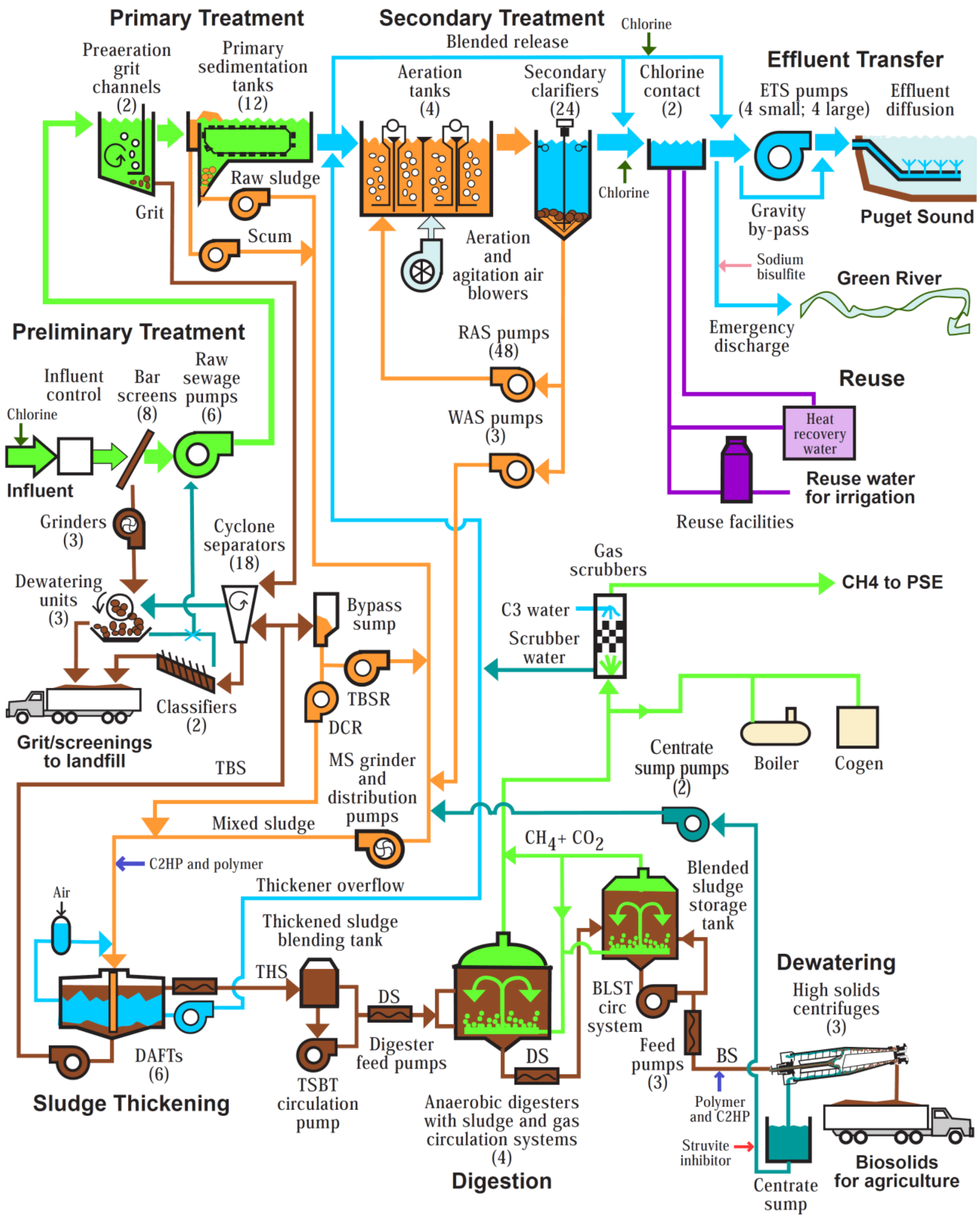
1.2 BACKGROUND

1.2.1 Description of Existing Plant

The STP was built in 1965 on a 94 acre site in Renton, Washington. The plant has been modified several times since 1965; a schematic of the current plant and an aerial overview are shown in Figures 1.1 and 1.2.

Wastewater enters the plant through the Eastside and South Interceptors. Rags and paper are removed through coarse bar screens and grit is removed in pre-aerated grit tanks. Screened, degritted wastewater flows to 12 primary clarifiers, where approximately 60 percent of total suspended solids (TSS) are removed. Primary clarifier effluent flows by gravity to four aeration basins.

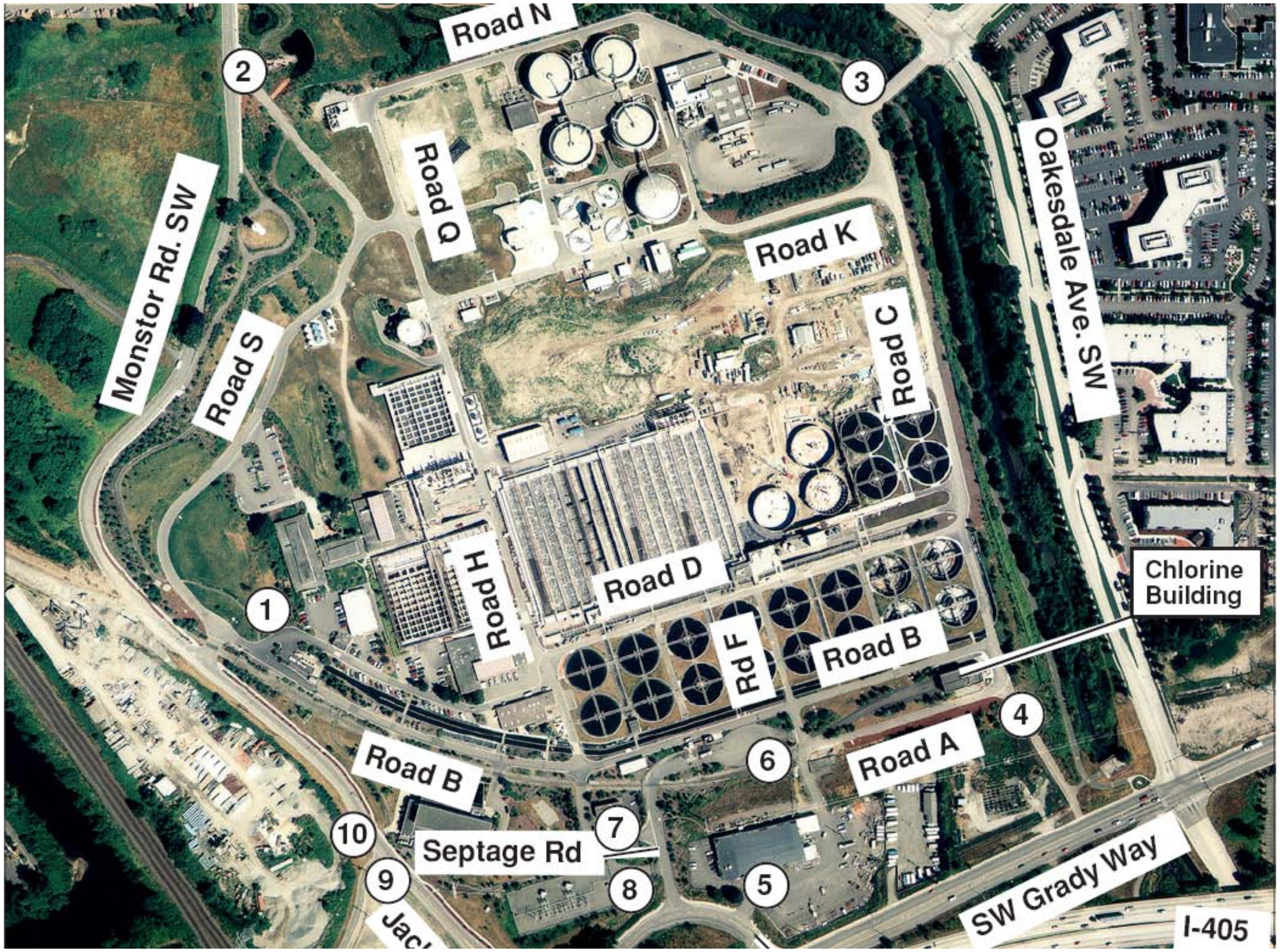
The aeration basins are operated in a plug flow mode and wastewater, mixed with return activated sludge (RAS) flows through the basin in a serpentine manner. The first one-eighth of each basin is not aerated and acts as selector, limiting growth of filamentous bacteria. Mixed liquor suspended solids (MLSS) are clarified in 24 secondary clarifiers. Secondary effluent is disinfected in chlorine contact channels using a hypochlorite solution prior to discharge in the Puget Sound.



STP PROCESS FLOW SCHEMATIC

FIGURE 1.1

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



STP AERIAL PHOTOGRAPH

FIGURE 1.2

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

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1.2.2 Summary of Current NPDES Permit

The STP'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 plant's main Puget Sound outfall. The current STP permit does not regulate effluent nitrogen but it does require the plant to monitor the final effluent for total ammonia (concentration and load), nitrate-nitrite, and total Kjeldahl nitrogen (TKN) concentration, monthly.

Table 1.1 Current NPDES Permit Summary
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Parameter	Average Monthly(1)	Average Weekly(2)
BOD_5	30 mg/L, 36,000 ppd, 85% removal of influent BOD_5	45 mg/L 54,000 ppd
TSS	30 mg/L, 36,000 ppd, 85% removal of influent TSS	45 mg/L, 54,000 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	0.5 mg/L	0.75 mg/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.

(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.

The current permit lists plant flows and loads:

- Maximum month design flow of 144 mgd
- Peak instantaneous design flow of 325 mgd
- Maximum month five day biochemical oxygen demand (BOD_5) loading of 251,000 pounds per day (ppd)
- Maximum month TSS loading of 235,000 ppd

1.3 NITROGEN LIMIT SCENARIOS

This section describes the process used to determine target nitrogen limits for use in project nitrogen removal scenarios. The nitrogen concentration in WWTP effluent is regulated to either protect human health or the environment. Since nitrate in drinking water can be responsible for the “blue baby syndrome”, the Environmental Protection Agency (EPA) has set a maximum contaminant limit goal (MCLG) of 10 milligrams per liter (mg/L) for nitrate (measured as nitrogen) in public drinking water supplies. From the perspective of effects on the human environment: since nitrogen can limit algal growth, decreasing effluent nitrogen concentration can improve the quality of the receiving water. The Lacey, Olympia, Tumwater, Thurston County (LOTT) Budd Inlet Treatment Plant in Olympia was the first large treatment plant discharging to Puget Sound to be given a nitrogen limit. This plant is limited to an average summer (for two periods from April through October) total inorganic nitrogen (TIN) concentration of 3 mg/L. TIN is defined as is the sum of ammonia, nitrate, and nitrite (TIN and DIN are the same). Several plants in Florida are now facing potential total nitrogen limits of less than 1 mg/L.

A summer season permit limit would be less stringent, in the sense that the limit could be met with smaller tank volumes and fewer other effects, than a maximum month limit (or even a maximum day limit) that was enforced year-round. This is because biological nitrification, typically a key step in nitrogen removal, is slower in cold temperatures. The extreme range of possible limits for total inorganic nitrogen based on this background would be from 1 mg/L (most stringent) to 10 mg/L TIN (least stringent) in terms of numerical value. From a compliance period perspective: a limit imposed as an average over the entire year would be least stringent and a maximum month (or even maximum day) limit imposed in the coldest months of the year would be the most stringent.

Based on these considerations, two permit scenarios were selected at the first project workshop on October 1, 2009 (Carollo Engineers, 2009a). The two permit scenarios given below represent the least and most stringent permit scenarios that workshop participants felt could reasonably be requested by Ecology, respectively:

1. Summer-season (May 1 through October 31) limit of 8 mg/L TIN
2. Year-round limit of 3 mg/L TIN imposed in the coldest month

1.4 FLOW AND LOAD BASIS

The work documented in this report evaluated the capacity of the existing STP treatment system and modifications to the existing system necessary to provide nitrogen removal for the design maximum month flow of 144 mgd. This corresponds to the rated maximum month flow from the current NPDES permit. The BOD_5, TSS, and ammonia loads that correspond to this flow were taken from Brown and Caldwell (2004) and from STP plant records for the year 2007. These are summarized in Table 1.2.

The design year-round maximum month flow and loads from Brown and Caldwell (2004) were used to evaluate the permit scenario of a year-round limit of 3 mg/L TIN. To evaluate the 8 mg/L (summer-only) TIN limit scenario maximum summer month flows and loads during the design year were determined from the Brown and Caldwell (2004) values using peak factors from the STP record for the years 2006 through 2008. These values are also summarized in Table 1.2.

**Table 1.2 Design Influent Flow and Loads
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division**

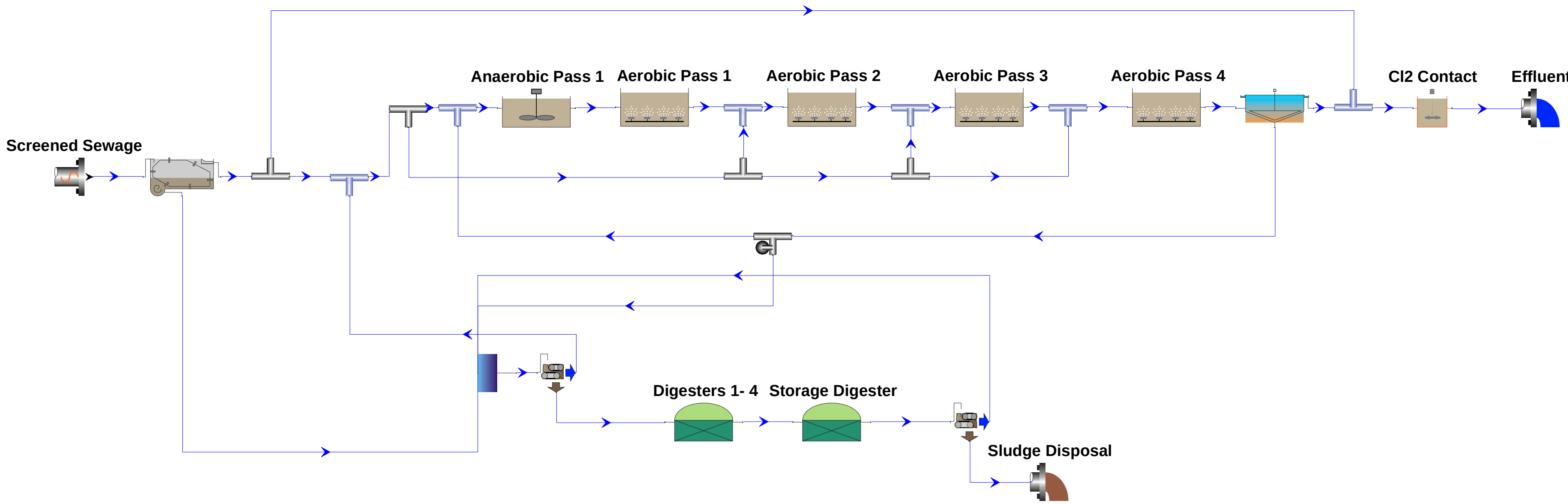
Description	Current Annual Average	Design Summer Maximum Month	Design Year-round Maximum Month(1)
Flow, mgd	85	98	144
BOD_5, ppd	164,000	231,000	251,000
TSS, ppd	168,000	221,000	235,000
NH4-N, ppd	16,300	26,200	23,600

Notes:
(1) Brown and Caldwell (2004)

1.5 NITROGEN REMOVAL CAPACITY ANALYSIS

Treatment plant models were developed by Carollo for this report and calibrated to existing plant data to evaluate the capacity of the existing plant to meet the two effluent permit scenarios defined above. As part of the work, Carollo prepared two models; a steady state model using Biotran, a proprietary Carollo spreadsheet model, and BioWin, commercial process analysis software from Envirosim. Both models included primary treatment, activated sludge reactors, secondary sedimentation tanks, solids thickening, digestion, and dewatering unit process and return flows. Figure 1.3 presents a schematic of the model developed in BioWin.

These calibrated models were used to define the capacity of the current treatment plant (with minor 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. For our analysis we assumed that one aeration basin and one secondary clarifier was out of service. This was a decision of the October 1, 2009 workshop. The analysis assumed that 23 out of the 24 clarifiers would be in service, even at the reduced flows required to meet the more stringent effluent limits. This assumption allows operation at higher MLSS concentrations while still maintaining the current solids loading rates on the clarifiers. This section describes the analysis of the STP data, the model calibration process, and the model results for the two effluent scenarios.



PROCESS SCHEMATIC FOR STP BIOWIN MODEL

FIGURE 1.3

KING COUNTY DEPARTMENT OF NATURAL
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ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

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1.5.1 Data Analysis

In preparation for the model analysis, operating data for the period from 2005 through 2009 were reviewed. Figure 1.4 presents a time-series graph of influent flow at the STP for the period. A full year of data for 2007 was taken as representative of the period and was used for calibration of the Biotran model. The average and maximum month flows for 2007 were 76.5 mgd and approximately 120 mgd, respectively.

Influent BOD_5 loadings in 2007 averaged approximately 165,000 ppd with a maximum month average of approximately 195,000 ppd. The maximum month TSS load has historically been approximately the same as the maximum month BOD_5 load. Daily influent loadings for the entire period are shown in Figure 1.5.

Three key parameters are especially important for successful activated sludge operation and model calibration: sludge settleability, temperature, and solids residence time (SRT). The data analysis for these three parameters is summarized in the sections below.

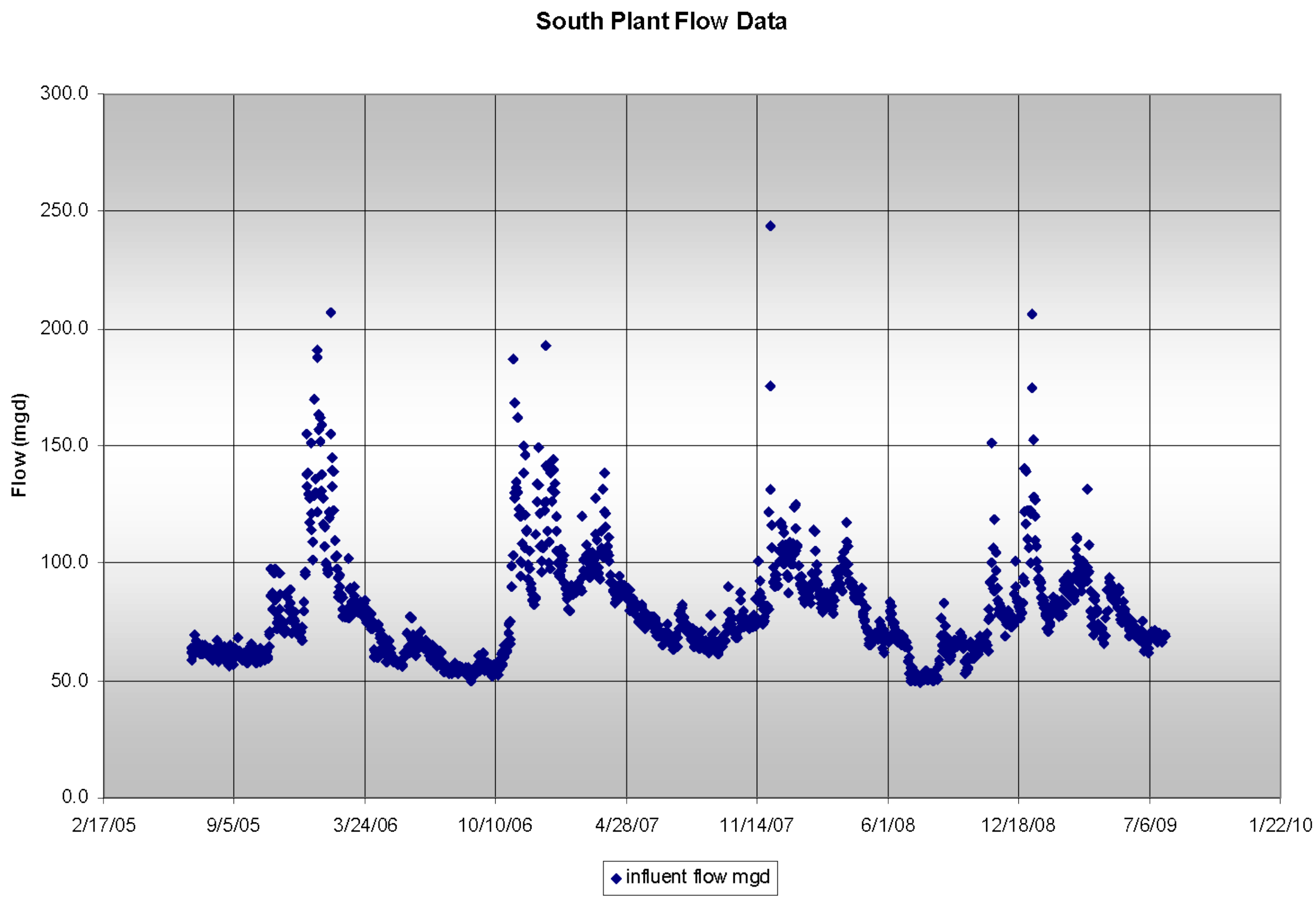
1.5.1.1 Sludge Settleability

The sludge volume index (SVI) gives an indication of sludge settling rates, which are important for solids capture in the secondary sedimentation tanks. SVI values for STP have mostly been below 150 milliliter per gram (mL/g) with several excursions as high as 250 mL/g in the last two years. Figure 1.6 shows a time-series plot of SVI data since 2007. Solids settling capacity can be calculated based on settling tests, or estimated from a statistically-derived formula. Brown and Caldwell (2004) included settling velocity data from tests in March and August of 2003. These data are compared in Figure 1.7 to data calculated using the Daigger and Pitman equations (Daigger, 1995 and Pittman, 1985) and using the default settling parameters from BioWin. The graph shows the calculated solids flux capacity in pounds of solids per square foot of clarifier cross-section per day (ppd/sf).

The solids flux rate based on the Daigger equation lies between the two values measured in 2003. For the initial modeling, the BioWin default values were used, but the effect of settleability on performance was considered in a sensitivity evaluation presented in the Chapter 2.

1.5.1.2 Temperature

Temperature affects biological growth and sludge settling. In general, for higher temperatures, growth rates and oxygen consumption in the activated sludge process increase, and settling rates may also increase as a result of lower fluid viscosity. At lower temperatures biological growth slows.



RAW SEWAGE FLOW FOR THE PERIOD FROM 2005 TO 2009

FIGURE 1.4

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

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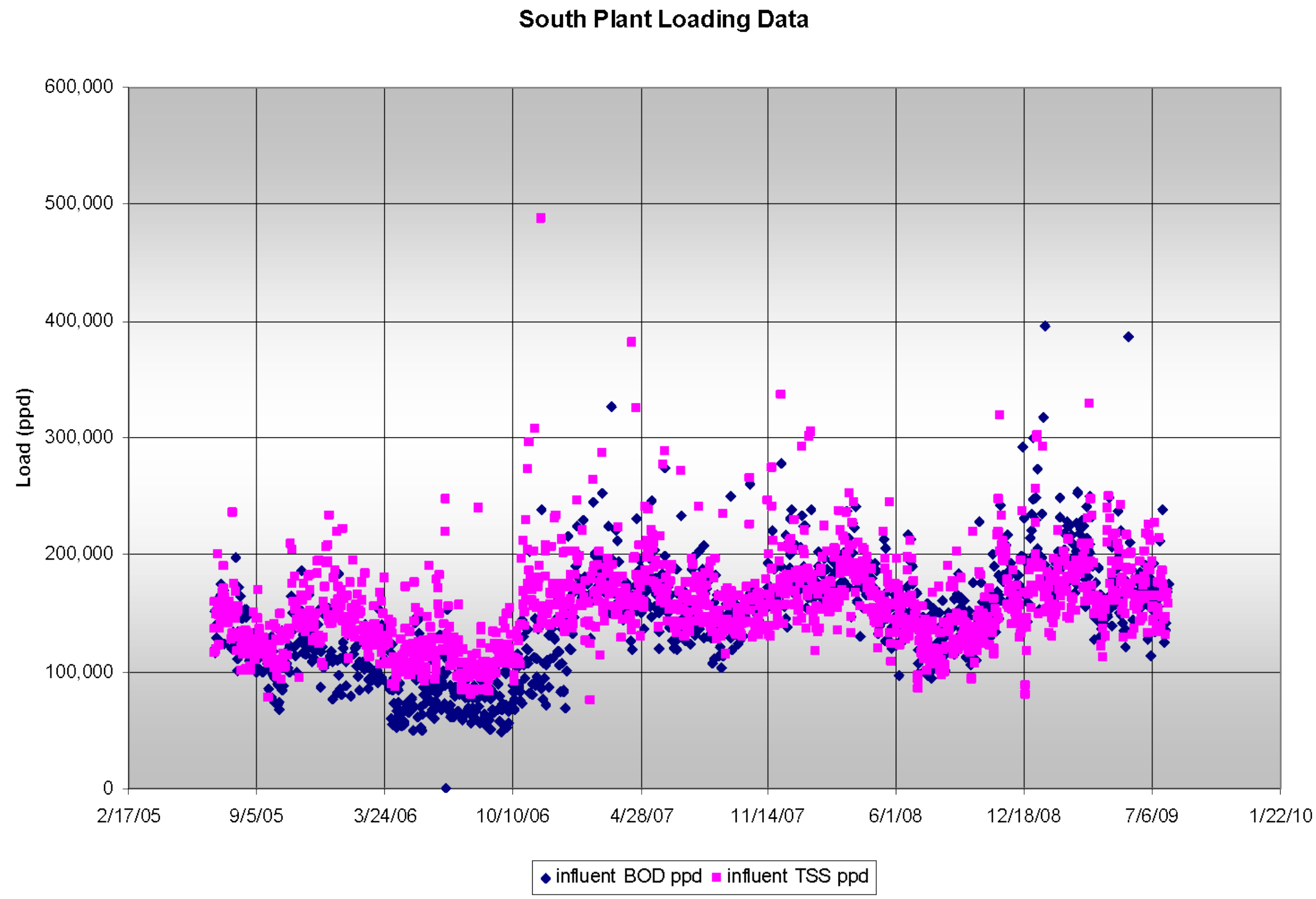

RAW SEWAGE LOADING DATA FOR THE PERIOD FROM 2005 TO 2009

FIGURE 1.5

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

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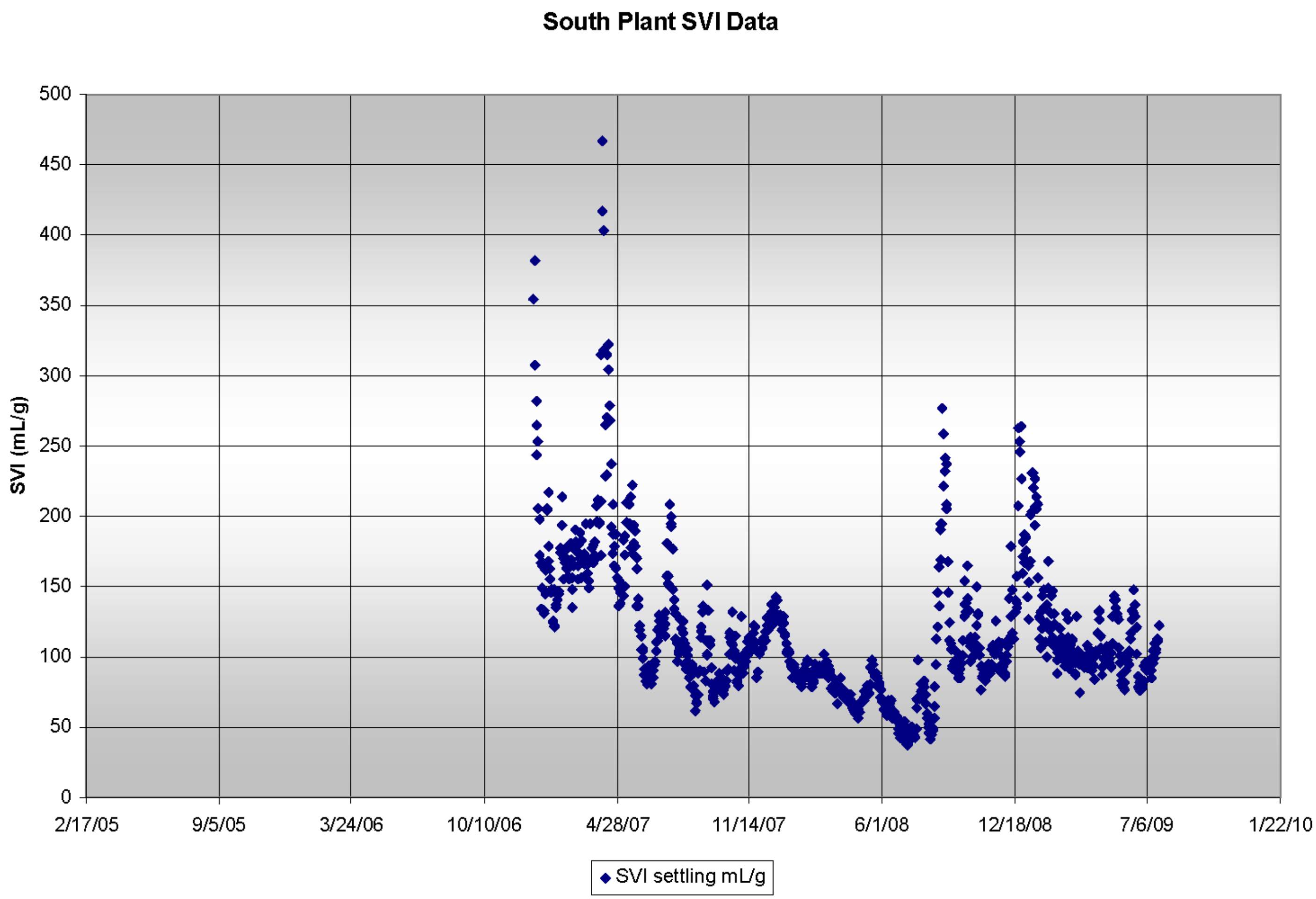

SVI DATA FOR THE PERIOD FROM 2007 TO 2009

FIGURE 1.6

KING COUNTY DEPARTMENT OF NATURAL
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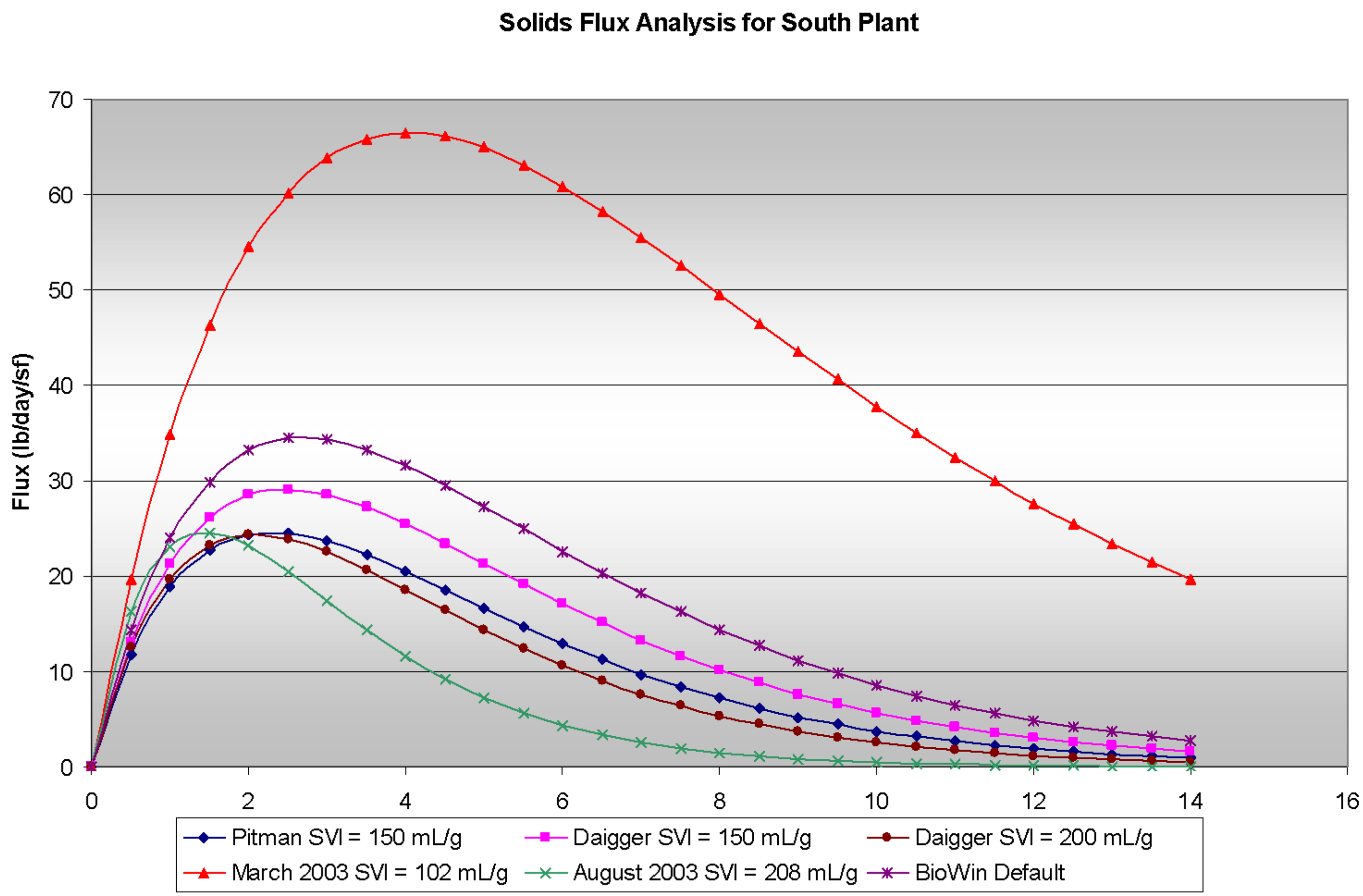


SETTLEABILITY DATA FROM 2003 TESTS COMPARED TO STANDARD SVI-BASED FORMULAS

FIGURE 1.7

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

Influent temperature data from 2005 through 2009 provided by the County were evaluated to determine the minimum 30-day running average summer (May 1 through October 31) temperature and the minimum 30-day running average year-round temperature. These data are shown in Figure 1.8. Based on the four years of data a minimum month summer temperature of 13.9 degrees Celsius (C) and a minimum month year-round temperature of 11.4 C were selected for use in the project.

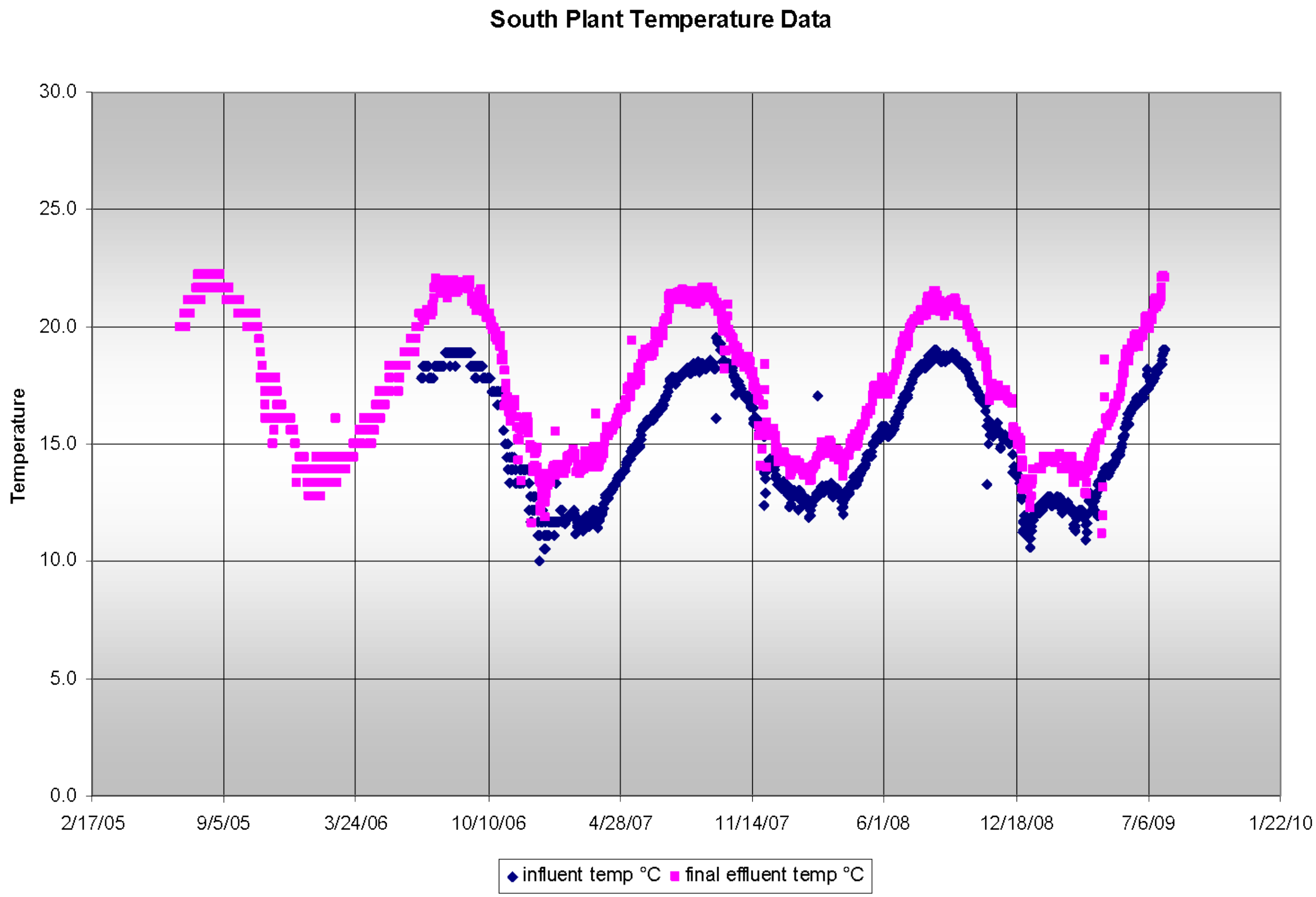
1.5.1.3 Solids Residence Time

The SRT of the activated sludge system is a key parameter for model calibration as it determines bacterial growth rates, which in turn determine oxygen consumption and sludge production for the system. Figure 1.9 presents data for aeration basin total SRT provided by the County. The SRT varied from a minimum of 2.1 days to a maximum of 5.8 days over the period of the data. The models used for this study were calibrated to the average total SRT during the 2007 calibration time period of 3.5 days.

A key group of organisms for this evaluation are the nitrifiers. These organisms are sensitive to temperature as is illustrated in Figure 1.10. This graph shows the washout, or minimum, SRT for the nitrifiers as predicted by Jenkins, et al. 2004. At the minimum summer temperature of approximately 14 C, nitrifying organisms are washed out of the system when the aerobic SRT is less that approximately 6 days. At the minimum year-round temperature of approximately 11 C, the nitrifying organisms are washed out of the system when the aerobic SRT is less than approximately 12 days. With one-eighth of the existing aeration tanks operated anaerobically, only seven-eighths of the total SRT count towards aerobic SRT. In other words, for the total average SRT of 3.5 days maintained in the STP during 2007 the aerobic SRT would have been approximately 3.1 days.

The summer nitrification temperature estimate presented in Figure 1.8 can be compared to the STP's full-scale nitrification testing experience. During the summer of 2000 the STP was operated at a 10 to 14 day total SRT with one-eighth of the basin unaerated (resulting in an aerobic SRT of 9 to 12 days) and the RAS rate at maximum flow. During this period the plant was able to operate with good nitrification and secondary effluent ammonia concentrations less than 1 mg/L and reasonably good denitrification; with secondary effluent nitrate concentrations in the range of 10 to 15 mg/L.

Based on this full-scale experience, modeling in BioWin and Biotran, and the minimum SRTs listed in Figure 1.6, the target aerobic SRT for the summer effluent scenario of 8 mg/L TIN was 9 days and the target aerobic SRT of the year-round effluent scenario of 3 mg/L TIN was 13 days.



TEMPERATURE DATA FOR THE PERIOD FROM 2005 TO 2009

FIGURE 1.8

KING COUNTY DEPARTMENT OF NATURAL
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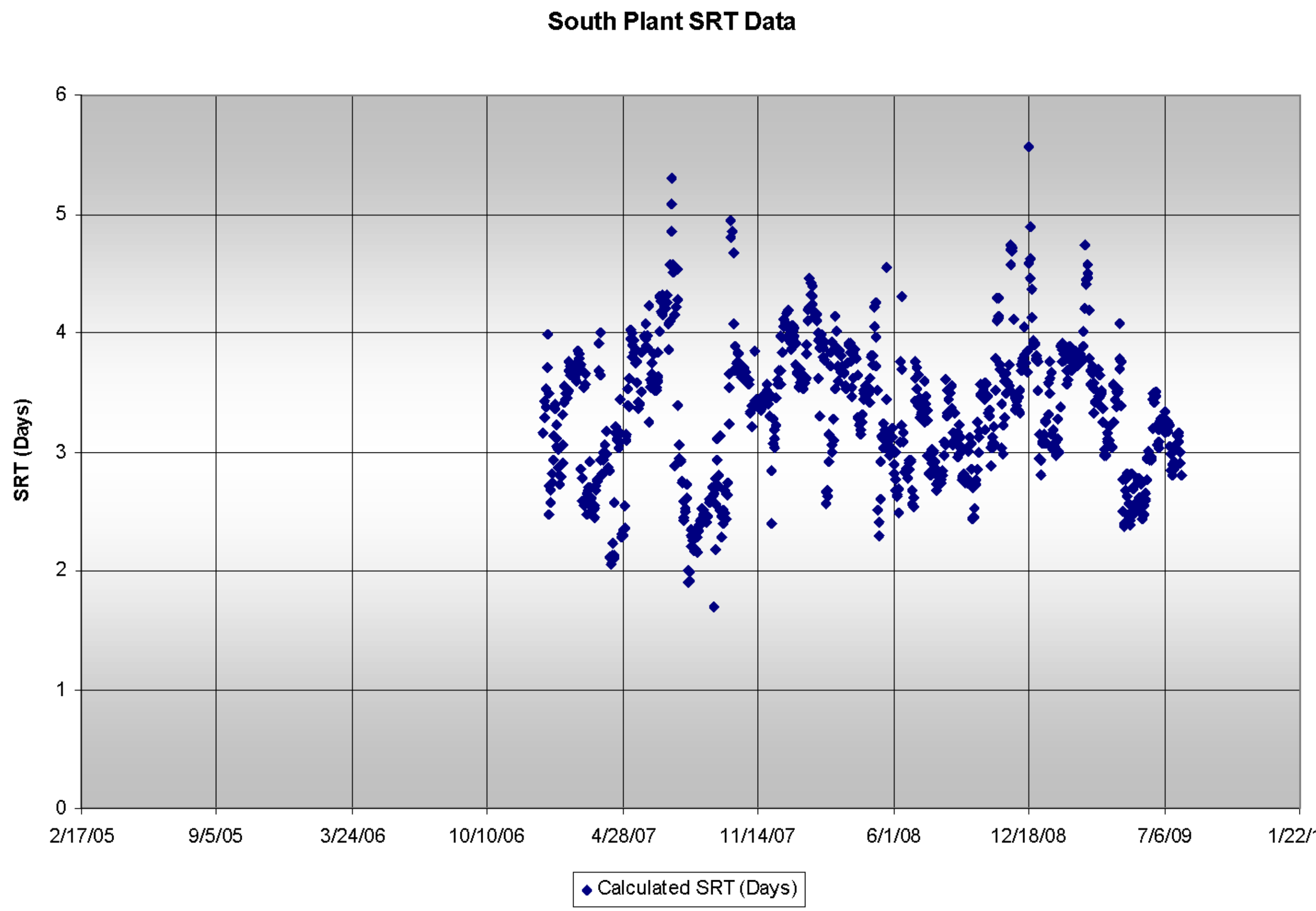
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



SRT DATA FOR THE PERIOD FROM 2005 TO 2009

FIGURE 1.9

KING COUNTY DEPARTMENT OF NATURAL
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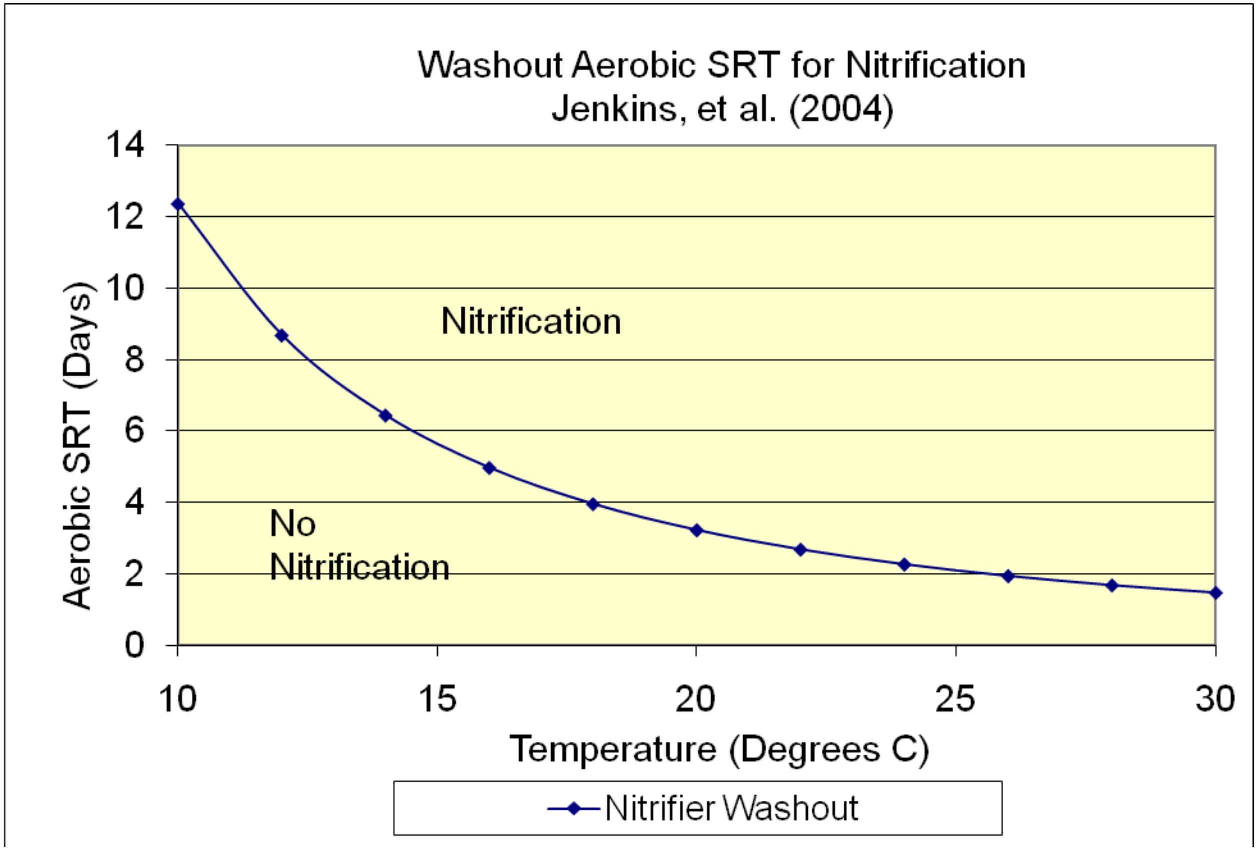
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



WASHOUT AEROBIC SRT VALUES FOR NITRIFIER ORGANISMS

FIGURE 1.10

KING COUNTY DEPARTMENT OF NATURAL
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ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

1.5.2 Model Calibration

The “*South Plant Peak Flow Management Report*” (Carollo Engineers, 2010) described three different approaches to the BioWin model calibration as summarized below:

1. The default values from BioWin for raw sewage

2. The values from Biotran calibrated to 2007 STP data

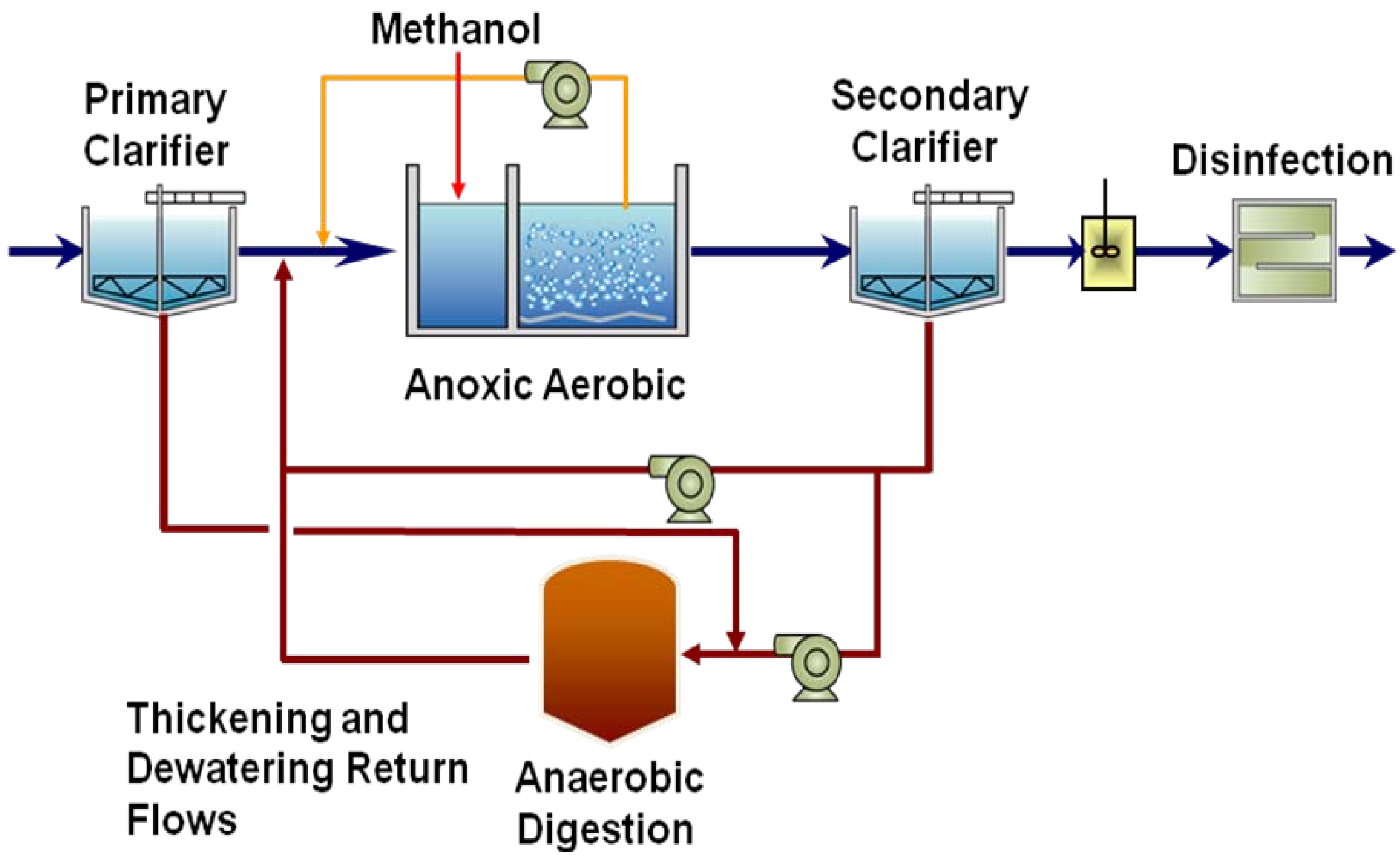
3. Values assumed in the 2000 Brown and Caldwell evaluation

The Peak Flow Management Report found little difference between the three different calibration approaches. Based on this finding, the second calibration approach, using 2007 STP data, was used to calibrate the model for this study. Data received from the County for the year 2007 was used to match primary organics removal, the amount of solids produced in waste activated sludge (WAS), and the recorded solids residence time for the average mixed liquor suspended solids for the period. Two primary parameters were used to produce the calibration: the apparent filterable BOD_5 fraction (filterable BOD_5 fraction (fbf) = 0.415) and the non-biodegradable volatile suspended solids (non-biodegradable volatile fraction (fvu) = 0.15). These values were used to produce wastewater characteristic ratios for the raw wastewater. These characteristic ratios were in turn used as input to a BioWin model of the entire STP.

1.5.3 Modeling Results TIN 8

Based on the calibrated BioWin model and an assumed aerobic SRT of 9 days, the secondary effluent scenario of 8 mg/L TIN can be met with a reduced maximum summer month flow of 36 mgd (or 37 percent of the design maximum summer month flow of 98 mgd). This scenario assumes one aeration basin and one secondary clarifier out of service as decided in the October 1, 2009 workshop. For this scenario the activated sludge basins would be operated in a Modified Ludzak-Ettinger (MLE) configuration shown in Figure 1.11. With this configuration, the entire first pass would be unaerated, increasing the unaerated fraction form 12.5 percent to 25 percent. The unaerated fraction would serve as the anoxic zone where in the 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 pump would be 360 percent of the influent flow. 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.

In the absence of oxygen, denitrifying bacteria use nitrate as an oxygen source. The MLE configuration is considered a pre-anoxic denitrification process, since the denitrification process precedes the nitrification process. This is an optimal configuration for denitrification because the denitrification process occurs in the zone with the highest BOD_5 concentration. However, when denitrification processes follow primary clarification, the BOD_5 available from the wastewater can limit the extent of denitrification.



MLE SCHEMATIC

FIGURE 1.11

KING COUNTY DEPARTMENT OF NATURAL
RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

It is generally thought that a BOD_5 to TKN ratio of at least 4 is required for denitrification (Randall et al., 1992). The BOD_5 to TKN ratio of the STP primary effluent is approximately equal to the minimum ratio. Through modeling it was determined that for the STP without an external carbon source, a 50 percent anoxic zone size would be required. Since this severely limits the capacity of the system, if was assumed that the anoxic zone size would be limited to 25 percent and an external carbon source in the form of methanol would be used. Table 1.3 summarizes the modeling results for this scenario.

To meet the TIN limit of 8 mg/L, the following modifications would be needed to the existing plant:

- Added baffle wall at the end of the first pass
- Mixed liquor return pumps capable of delivering 360 percent of the influent flow
- Methanol delivery system and methanol storage
- Additional diffusers to the second pass of the aeration basins
- Additional plant capacity for the remainder of the design year flow (or 62 mgd maximum summer month). This will be addressed in the subsequent chapter.

Table 1.3 Current Configuration – TIN 8 mg/L Scenario Modeling Results
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

	Value
Design Maximum Summer Month Flow	36 mgd
Aeration Basins	
Aeration Basins in Service	3
Unaerated Fraction	25%
RAS Rate	58%
MLR Rate	360%
MLSS Concentration	3,700 mg/L
Aeration Air Requirement	40,000 scfm
Methanol Feed	
Flow Rate	1,400 gpd
COD Load	13,900 ppd COD
Secondary Clarification	
Secondary Clarifiers in Service	23
Secondary Effluent	
Ammonia	0.2 mg/L
Nitrate	7.5 mg/L
Nitrite	0.07 mg/L
TIN	7.8 mg/L

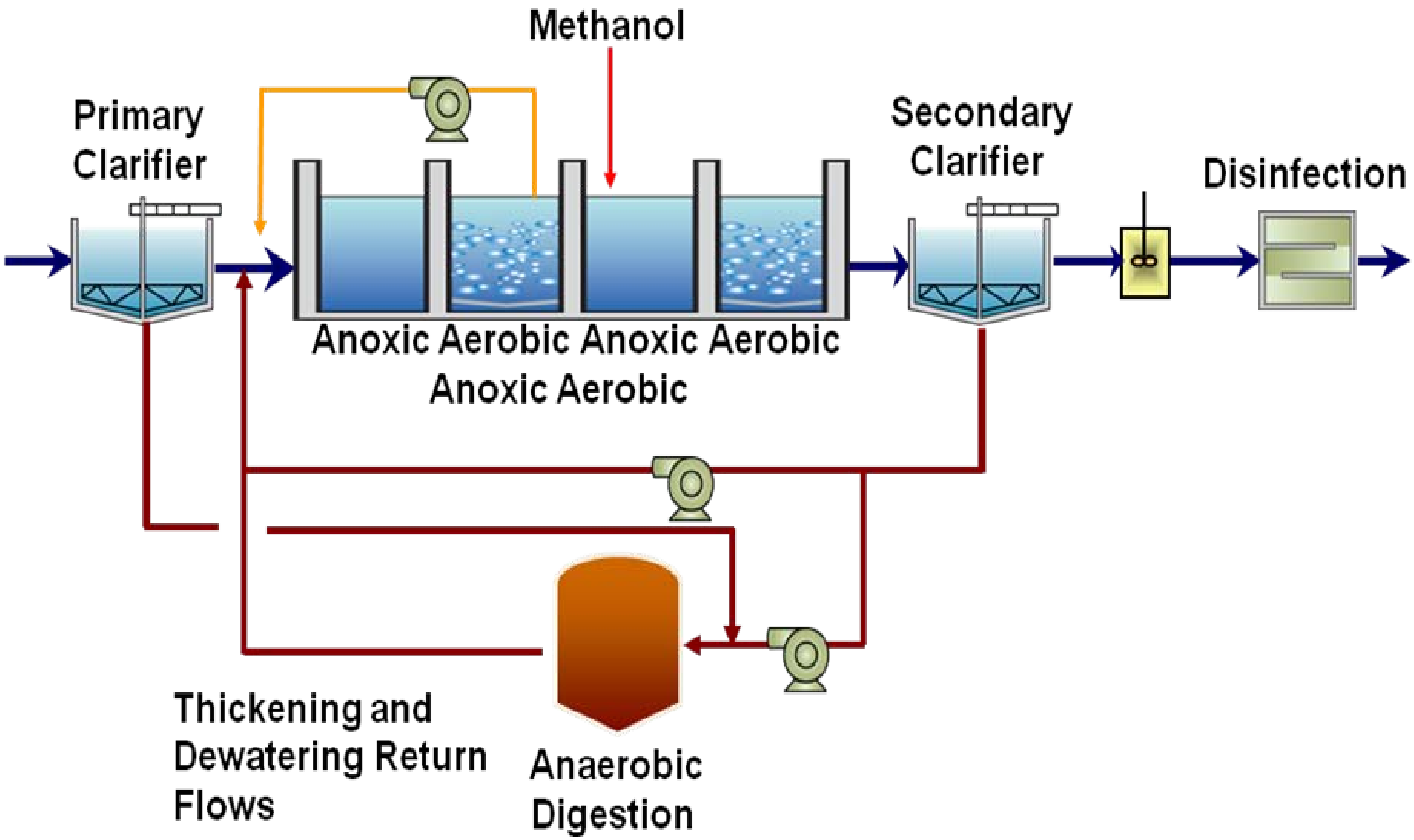
1.5.4 Modeling Results TIN 3

Based on the calibrated BioWin model and an assumed aerobic SRT of 13 days, the secondary effluent scenario of 3 mg/L TIN can be met with a reduced maximum month flow of 30 mgd (or 21 percent of the design maximum month flow of 144 mgd). This capacity rating assumes one aeration basin and one secondary clarifier out of service, as decided at the October 1, 2009 workshop. For this scenario the activated sludge basins would be operated in a Bardenpho configuration shown in Figure 1.12. With this configuration, the entire first pass would be unaerated, the second and third passes would be aerated, 80 percent of the fourth pass would be unaerated, and 20 percent of the fourth pass would be aerated.

This process would increase the unaerated fraction form 12.5 percent to 45 percent. The Bardenpho process incorporates both pre-anoxic and post-anoxic denitrification. The first two zones (or the first three passes at STP) would function very similarly to the MLE process described above. The last two zones (or the last pass at STP) are polishing zones that, combined with an external carbon source, can reduce the residual TIN to values less than 3 mg/L. Table 1.4 summarizes the modeling results for this scenario.

To meet the TIN limit of 3 mg/L, the following modifications would be needed to the existing plant:

- Three additional baffle walls, one at the end of the first pass and the second and third in the fourth pass
- Mixed liquor return pumps capable of delivering 350 percent of the influent flow
- Methanol delivery system and methanol storage
- Additional plant capacity for the remainder of the design year flow (or 114 mgd maximum summer month). This will be addressed in the subsequent chapter.



BARDENPHO SCHEMATIC

FIGURE 1.12

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

Table 1.4	Current Configuration – TIN 3 mg/L Scenario Modeling Results South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division
	Value
Design Maximum Summer Month Flow	30 mgd
Aeration Basins	
Aeration Basins in Service	3
Unaerated Fraction	45%
RAS Rate	100%
MLR Rate	350%
MLSS Concentration	3,700 mg/L
Aeration Air Requirement	20,500 scfm
Methanol Feed	
Flow Rate	150 gpd
COD Load	1,500 ppd COD
Secondary Clarification	
Secondary Clarifiers in Service	23
Secondary Effluent	
Ammonia	0.4 mg/L
Nitrate	2.15 mg/L
Nitrite	0.1 mg/L
TIN	2.65 mg/L

1.6 CONCLUSIONS

This project was initiated based on the South Puget Sound Study findings which suggest that the South Puget Sound may have excess nitrogen. A project team was assembled to evaluate the impacts of potential future nitrogen limits on the capacity of the STP. A full-plant model was developed and calibrated to operating data collected at the plant. The project team decided on two effluent nitrogen scenarios representing the anticipated “least stringent” and “most stringent” permitting scenarios at the October 1, 2009 workshop. At this workshop, the project team also decided that the capacity rating of the current plant to meet the two target nitrogen effluent scenarios would be determined with one aeration basin and one secondary clarifier out of service.

Based on these assumptions, the modeled capacity of the current STP to meet the “least stringent” summer effluent limit of 8 mg/L TIN was 36 mgd. To meet this effluent limit, minor modifications would be needed at the current plant including the addition of baffle walls, MLR pumps and a chemical delivery system. Major modifications that would be needed would be the construction of a new treatment plant to treat the remainder of the summer flow (approximately 62 mgd).

Based on these assumptions, the modeled capacity of the current STP to meet the “most stringent” year-round effluent limit of 3 mg/L TIN was 30 mgd. To meet this effluent limit, minor modifications would be needed at the current plant including the addition of baffle walls, MLR pumps and a chemical delivery system. Major modifications that would be needed would be the construction of a new treatment plant to treat the remainder of the flow (approximately 114 mgd). Chapter 2 addresses alternatives to treat the entire flow to the two target effluent nitrogen limits.

SOUTH PLANT NITROGEN REMOVAL SCENARIOS

2.1 INTRODUCTION

Chapter 1 described project assumptions and evaluated how much flow the existing South Treatment Plant (STP) 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 and what modifications would be required for nitrogen removal. This chapter (Chapter 2) describes potential effects on to the STP (e.g., tankage, footprint, cost, greenhouse gas emissions) if it were required to meet the assumed seasonal or year-round limit while maintaining its current rated capacity (144-million gallons per day (mgd) max month year-round and 98-mgd max month during summer).

Four nitrogen (N) removal alternatives were selected for evaluation under each assumed permit limit. Two representative alternatives, one each for the seasonal limit and annual limit, were subsequently selected for a more detailed cost estimate, sensitivity analysis, and sustainability analysis. The cost estimates are considered to be order of magnitude estimates, i.e., in the +50 to -30 percent accuracy range.

The representative alternative in each case was the approach that best met the weighted evaluation criteria developed by the project team for each nitrogen removal scenario. It is intended to be a “representative” approach by which the costs and effects of implementing nitrogen removal at South Plant can be assessed.

2.2 ALTERNATIVES SCREENING

2.2.1 Nitrogen Removal Alternatives

Table 2.1 summarizes four different classes of nitrogen removal alternatives. These were the four classes of alternatives discussed at the first project workshop (Carollo, 2009a). At the workshop a large number of possible treatment scenarios for nitrogen removal were considered and screened by consensus of the meeting to a narrower range of alternatives as discussed below.

2.2.1.1 <u>Land-based Alternatives</u>

Land-based alternatives rely on anoxic wetting and aerobic drying cycles to convert ammonia to nitrate and nitrate to nitrogen gas. The nitrifying and denitrifying organisms are present in both the wastewater and the soil communities. All of these alternatives are land intensive and would not fit on the available site at STP. It is not likely that any of these alternatives could reliably meet either of the two selected effluent permit levels for TIN.

Table 2.1 Nitrogen Removal Alternatives South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division			
Land Based	**Aquatic**	**Chemical**	**Biological**
Infiltration Basins	Wetlands	Ion Exchange	Suspended Growth
Overland Flow	Wetlands	Ion Exchange	Suspended Growth
Spray Irrigation	Floating Aquatic Plants	Crystallization Breakpoint Chlorination	Hybrid Side Stream

2.2.1.2 Aquatic Alternatives

Aquatic alternatives rely on aerobic biological processes to convert ammonia to nitrate and anoxic biological processes to convert nitrate to nitrogen gas. As with the land-based alternatives, these processes are land intensive and would not fit on the available site at STP. Furthermore, experience with these systems elsewhere indicates that they would not likely be able to reliably meet either of the two effluent limit scenarios.

2.2.1.3 Chemical Alternatives

Chemical alternatives rely on changes to effluent quality through chemical reactions. This section summarizes these processes.

In ion exchange treatment systems the ammonium ion (NH_4^+) and the nitrate ion (NO_3^-) displace ions on a natural or synthetic ion exchange resin. Clinoptilolite is one of the most frequently used resins, due to its high affinity for ammonium and it's relatively low cost.

In air stripping, nitrogen - specifically, ammonia - can be stripped from the wastewater into the atmosphere by passing air through the wastewater. To ensure effective N removal, lime or caustic are typically added to raise the wastewater pH above pH 10.5-11. The high pH converts most of the ammonia species in wastewater to the molecular NH_3 form, which is volatile. In general, this process requires large quantities of chemical, which produce large quantities of chemical sludge, and is less effective at the relatively low wastewater temperatures of the STP than it would be in a warmer climate. A draw back of air stripping is that while ammonia is removed from the water it is added to the atmosphere, potentially contributing to air pollution.

Crystallization is the process by which nitrogen and phosphorus are removed through the formation of crystals such as struvite (ammonium magnesium phosphate - $NH_4MgPO_4{\cdot}6H_2O$). The Ostara Company produces struvite as a fertilizer in a proprietary fluidized bed reactor. This process is ideally suited as a side stream treatment on the anaerobic digester return stream for treatment plants employing biological phosphorus removal. Ammonia removal by struvite formation is usually limited by available phosphorus. Typical ammonia removal through this process ranges from 10 to 15 percent. Since phosphorus removal is not required in the scenarios considered for this report, struvite crystallization was not considered further for the STP.

Breakpoint chlorination is the process by which sufficient chlorine is added to stepwise oxidize ammonium to chloramines and finally to nitrogen gas, as summarized in the following reaction:

$2NH_4^+ + 2HOCl \rightarrow 2NH_2Cl + HOCl \rightarrow NHCl_2 + NOH \rightarrow N_{2(gas)} + HOCl + HCl$
(This reaction is not balanced and does not show H_2O and H^+)

As demonstrated in the above reaction, approximately 1.5 moles of hypochlorite (HOCl) are required for every mole of ammonium reduced. For the STP with an average effluent ammonia concentration of 30 milligrams per liter (mg/L), this process would require hypochlorite doses of approximately 200 mg/L. For comparison, the current hypochlorite dose for disinfection at the STP is about 2-2.5 mg/L with an annual product cost around $370,000. If breakpoint chlorination were implemented at the STP, additional costs would need to be incurred for alkalinity replacement. As is shown in the above reaction, breakpoint chlorination produces an acid which would cause the pH to decrease without an alkalinity supplement.

None of the chemical alternatives were selected for further evaluation due to their high operating costs and low effectiveness at temperatures typical of the Pacific Northwest.

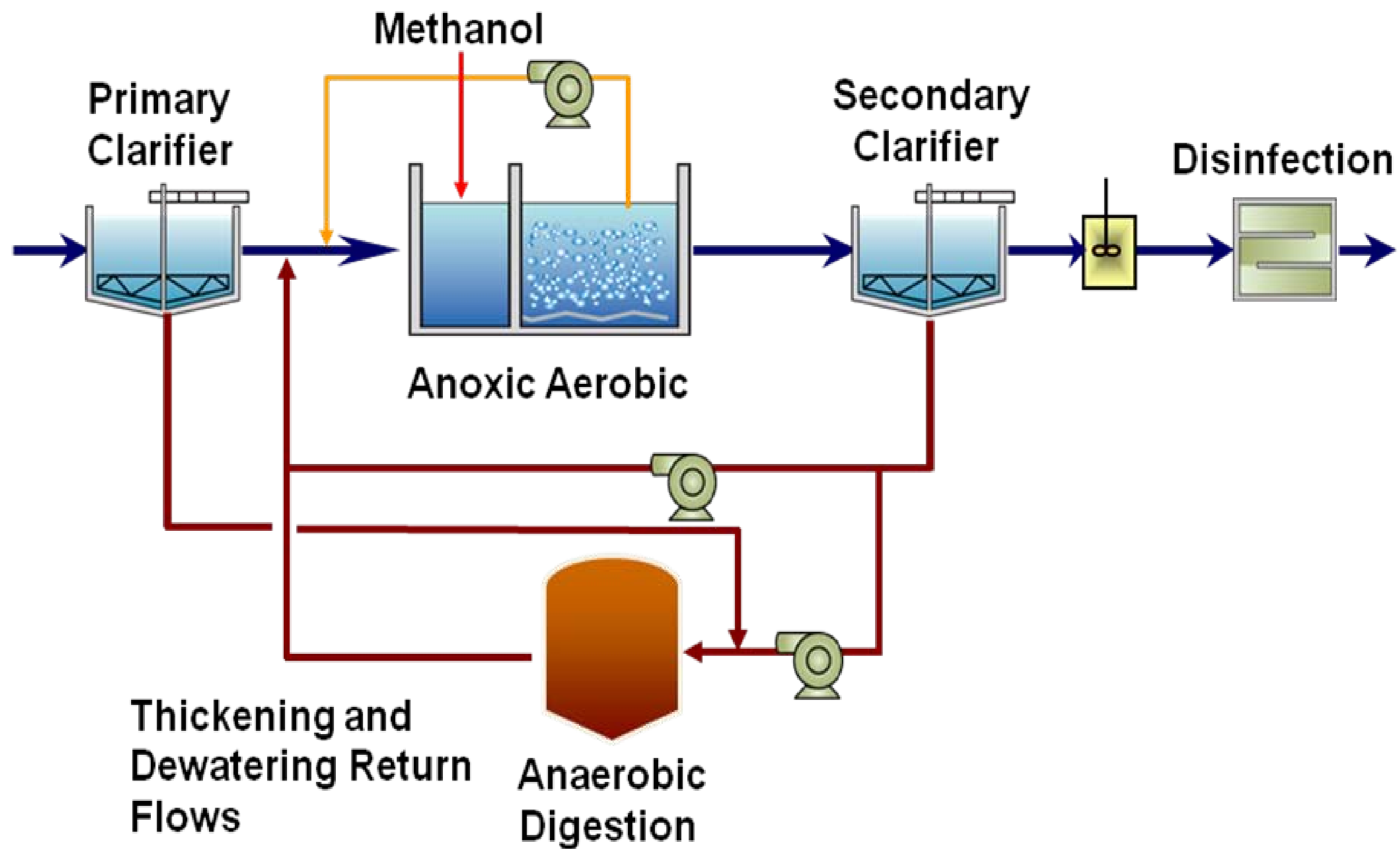
2.2.1.4 <u>Biological Alternatives</u>

Biological nitrogen removal (BNR) alternatives can be divided into four basic groups: suspended growth, attached growth, hybrid (both suspended and attached growth), and side stream treatment. These alternatives can be coupled with a clarifier as shown in Figure 2.1 or with a membrane filter to operate as a membrane bioreactor (MBR) process. The current STP secondary process is a suspended growth, conventional activated sludge (CAS) process with clarifiers.

2.2.1.4.1 *Suspended Growth Alternatives*

In the suspended growth nitrogen removal alternatives, the nitrifying and denitrifying organisms are suspended in the activated sludge mixed liquor. Examples of feasible suspended growth processes are the Modified Ludzak-Ettinger (MLE), Bardenpho, and step feed configurations with alternating anoxic and aerobic zones. This section briefly describes each of these configurations.

A schematic of an MLE configuration is shown in Figure 2.1. The MLE process includes an unaerated zone followed by an aerated zone with mixed liquor return (MLR) flow (in the range of 200 to 500 percent of the influent flow) from the aerated zone back to the anoxic zone. In the unaerated, anoxic zone denitrifying bacteria convert nitrate to nitrogen gas and in the aerobic zone, the nitrifying organisms convert ammonia to nitrate. This configuration is considered a pre-anoxic denitrification process, since the denitrification process precedes the nitrification process.



MLE SCHEMATIC

FIGURE 2.1

KING COUNTY DEPARTMENT OF NATURAL
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ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT
PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

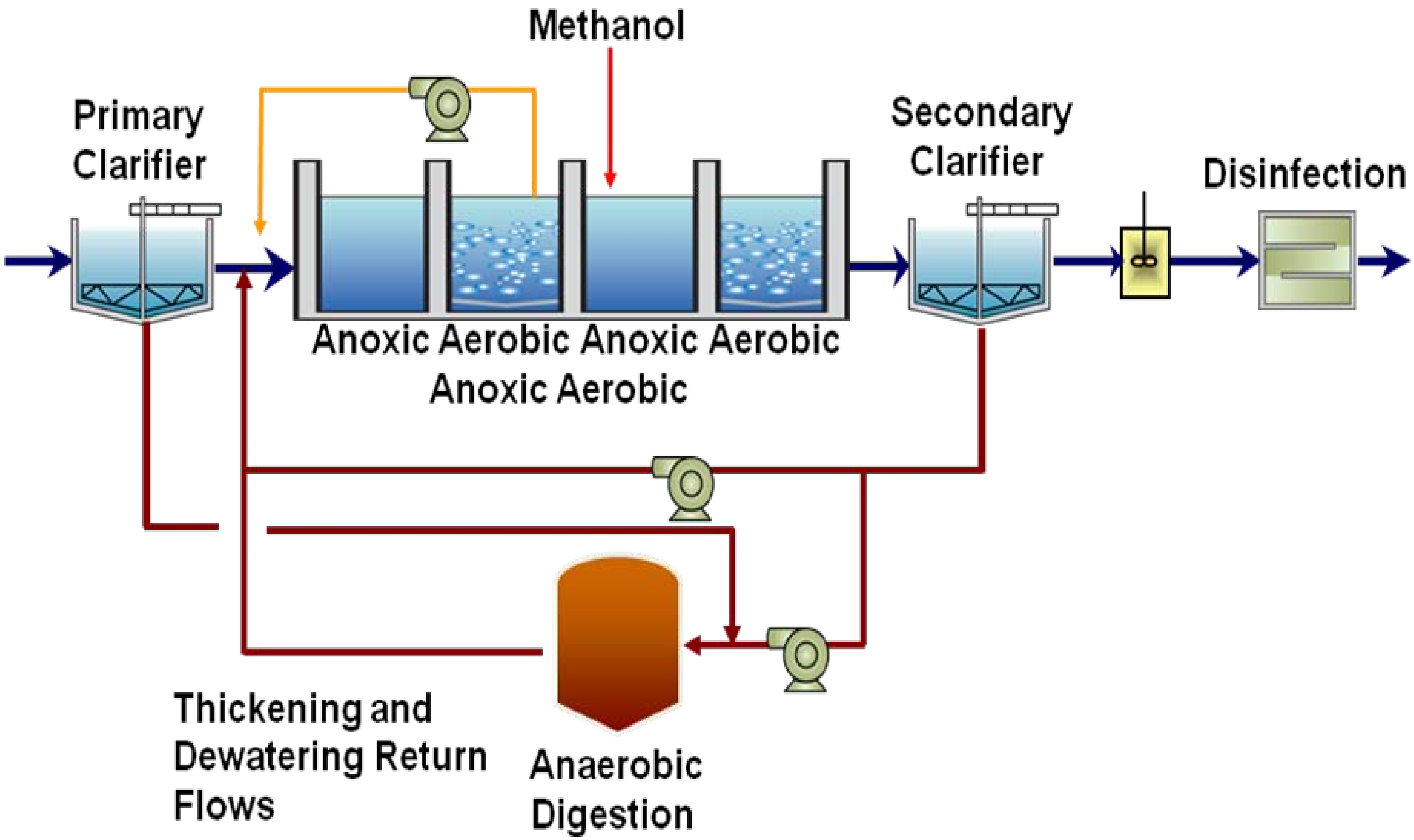
This is an optimal configuration for denitrification because the denitrification process occurs in the zone with the highest food or five-day biochemical oxygen demand (BOD_5) concentration. However, when denitrification processes follow primary clarification, the BOD_5 available from the wastewater can limit the extent of denitrification and an external carbon source (methanol is the most common carbon source used currently) could be required for effective nitrogen removal. The efficiency of the MLE process depends on the carbon to nitrogen ratio of the aeration basin influent, the MLR flow rate, and the size of the anoxic zone. Generally, this process cannot meet TIN limits below 5 mg/L and in most situations is better suited to meet a TIN limit in the range of 8 to 12 mg/L. This process can be coupled with a clarifier as shown in Figure 2.1 or with a membrane filter and operated as a MLE MBR process.

A schematic of a Bardenpho configuration is shown in Figure 2.2. This is a four-zone process with an initial anoxic zone, followed by an aerobic zone, which is followed by another anoxic zone and a final aerobic zone. This process also includes a MLR from the second zone to the first zone, typically in the range of 200 to 500 percent of the influent flow. The Bardenpho process incorporates both pre-anoxic and post-anoxic denitrification. The first two zones function identically to the MLE process described above. The last two zones are polishing zones that, combined with an external carbon source, can reduce the residual TIN to values less than 3 mg/L. This process can be coupled with a clarifier as shown in Figure 2.2 or with a membrane filter and operated as a Bardenpho MBR process.

A step feed configuration includes multiple anoxic and aerobic zones with the activated sludge influent split between each of the anoxic zones and the return activated sludge (RAS) directed to the first anoxic zone. A schematic of the step feed process is shown in Figure 2.3. This process is very similar to the MLE configuration, except that instead of a MLR stream, the nitrate rich effluent from the aerobic zone proceeds to an anoxic zone. The step feed process typically obtains comparable ammonia removal and better nitrogen removal than a plug flow process with the same flow and tank volume. This occurs because the split feed dilutes the mixed liquor suspended solids (MLSS) as it travels through the aeration basin, permitting a higher solids inventory to be maintained for a given clarifier flow rate. Conversely, a step feed process of the same volume can accommodate a higher flow for a given degree of nitrogen removal, but with higher effluent ammonia concentrations. Step feed can be combined with a post-anoxic zone in the last pass to meet low effluent TIN limits.

2.2.1.4.2 *Attached Growth Alternatives*

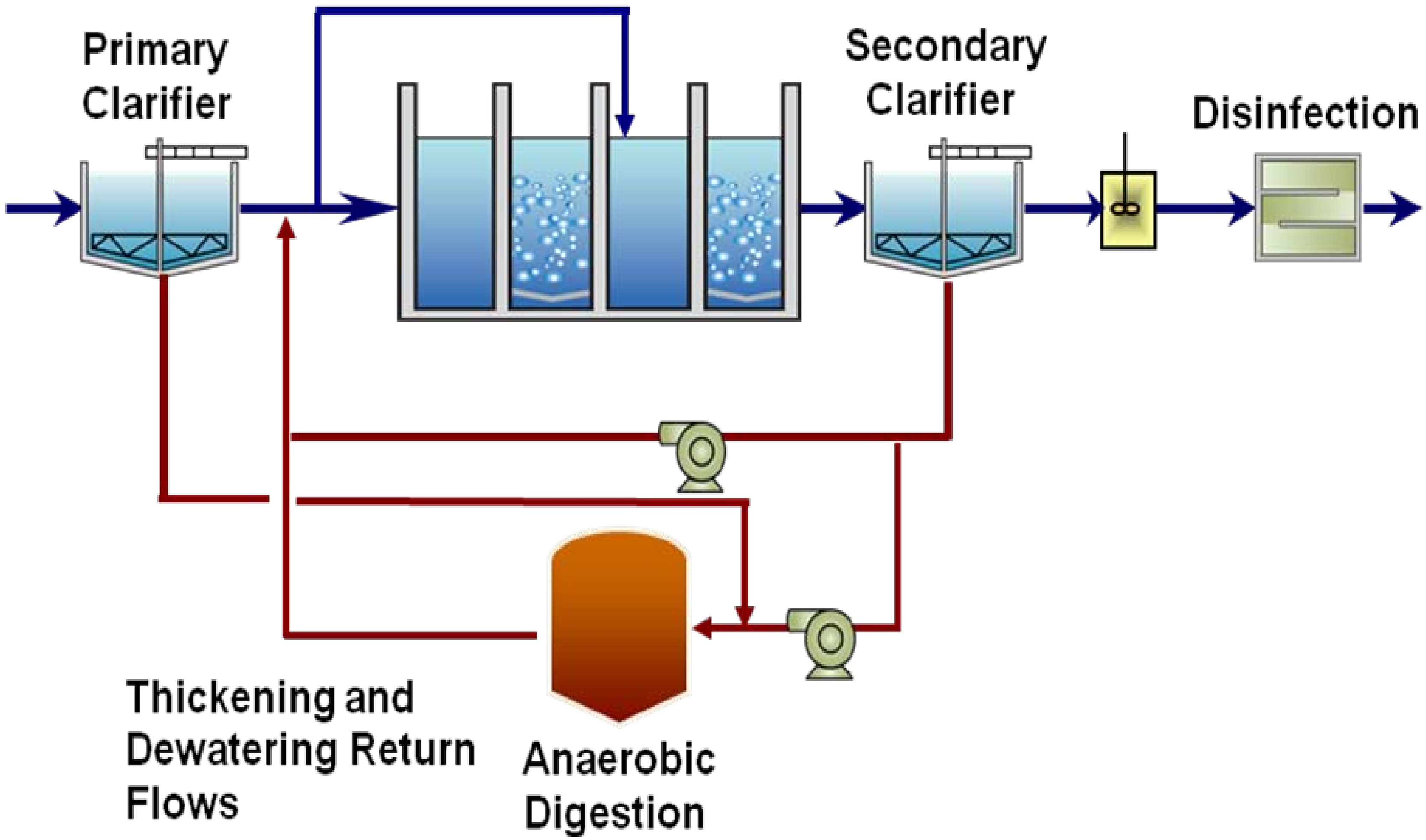
In attached growth nitrogen removal processes, the nitrifying and denitrifying bacteria are attached to solid media. Attached growth nitrogen removal alternatives include stationary bed, trickling filter, and moving bed applications.



BARDENPHO SCHEMATIC

FIGURE 2.2

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



STEP FEED SCHEMATIC

FIGURE 2.3

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

Examples of the stationary bed process are the biological aerated filter (BAF) and the denitrifying filter (DNF). Generally, BAFs are used exclusively for nitrification followed by a DNF for denitrification. In these filters, biomass grows on expanded shale media or polystyrene pellets, and usually, no additional clarification or filtration is required. Both the BAF and DNF follow the CAS process. The initial DNFs were single media, downflow, deep bed filters. Many DNFs are now being marketed by the BAF manufacturers that are upflow reactors. If filtration is not required, these upflow DNFs can be more highly loaded than the downflow counterparts. DNFs require a source of carbon; usually methanol is added. This process can provide nearly complete denitrification. A schematic of a BAF/DNF process for the STP is shown in Figure 2.4.

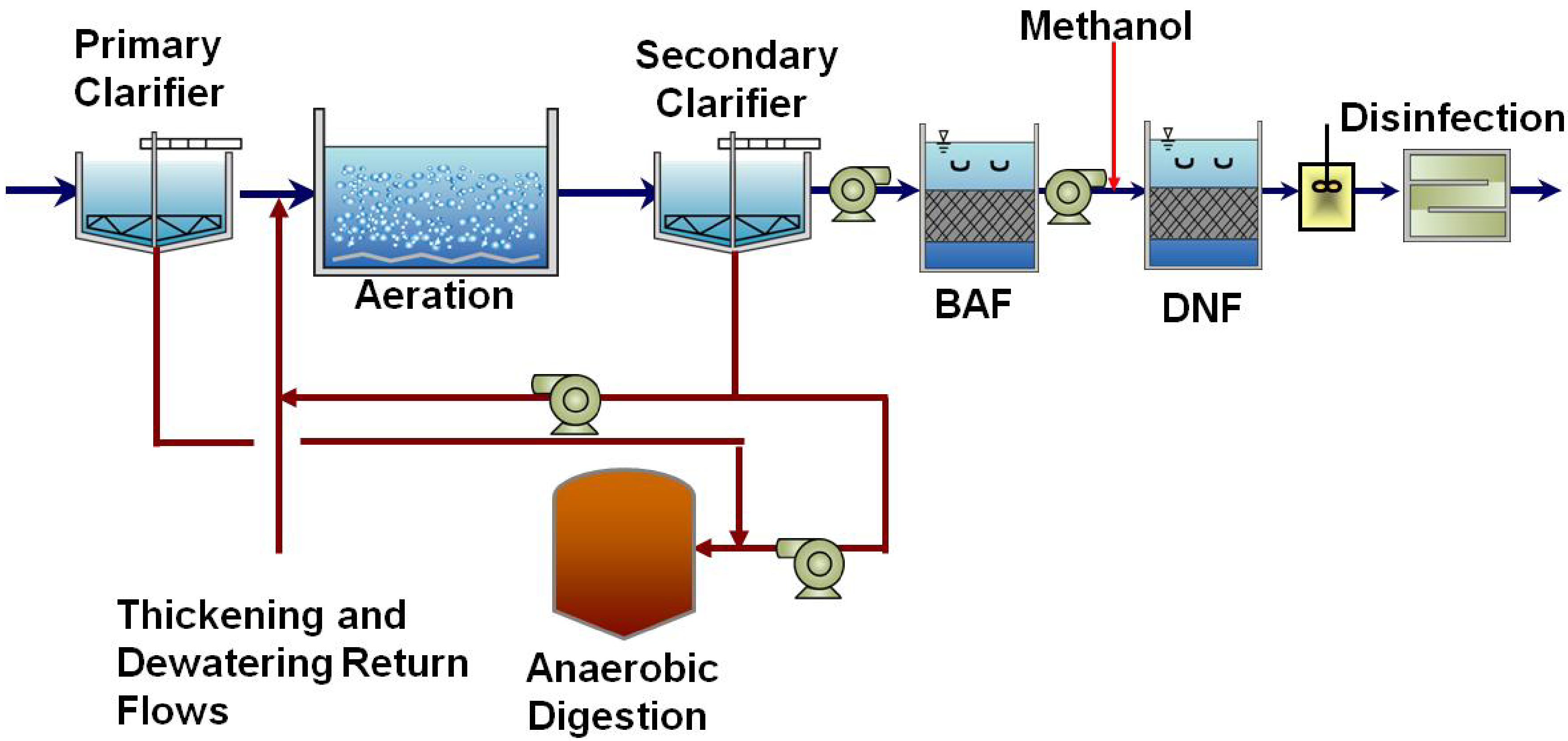
In trickling filters, wastewater is distributed over solid media which were originally rocks and are now almost exclusively a plastic cross flow media. The trickling filter process can provide nitrification with the denitrification process occurring in a separate DNF.

The moving bed bioreactor (MBBR) is a reactor tank containing random media upon which microorganism growth is facilitated by aeration. Existing activated sludge basins could be retrofitted to MBBR basins. The media generally consists of plastic wagon wheels or sponges as illustrated in Figure 2.5.

2.2.1.4.3 *Hybrid Alternatives*

A hybrid process combines suspended growth with attached growth. The main hybrid alternative for nitrogen removal is the integrated fixed film activated sludge (IFAS) process. In an IFAS process, plastic media, ropes, or sponges are added to an aeration tank to provide surfaces upon which bacteria attach and grow with the intent of increasing the overall biomass inventory in the aeration tank (see Figure 2.5 for media examples). An IFAS process is configured like an activated sludge process with RAS introduced into the first reactor tank in the process. Biomass growing on the media allows for greater nitrogen removal with no increase in the overall aeration basin or clarifier volume. Most IFAS media systems are proprietary, but there are many suppliers, allowing competitive selection of IFAS media and equipment. The IFAS system differs from the previously discussed MBBR system in that it incorporates both fixed film processes (the biofilm growing on the media) with suspended growth processes through the RAS recycle.

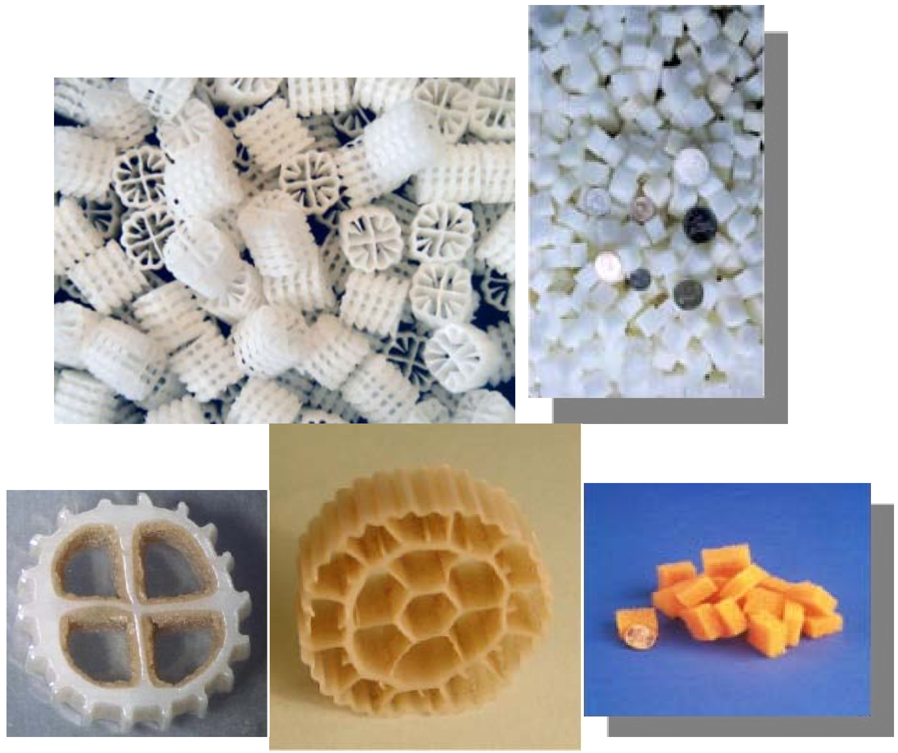
Most IFAS systems only add media to aerobic zones; however, at least one supplier has some experience with the use of fixed media in anoxic zones. The IFAS process can be configured in either the MLE configuration or the Bardenpho configuration to add nitrogen removal capacity to existing aeration basins. The IFAS process requires intermediate screens and/or internal recirculation pumping at the end of the aeration basin to keep the media evenly distributed in the reactor. A schematic of an MLE IFAS alternative for the STP is shown in Figure 2.6.



BAF/DNF SCHEMATIC

FIGURE 2.4

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

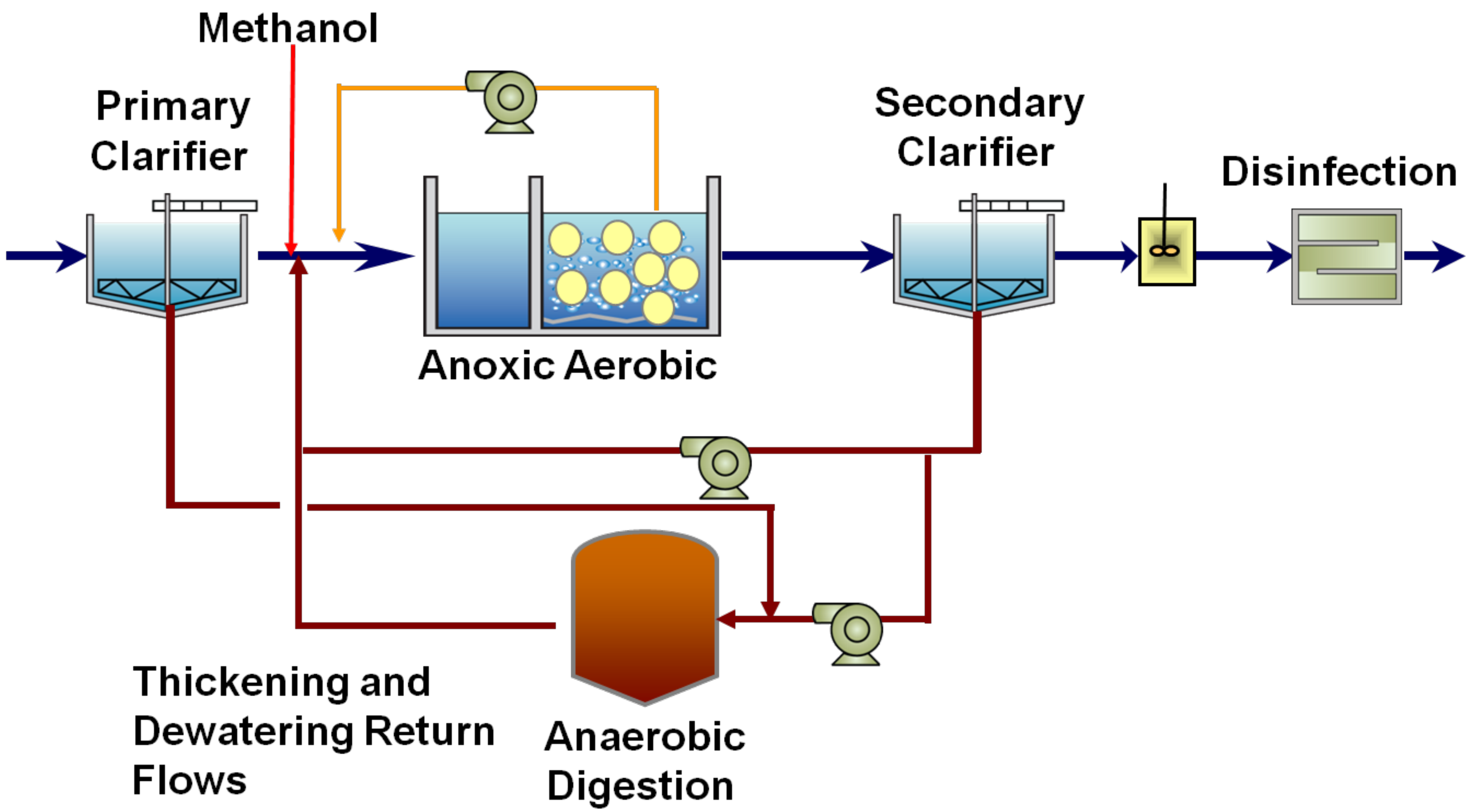


EXAMPLES OF MEDIA USED IN MBBR AND IFAS PROCESSES

FIGURE 2.5

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

carollo



MLE IFAS SCHEMATIC

FIGURE 2.6

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

2.2.1.4.4 *Side stream Alternatives*

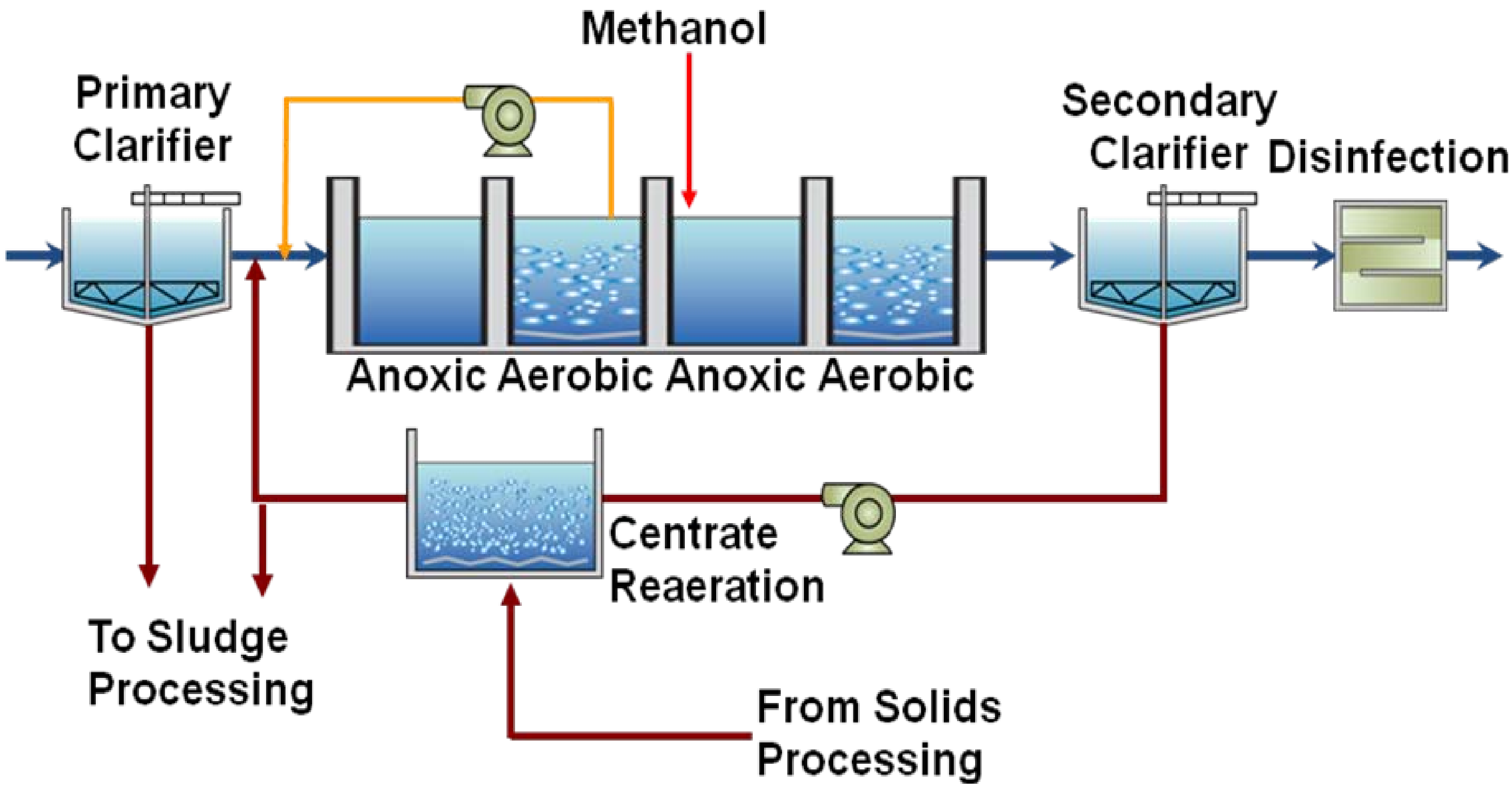
Solids treatment processes, including the anaerobic digestion process employed at the STP, usually generate return flows, or side streams, rich in nutrients. In anaerobic digestion carbonaceous components of the treated sludge stream are converted to methane gas. Mineralized nutrients like nitrogen and phosphorus compounds remain in the liquid stream that is returned to the main liquids treatment process in the side stream flow from sludge dewatering.

A number of processes, many of them proprietary, have been developed for treatment of ammonia-rich side streams from solids processing facilities. These include the Sharon® process, which operates by encouraging a special pathway for nitrogen removal: instead of employing the normal, four-stepped, process of conversion of ammonia to nitrite and then to nitrate and from nitrate to nitrite and then to nitrogen gas, this process proceeds at elevated temperature to encourage a two-step conversion from ammonia to nitrite and from nitrite directly to nitrogen gas. A full-scale installation of a Sharon® process recently was constructed in New York City.

Another proprietary process, Anammox®, employs special bacteria that oxidize ammonia using nitrite and nitrate as electron acceptors. This process, which doesn't require oxygen, operates at elevated temperature and requires strict control of pH. It operates at high (30-50 day) solids residence time (SRT). It can be operated with Sharon®. This process has been operated only at bench scale to date in the United States (U.S.). The first full-scale Anammox® plant was started up in the Netherlands in 2002 and several are installed for operation in Europe.

The InNitri® process provides nitrification of side stream flows and employs what is called bioaugmentation to return a stream of waste nitrifying organism to the main activated sludge treatment system to increase the number of viable organisms there. Although developed over ten years ago, currently there are no full-scale InNitri® installations. Two applications have progressed to pilot scale in the U.S., which has led to one full-scale installation currently being bid for construction.

Perhaps the most fundamental side stream treatment alternative is centrate reaeration. A schematic of this alternative is shown in Figure 2.7. In this alternative the ammonia-rich centrate is combined with the high-suspended solids concentration RAS stream in a separate basin, where the high ammonia concentrations yield faster transformation rates of ammonia to nitrate. Nitrifiers grown in the side stream reactor are returned to the liquid stream nitrification process. An alternate configuration is to locate the treatment tank directly on the centrate return stream. This side stream treatment process can be used with a nitrogen removal alternative to add capacity. Centrate reaeration was selected at the workshop to serve as the representative process for side stream treatment.



CENTRATE REAERATION SCHEMATIC

FIGURE 2.7

KING COUNTY DEPARTMENT OF NATURAL
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ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

2.2.2 Initial Alternatives Screening Results

At the first workshop in October 2009, four nitrogen removal alternatives were selected for further evaluation for each nitrogen removal scenario. These selected alternatives represent a range of different biological alternatives including suspended growth, attached growth, and hybrid processes. For the 8 mg/L TIN (summer-only) scenario, the selected processes were:

- MLE
- MLE – MBR
- MLE – IFAS
- BAF/DNF

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

- Bardenpho
- Bardenpho – MBR
- Bardenpho – IFAS
- BAF/DNF

The following section discusses initial evaluation of these alternatives and selection of a representative alternative for each nitrogen removal permit scenario for a more detailed evaluation. For each representative alternative, side stream treatment was evaluated to determine whether additional treatment could reduce the footprint and cost of the alternative.

2.2.3 Nitrogen Removal Alternatives Analysis

The four selected alternatives for each nitrogen limit scenario were evaluated to determine a relative cost and footprint for each alternative. This section summarizes these findings.

2.2.3.1 <u>8 mg/L TIN (summer-only) Scenario</u>

For each of the alternatives evaluated under the 8 mg/L TIN (summer-only) scenarios, except for the BAF/DNF alternative, it was assumed that the aeration basins would operate with a 9-day aerobic SRT during maximum summer month flows (98 mgd) with one basin out of service. Additionally, it was assumed that new aeration tanks would be the same side water depth as the current tanks.

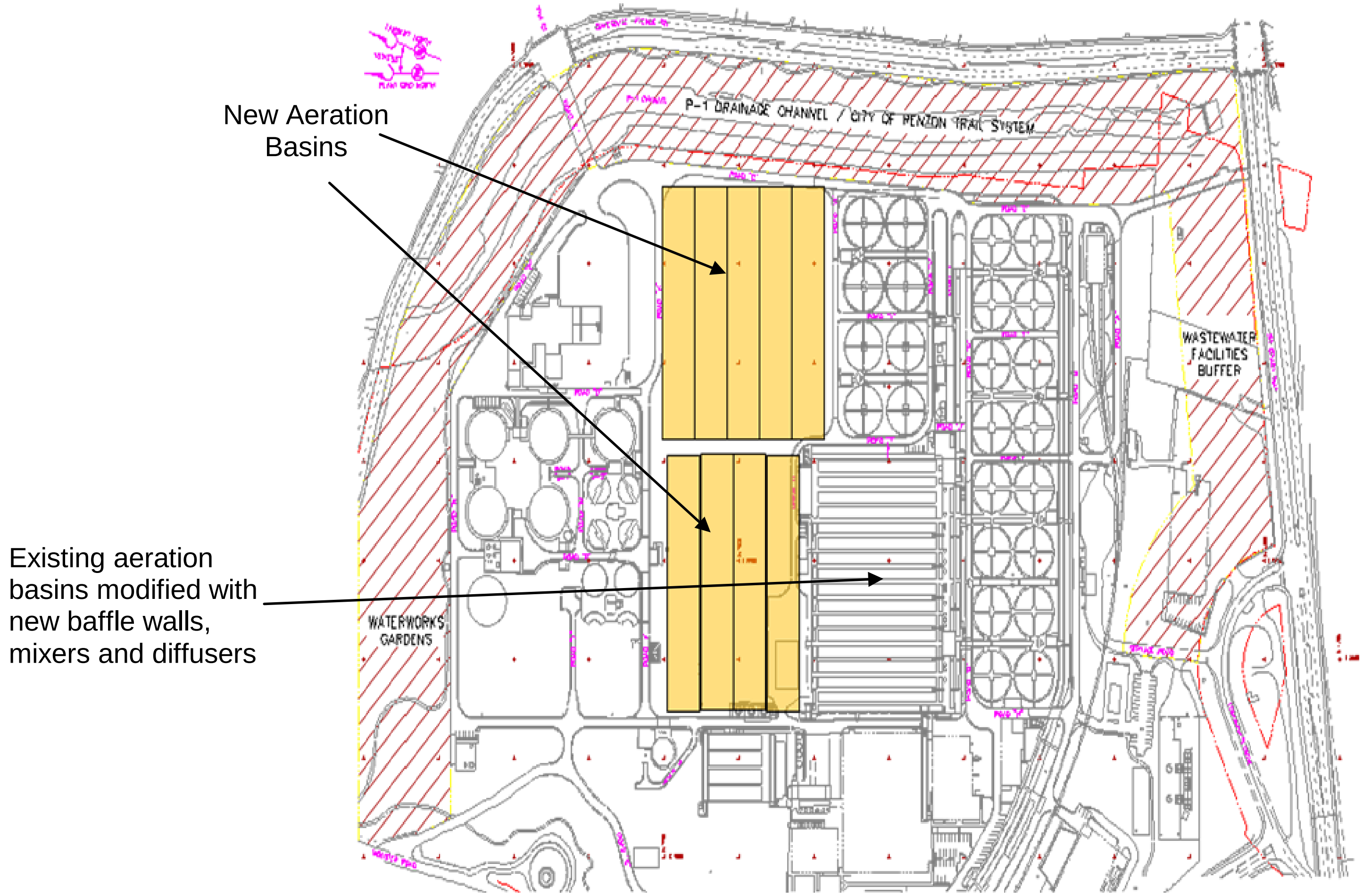
For the MLE alternative, nine new aeration tanks with a total volume of 42 million gallons (MG) would be required in addition to the existing four aeration tanks. The existing four tanks would provide a capacity of 30 mgd (assuming one tank out of service) and the additional nine aeration tanks would provide an additional 68-mgd capacity. All of the aeration tanks (existing and new) would require baffles, mixers, mixed liquor return pumps and methanol storage and dosing equipment. No additional clarifiers would be required. The capacity of the existing plant would be less than the de-rated capacity described in Chapter 1 because this alternative assumes that all the summer maximum month flow is directed to the existing clarifiers, while the capacity rating in Chapter 1 assumed only 30-40 mgd through the existing clarifiers. This higher flow results in a decreased MLSS concentration and reduces the capacity of the existing plant to meet projected growth consistent with the Regional Wastewater Services Plan or to respond to future, more restrictive, effluent standards. This alternative would fit on the site but would leave no room for expansion. Figure 2.8 provides a schematic of the footprint of this alternative.

For the MLE-MBR alternative, two new aeration tanks and 11 new membrane tanks would be built with a capacity for 62 mgd of maximum month flow. This new MBR facility would be operated as a separate, parallel secondary process. The two new MBR aeration tanks (with a volume of 4.7 MG each) would have a greater capacity than the CAS aeration tanks because the membranes can perform at a very concentrated MLSS concentration compared to the clarifiers. The existing aeration tanks and clarifiers would be modified for the MLE process, and have a capacity of 36 mgd assuming one aeration tank out of service. No additional clarifiers would be required. As is shown in Figure 2.9, this alternative would fit on the site and would retain room for expansion to meet projected growth.

In the MLE-IFAS alternative, the existing aeration basins would be converted to IFAS basins. Depending on manufacturer's claims and assumed packing densities, (between 1 to 5) new aeration basins would be required with a volume of 4.7 MG each. This alternative would fit on the site as is shown in Figures 2.10 and 2.11.

For the BAF/DNF 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, 25 BAF units and 14 DNF units would be added. This sizing was based on an ammonia loading rate of 60 pounds per day per thousand cubic foot (ppd/kcf) of filter volume for nitrification and 120 ppd/kcf of nitrate loading for denitrification. Methanol addition would be required at the DNF. This alternative fits on the site and allows for expansion as is shown in Figure 2.12.

Table 2.2 summarizes the footprint requirements of each alternative. Footprint estimates are primarily for comparative purposes and do not currently account for other features that can consume footprint such as roads, odor control, and ancillary equipment. The MLE alternative requires the greatest footprint and provides very little space for the plant to expand to treat future flows or to respond to future changes in effluent quality requirements while the BAF/DNF and MLE-MBR alternatives provide the most available space for future expansion. The MLE-IFAS alternative could be very attractive from a footprint standpoint if the most aggressive of the manufacturer's performance and design criteria could be confirmed.



MLE FOOTPRINT 8 MG/L TIN (SUMMER ONLY)

FIGURE 2.8

KING COUNTY DEPARTMENT OF NATURAL
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ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

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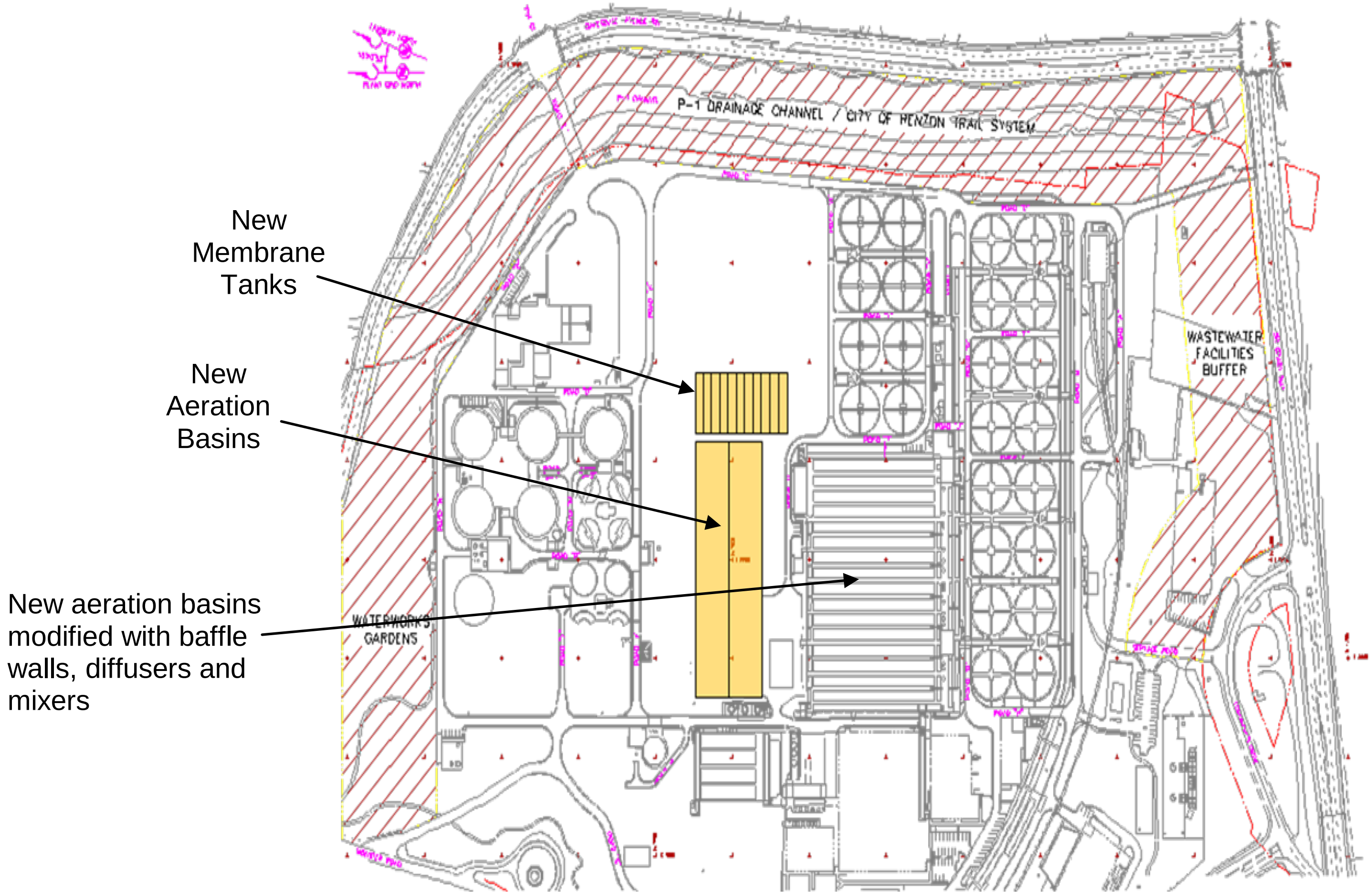

MLE – MBR 8 MG/L TIN (SUMMER ONLY) FOOTPRINT

FIGURE 2.9

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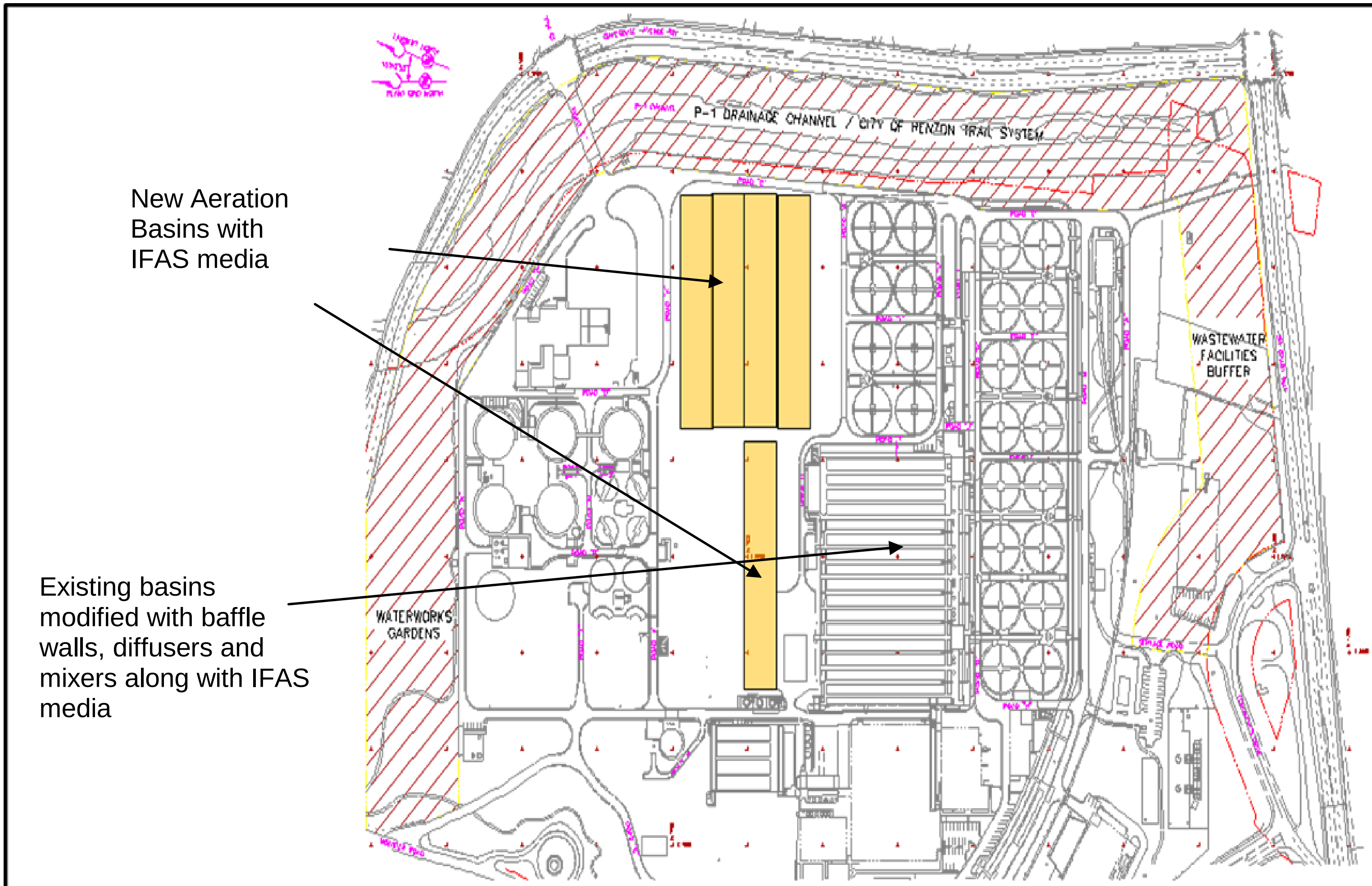
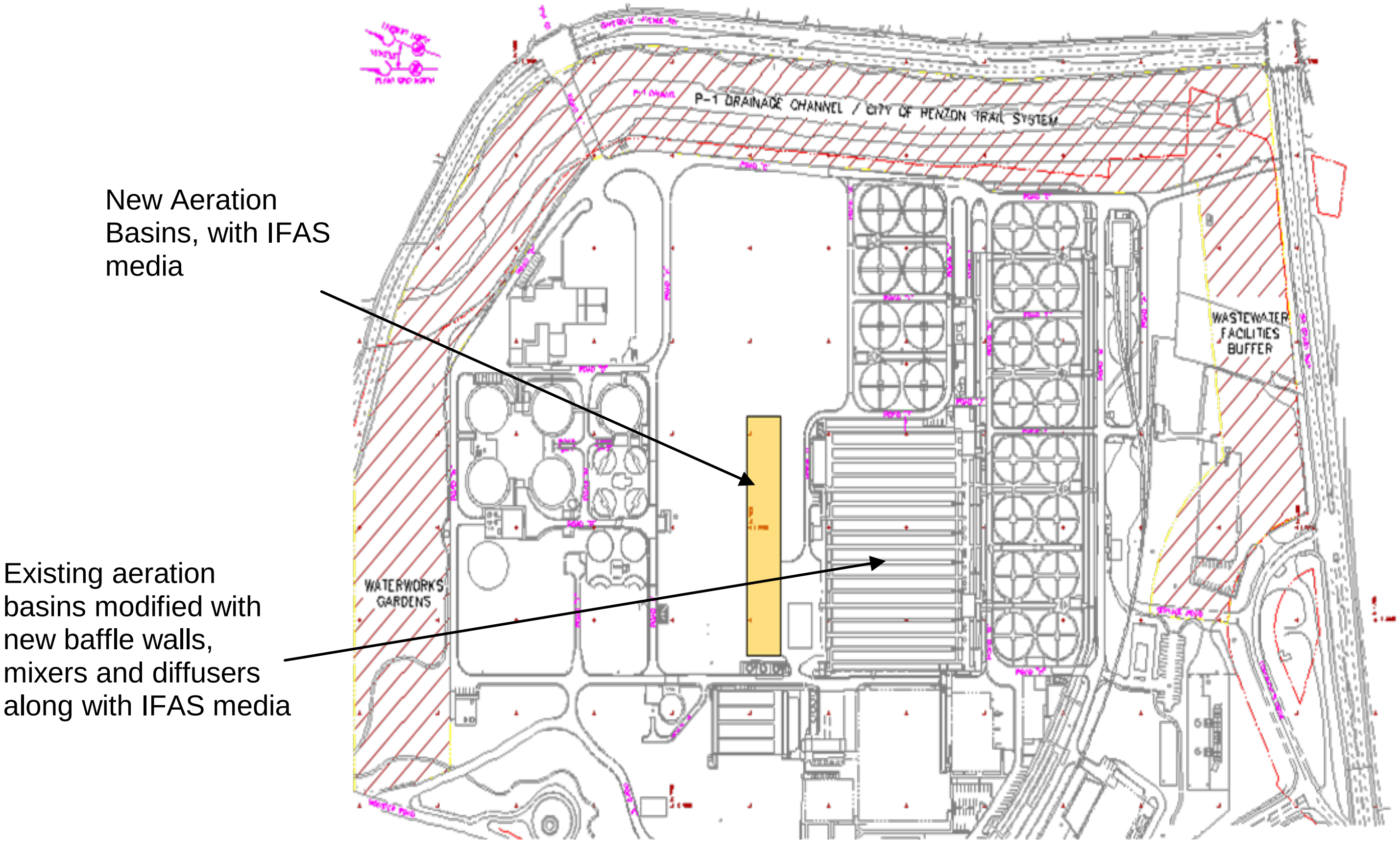
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



MLE – IFAS FOOTPRINT 8 MG/L TIN (SUMMER ONLY) (CONSERVATIVE SIZING)

FIGURE 2.10

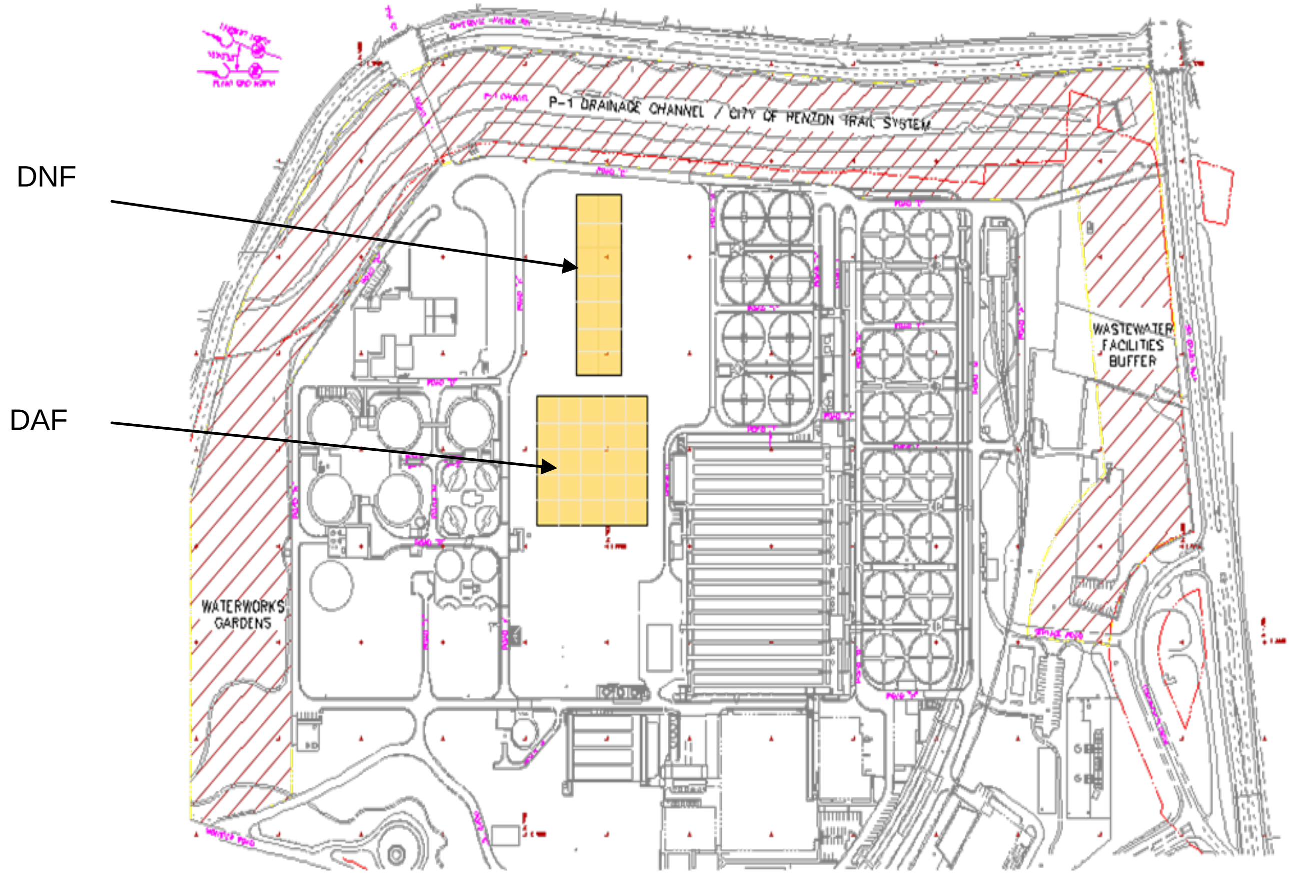
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



MLE – IFAS FOOTPRINT 8 MG/L TIN (SUMMER ONLY) (AGGRESSIVE SIZING)

FIGURE 2.11

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



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

FIGURE 2.12

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

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Table 2.2 8 mg/L TIN (Summer-only) Alternative Footprint Analysis South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division				
	MLE	**MLE-MBR**	**MLE-IFAS**	**BAF / DNF**
Total added basins, acres	8.3	2.5	.9 to 4.4	2.3
Approximate full-buildout capacity assuming no expansion on the biosolids site(1)	144 mgd	270 mgd	210 – 360 mgd	270 mgd

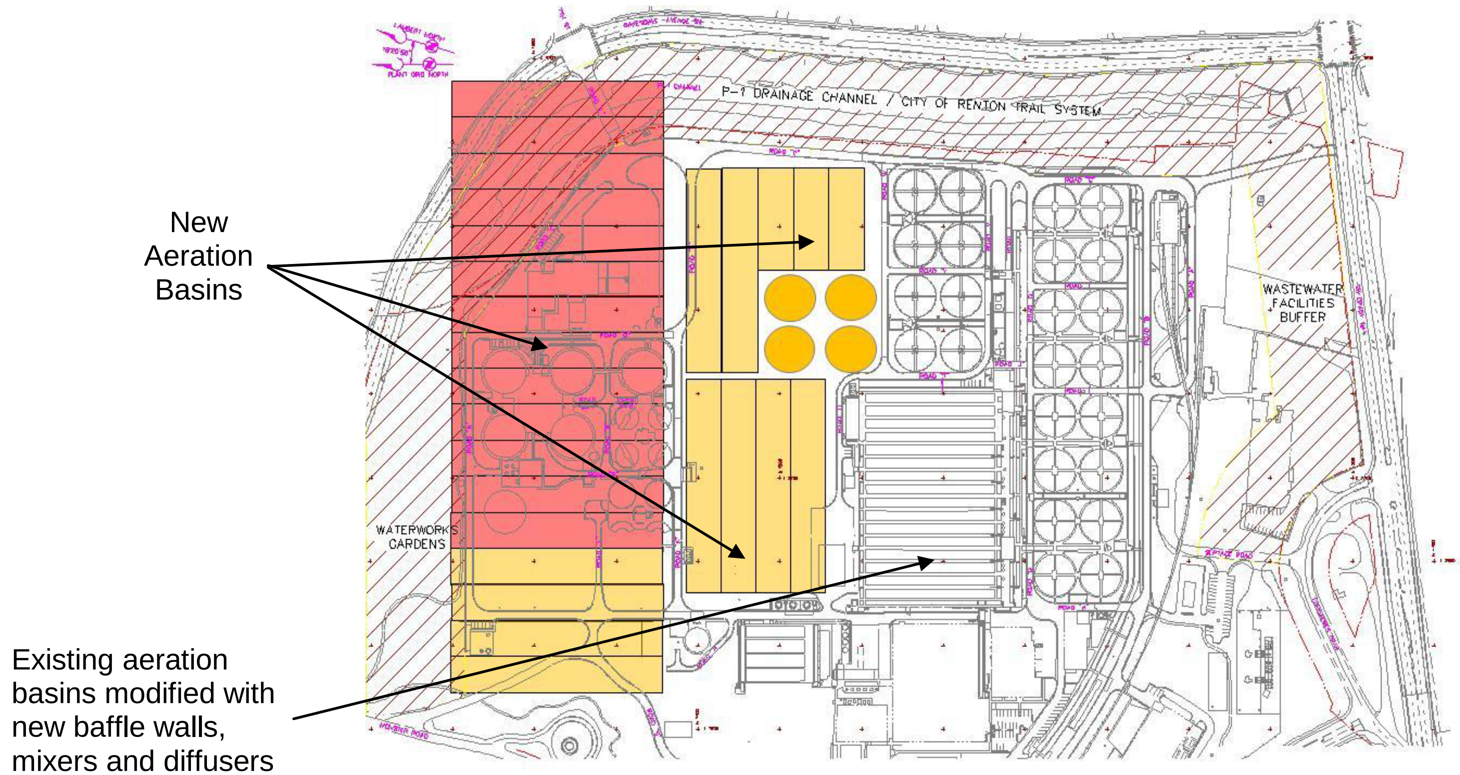
Notes:
(1) Capacity ratings are based on maximum month flows during the summer months. The maximum month flow capacity of the current plant for summer flows is 98 mgd. The assumed density of aeration basins is based on the proposed STP site buildout layout provided by the County. No extra allowances were made for roads or ancillary facilities.

2.2.3.2 3 mg/L TIN (Year-round) Scenario

For the first three of the 3 mg/L TIN (year-round) scenarios (excluding the BAF/DNF alternative), it was assumed that the aeration basins would operate at a 13-day aerobic SRT during the maximum month loads and flows (144 mgd) with one basin out of service. Modification of the existing aeration tanks would be required for each of these three alternatives. Methanol addition would be required for all four alternatives.

For the Bardenpho alternative, 24 new aeration tanks (each with a volume of 4.6 MG) and four new secondary clarifiers would be required in addition to the existing four aeration tanks and 24 clarifiers. Once modified, the existing four tanks would provide a capacity of 17 mgd (assuming one aeration tank is out of service) and the additional 24 aeration tanks would provide an additional capacity of 127 mgd. All of the aeration tanks would require baffles, mixers, MLR pumps, and methanol storage and dosing equipment. The capacity of the existing plant is less than the de-rated capacity described in Chapter 1 because this alternative assumes that all the maximum month flow is directed to the existing clarifiers, while the capacity rating in Chapter 1 assumed only 30 mgd through the existing clarifiers. This higher flow results in a decreased MLSS concentration and reduces the capacity of the existing plant. This does not fit within the available site area. Figure 2.13 provides a schematic of the footprint impact of this alternative.

For the Bardenpho MBR alternative, the existing plant would be de-rated to approximately 30 mgd and a parallel MBR plant would be added consisting of seven new aeration tanks (with a total volume of 25 MG) and 20 new membrane tanks. Membrane tank sizing was based on continuous 20 degree flux rates of 15 gallons per day per square foot (gpd/sf) of membrane area. As is shown in Figure 2.14, this alternative fits on the site and allows room for minimal expansion. In this design the existing activated sludge system would handle peak flow rates. It was assumed that the peak flows up to 242 mgd would pass through the existing activated sludge clarifiers while the MBR process was operated at a constant flow of approximately 114 mgd.



BARDENPHO 3 MG/L TIN (YEAR ROUND) FOOTPRINT

FIGURE 2.13

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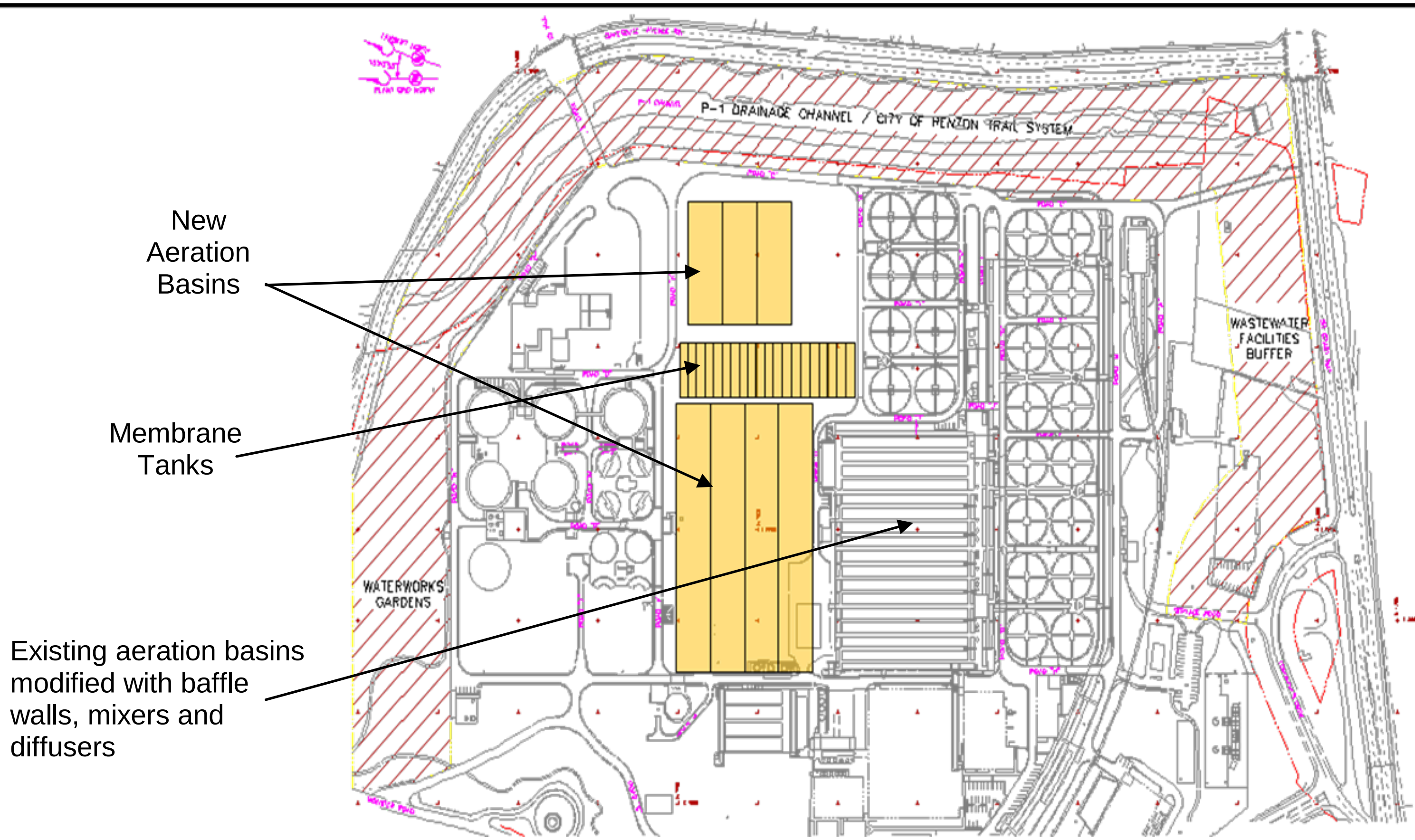
RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



BARDENPHO - MBR 3 MG/L TIN (YEAR ROUND) FOOTPRINT

FIGURE 2.14

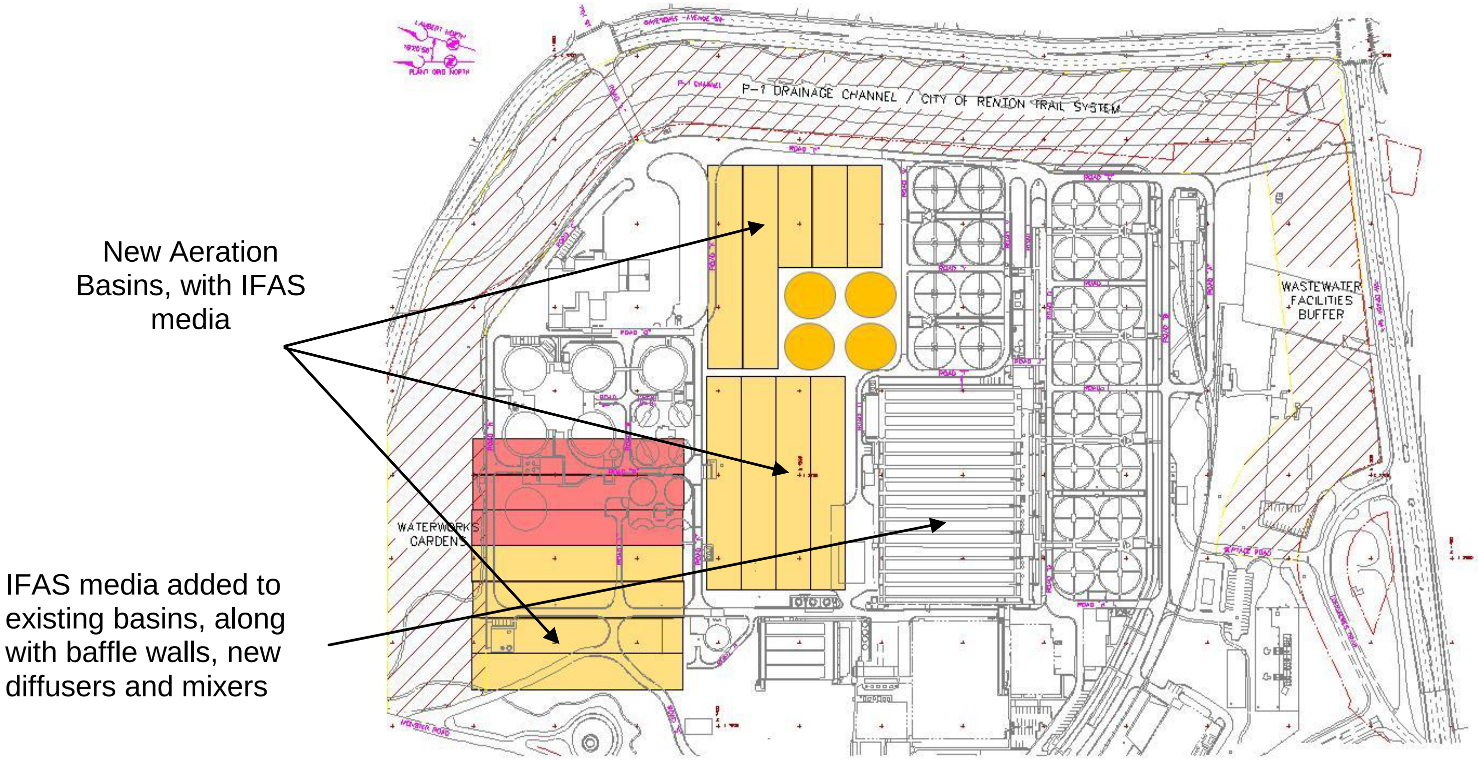
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

The adequacy of any nutrient removal scheme depends on the interplay between loading and regulatory requirements. The Bardenpho MBR alternative was sized on the assumption that nitrogen removal requirements would be met over a maximum month of loading. The analysis was based on steady state modeling in Carollo's Biotran program and in the commercial model BioWin, but a sensitivity analysis was performed in BioWin to investigate the effects of dynamic loading.

In the Bardenpho-IFAS alternative, the existing aeration basins would be converted to IFAS basins. Depending on manufacturer's claims and assumed packing densities, between 2 to 16 new aeration basins (with a volume of 4.4 MG each) would be required. An initial conservative sizing for IFAS using random media was based on the default packing density from the BioWin media reactor of 25 percent. Subsequent communication from the random media manufacturer indicated that densities up to 65 percent could be used. For the conservative sizing assumption (using the 25 percent packing density), four new secondary clarifiers were assumed to allow the plant to run at a higher MLSS concentration. As is shown in Figure 2.15, the conservative sizing assumption would not fit on the site. However, a Bardenpho IFAS alternative would fit on the site assuming the aggressive sizing assumption shown in Figure 2.16. The aggressive sizing was based on the assumption that an effective MLSS concentration in the existing aeration tanks could be maintained by use of sponge media of approximately 8,500 mg/L, including both free and embedded biomass. This assumption has been based on experience at one operating facility in the U.S. Sizing for this alternative by the manufacturer assumed 10,000 gpd of methanol use, approximately three times the amount required for the Bardenpho MBR alternative.

For the BAF/DNF 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 3 mg/L TIN (year-round) limit, 52 BAF units and 19 DNF units would be added. This sizing was based on a loading rate of 28 ppd/kcf for nitrification and 98 ppd/kcf of nitrate loading for denitrification. Methanol addition would be required for the DNF. Peak hydraulic flows of 242 mgd would be handled through the existing plant as they currently are, with up to 144 mgd going to the BAF and DNF and the remaining flow going to effluent. This alternative fits on the site and allows for minimal expansion as is shown in Figure 2.17.

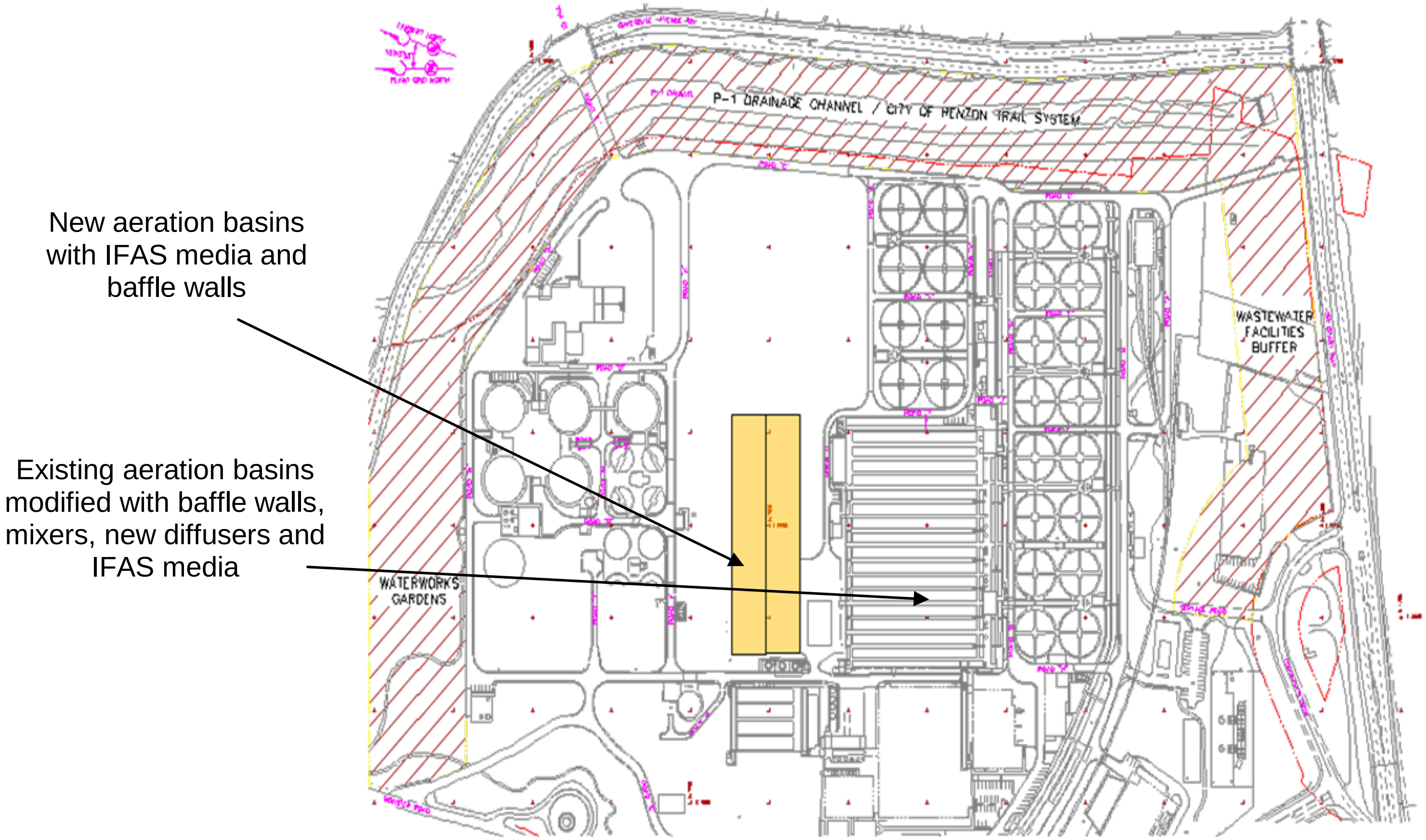
Table 2.3 summarizes the footprint requirements of each alternative. Footprint estimates are primarily for comparative purposes and do not account for additional features that can consume footprint such as roads, odor control, and ancillary equipment, etc. The Bardenpho alternative requires the greatest footprint and does not fit on the site while the BAF/DNF and Bardenpho-MBR alternatives provide the most available space for future expansion. The Bardenpho-IFAS alternative could be very attractive from a footprint standpoint if the aggressive version of manufacturer's claims and assumed packing densities could be confirmed.



BARDENPHO - IFAS 3 MG/L TIN (YEAR ROUND) FOOTPRINT CONSERVATIVE SIZING

FIGURE 2.15

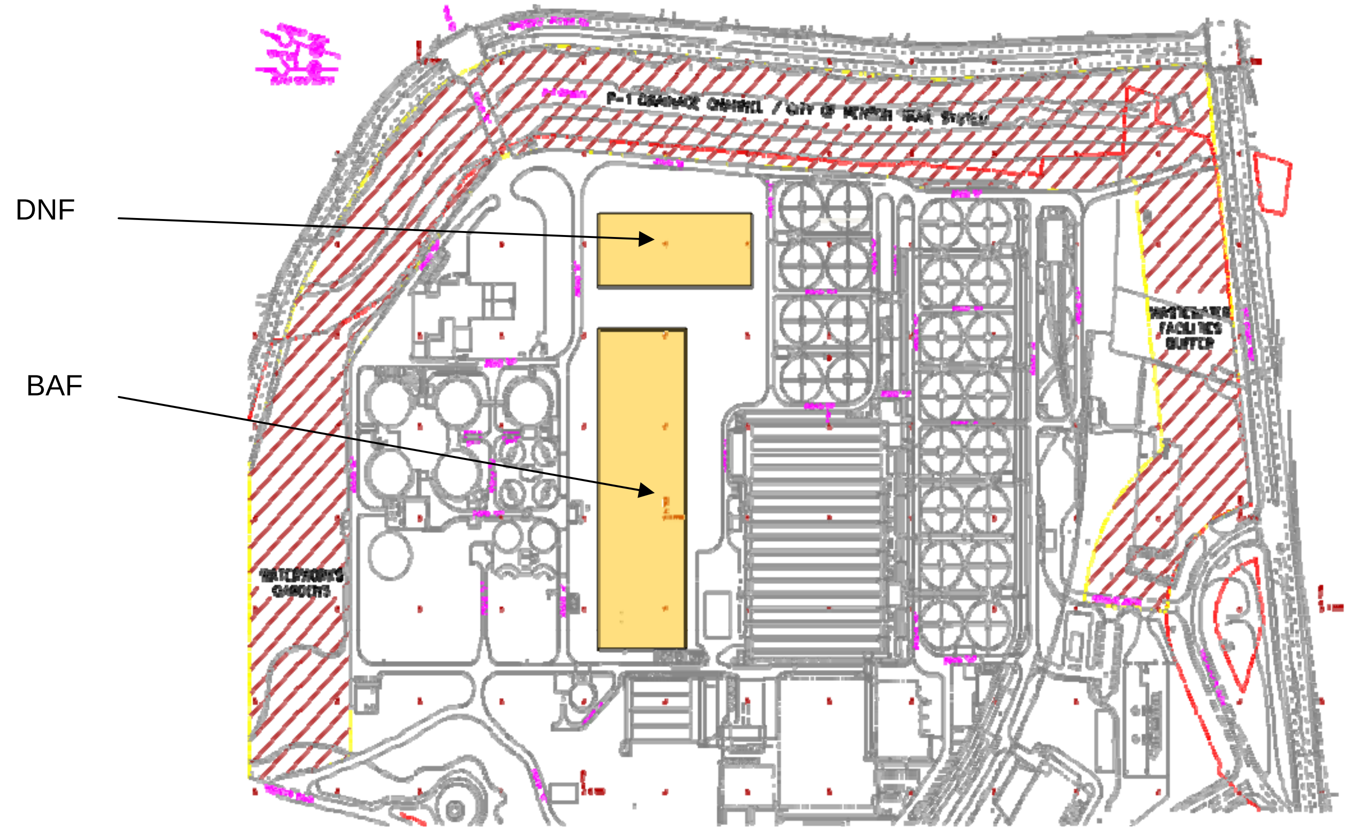
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



BARDENPHO - IFAS 3 MG/L TIN (YEAR-ROUND) FOOTPRINT AGGRESSIVE SIZING

FIGURE 2.16

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



BAF/DNF 3 MG/L TIN (YEAR-ROUND) FOOTPRINT

FIGURE 2.17

KING COUNTY DEPARTMENT OF NATURAL
RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

Table 2.3 3 mg/L TIN (Year-round) Alternative Foot Print Analysis South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division

	Bardenpho	Bardenpho-MBR	Bardenpho-IFAS	BAF / DNF
Total added basins, acres	23.2	6.7	1.8 – 11.6	4.3
Full buildout capacity assuming no expansion on the biosolids site(1)	TL(2)	170 mgd	TL - 300 mgd	240 mgd

Notes:
(1) Capacity ratings are based on maximum month flows. The maximum month flow capacity of the current plant is 144 mgd. The assumed density of aeration basins is based on the proposed STP site buildout layout provided by the County. No extra allowances were made for roads or ancillary facilities.
(2) TL = estimated foot print is too large and does not fit on the site.

2.3 ALTERNATIVES EVALUATION

Based on team input from the first workshop, the four alternatives for each nitrogen limit scenario were evaluated based on the following cost and non-cost criteria:

- Onsite capital costs: Approximate planning level capital costs were estimated for construction of facilities on the STP site. Treatment of future flows off-site was not considered. Capital costs included construction costs and appropriate additional allowances for contingency, allied cost, sales tax, and other anticipated ancillary costs. Costs were indexed to estimated unit prices for March 15, 2010. The expected accuracy range for 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. Cost assumptions are summarized in Appendix B.

- Operation and Maintenance (O&M) costs: Approximate O&M costs were considered based on average annual flows and loads for a midpoint flow. The midpoint flow was established as the average between the 2007 average annual flow of 84.9 mgd and the estimated 108 mgd average annual flow associated with the maximum month design capacity of 144 mgd. The costs were therefore based on an average annual flow of 96.5 mgd. O&M costs included: labor, energy, and chemical costs and allowances for structural maintenance and equipment replacement. 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.

- Risk: Risk was defined in reference to the County's familiarity with the process and the number of worldwide installations.

- Future Flexibility: Future flexibility was only considered for the 8 mg/L TIN (summer-only) effluent scenario and was defined as the ability of the selected process to meet a future 3 mg/L TIN (year-round) limit.

- Footprint: An approximate process footprint for each alternative was determined based on the area required for new process tanks. No allowances were made for ancillary facilities.

- Energy: Energy use was estimated for each alternative based on factors such as estimated blower demand, pumping, and membrane air scour needs.

- Odor: The odor production potential of each alternative was qualitatively compared to the other alternatives for each nitrogen limit scenario.

- Compatibility with existing processes: The compatibility with existing processes was defined as whether or not the selected process would result in stranding of significant assets, such as secondary clarifiers.

- Biosolids Quality: The biosolids quality (nitrogen and phosphorus content) was qualitatively compared for each alternative to adversely impact on the beneficial use of biosolids.

- Reclaimed water quality/quantity: Both reclaimed water quality and quantity were compared for each alternative. Aspects of this comparison included whether the alternative produced an easily filterable effluent and whether the alternative left room on the site for future reclaimed water filters.

Each of these criteria was scored from 1 (low) to 3 (high) based on scoring definitions provided in Appendix A. The weighting for each criterion was established by the team at the second workshop. Criterion weights for capital and O&M costs were maintained at a weight of 1 since workshop participants did not want cost factors to overshadow evaluation of other factors. Table 2.4 and 2.5 present the weighted results for each effluent limit scenarios. Based on this analysis, the two leading alternatives for both effluent limit scenarios were the MBR and BAF/DNF. The County decided to select the MBR system as the representative alternative for both effluent limit scenarios. The team concluded that the BAF/DNF system should be considered in more detail at a facility planning or pre-design level. Since aggressive IFAS sizing potentially offers a very competitive alternative, the County may want to consider pilot testing to determine the optimum kinetic parameters and packing densities.

Table 2.4 8 mg/L TIN (Summer-only) Scoring Matrix
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Criteria	Weight	Score MLE	MBR	IFAS A[1]	IFAS C[2]	BAF
Onsite Capital Cost	1	3	2	3	1	3
O&M Cost	1	3	1	2	2	2
Risk	2	3	3	0[3]	1	2
Future Flexibility	2	1	3	3	1	3
Footprint	3	1	3	3	2	3
Energy	2	3	2	3	1	2
Odor	1	2	2	2	2	2
Compatibility with existing processes	1	3	3	3	3	3
Biosolids Quality	1	2	2	2	2	2
Reclaimed Water Quality/Quantity	1	1	3	2	2	2
Un-weighted Total		22	24	F[4]	17	24
Weighted Total		31	38	F[4]	24	37

Notes:
(1) IFAS A stands for the aggressive sizing of IFAS.
(2) IFAS C stands for the conservative sizing of IFAS.
(3) The aggressive IFAS sizing was determined to be too risky based on the manufacturer's lack of sufficiently demonstrated approach to tank sizing. The County may want to consider pilot testing to further support this consideration.
(4) A score of a "0" on any of the criteria results in a failure of that alternative.

Table 2.5 3 mg/L TIN (Year-round) Scoring Matrix
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Criteria	Weight	Score MBR	IFAS A(1)	IFAS C(2)	BAF
Onsite Capital Cost	1	2	3	3	2
O&M Cost	1	1	1	3	2
Risk	2	3	0(3)	1	2
Footprint	3	2	3	0(4)	2
Energy	2	1	3	2	2
Odor	1	2	2	2	2
Compatibility with existing processes	1	3	3	3	3
Biosolids Quality	1	2	2	2	2
Reclaimed Water Quality/Quantity	1	3	2	1	2
Un-weighted Total		19	F(5)	F(5)	19
Weighted Total		27	F(5)	F(5)	27

Notes:
(1) IFAS A stands for the aggressive sizing of IFAS.
(2) IFAS C stands for the conservative sizing of IFAS.
(3) The aggressive IFAS sizing was deemed to be too risky based on the manufacturer's lack of an adequate explanation for tank sizing. This alternative should be pilot tested before further consideration.
(4) The conservative sizing of IFAS was given a "0" for footprint since this alternative did not fit on the site.
(5) A score of a "0" on any of the criteria results in a failure of that alternative.

2.4 ALTERNATIVES SUBJECT TO MORE DETAILED ANALYSIS

2.4.1 Necessary Equipment

Two alternatives, one each for the seasonal limit and annual limit, were selected for a more detailed cost estimate, sensitivity analysis, and sustainability analysis:

- 8 mg/L TIN summer permit level: Parallel MLE/MLE MBR process
- 3 mg/L TIN (year-round) permit level: Parallel Bardenpho/Bardenpho MBR process

Significant elements of each alternative are summarized below.

2.4.1.1 <u>8 mg/L TIN (summer-only) permit level: Parallel MLE/MLE MBR process</u>

In this alternative the existing activated sludge aeration tanks and clarifiers would be retained. The aeration tanks would be modified to provide for internal recycle of mixed liquor to unaerated zones, which would be operated in anoxic mode for denitrification, rather than in the current anaerobic mode for encouragement of phosphorus accumulating organisms for settleability control. Methanol feed equipment would be provided to support denitrification. The existing tanks and clarifier would be de-rated to a maximum month capacity of 36 mgd for operation during the summer months for nitrogen removal. A parallel MBR process would be constructed to provide nitrogen removal for the summer months for the remaining flow. With a maximum month flow of 98 mgd during the summer, the parallel MBR process would be designed for a maximum month summer flow of 62 mgd. Winter season operation of the MLE-MBR facilities and the existing facilities will need to be addressed during any design phase. These considerations should include further evaluation of existing facilities needed to control settleability during winter operation so peak storm flows could be properly processed. It was assumed that MBR facilities would only be operated during the summer months for nitrogen removal. For calculation of effects it was assumed that the MBR facilities would be operated for a total of seven months per year, allowing for three weeks of startup operation and one week of shut-down operation for each six-month summer season. It was assumed that the MBR tanks would be drained and cleaned and remain out of service during the winter. Major elements of each upgrade include:

MLE BNR upgrade of existing aeration tanks:

- Installation of internal recycle pumps and piping
- Odor control covers for the aeration tanks
- Odor treatment equipment
- Installation of additional mixers in the first stage of the aeration tanks
- Modifications to the aeration tank air diffuser grids

Parallel MLE BNR MBR process:

- New unaerated and aerated aeration tanks
- Mixers and diffusers
- Odor control covers for the reactor tanks
- Odor treatment equipment
- New blowers
- New membrane tanks
- New membrane equipment building
- Chemical feed equipment and building (including methanol)
- MBR tank odor control covering

- MBR tank roof
- Membranes and support equipment

2.4.1.2 3 mg/L TIN (year-round) permit level: Parallel Bardenpho/Bardenpho MBR process

In this alternative the existing activated sludge aeration tanks and clarifiers would be retained. The aeration tanks would be modified to provide for 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 unaerated zones. Methanol feed would be provided. The modified existing tanks and clarifiers would be de-rated to a maximum month capacity of 30 mgd for operation year round for nitrogen removal. A parallel MBR process would be constructed to provide nitrogen removal year round for the remaining flow. With a maximum month flow of 144 mgd to the STP, the parallel MBR process would be designed for a maximum month flow of 114 mgd while 30 mgd is treated by the modified existing tanks. It is anticipated that this parallel design would accommodate the current peak hour secondary flow rating of 242 mgd. During peak storm events, 114-mgd would be directed to the MBR process and 128 mgd would be treated through the existing system modified for Bardenpho operation. Major elements of each upgrade include:

Bardenpho BNR upgrade of existing aeration tanks:

- Installation of internal recycle pumps and piping
- Odor control covers for the aeration tanks
- Odor treatment equipment
- Installation of additional mixers in the first and third stages of the aeration tanks
- Additional baffle walls
- Modifications to the aeration tank air diffuser grids

Parallel Bardenpho BNR MBR process:

- New unaerated and aerated aeration tanks
- Mixers and diffusers
- Odor control covers for the reactor tanks
- Odor treatment equipment
- New blowers
- New membrane tanks

- New membrane equipment building
- Chemical feed building
- MBR tank odor control covering
- MBR tank roof
- Membranes and support equipment

2.4.2 Site layout

The proposed site layouts for the representative alternatives are presented in Figures 2.9 and 2.14.

2.4.3 Cost

Following selection of representative alternatives, the preliminary cost estimates prepared for the alternatives screening were adjusted to reflect factors not considered in the preliminary screening, such as odor control covering and treatment costs. The cost estimates were based on a preliminary quantity estimate for excavation and concrete for new tanks and estimated cost for new equipment. To these direct costs were added allowances 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.). 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 March 15, 2010. The expected accuracy range for 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. Cost assumptions are summarized in Appendix B.

Tables 2.6 and 2.7 present summaries of estimated costs for upgrade of the STP to provide for nitrogen removal for the two potential permit levels. The estimates include the cost of odor control covers and equipment for the reactor tanks. The existing CAS process does not currently have complete odor control covers and treatment for the aeration tanks, but the tanks are under a current upgrade to provide this. Costs for provision of these were therefore not included. The tables present summaries of costs for major project elements in five columns:

- Operation of the existing CAS
- Upgrade of the existing CAS to provide for BNR
- New Parallel MBR BNR facilities

- The total estimated cost for the BNR upgrade
- The difference in cost between the BNR upgrade and the cost of the existing CAS

The differential present worth cost for nitrogen removal (column 6 in Tables 2.6 and 2.7) is the present worth cost of the nitrogen removal upgrade (column 3 in Tables 2.6 and 2.7) plus the present worth cost of the parallel MBR facilities (column 4 in Tables 2.6 and 2.7) minus the present worth cost of CAS (column 2 in Tables 2.6 and 2.7). The estimated total incremental present worth cost (including both incremental capital costs and incremental operating costs) for upgrade of the STP to an 8 mg/L TIN summer discharge permit level is approximately $680 million. The estimated incremental present worth cost for upgrade to meet the requirements of a 3 mg/L TIN (year-round) discharge permit limit is approximately $1,430 million.

The costs shown in the table are estimated costs for the unit processes shown based on process calculations by Carollo Engineers. As a comparison of capital costs, the lump sum construction cost for the aeration tanks for the new Brightwater Treatment Plant was approximately $50 million for a design capacity of 36 mgd or approximately $1.40 per gallon of max month flow capacity. The estimated construction cost from the current cost estimate for the MBR aeration tanks for the 3 mg/L year-round permit limit was approximately $200 million without contingency but including all other allowances or approximately the same unit cost as Brightwater for 144 mgd of capacity. The estimated operating cost from the STP budget for secondary treatment power is in the range of $1.5 to $2.0 million dollars per year. For comparison, the estimated total annual operating and maintenance cost in the current estimate for secondary treatment for the future year intermediate between current flows and design flows (89 mgd average flow) is $1.8 million per year including approximately $1.3 million for power,and $600,000 per year for labor. In the current estimate, O&M cost for structural and equipment maintenance and replacement were based on a percentage allowance of capital cost. Since the capital cost estimates were not available for the existing operation these costs were not included in the estimated O&M costs for CAS. It is estimated that operating costs would increase to a total of almost $15 million annually for the 8 mg/L TIN (summer-only) permit limit and $35 million annually for the 3 mg/L TIN (year-round) permit limit based on a similar distribution of costs for labor, power, odor control, and structural and equipment maintenance.

Table 2.6 Estimate Summary for 8 mg/L TIN (Summer-only) Permit Level Upgrade to the STP
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Element	CAS	MLE Upgrade	MLE MBR	Total BNR Upgrade	Difference
Present Worth Cost, $ Million					
Capital Cost(1)	$0	$105	$425	$530	$530
Operation and Maintenance(2)	$25	$46	$129	$176	$149
Total Present Worth	**$25**	**$151**	**$554**	**$706**	**$679**

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 March 2010 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.

Table 2.7 Estimate Summary for 3 mg/L TIN (Year-round) Permit Level Upgrade to the STP
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Element	CAS	Bardenpho Upgrade	Bardenpho MBR	Total BNR Upgrade	Difference
Present Worth Cost, $ Million					
Capital Cost (1)	$0	$188	$779	$967	$958
Operation and Maintenance(2)	$25	$128	$394	$522	$475
Total Present Worth	**$25**	**$316**	**$1,173**	**$1,489**	**$1,434**

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 March 2010 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.

2.4.4 Sensitivity Analysis

Following selection of representative alternatives for each permit level, a sensitivity analysis was performed to determine the response of the representative alternative to potential changes in conditions of operation from assumed conditions. Sensitivity was investigated in three areas:

1. Sensitivity to dynamic loadings including dewatering schedule
2. Sensitivity to excursions in sludge volume index (SVI)
3. Sensitivity to loss of aeration blowers

These sensitivity factors were selected during the first project workshop in October 2009. In addition to sensitivity to dewatering schedule, consideration of the effects of side stream treatment on nitrogen removal was also included as part of the sensitivity analysis for dynamic loading.

2.4.4.1 <u>Sensitivity to Dynamic Loading</u>

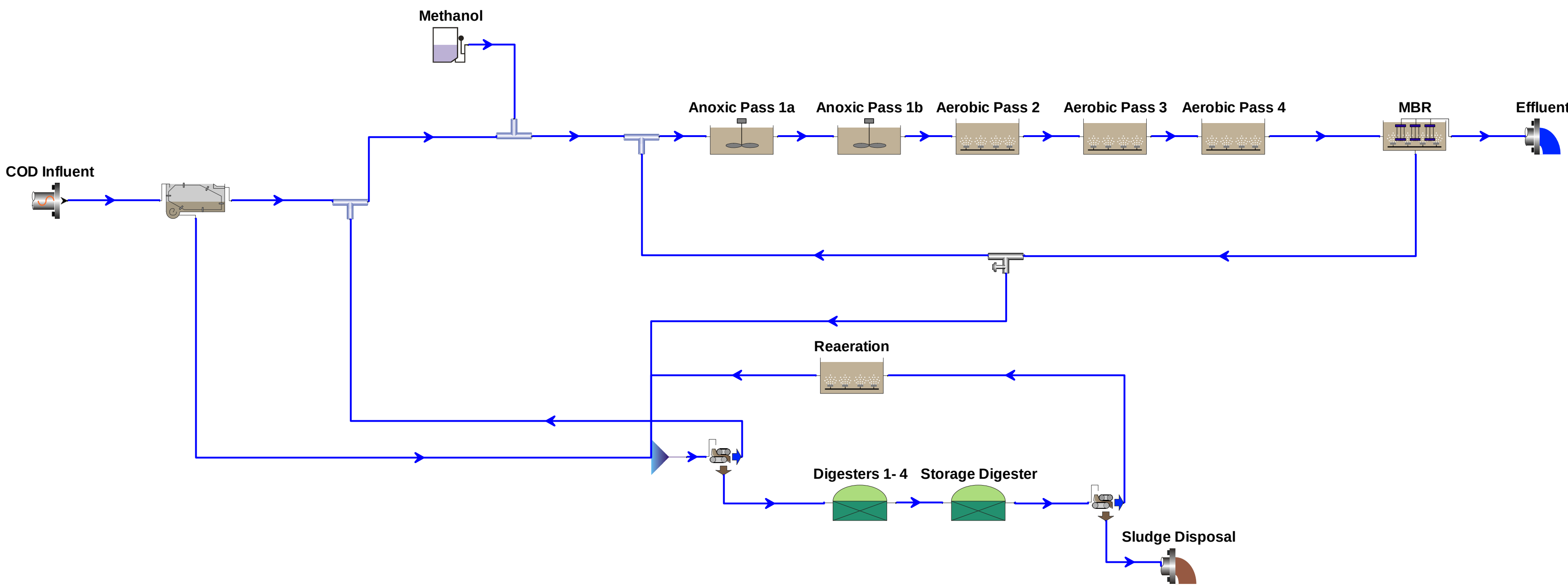
In order to determine sensitivity of the representative alternatives to dynamic loading two different sources of dynamic instability were considered:

1. Dynamic influent loading
2. Dynamic dewatering return flows

Preliminary analysis of process alternatives was based on steady state modeling of unit processes using both Carollo's Biotran spreadsheet and the commercial software BioWin. In steady state modeling, maximum month loadings are identified based on plant records and peaking factors are used to estimate dynamic loading effects. For the current analysis, dynamic models were developed to represent potential effects of diurnal variation in loadings from both the influent sewer and from dewatering return flows. Diurnal variation in flow and loading was assumed based on Carollo sampling and flow measurement for Central Contra Costa Sanitary District in California, a King County peer agency. To simulate the impact of dewatering schedule on potential nitrogen removal, two potential schedules were modeled:

1. Seven days per week and eight hours per day
2. Seven days per week and centrate flow equalization

A schematic of the recommended configuration developed in BioWin for the 8 mg/L TIN (summer-only) permit level is shown in Figure 2.18. A schematic for the recommended configuration for the 3 mg/L TIN (year-round) permit level is presented in Figure 2.19.

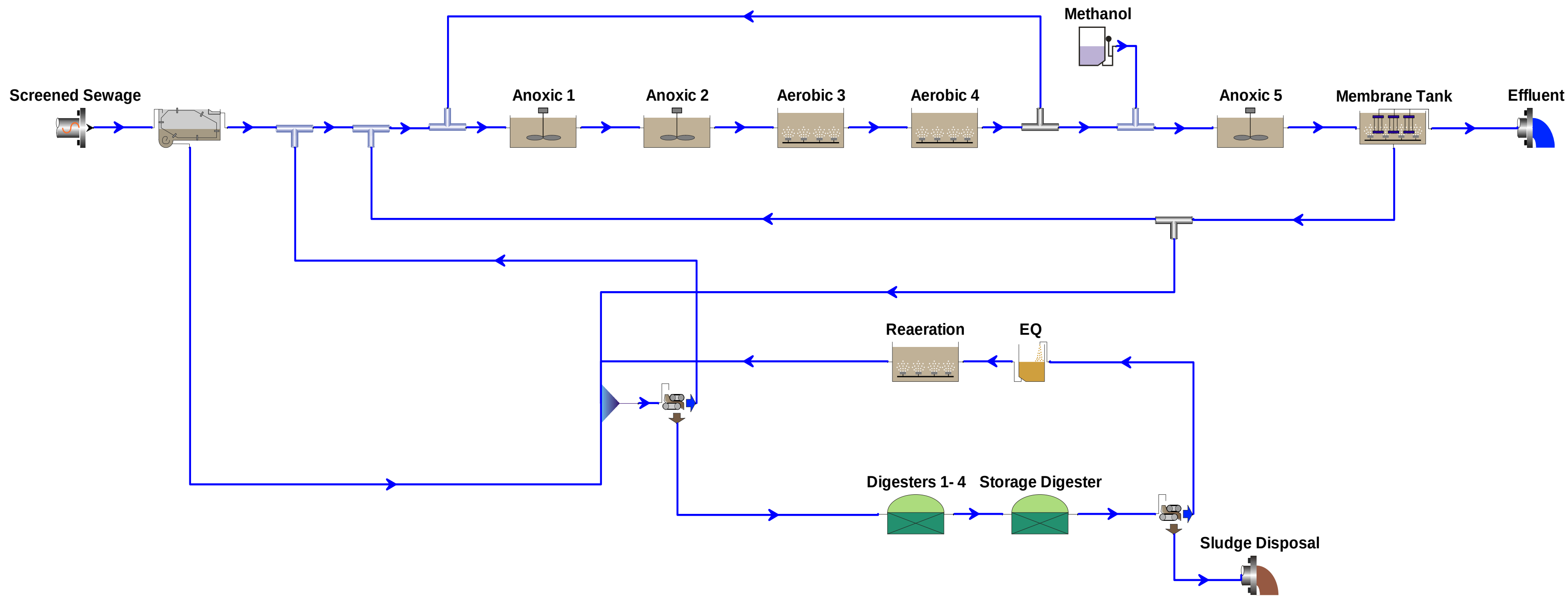


BIOWIN SCHEMATIC – 8 MG/L (SUMMER ONLY) PERMIT LEVEL

FIGURE 2.18

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS

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



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

FIGURE 2.19

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

Assumed influent flow and concentration variation for the two permit levels are shown in Figures 2.20 and 2.21. Predicted dynamic TIN effluent concentrations are shown on Figures 2.22 and 2.23, respectively for the 8 mg/L (summer-only) and 3 mg/L (year-round) permit level. Simulations were conducted for the new MBR units which would be constructed in parallel to existing units upgraded as discussed for nitrogen removal. It is anticipated that dynamic behavior of the conventional nitrogen removal units would be similar to that of the new parallel MBR units. For each permit level, simulations were performed under three different scenarios:

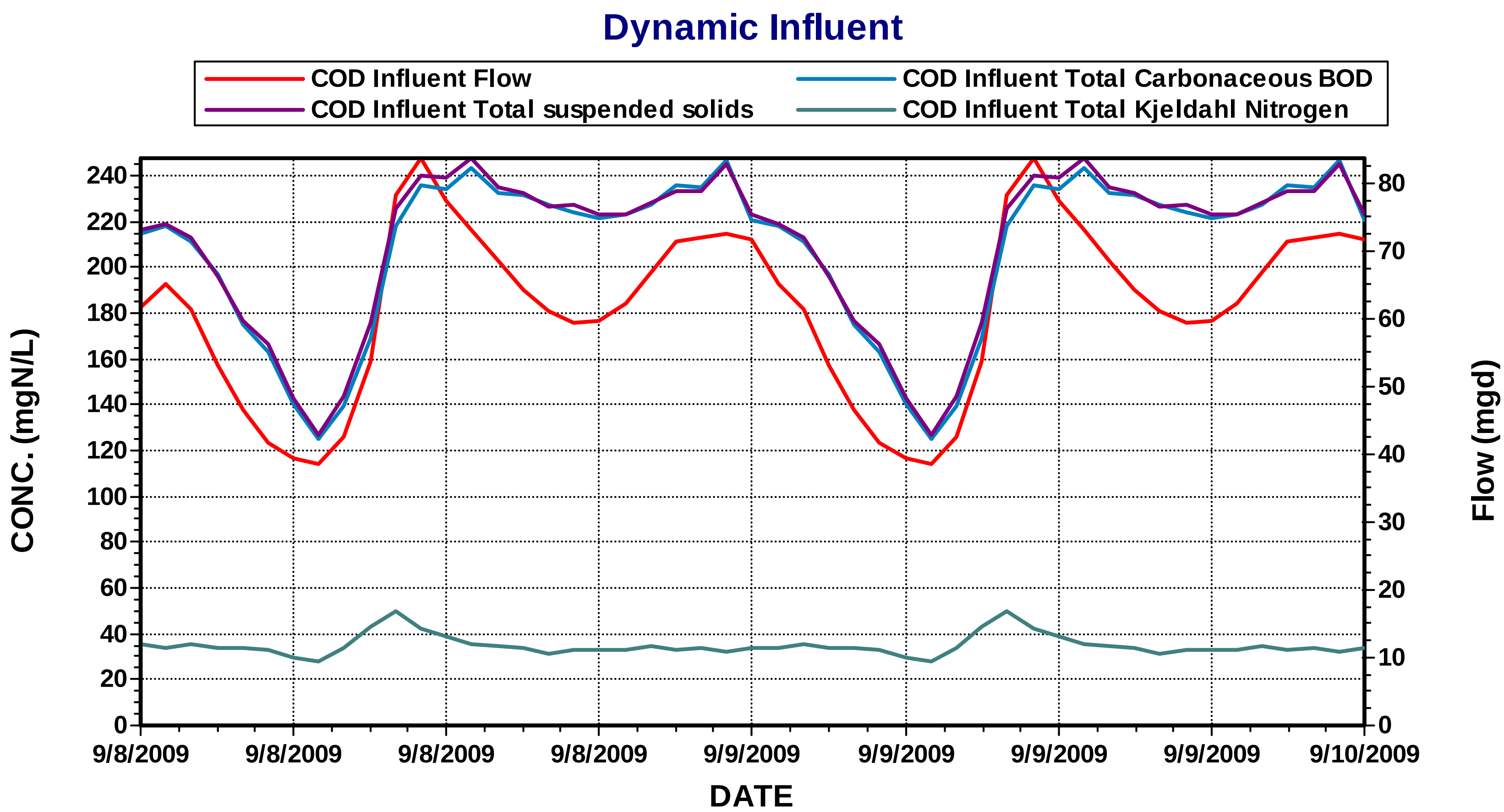
- No centrate reaeration or centrate equalization
- Centrate reaeration but no equalization
- With both equalization and reaeration of centrate

For the 8 mg/L TIN (summer-only) permit level it was found that neither centrate reaeration nor equalization were required to keep the average effluent TIN under 8 mg/L, but that without centrate reaeration and equalization there were peak hourly excursions above the 8 mg/L TIN level. A compromise configuration with centrate reaeration but without equalization is shown in the figures and was assumed in calculating costs. Different locations for the centrate equalization tank were investigated: on the dewatering return line, on the RAS line, and on the return line from the dissolved air flotation thickener (DAFT) tanks. Location of the centrate equalization tank on the centrate line indicated the lowest overall plant effluent TIN. An internal recycle configuration was initially explored for the 8 mg/L TIN (summer-only) permit level, but the modeling indicated that separate recycle beyond the recycle from the membrane tank was not required to control TIN to the 8 mg/L permit level. Likewise, use of a de-aeration tank on the return flow pipe from the membrane tank did not significantly improve effluent TIN performance.

For the 3 mg/L TIN (year-round) permit level the modeling indicated that both centrate reaeration and equalization would be required to keep the average effluent TIN comfortably under the 3 mg/L TIN (year-round) level. Even with both features, however, peak hourly excursions above the permit level were seen in the simulation. It was found that an internal recycle system with up to 600 percent recycle ratio, in addition to the 400 percent recycle flow from the membrane tanks, was required to keep effluent TIN levels under the 3 mg/L TIN (year-round) level.

2.4.4.2 <u>Sensitivity to excursions in SVI</u>

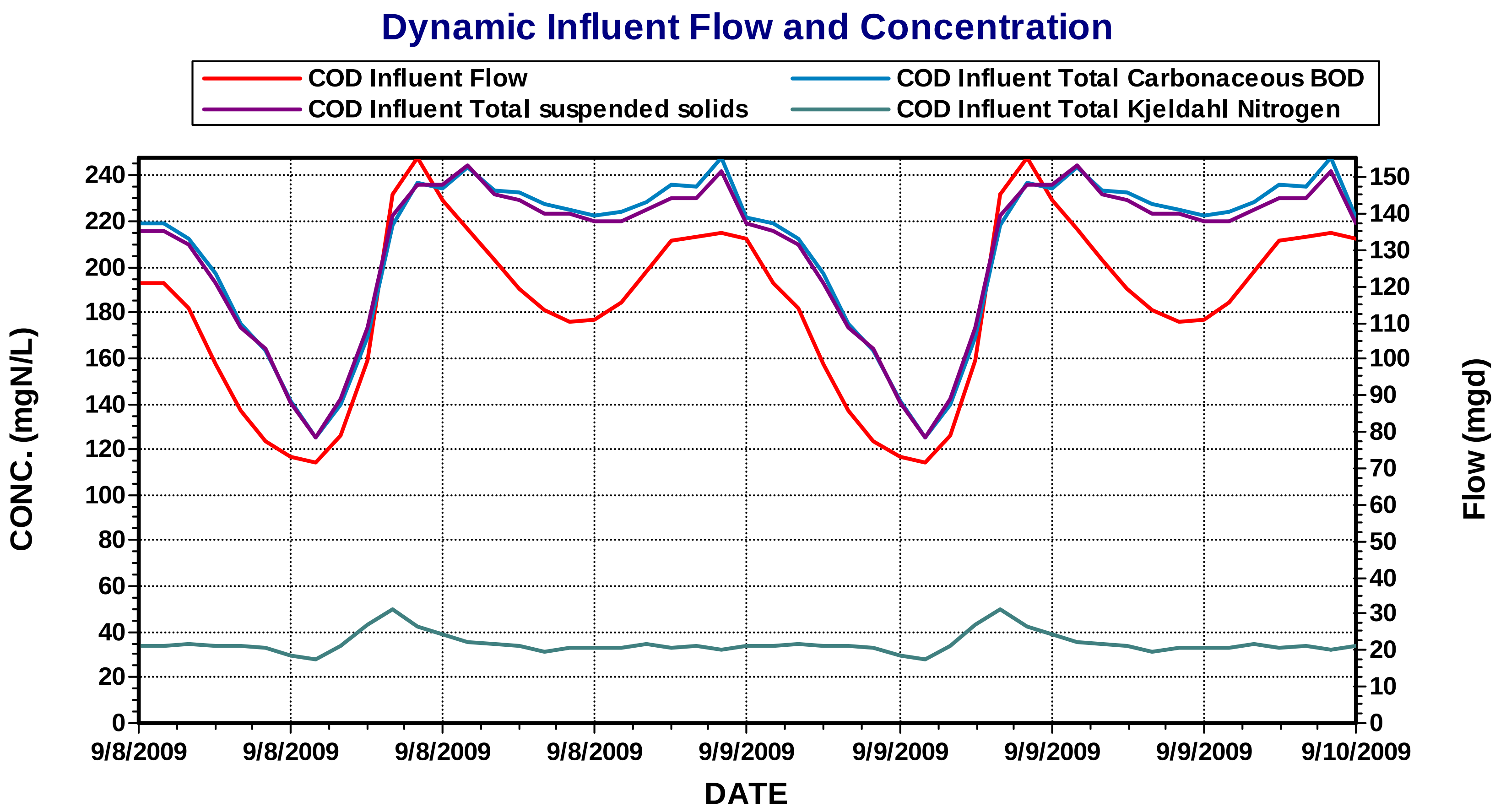
The selected alternatives for nitrogen removal both include membrane separation of biological treatment solids, rather than gravity tanks as used in the current plant. Thus, sludge settleability is not a significant issue for the parallel MBR stream. Variations in SVI would continue to affect the upgraded activated sludge system, but since existing facilities have been de-rated significantly for nitrogen removal, overflow rates on secondary sedimentation tanks would be much lower than under current operation.



DYNAMIC INFLUENT FLOW AND CONCENTRATION 8 MG/L TIN (SUMMER ONLY) PERMIT LEVEL

FIGURE 2.20

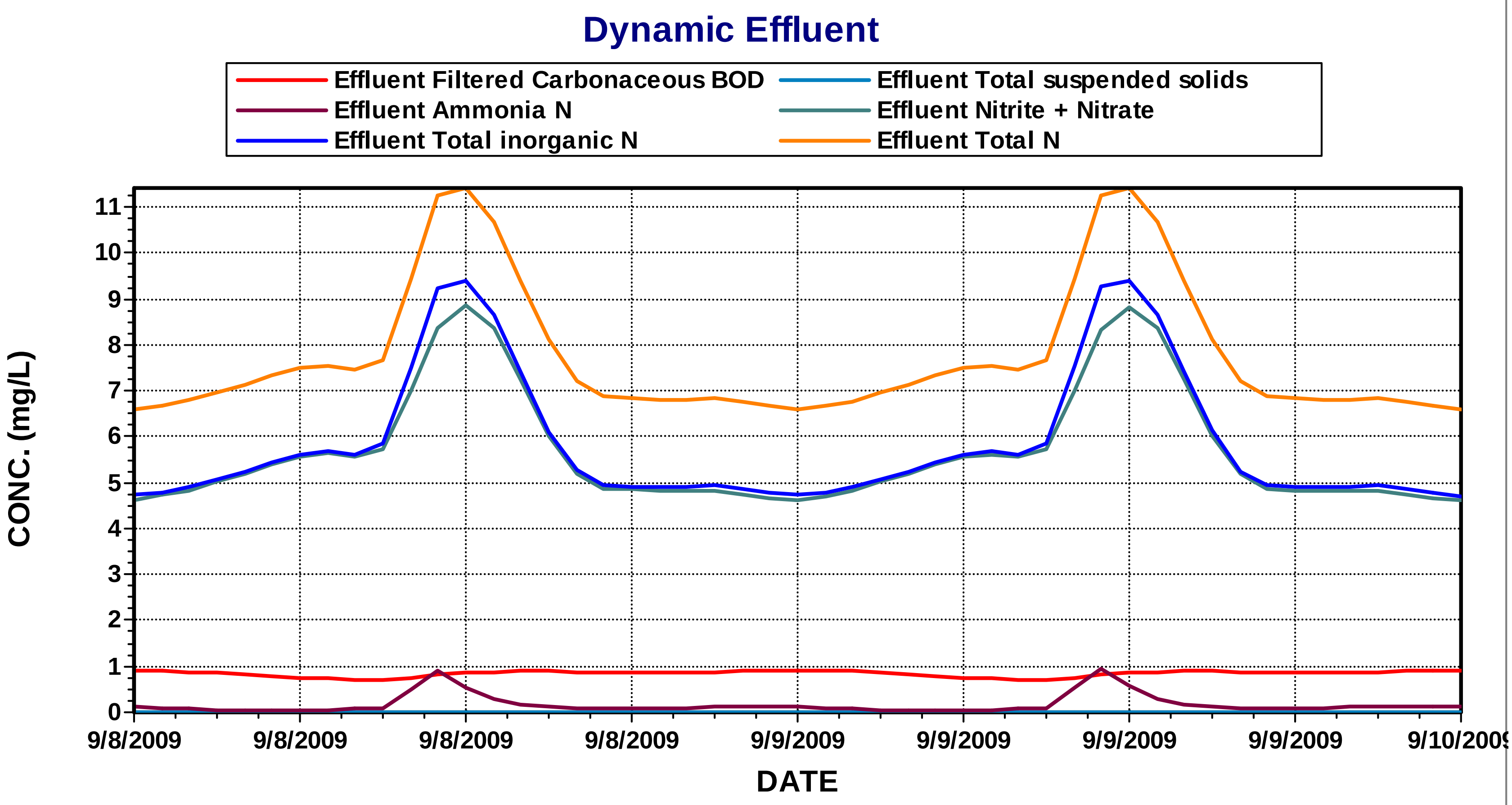
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



DYNAMIC INFLUENT FLOW AND CONCENTRATION 3 MG/L TIN (YEAR ROUND) PERMIT LEVEL

FIGURE 2.21

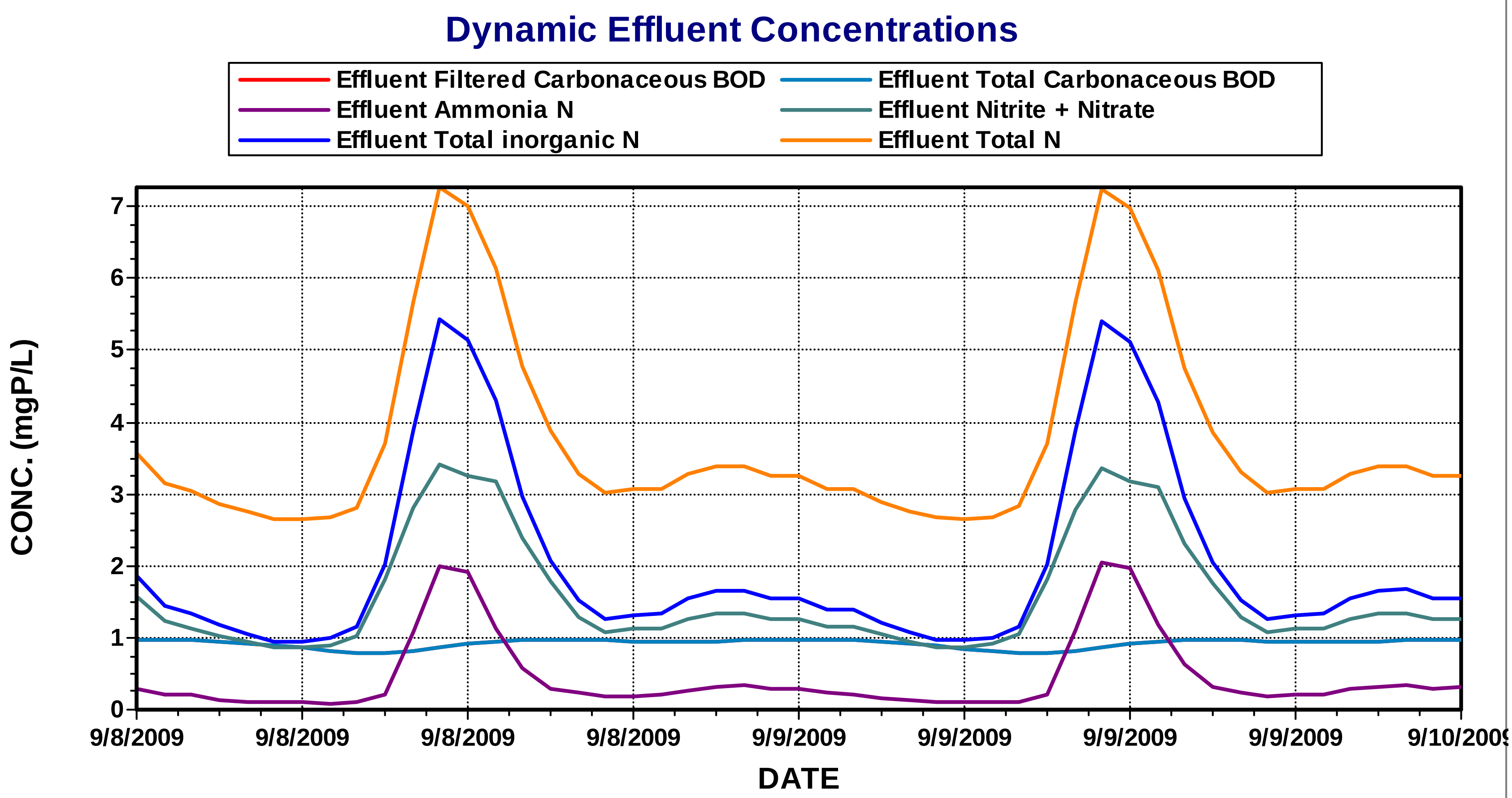
KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



DYNAMIC EFFLUENT FLOW AND CONCENTRATION 8 MG/L TIN (SUMMER ONLY) PERMIT LEVEL

FIGURE 2.22

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT



DYNAMIC EFFLUENT FLOW AND CONCENTRATION 3 MG/L TIN (YEAR ROUND) PERMIT LEVEL

FIGURE 2.23

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

carollo

Figure 2.24 presents a state point diagram for secondary clarifiers based on operation in a Bardenpho configuration using existing secondary sedimentation tanks. The state point diagram compares the operating conditions for solids loading to the theoretical settling flux in pounds per day per square foot (ppd/sf) of tank area as a function of MLSS concentration.

Under the conditions required, the overflow rate on the tanks would be less than 150 gallons per day per square foot (gpd/sf) with a MLSS concentration of 3,000 mg/L. The state point diagram reflects an estimate of settling characteristics assuming an operating SVI of approximately 150 milliliters per gram (mL/g). The diagram was prepared with a peak factor to the Bardenpho BNR system of 3.0 at peak wet weather flow. The diagram indicates sufficient capacity under these conditions. Calculations based on generic models for the relationship relating settling velocity to SVI indicate that the tanks could operate with a MLSS concentration of 3,000 mg/L at a peak flow up to approximately 65 mgd with SVI values over 200 mL/g.

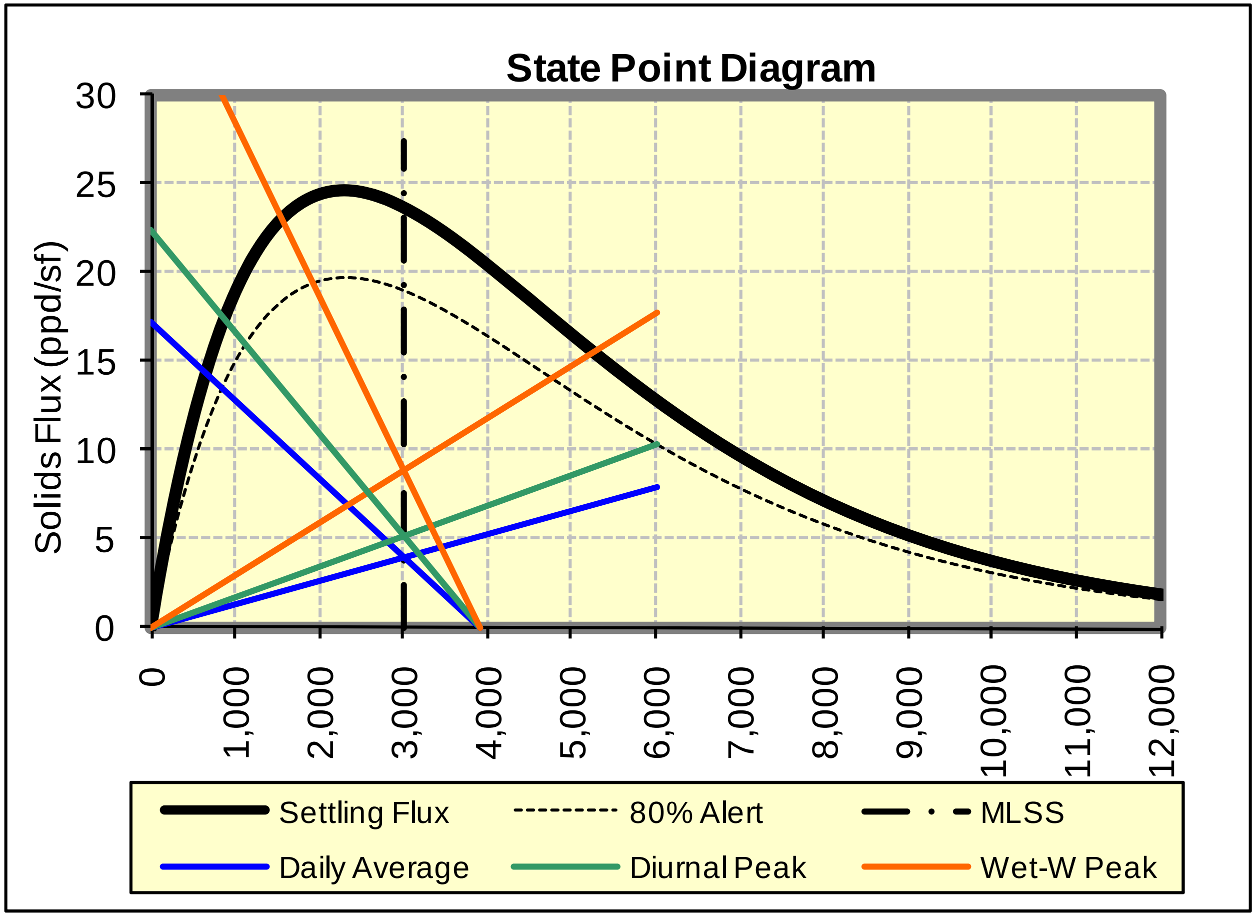
2.4.4.3 Sensitivity to loss of aeration blowers

The current blower capacity of the STP is 195,000 cubic feet per minute (cfm), provided by 10 units of various sizes. The capacity of the largest unit is 23,300 cfm, so the capacity of the system with the largest unit out of service would be 171,000 cfm. The estimated maximum month aeration demand for BNR operation of the existing four aeration tanks is less than 20,000 cfm, so there would be sufficient blower capacity for operation of the existing tanks, assuming new blower capacity were provided for the parallel MBR tanks. Required blower capacity is less than current demands because flow would be off-loaded from existing tanks by new parallel MBR tanks in the event that nitrogen removal were required, even though the oxygen demands for BNR exceed that required for carbonaceous treatment. If blower capacity from the existing blower system were used to meet part of the demand for parallel MBR aeration, then adequate standby capacity would need to be provided by additional blowers.

2.5 GREENHOUSE GAS COMPARISON

2.5.1 Overview

Effects of nitrogen removal upgrades on generation of greenhouse gas (GHG) emissions from the STP were evaluated. This section provides an estimate of GHG emissions of the existing system compared to those that would be expected if the STP were required to remove nitrogen to the two different permit levels identified above.



STATE POINT DIAGRAM FOR BARDENPHO BNR

FIGURE 2.24

KING COUNTY DEPARTMENT OF NATURAL
RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

2.5.2 Background

The State of California adopted the Global Warming Solutions Act of 2006 (also known as Assembly Bill 32 (AB 32)) in September of 2006. This Act is the first regulatory program in the U.S. that will require many public and private agencies statewide to reduce GHG emissions to 1990 levels by 2020 and 80 percent below 1990 levels by 2050. Currently, there is no specific mandate for reduction that applies to publicly owned treatment works (POTWs); however, the California Air Resources Board (CARB) has stated that POTWs could be included in the near future and early voluntary reporting is recommended. Due to the absence of any specific guidance based in Washington State law, the procedures and methodologies which have been implemented in California were used to develop an estimate of GHG emissions associated with nitrogen removal upgrade at the STP.

The estimates use the methodologies presented in and recommended by the California Climate Action Registry General Reporting Protocol (CCAR GRP), a set of measuring standards and protocols aligned with the international GHG Protocol Initiative and adapted to California. AB 32 recommends using this protocol “where appropriate and to the maximum extent feasible.” Agencies that choose to participate in the CCAR process will not be required to significantly alter their reporting except as determined by CARB for compliance purposes.

Emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) GHG emissions were estimated. These gases are relevant to and comprise the majority of GHG emissions generated from treatment of wastewater. The estimated annual GHG emissions from the operation of the CAS process at the STP are compared to emissions from operation of unit processes required to remove nitrogen. In general, annual GHG emissions are a function of the flow treated, the influent water quality, and the treatment processes used. A description of the calculation methodology is provided in the following section. The GHG estimates provided are for secondary and nitrogen removal processes and solids handling.

2.5.3 Methodology

The development of GHG emissions estimates requires a set of “boundary” conditions to define the life cycle stages, the unit processes, and the time frame that is included in the analysis. For this inventory, both construction and operations effects were considered. These included:

- Construction of new tanks and equipment for BNR processes
- Operation of the CAS process compared to BNR processes
- Production and hauling of chemicals consumed for treatment (this includes methanol required for nitrogen removal)
- Production and hauling of replacement materials consumed for treatment (this included membranes required for MBR treatment)

- Production and hauling of materials for construction of new tanks and equipment

2.5.4 Categories and Sources of GHG Emissions

There are two categories of emissions, direct and indirect, that were identified and evaluated:

- Direct Emissions: Direct emissions are those resulting from sources owned or controlled by the County, such as stationary combustion sources, mobile combustion sources, and treatment unit processes. For this inventory, this includes treatment unit process emissions, and N_2O emissions from effluent discharge.
- Indirect Emissions: Indirect emissions are those originating from the actions of the agency, but produced by sources owned or controlled by another entity. For this inventory, this includes: production of purchased electricity for the operation of the facility, manufacturing of chemicals and replacement materials used to treat the wastewater, and transport of the chemicals and replacement materials to the facility.

2.5.5 Estimate of GHG Emissions in Terms of "CO_2 Equivalents"

The major sources of GHG emissions were identified and categorized, and appropriate emission factors were determined. The data was then transferred into Carollo's GHG emissions inventory model to calculate the quantities of CO_2, CH_4, and N_2O emissions generated from each source. Major sources included:

- Electricity Consumption (kilowatt-hours (kWh)) multiplied by Emission Factor
- Vehicle Fuel Consumption (gallons or miles traveled) multiplied by Emission Factor
- Chemical or Material Produced (unit weight) multiplied by Specific Energy (unit energy per unit weight of material or chemical) multiplied by Emission Factor

Emissions were converted into carbon dioxide equivalent (CO_2e) emissions. The major GHG in the atmosphere is CO_2. Other GHGs differ in their ability to absorb heat in the atmosphere. For example, CH_4 has 21 times the capacity to absorb heat relative to CO_2 over a 100-year time horizon, so it is considered to have a global warming potential (GWP) of 21. N_2O has 310 times the capacity to absorb heat over a 100-year time horizon having a GWP of 310. Therefore, a pound of emissions of CO_2 has much less climatic impact than a pound of CH_4 or N_2O, but typically CO_2 is emitted in such large quantities compared to the other two GHGs that it dominates the final result. CO_2e emissions are calculated by multiplying the amount of emissions of a particular GHG by its GWP (see Table 2.8).

Example:

What is the CO_2e of one ton of CH_4 emissions?

1 ton CH_4 x 21 (GWP, tons CO_2e/tons of CH_4 emitted) = 21 tons CO_2e

Table 2.8	Greenhouse Gases and Global Warming Potentials South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division
Greenhouse Gas	**GWP(1) (Unit Mass CO_2e/Unit Mass of GHG Emitted)**
CO_2	1
CH_4	21
N_2O	310

Notes:
(1) GWPs are from the Intergovernmental Panel on Climate Change Second Assessment Report (1996) for a 100-year time horizon. These GWPs are still used today by international convention and the U.S. to maintain the value of the CO_2 "currency," and are used in this inventory to maintain consistency with international practice.

2.5.6 Description of GHG Emissions Estimates

This section provides a summary of the system being evaluated, a brief description of types of annual GHG emissions considered in this analysis, and the sources of information used.

The system to be evaluated is defined as the construction of new nitrogen removal facilities for the STP and subsequent operations compared to operation of the existing STP without significant nitrogen removal. Liquids stream treatment processes included in the analysis were: CAS aeration tanks, nitrogen removing activated sludge aeration tanks, and membrane tanks. The GHG emission effects of other treatment processes at the STP, including influent screening, grit removal, primary treatment, secondary sedimentation, and disinfection were considered to be largely unaffected by addition of nitrogen removal and therefore not included in the analysis. Solids handling unit processes considered include: anaerobic digestion and truck transport of solids for disposal. The STP has sludge thickening and dewatering processes, but the GHG effects of these were considered to be similar for both conventional and nitrogen removal alternatives and were therefore not included in the analysis.

2.5.7 Direct GHG Emissions

2.5.7.1 Process Emissions

GHG emissions are not only generated due to the energy consumed for operating the STP. CH_4 and N_2O are also emitted as a by-product of wastewater treatment processes.

2.5.7.1.1 *Methane*

Wastewater from domestic and industrial sources is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants. Soluble organic matter is removed using biological processes in which microorganisms consume the organic matter for cell maintenance and growth. The resulting biosolids are removed from the effluent prior to discharge to the receiving water. At the STP microorganisms biodegrade the soluble organic material under both anaerobic and aerobic conditions. Anaerobic conditions can generate CH_4 emissions, but its unlikely that any significant CH_4 production is taking place in the STP anaerobic selector tanks. Methane formation requires continuously anaerobic conditions with cell growth times exceeding four days. The STP liquid stream anaerobic zones have a solids residence time of less than one day and are immediately followed by aerobic zones; it is therefore unlikely that methane-forming bacteria have any significant growth in this system. This assumption was verified by multi-species modeling of biological growth in the tanks. The modeling predicted that there would be essentially no growth of methanogenic bacteria in the STP liquids treatment process. The STP has anaerobic digesters, which generate significant quantities of CH_4. In 2007, approximately 11 percent of digester gas at the STP was flared. Of the remaining 89 percent of the gas, approximately 16 percent was used for digester heating, 16 percent was used on-site to produce electricity (co-gen) and the remainder (57 percent) was sold as fuel to Puget Sound Energy. There may be some fugitive emissions of CH_4 from the STP anaerobic digesters, but there is no reason to think that there would be significant differences between conventional and nitrogen removing activated sludge processes in their tendency to produce fugitive emissions of CH_4. Nitrogen removing activated sludge processes would be expected to generate less volatile waste solids due to the longer solids residence times used in treatment, but there is no reason to think that the amount of gas flared would be different with nitrogen removal in the liquid process. Therefore, CH_4 process emissions were not included in the analysis.

2.5.7.1.2 *Nitrous Oxide*

N_2O emissions are estimated by methodologies adapted from the 2006 International Panel on Climate Change (IPCC) Guidelines for National GHG Inventories and Section 8.2 of the U.S. EPA document, GHG Emissions and Sinks (1990-2006). These methodologies identify that N_2O emissions are generated at:

1. Centralized wastewater treatment plants (WWTPs) *without* nitrification/denitrification (NDN)
2. Centralized WWTPs *with* NDN
3. From effluent discharged to receiving aquatic environments

Since NDN treatment is the central topic of this report, estimates of N_2O emissions are of significant importance. To identify the impact of implementing nitrogen removal by NDN at the STP, emissions of CAS treatment without NDN were compared to estimated emissions in the future with NDN. Estimates of N_2O emissions generated are dependent on the population (industrial and domestic) served by the treatment plant and the measured average daily total nitrogen load discharged from the STP.

2.5.7.2 <u>On-site Stationary Combustion</u>

Stationary combustion refers to the combustion of fuels to produce electricity, heat, or motive (mechanical) power using equipment in a fixed location. Typical stationary combustion units at WWTPs include boilers, flares, turbines, furnaces, and internal combustion engines. It is estimated that approximately 11 percent of STP digester gas is currently flared and approximately 16 percent of the remainder is currently used for digester heating. It is possible that BNR liquid stream treatment could result in less digester gas flaring because of the relatively smaller amount of waste solids production compared to CAS, but because digester flaring could be independent of total gas production, stationary combustion GHG effects were not included in the analysis.

2.5.8 Indirect GHG Emissions

2.5.8.1 Operation of Treatment Facilities

GHG emissions estimates from the operation of the treatment facilities are based on the total annual electricity demand (kWh per year). Annual energy demands were estimated using Carollo models for wastewater treatment for CAS treatment compared to models of operation of existing facilities in a modified configuration for nitrogen removal combined with MBRs configured for nitrogen removal. This is typically the most significant source of GHG emissions for WWTPs.

2.5.8.2 Chemical Production

The CCAR GRP considers energy required for the production of chemicals consumed in treatment processes to be outside the boundary of this type of inventory. However, in order to provide a more complete analysis of the effects imposed by the existing system, the energy consumed for chemical production is included in this inventory. The energy used per unit chemical consumed was calculated using conversion factors from Owen (1982). The only chemical considered in this analysis was methanol, which is required for nitrogen removal at the STP, but not for CAS treatment. Annual chemical consumption was based on estimates from Carollo's biological process modeling.

2.5.8.3 Replacement Material Production

The CCAR GRP also considers energy required for the production/replacement of spent materials used in treatment processes to be outside the boundary of this type of inventory. However, in order to provide a more complete analysis of the effects imposed by the existing system, the energy consumed for material production was included in this inventory. The energy used per unit mass of material consumed was calculated using conversion factors from Owen (1982). The replacement material production considered the membrane replacement estimated from Carollo modeling. No other material replacement values were estimated.

2.5.8.4 Chemical Handling

Estimates of GHG emissions generated from the transport of chemicals were based on the type of truck used, the type of fuel consumed, and the distance from the chemical's distribution center. The chemical handling considered the methanol consumption for BNR and citric acid consumption for membrane cleaning estimated from Carollo modeling.

2.5.8.5 Solids Handling

Estimates of GHG emissions generated from the transport of grit and biosolids are based on the type of truck used, the type of fuel consumed, and the distance to the disposal site. Carollo used data estimated from Carollo models for sludge production of CAS compared to nitrogen removal alternatives. Estimates for fuel consumption were based on the disposal of biosolids to the Boulder Park site in Eastern Washington.

2.5.8.6 Replacement Material Handling

Estimates of GHG emissions generated from the transport of replacement materials are based on the type of truck used, the type of fuel consumed, and the distance from the material's distribution center and disposal site (an Eastern Washington land fill). Carollo applied assumptions for the truck type and fuel type consumed. The only replacement material estimated was membranes for the BNR alternatives.

2.5.8.7 Construction Materials

Estimates for the indirect GHG emissions from production and transport of construction materials for new MBR BNR facilities were estimated from quantity estimates for construction using factors for conversion to GHG emissions.

2.5.8.8 Offsets

Offsets in this analysis are those emissions that were once generated from the consumption of purchased electricity, but are now avoided (or are no longer emitted) since the energy is now supplied by a renewable energy source. This analysis included estimated differences in production of digester gas which is scrubbed and sold to the Puget Sound Energy.

2.5.9 Summary of GHG Emissions Estimates

A summary of the results of the GHG analysis for the project is presented in Table 2.9 and Figure 2.25. The table shows the cumulative emissions estimated for each alternative in each category of GHG emission. The figure presents a bar chart representing the total estimate annual production of CO_2e for the three process alternatives:

- CAS
- BNR with an effluent permit goal of 8 mg/L TIN for the six summer months of the year by conversion of the existing aeration tanks to an MLE process with treatment of the remaining flow by MLE MB (Operation in CAS the remainder of the year)

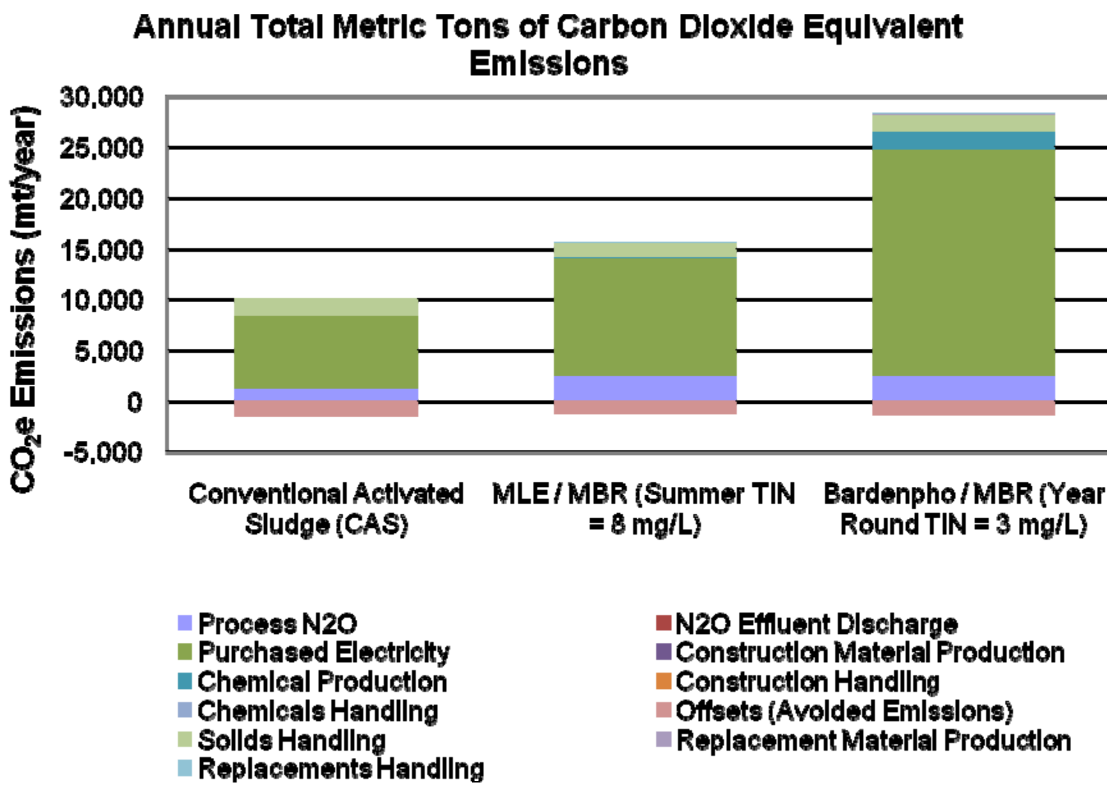
- BNR with an effluent permit goal of 3 mg/L TIN (year-round) by conversion of the existing aeration tanks to a Bardenpho process with treatment of the remaining flow by Bardenpho MBR

The results indicate that the impact of a summer-only effluent permit level of 8 mg/L TIN would result in an approximately two thirds more GHG emissions than for secondary treatment at the STP. A 3 mg/L TIN year-round limit would than result in approximately three times more emissions of equivalent GHG emissions. The primary sources of increased GHG emissions are process N_2O and purchased electricity. Table 2.9 also shows the number of vehicles that would need to be added to the Puget Sound region to have an equivalent impact on regional GHG emissions as addition of either of the two nitrogen removal permit scenarios. It is seen that implementation of the 8 mg/L (summer-only) permit level would have the equivalent impact of adding 1,200 vehicles to the Puget Sound region, while implementing the 3 mg/L year round permit limit would be equivalent to adding nearly 4,000 vehicles to the region.

Table 2.9 Estimated Annual Total Metric Tons of Carbon Dioxide Equivalent Emission
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Emission Type	**CAS**	**MLE / MBR (Summer TIN = 8 mg/L)**	**Bardenpho / MBR (Year Round TIN = 3 mg/L)**
Direct			
Process N_2O	1,106	2,420	2,420
N_2O Effluent Discharge	38	13	6
Indirect			
Offsets (Avoided Emissions)	-1,396	-1,100	-1,246
Purchased Electricity	7,255	11,615	22,264
Construction Material Production	0	11	37
Chemical Production	0	93	1,739
Replacement Material Production	0	93	237
Construction Handling	0	6	22
Solids Handling	1,698	1,292	1,515
Chemicals Handling	0	19	49
Replacements Handling	0	5	13
Total	**8,700**	**14,468**	**27,055**
Relative Value (%)	**100%**	**166%**	**311%**
Equivalent Number of Vehicles[1]	**1,582**	**2,782**	**5,302**
Relative Number of Vehicles	**0**	**1,200**	**3,720**

Notes:
(1) Based on EPA estimate of 5.5 metric tons of annual CO_2 equivalent emissions for an average vehicle (http://www.epa.gov/oms/climate/420f05004.htm).



GHG COMPARISON

FIGURE 2.25

KING COUNTY DEPARTMENT OF NATURAL
RESOURCES AND PARKS
ASSESSMENT OF POTENTIAL NITROGEN REMOVAL TECHNOLOGIES AT THE SOUTH TREATMENT PLANT AND THEIR IMPACT ON FUTURE WATER REUSE PROGRAM DEVELOPMENT

2.6 FINDINGS AND CONCLUSIONS

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

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

The estimated costs and other effects of meeting each of these potential future permit requirements were compared to continuation of the current practice of CAS operation to meet a secondary treatment permit for discharge to Puget Sound. A wide range of potential alternatives were considered and screened to four final alternatives for each permit level. Costs of each of these upgrade strategies were estimated 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 final ranking indicated that for the 8 mg/L TIN (summer-only) permit level, the most promising upgrade strategy would be to upgrade the existing CAS process at the STP to provide for anoxic and aerobic treatment in two treatment stages by a MLE process and to construct a parallel nitrogen removing MBR process to treat the remainder of the flow. For the 3 mg/L TIN (year-round) discharge alternative a similar strategy was selected, but using a four-stage anoxic and aerobic process (the Bardenpho process). It was concluded that two other processes, BAF/DNF and IFAS processes, were potentially cost-effective and have similar enough other effects that they should be considered further in the future.

A sensitivity analysis was conducted to evaluate potential effects of diurnal loading variation and variation in the schedule of sludge dewatering operations, variation in activated sludge settleability, and the impact of air blower outage on nitrogen removal. It is concluded that sludge dewatering return flow equalization and treatment would be necessary to ensure meeting a 3 mg/L TIN (year-round) permit limit, but that equalization would be less necessary with the 8 mg/L TIN (summer-only) permit limit. It was concluded that variation in sludge settleability would have less impact on the MBR process selected than is experienced today with the CAS process for secondary treatment. It was assumed that additional aeration blowers would be constructed for new MBR treatment facilities at the STP and that sufficient redundancy would be constructed to provide for blower outage.

The incremental present worth cost for upgrade of the STP to meet an 8 mg/L TIN permit level during the summer months is estimated at a present worth cost of approximately $680 million more than continuing operation of secondary treatment over the next twenty years. The estimated incremental present worth cost for upgrade to meet a 3 mg/L TIN (year-round) permit level is in approximately $1,430 million more than the cost of continuing with secondary treatment.

In addition to evaluation of incremental present worth costs, an estimate of GHG emissions was conducted. It was concluded that meeting an 8 mg/L TIN summer permit level would result in nearly two thirds more GHG emissions from the STP compared to the currently-used CAS process and that 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 STP. The primary sources of increased GHG emissions were estimated increases in purchased electricity and N_2O released during nitrogen removal treatment. Addition of these treatment technologies to the STP would have a similar GHG effect to addition of between 1,000 and 4,000 vehicles to the Puget Sound region, depending on the permit level implemented.

The most significant conclusions from this analysis were:

- The incremental present worth cost for upgrade of the STP to meet an 8 mg/L TIN permit level during the summer months is estimated at a present worth cost of approximately $680 million more than continuing operation of secondary treatment over the next twenty years.
- The estimated incremental present worth cost for upgrade to meet a 3 mg/L TIN (year-round) permit level is in approximately $1,430 million more than the cost of continuing with secondary treatment.
- Meeting an 8 mg/L TIN summer permit level would result in nearly two thirds more GHG emissions from the STP compared to the currently-used CAS process.
- 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.

SOUTH PLANT NITROGEN REMOVAL EFFECT ON RECLAIMED WATER PRODUCTION

3.1 INTRODUCTION

The South Treatment Plant (STP) currently performs secondary treatment for up to 144 million gallons per day (mgd) of flow on a maximum month basis for discharge to Puget Sound. Substantial removal of ammonia is not achieved. Reclaimed water filtration facilities for up to 1.5 mgd of secondary effluent are currently available. Implementation of nitrogen removal at the STP could have a significant effect on reclaimed water availability, potential customers, and quality, depending on the technology selected.

Previous chapters presented analysis used a basis for the information contained herein. Chapter 1 reported development of two target permit levels for nitrogen removal:

- 8 mg/L total inorganic nitrogen (TIN) from May through October
- 3 mg/L TIN year-round

Chapter 2 reported results of a screening of a wide range of potential nitrogen removal treatment scenarios to one potential technology for each permit level as follows:

- Parallel Modified Ludzack-Ettinger (MLE) – membrane bioreactor (MBR) process for the 8 milligrams per liter (mg/L) summer TIN limit
- Parallel Bardenpho – MBR process for the 3 mg/L year round TIN limit

This chapter discusses potential effects of the selected alternative on reclaimed water production and compared to the cost of implementing reclaimed water production for the current, non-nitrified effluent.

3.2 SUMMARY OF RECLAIMED WATER STANDARDS

The legislative basis for reclaimed water regulation in the State of Washington is contained 90.46 RCW - Reclaimed Water Use. The current *Water Reclamation and Reuse Standards* (Standards) date from 1997 and have been prepared jointly by the Department of Health (DOH) and the Department of Ecology (Ecology) (See DOH and Ecology 1997). These standards define reclaimed water in four classes based on quality as summarized in Table 3.1. Nitrogen removal is not required in general for any of the four classes, but is required for specific uses. Uses mentioning nitrogen removal in the *Water Reclamation and Reuse Standards* are summarized in Table 3.2.

Current standards are under review. New rules are expected by December 2010. This analysis is based on the current regulations.

Table 3.1 Definitions of Reclaimed Water
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

"Reclaimed water" means water derived in any part from wastewater with a domestic wastewater component that has been adequately and reliably treated, so that it can be used for beneficial purposes. Reclaimed water is not considered a wastewater.
"Class A Reclaimed Water" 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.
"Class B Reclaimed Water" means reclaimed water that, at a minimum, is at all times an oxidized, 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.
"Class C Reclaimed Water" means reclaimed water that, at a minimum, is at all times an oxidized, 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 23 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 240 per 100 milliliters in any sample.
"Class D Reclaimed Water" means reclaimed water that, at a minimum, is at all times an oxidized, 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 240 per 100 milliliters, as determined from the bacteriological results of the last 7 days for which analyses have been completed.

Table 3.2	Summary of Reclaimed Water Uses Requiring Nitrogen Removal South Plant Nitrogen Removal Study King County Department of Natural Resources and Parks Wastewater Treatment Division
Intended Use	**Nitrogen Removal Requirement**
Groundwater Recharge by Surface Percolation	The secondary treatment process to provide oxidized wastewater shall include an additional step to reduce nitrogen
Direct Recharge to Potable Ground Water	Total nitrogen $\leq$10 mg/L as N
Discharge to Wetlands	Total Kjeldahl nitrogen (as nitrogen) 3 mg/L
Non-restricted Recreational Impoundments	Nitrogen removal to reduce levels of phosphorus and/or nitrogen is recommended

The Standards give the following requirement for disinfection:

> *Where chlorine is used as the disinfectant in the treatment process a minimum chlorine residual of at least 1 mg/L after a contact time of at least 30 minutes is required. (DOH and Ecology, September 1997, Section I, Article 9, Section 5 [a])*

This requirement does not explicitly state whether the chlorine residual should be measured as free or total chlorine.

Since the reclaimed water standards were issued in 1997, the design manual for wastewater treatment plants, the Criteria for Sewage Works Design (Orange Book), has been updated and a revised issue released in 2006. The Orange Book guidelines for chlorine disinfection requirements have changed in this revised manual and now state:

> *When using chlorine as the disinfectant, state reclaimed water standards require a minimum CT of 30, based on a minimum free available chlorine residual of 1.0 mg/L after a t10 contact time of at least 30 minutes. The basis for using this method is disinfection requirements developed for the safe drinking water act.*
>
> *An alternate approach is to provide a CT of 450 based on a total chlorine residual of at least 5 mg/L after a modal contact time of at least 90 minutes. Note this approach may not provide the same level of pathogen inactivation as well the first. This approach, used in the state of California, prescribe a level of disinfection to provide essentially pathogen free water (Ecology, October 2006, E1-4.5.1 B).*

The new Rule limits the contact time (CT) to 30 mg/L-min based on a free chlorine residual and a T_{10} CT. The new draft standards "permit an alternative CT measurement such as total chlorine residual and a modal T value it if is demonstrated to the satisfaction of the departments that the alternative disinfection process provides an equivalent degree of human health and environmental protection."

3.3 RECLAIMED WATER EVALUATION

3.3.1 Reclaimed Water Effects

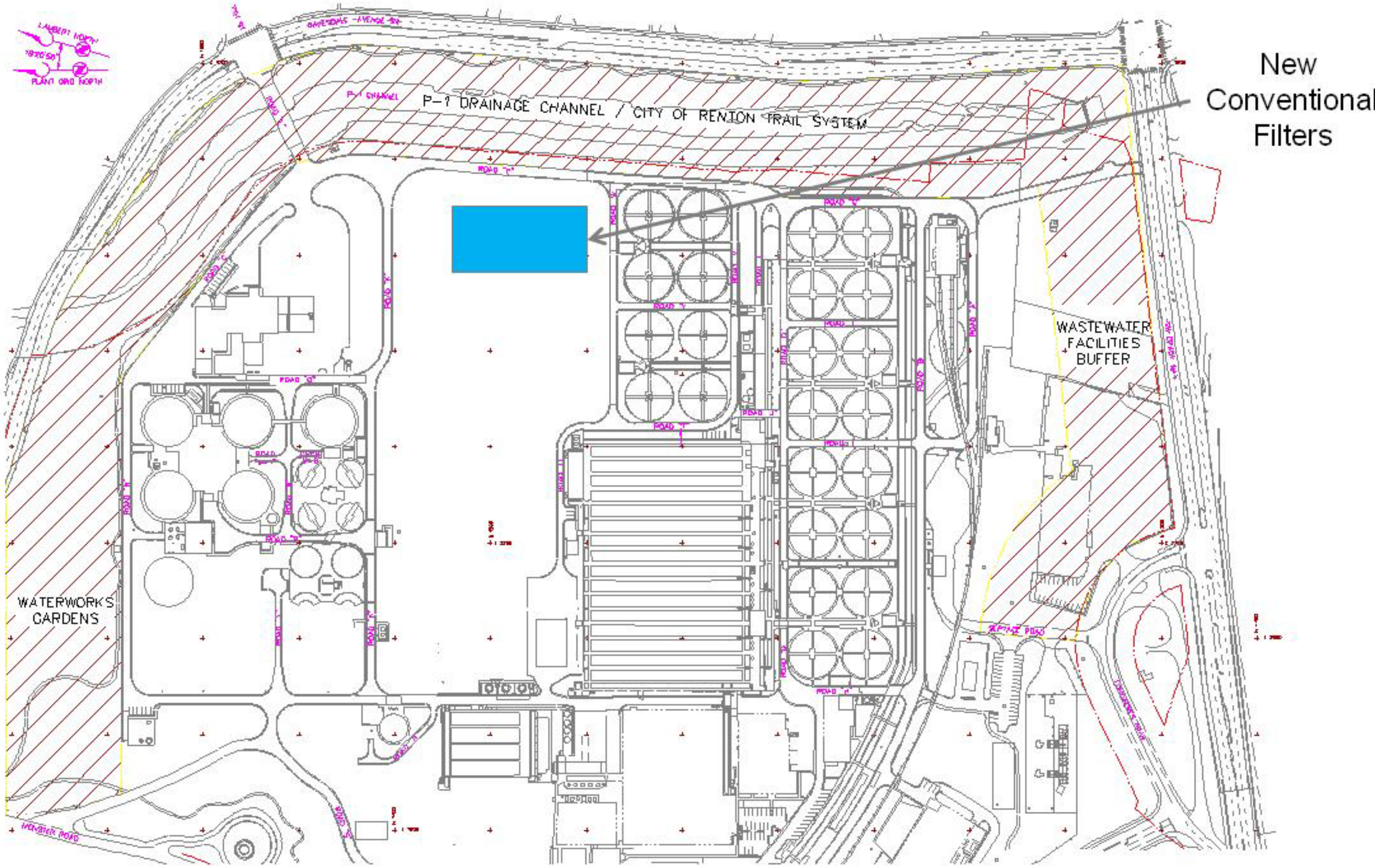
The current flow of the STP during the summer season when reclaimed water could be potentially used for irrigation is approximately 98 mgd. Coagulation, flocculation, and filtration or membrane filtration would be required to implement production of 98 mgd of reclaimed water from the current non-nitrified secondary effluent. Assuming a typical rapid mix detention time of 1 second, flocculation detention time of 20 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 38,000 square foot (sf) of coagulation, flocculation, and filtration facilities would be required. This sizing assumes two standby units out of a total of 45. Figure 3.1 shows how these facilities could fit on the existing site. The capacity of the existing filtration units was not included in the current analysis.

The MLE – MBR alternative for operation for an 8 mg/L TIN permit level during the May through October period would produce up to 62 mgd of MBR effluent water during the summer that would substantially meet the requirements for Class A reclaimed water. To produce reclaimed water equaling the full current dry weather flow of 98 mgd, sand filtration of 36 mgd from the existing secondary clarifiers would be needed. Assuming rapid mix detention time of 1 second, flocculation detention time of 20 minutes, and a maximum month hydraulic loading rate of 4 gpm/sf for the rapid sand filters, a total of approximately 13,000 sf of coagulation, flocculation, and filtration facilities would be required with one unit out of 17 out of service. Figure 3.2 shows how these facilities could fit on the existing site.

The Bardenpho – MBR upgrade strategy would produce up to 114 mgd of MBR effluent year round that would substantially meet the requirements of Class A reclaimed water. This means that the STP could provide reclaimed water for almost the entire average wet weather design flow if the 3 mg/L TIN year-round alternative were implemented.

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. However, this requirement would be the same for the 8 mg/L TIN summer effluent scenario, the 3 mg/L TIN year round effluent scenario, and production of reclaimed water from the current plant (non-nitrified effluent). 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.

Current Non-Nitrified Effluent



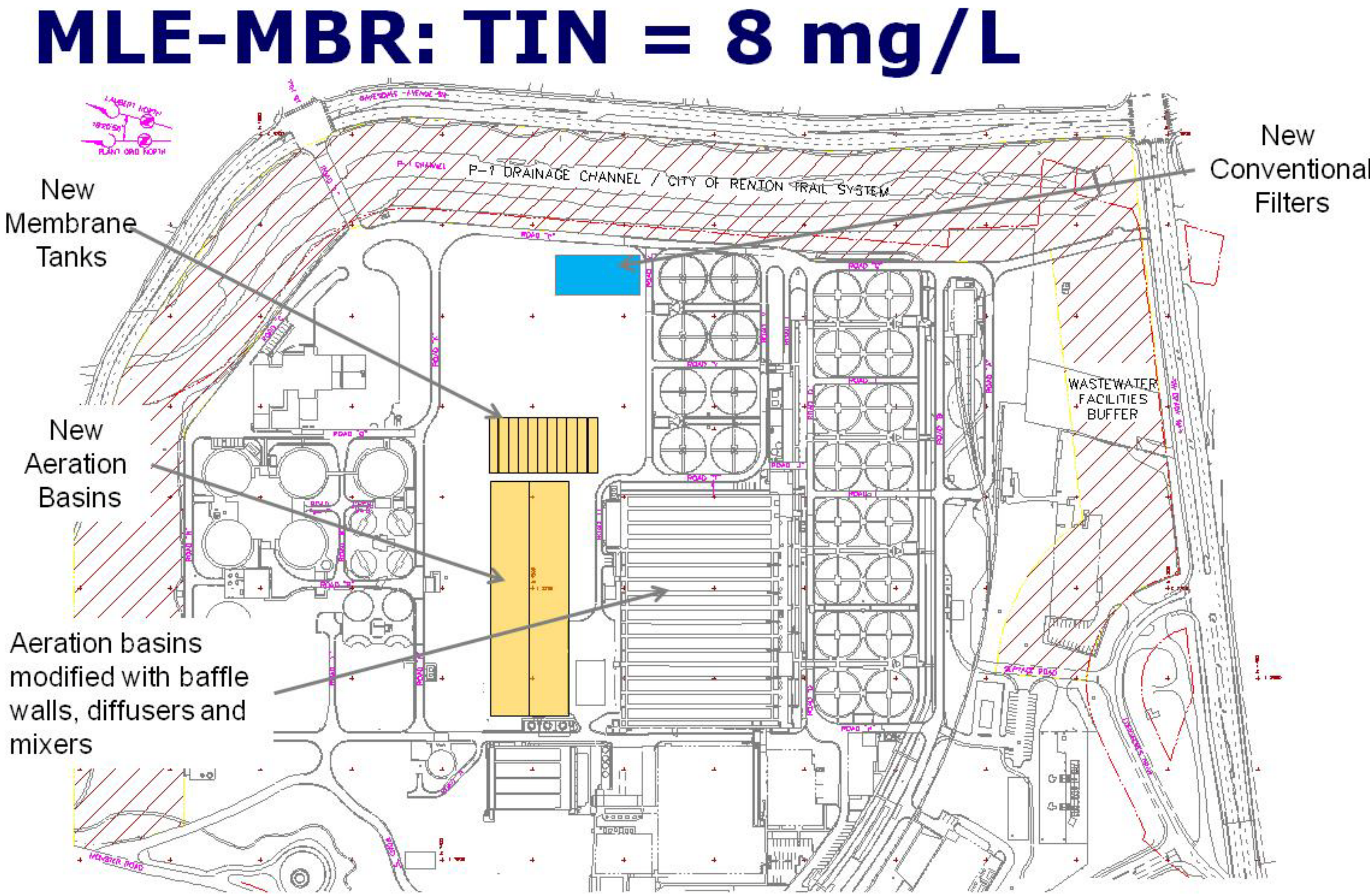
SITE REQUIREMENTS FOR 98 MGD OF CONVENTIONAL FILTRATION

FIGURE 3.1

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS

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

carollo



SITE REQUIREMENTS FOR 33 MGD OF CONVENTIONAL FILTRATION

FIGURE 3.2

KING COUNTY DEPARTMENT OF NATURAL RESOURCES AND PARKS

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

3.3.2 Reclaimed Water Options Costs

Table 3.3 compares the planning level costs of reclaimed water production for the full 98 mgd summer flow for the current non-nitrified secondary effluent to the requirements for additional filtration assuming nitrogen removal upgrade by a parallel MBR process for either the 8 mg/L (summer only) or the 3 mg/L (year-round) TIN permit level. As shown in Table 3.3, there would be no additional cost to implement reclaimed water production for the full summer flow of 98 mgd if the 3 mg/L (year-round) TIN permit limit project is implemented.

Table 3.3 shows that the cost of implementing reclaimed water by conventional filtration is approximately $104 million in present worth capital and operating and maintenance costs. If a 3 mg/L (year-round) TIN permit limit project using parallel MBR were implemented, this cost would be avoided.

The planning level present worth cost of implementing 36 mgd of reclaimed water production for non-nitrified effluent would be approximately $45 million. This would represent a savings of approximately $59 million over providing full summer reclaimed water production today from non-nitrified STP effluent. This relative savings in reclaimed water production would be realized if the 8 mg/L (summer-only) parallel MBR project were implemented.

Table 3.3 Summary of Relative Reclaimed Water Costs Effects
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Treatment Process	Current Approach. Non-nitrified Secondary Effluent. No new facilities. Summer only.	8 mg/l TIN Summer Limit Parallel MLE-MBR Processes		3 mg/l TIN All-year Limit
Add'l Sand Filtration Req'd	98 mgd sand filters	MLE Effluent 36 mgd sand filters	MBR Effluent 62 mgd - no sand filters	MBR Effluent 114 mgd – no sand filters
Capital Cost	$57M	$23M	$0	$0
Annual O&M Cost	$3.1M/yr	$1.4M/yr	$0	$0
Disinfection	Assumed equal cost for all alternatives.			
Present Worth O&M	$47M	$22M		$0
Total Present Worth	**$104M**	**$45M**		**$0**

3.3.3 Other Effects

In addition to economic effect, there would be other effects of implementing either an 8 mg/L (summer-only) or a 3 mg/L (year-round) TIN effluent permit limit project on potential reclaimed water production. Key effects include additional land use, energy consumption, and greenhouse gas (GHG) consumption. They are summarized in Table 3.4.

Table 3.4 Summary of Other Relative Reclaimed Water Effects
South Plant Nitrogen Removal Study
King County Department of Natural Resources and Parks Wastewater Treatment Division

Element	Current Approach Non-nitrified Secondary Effluent (98 mgd treated)	8 mg/L TIN Summer Effluent Limit, Parallel MLE-MBR (36 mgd treated)	3 mg/L TIM Year-round Effluent Limit, Parallel Bardenpho-MBR (0 mgd treated)
Impact			
Land area (sf)	*38,000*	*13,000*	*0*
Energy consumption (kWh/year)	*200,000*	85,000	*0*
GHG Emissions (metric tons of annual eCO_2)	*300*	*100*	*0*

3.4 CONCLUSIONS

The selected alternatives for implementation of nitrogen removal at the STP include membrane filtration of a portion of the final effluent for two different flows depending on the permit level for nitrogen removal required. This presents an opportunity for reclaimed water use. If nitrogen removal were implemented at the STP, between 36 and 98 mgd of effluent would be made available that would be suitable for reclaimed water use. Assuming that the costs of production of this water were required for nitrogen removal in any case, this water would be available for reclaimed use at a relative savings over the costs of production of the water using conventional gravity sand filtration. Cost savings would be in the range of $45 to $104 million, depending on the level of nitrogen removal required. There would also be a savings in land area of between one quarter and one acre and a savings of a small amount in electricity consumption and GHG emissions, compared to production of the same amount of reclaimed water using media filtration if nitrogen removal treatment facilities were not available.

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APPENDIX A
EVALUATION CRITERIA

	TIN 3 Score Reasoning			
Criteria	**MBR**	**IFAS Linpor**	**IFAS Kruger**	**BAF**
Capital Cost	> 1.25 X lowest cost = 2	lowest cost = 3	< 1.25 x lowest = 3	> 1.25 X lowest cost = 2
	1.37	1.00	1.24	1.48
O&M Cost, PW	> 1.5 x lowest = 1	> 1.5 x lowest = 1	lowest = 3	< 1.5 x lowest = 2
	1.58	1.50	1.00	1.41
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 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
Footprint, sf	< 1.5 x lowest = 2	Lowest impact = 3	> 1.5 x lowest = 1	< 1.5 x lowest = 2
	607,429	425,880	849,221	560,030
	1.43	1.00	1.99	1.31
Energy	> 1.5 x lowest = 1	Lowest = 3	< 1.5 x lowest = 2	< 1.5 x lowest = 2
	1.69	1.00	1.30	1.49
Odor	All processes equally odoriforous	All processes equally odoriforous	All processes equally odoriforous	All processes equally odoriforous
Compatibility with existing processes	No stranded assetts	No stranded assetts	No stranded assetts	No stranded assetts
Biosolids Quality	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2
RW Quality	Reclaimed water quality effluent = 3	Nitrifying system, better effluent = 2	nitrifying system, better effluent, no room for filters = 1	Nonnitrifying system = 1

	TIN 8 Score Reasoning				
Criteria	**MLE**	**MBR**	**IFAS Linpoor**	**IFAS Kaldness**	**BAF**
Capital Cost	Lowest capital cost = 3	< 2 X lowest cost = 2	< 1.25 X lowest = 3	> 2 X lowest = 1	< 2 X lowest = 2
	1.00	1.72	1.15	2.11	1.73
O&M Cost, PW	Lowest cost = 3	> 2 X lowest cost = 1	< 2 x lowest = 2	< 2 x lowest = 2	< 2 x lowest = 2
	1.00	2.11	1.72	1.69	1.77
Risk	Very similar to existing process. County familiar with process. Numerous US installations in size range = 3	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 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
Future Flexibility	Cannot meet future limit of 3 mg/L = 1	Can meet future limit of 3 mg/L = 3	Can meet future limit of 3 mg/L = 3	Cannot meet future limit of 3 mg/L = 1	Can meet future limit of 3 mg/L = 3
Footprint, sf	> 1.5 x lowest alternative = 1	< 1.25 x lowest alternative = 3	Lowest impact = 3	> 1.25 X lowest = 2	< 1.25 x lowest alternative = 3
	725,935	438,148	383,196	500,016	457,745
	1.89	1.14	1.00	1.30	1.19
Energy	Lowest energy use = 3	< 1.5 x lowest = 2	< 1.25 x = 3	> 1.5 x lowest = 1	< 1.5 x lowest = 2
	1.00	1.26	1.10	1.71	1.34
Odor	All processes equally odoriforous	All processes equally odoriforous	All processes equally odoriforous	All processes equally odoriforous	All processes equally odoriforous
Compatibility with existing processes	No stranded assetts	No stranded assetts	No stranded assetts	No stranded assetts	No stranded assetts
Biosolids Quality	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 3	Nitrogen removed by N2 gas evoluation, some N lost from biosolids = 2
RW Quality	Nitrifying system, better effluent quality, but no room on site for more filters = 1	Reclaimed water quality effluent = 3	Nitrifying system, better effluent = 2	Nitrifying system, better effluent = 3	Nonnitrifying system = 1

APPENDIX B
COST ASSUMPTIONS AND SUMMARIES

Client:	**King County**
Project:	**Nutrient Removal Analysis - 3 mg/L Year-round TIN**
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%**
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 Costs (Planning, Design, CM, Permits, etc.)	**45%**
Sales tax, %	**10.0%**
ENR Cost Index	**10350**
Present Worth Factor	14.87747

Cost Comparison of Treatment Alternatives
King County
Nutrient Removal Analysis - 8 mg/L Summer TIN (98 mgd Max Month Flow)

Treatment Element	CAS	MLE	MLE MBR	Total NR Cost	Difference
Capital Cost, $					
Fine Screening	$0		$11,000,000	$11,000,000	$11,000,000
CAS Aeration Tanks	$0			$0	$0
BNR Reactor Tanks	$0	$105,200,000		$105,200,000	$105,200,000
MBR Reactor Tanks	$0		$179,600,000	$179,600,000	$179,600,000
MBR Membrane Tanks and Equipment	$0		$227,800,000	$227,800,000	$227,800,000
Centrate Treatment Tanks	$0		$6,300,000	$6,300,000	$6,300,000
Total Project Cost	**$0**	**$105,000,000**	**$425,000,000**	**$530,000,000**	**$530,000,000**
Design Max Month Flow (mgd)	98	33	65	98	98
Unit Project Cost ($/gpd)	$0.00	$3.18	$6.54	$5.41	$5.41
Operation and Maintenance Cost, $/year					
Fine Screening	$0	$0	$660,000	$660,000	$660,000
CAS Aeration Tanks	$1,730,000	$721,000	$0	$721,000	-$1,009,000
BNR Reactor Tanks	$0	$2,390,000	$0	$2,390,000	$2,390,000
MBR Reactor Tanks	$0	$0	$2,870,000	$2,870,000	$2,870,000
MBR Membrane Tanks and Equipment	$0	$0	$4,920,000	$4,920,000	$4,920,000
Centrate Treatment Tanks	$0	$0	$200,000	$200,000	$200,000
Total	**$1,700,000**	**$3,100,000**	**$8,700,000**	**$11,800,000**	**$10,000,000**
Present Worth Cost, $ Million					
Capital	$0	$105	$425	$530	$530
Operation and Maintenance	$25	$46	$129	$176	$149
Total Present Present Worth	**$25**	**$151**	**$554**	**$706**	**$679**

Cost Comparison of Treatment Alternatives
King County
Nutrient Removal Analysis - 3 mg/L Year-round TIN (144 mgd Max Month Flow)

Treatment Element	CAS	Bardenpho Upgrade	Bardenpho MBR	Total NR Upgrade	Difference
Capital Cost, $					
Fine Screening	$0		$14,100,000	$14,100,000	$14,100,000
CAS Aeration Tanks	$0			$0	$0
BNR Reactor Tanks	$0	$179,800,000		$179,800,000	$179,800,000
BNR Secondary Sed Tanks	$0	$8,300,000		$8,300,000	
MBR Reactor Tanks	$0		$385,300,000	$385,300,000	$385,300,000
MBR Membrane Tanks and Equipment	$0		$367,600,000	$367,600,000	$367,600,000
Centrate Treatment Tanks	$0		$12,100,000	$12,100,000	$12,100,000
Total Project Cost	**$0**	**$188,000,000**	**$779,000,000**	**$967,000,000**	**$959,000,000**
Design Flow, mgd	144	30	114	144	144
Unit Project Cost ($/gpd)	$0.00	$6.27	$6.83	$6.72	$6.66
Operation and Maintenance Cost, $/year					
Fine Screening			$1,315,000	$1,315,000	$1,315,000
CAS Aeration Tanks	$1,840,000			$0	-$1,840,000
BNR Reactor Tanks		$7,212,000		$7,212,000	$7,212,000
BNR Secondary Sed Tanks		$1,367,000		$1,367,000	
MBR Reactor Tanks			$11,764,000	$11,764,000	$11,764,000
MBR Membrane Tanks and Equipment			$13,013,000	$13,013,000	$13,013,000
Centrate Treatment Tanks			$410,000	$410,000	$410,000
Total	**$1,800,000**	**$8,600,000**	**$26,500,000**	**$35,100,000**	**$31,900,000**
Present Worth, $ Million					
Capital	$0	$188	$779	$967	$959
Operation and Maintenance	$27	$128	$394	$522	$475
Total Present Worth	**$27**	**$316**	**$1,173**	**$1,489**	**$1,434**